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Development of 2.5 MeV and 14.8 MeV Mono-energetic Neutron Fields

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1. Introduction

A mono-energetic neutron reference field is a standardized radiation field that comprises a beam of neutrons with a single, well-defined energy. The International Organization for Standardization has established standards for mono-energetic neutron reference fields within the energy range of 1 keV to 20 MeV, which specify the energy of neutron beam [1]. These standards guarantee that measurements conducted using various instruments and in different laboratories can be compared and validated.

The D(d, n)^{3}He and T(d, n)^{4}He reactions, known as DD and DT fusion reactions, respectively, are renowned for their relatively high neutron production cross-section. These reactions can be represented by the following equations:

$$\begin{aligned} D + D &\rightarrow {}^3He + n + 3.27\,MeV \\ D + T &\rightarrow {}^4He + n + 17.6\,MeV \end{aligned} \qquad (1)$$

Both reactions are exothermic and can be initiated using beams with energies in the range of a few hundred keV.

In order to establish standards for mono-energetic neutron measurements, the Korea Research Institute of Standards and Science (KRISS) has developed 2.5 MeV and 14.8 MeV mono-energetic neutron reference fields using the DD and DT reactions. The DD and DT reactions are expected to emit ~1×10^7 n/s and <5×10^8 n/s, respectively. This presentation will cover the development process and preliminary measurement results.

2. Methods and Results

To generate 2.5 MeV and 14.8 MeV mono-energetic neutrons, deuteron beams were directed towards a solid-state target containing deuterons or tritium nuclei. An electrostatic accelerator with a beamline was utilized to accelerate deuterons, and a cylindrical reaction chamber was developed for targets. Targets composed of deuterated titanium (TiD) and tritiated titanium (TiT) were prepared. Neutron production was measured and validated using ^{3}He proportional counter detectors and Cs_2LiYCl_6:Ce (CLYC) scintillator detectors.

2.1 Accelerator

A High Voltage Engineering Europa B.V. electrostatic accelerator, capable of producing a maximum beam current of 0.5 mA and maximum beam energy of 400 keV, was installed at KRISS. To validate the performance of the accelerator, the maximum beam current was measured at the Faraday cup, located at the end of the approximately 7-m-long beamline, when operating at maximum energy, as shown in Fig. 1. The accelerator control software provides a GUI-based interface on the control PC for monitoring the beam profile. Additionally, the beam size can be adjusted by modifying the focusing parameters, allowing the beam at the Faraday cup to be focused to a few mm in width [2].

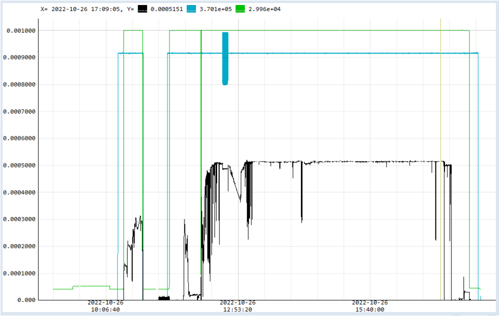

Fig. 1. Beam current (black, >500 μA) at the Faraday cup, terminal voltage (light blue, 370 kV), and extraction voltage (green, 30 kV). They were stable for more than 4 hours.

2.2 Targets and Reaction Chamber

The TiD and TiT targets were designed to accurately measure neutron fluence with uncertainties within a few percent of neutron measurement standards. To optimize the thickness of the targets, Monte Carlo simulation results were utilized, and it was determined that the TiD target should be 300 μg/cm^2, and the TiT target should be 250 μg/cm^2 [3]. Although increasing the thickness of the targets would result in a higher emission rate, our emission rate requirement was limited by laboratory wall-shielding to <5×10^8 n/s, making a 250 μg/cm^2-thick TiT target suffices.

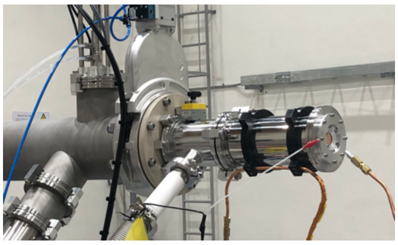

Fig. 2. Target chamber with TiD target at the end of the beamline. The TiD target is on a copper backing plate, shown at the end of the chamber.

A cylindrical chamber was designed as a prototype system to mount the target and installed at the end of the beamline. The chamber is equipped with an air-cooling system, as shown in Fig. 2, and the TiD target material is facing inward and located on the copper backing plate.

