Proceedings of the Reactor Physics Asia 2023 (RPHA2023) Conference
Gyeongju, Korea, October 24-25, 2023

Development of neutron monitoring detector and neutron-induced fission experiment at the NDPS

Dal-Ho Moon [a*], Sung-Chul Yang [a], Charles Akers [b], Cheolmin Ham [b], Kwang Bok Lee [b], Seung-Woo Hong [b]
[a]*Nuclear Physics Application Research Division, Korea Atomic Energy Research Institute, Daejeon 34057, Republic of Korea*
[b]*Rare Isotope Science Project, Institute for Basic Science, Daejeon 34000, Republic of Korea*
[*]*Corresponding author: dhmoon@kaeri.re.kr*

***Keywords : Nuclear Data Production System, fast neutron, Time-of-Flight, PPAC, Fission**

1. Introduction

As the importance of neutron-induced nuclear data increases, there is a growing demand for nuclear data measurements across a wide range of incident neutron energies. In order to meet these demands, the neutron Time-of-Flight (TOF) facility Nuclear Data Production System (NDPS) at the Rare isotope Accelerator complex for ON-line experiments (RAON) is under construction [1-3]. To monitor the neutron flux at NDPS, a Parallel Plate Avalanche Counter (PPAC) has been developed as a neutron detector [4]. The detection efficiency and timing resolution of developed PPAC were measured using an Am alpha source. The neutron beam measurement experiment was conducted using a PPAC neutron detector with a thorium converter produced by electrodeposition [5].

As one of the experiments in the early stage of NDPS, there is a plan for the measurement of fission cross section. The chamber with a diameter of 1000 mm was fabricated, and we are currently conducting vacuum test as well as the DAQ system.

2. Neutron monitoring detector

To accurately measure the neutron flux in neutron TOF facility, it is necessary to develop detectors capable of monitoring neutrons in real-time [6]. For neutron flux monitoring in the NDPS, we have designed PPAC for neutron detection. Since neutron measurement is conducted using the TOF method, a detector with good timing resolution is required.

2.1 PPAC for neutron detector

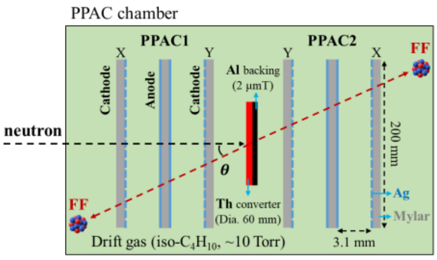

Fig. 1 Thorium converter and PPAC detectors were fabricated to monitor fast neutrons by measuring the two fission fragments generated through the Th(n,f) reaction in a coincidence method.

In order to monitor fast neutrons produced at NDPS, a PPAC with an active area of 20 × 20 cm^2 was developed. The electrodes were fabricated by coating Ag with a thickness of 30 nm onto a 2.5 μm thickness Mylar substrate. The electrodeposited thorium was employed as a fast neutron converter, and details regarding the fabrication of the neutron converter are explained in Section 2.2. The internal gas utilized was isobutane at a pressure of 10 Torr, and the PPAC setup for neutron detection is illustrated in Fig. 1. When neutrons collide with the thorium converter, nuclear fission reactions can occur, generating two fission fragments. The incident neutrons are monitored by measuring these fission fragments using the PPAC detector.

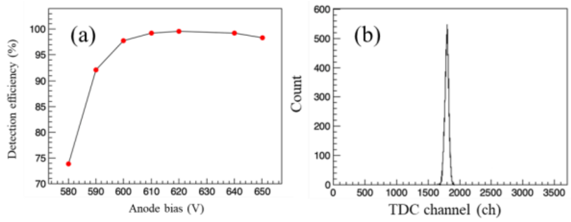

Fig. 2 (a) The detection efficiency measured using an Am alpha source. (b) The TOF peak measured with a TDC module, and it shows a timing resolution value of approximately σ~550 ps.

The detection efficiency and timing resolution of PPAC were measured using an Am alpha source. To create an electron avalanche effect, voltage to the anode was applied while keeping the cathode as ground. The detection efficiency as a function of anode bias is depicted in Fig. 2(a). At a voltage of 580 V, the avalanche effect was insufficient, resulting in low detection efficiency, whereas, at voltages of approximately 600 V or higher, a detection efficiency of over 99 % was achieved. Fig. 2(b) illustrates the values of timing resolution, showing a result of approximately σ~550 ps.

2.2 Fast neutron converter

Thorium coated on aluminium was employed as a neutron converter for measuring fast neutrons. The Th(n,f) reaction exhibits a cross section of approximately 1 barn in the high-energy neutron region above a few MeV, and its cross section is relatively well-known, making it suitable for monitoring purposes. Furthermore, due to the absence of cross section in the low-energy region, there is an advantage in reducing background events caused by low-energy neutrons.

The thorium coating was produced using an in-house electrodeposition system. A solution was prepared using thorium nitrate powder and isopropyl alcohol. To simultaneously detect both fission fragments generated by the fission reaction, a thin aluminum backing with a thickness of 2 μm was utilized. During the deposition, a mask was used to electroplate thorium in a circular shape with a diameter of 60 mm. Th-232 undergoes alpha decay with a half-life of approximately 14 billion years. The amount of deposited thorium was determined by measuring the emitted alpha. The areal density of thorium obtained through alpha spectrometry [7] was measured to be approximately 300 μg/cm^2.

2.3 Neutron measurement experiment

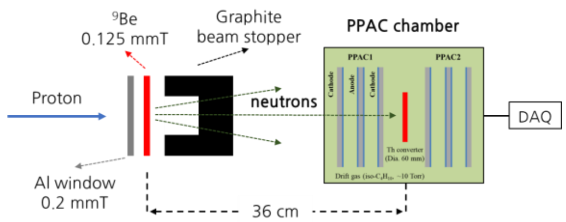

Fig. 3 The neutron measurement experiment was conducted using the KIRAMS facility. To generate fast neutrons, a Be target was employed, and for neutron detection, the developed PPAC neutron detector was utilized.

Using the PPAC neutron detector after the performance evaluation, neutron measurement experiments were conducted. A 45 MeV proton beam with a current of 100 nA from the Korea Institute of Radiological & Medical Sciences (KIRAMS) was employed, and the ^{9}Be(p,n)^{9}B reaction was utilized to generate fast neutrons as described in Fig. 3. The incident neutrons collide with the thorium converter installed within the PPAC, leading to nuclear fission reactions and the production of fission fragments, which can be detected by the PPAC. In this manner, neutrons could be measured by counting the number of fission fragments detected per second. Fig. 4 depicts events measured by the coincidence method for fission fragments generated by neutrons [8]. To validate the experimentally obtained count rate, Monte-Carlo simulation codes, PHITS and GEANT4, were used. The ^{9}Be(p,n)^{9}B reaction was calculated using the Distorted Wave Born Approximation (DWBA) model within PHITS [9], while other calculations related to the Th(n,f) reaction and the transport of fission fragments were conducted using GEANT4. The simulated count rate was determined to be 1.71 count/s, and the experimentally obtained value closely matched at 1.74 count/s, demonstrating a good agreement.

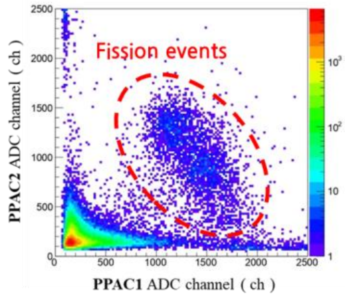

Fig. 4 The fission events induced by neutrons were detected with the coincidence method. Background coincidence events occurred in the low ADC channels, and these events were removed to measure the count rate.

3. Fission experiment

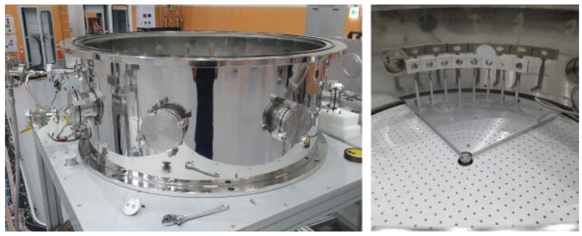

Fig. 5 As part of the initial experiments in NDPS, a fission cross section measurement experiment is planned, and for this purpose, the detector and DAQ system have been prepared.

One of the methods for treating nuclear waste, such as actinide elements found in spent fuel, is utilizing fission reactions. Therefore, having accurate knowledge of the fission cross section for these elements is crucial. Furthermore, considering the Th-U fuel cycle, it is important to measure the fission cross section for Th-232 and U isotopes, making cross section data across various energy ranges demanded. To fulfill these needs, NDPS is planning a fission experiment and a chamber with a diameter of 1000 mm has been fabricated. By installing silicon detectors at different angles inside the chamber, the angular distribution of fission fragments and fission cross section can be measured. To measure the incoming neutron flux onto the fission target, a reference reaction such as the U(n,f) reaction is planned for use. The DAQ system is composed of NIM and VME modules, and fission fragments measurement is performed using a Cf spontaneous fission source to evaluate operation of the DAQ system and the silicon detector.

4. Conclusions

A neutron TOF facility, NDPS, capable of generating neutrons with energies in the tens of MeV, is currently under construction at the RAON. A neutron detection system, PPAC, has been developed to monitor the neutron flux of NDPS in real-time, and performance evaluation as well as neutron measurement experiments have been completed. The developed neutron monitoring detector has been installed in preparation for beam commissioning at the NDPS. As part of the initial experiments at the NDPS, preparations are being made for a fission experiment. For this purpose, a chamber with a diameter of 1000 mm has been fabricated, and silicon detectors and DAQ setup have been established, with basic tests conducted.

REFERENCES

[1] Jeong, S., et al., *A brief overview of RAON physics.* Journal of the Korean Physical Society, 2018. **73**: p. 516-523.
[2] Kang, B.H., et al., *ISOL facility for rare isotope beams at RAON.* Journal of the Korean Physical Society, 2013. **63**: p. 1473-1476.
[3] Ham, C., et al., *Overview of nuclear data production system at RAON.* Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 2023. **541**: p. 363-365.
[4] Lee, K., et al., *Development of neutron detection systems at the NDPS of RAON.* Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 2023. **541**: p. 65-68.
[5] Moon, D.-H., et al., *Development and characterization of thorium coatings by using an electrodeposition system and alpha spectroscopy.* Journal of the Korean Physical Society, 2023: p. 1-7.
[6] Andriamonje, S., et al., *Experimental studies of a Micromegas neutron detector.* Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2002. **481**(1-3): p. 120-129.
[7] Sibbens, G., et al., *Preparation of 240 Pu and 242 Pu targets to improve cross-section measurements for advanced reactors and fuel cycles.* Journal of Radioanalytical and Nuclear Chemistry, 2014. **299**: p. 1093-1098.
[8] Tarrio, D., *Neutron-induced fission fragment angular distribution at CERN n TOF: The Th-232 case. 2012*. Ph. D. Thesis, University of Santiago de Compostela.
[9] Hashimoto, S., et al., *New Approach for Nuclear Reaction Model in the Combination of Intra-nuclear Cascade and DWBA.* Nuclear Data Sheets, 2014. **118**: p. 258-261.