2.3 Measurements using a ^{3}He Detector with Moderator

Neutrons from the DD reaction were measured using a ^{3}He proportional counter (SP9, Centronic Co., UK) with a high-density polyethylene moderator (HDPE, Bonner sphere). The SP9 detectors were calibrated, and the thickness of the moderator was determined to have a relatively high response at 2.5 MeV. The neutron fluence from the DD target was measured using two SP9 detectors, one with a 17.8-mm and the other with a 20.3-mm-diameter Bonner sphere. At a distance of 150 cm in the 90-degree direction, and for 200 keV deuteron beams with a beam current of 10 μA, the preliminary fluence was 7.81 $cm^{-2}s^{-1}$ (3.8 %) and 8.30 $cm^{-2}s^{-1}$ (3.8 %). An example distribution of neutron measurement with the SP9 detector is shown in Fig. 3.

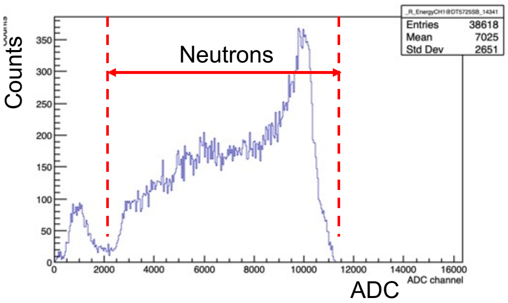

Fig. 3. Measured 2.5 MeV neutron events using an SP9 detector with a 17.8-mm HDPE moderator.

2.4 Measurements using a CLYC scintillator

The CLYC scintillator detector is recognized for its ability to separate neutron and gamma signals using pulse shape discrimination (PSD) and for its good energy resolution (< 4 %). A ^{7}Li-enriched CLYC detector (CLYC-7) is well-suited for fast neutron measurements [4, 5]. We used a CLYC-7 detector to measure neutrons from the DD reaction. The resulting spectrum in Fig. 4 shows distinct peaks from the ^{35}Cl(n, α) and ^{35}Cl(n, p) reactions.

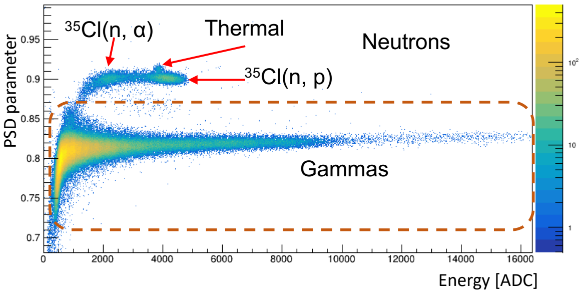

Fig. 4. The separation of neutrons and gamma rays using a CLYC-7 detector.

2.5 Neutron Productions Condition

For the measurements of 2.5 MeV and 14.8 MeV neutrons, the detector must be positioned at a specific angle relative to the incident deuteron. The measurement angle can be calculated using two-body kinematic relations and the incident deuteron beam energy. However, the deuteron energy is not constant within the solid target due to energy loss. To account for this, the effective acceleration voltage for incident beams was estimated using simulation, as shown in Table I. These estimates will be validated by measurements later.

Table I: Neutron Production Conditions

	DD	DT
Aiming neutron energy	2.5 MeV	14.8 MeV
Detection angle (relative to incident direction)	90 deg	0 deg
Beam current	3 μA	10 μA
Ideal acceleration voltage	200 kV	110 kV
Effective acceleration voltage	250 kV	170 kV

3. Conclusions

We utilized a 400 kV electrostatic accelerator with TiD and TiT targets at KRISS to generate a mono-energetic neutron field with energies of 2.5 MeV and 14.8 MeV. The neutrons produced from DD and DT reactions were measured using a ^{3}He neutron detector with a moderator and a CLYC scintillator detector. The fluence of the DD and DT reactions was accurately measured, and the irradiation service for 2.5 MeV and 14.8 MeV neutron fields will be initiated soon.

REFERENCES

[1] ISO8529-1, Neutron reference radiations fields – Part 1: Characteristics and methods of production, ISO-8529-1, 2021
[2] HyeoungWoo Park, Sinchul Kang, Jungho Kim, Hyeonseo Park, Joong Hyun Kim, and Young Soo Yoon, Development of a monoenergetic neutron field utilizing an accelerator deuteron beam, Journal of Korean Physical Society, Submitted 2023.
[3] Young Soo Yoon, Jungho Kim, Hyeoungwoo Park, and Hyeonseo Park, Development of A 14.8 MeV Mono-energetic neutron field in Korea Research Institute of Standards and Science, Radiation Protection Dosimetry, Accepted 2022.
[4] N. D'Olympia et. al., Optimizing Cs2LiYCl6 for fast neutron spectroscopy, Nuclear Instruments and Methods in Physics Research A, 694, 140-146, 2012
[5] Sinchul Kang, Jungho Kim, Joong Hyun Kim, Hyeonseo Park, Hyeoungwoo Park, and Young Soo Yoon, Neutron irradiation facilities, neutron measurement system, and mono-energetic neutron fields at KRISS, Journal of Korean Physical Society, Published online, 2023.