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Technology Development of A Neutron Resonance Transmission Analysis Using A Laser Driven Neutron Source

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ABSTRACT

The technology development studies to use a laser-driven neutron source (LDNS) in a compact Neutron Resonance Transmission Analysis (NRTA) system have been carried out in three parts: a neutron moderator, neutron detector, and data acquisition system. The neutronic characteristics of various moderators were investigated using the Monte Carlo simulation to design a moderator by taking advantage of the short pulse of the LDNS. The research and development works for a neutron detector having a high neutron efficiency with a low gamma sensitivity and a data acquisition system having a low measurement error at high counting rates have been carried out in collaboration with Kyoto University. In addition, the demonstration experiment was carried out using a laser-driven epithermal neutron source developed by the Nuclear Photonics (NP) group at Osaka University to verify the feasibility of NRTA. In this paper, the details of the research processes were presented.

INTRODUCTION

As one of active neutron non-destructive assay (NDA) techniques, Neutron Resonance Transmission Analysis (NRTA) [1] using the accurately known neutron cross section data has been used to characterize nuclear materials (NM) [2-6]. To conduct NRTA experiments, a pulsed epithermal neutron source with the time-of-flight (TOF) technique [7] is required. In order for NRTA to be widely used in various facilities that need to measure NMs, the NRTA system must be compact. In order to achieve this compactness, shortening of the neutron flight distance and downsizing of the neutron source are the essential factors, and recent significant advances in laser technology may provide an answer to these factors. As one of the new types of pulsed neutron sources, the Laser-Driven Neutron Sources (LDNS) have been being developed [8-14], and the

LDNS is able to generate very short-pulsed neutron beams because this source has a short pulse width and small volume of neutron generation point. Moreover, with the downsizing and upgrading of the laser system itself [15, 16], the compactness of the neutron source system is also expected. These features have the advantage of designing a compact NRTA system.

In order to use the LDNS in a compact NRTA system, it is necessary to optimize a measurement system. For this reason, at present, the technology development studies have been carried out in three parts: a neutron moderator, neutron detector, and data acquisition system. In addition, the demonstration experiment was carried out using a high-power laser to verify the feasibility of NRTA using the LDNS experimentally. In this paper, we present the details of the research processes.

DEVELOPMENT STUDY

A. Neutron moderator

The neutron moderator is used to slow down the fast neutrons (~MeV) emitted from the LDNS to the resonance energy region required by NRTA. To carry out the accurate TOF measurements with high resolutions for NRTA, it is important not only to obtain epithermal neutrons efficiently but also to suppress the neutron broadening effects in the moderator. In the present study, the neutronic characteristics of various types of the moderator for the neutron intensity and energy resolution were investigated using the Monte Carlo simulation code PHITS [17] with JENDL-4.0 [18]. The neutron moderator consisted of a top moderator and CH_2 moderator. In the simulation, the incident neutron energy E_0 was 1 MeV. The detectors of detection efficiency 100% were set at the position 0.5 m away from the moderator. Base on the simulation results, we calculated the neutron intensities in the energy region from 1 to 100 eV with the neutron flight distance L = 0.5 m and neutron energy resolutions at 10 eV with L = 5 m. As shown in **Figure 1**, using tungsten (W) as the top moderator was effective to increase the neutron intensity for about above incident neutron energy 7.5 MeV, and it is due to the increase of the (n, 2n) reactions of W with increasing the incident neutron energy. In addition, from the simulation results, we confirmed that it is essential to design slimly and widely the moderator to obtain a higher neutron intensity maintaining a good energy resolution.

B. Neutron detector and data acquisition system

In the compact NRTA system using the LDNS, the short-distance TOF measurements have a high counting rate and large gamma-ray background due to 2.2 MeV gamma-rays emitted by the neutron capture of hydrogen in the moderator. Since the LDNS is still under development, the neutron flux is not sufficient, and it is desirable to use a detector with high detection efficiency. For these reasons, we have been developing a neutron detector having high efficiency to neutrons and low efficiency to high energy gamma-rays, and a data acquisition system having a low measurement error at high counting rates. The performance experiment of the developed ^{6}Li

detector (prototype detector) was carried out at the Kyoto University Institute for Integrated Radiation and Nuclear Science - Linear Accelerator (KURNS-LINAC) [19]. The measured results were normalized by the measurement time, and the performance results of the prototype detector were compared with the 1 cm thick ^{6}Li detector (typical detector). As shown in **Figure 2**, the results of the pulse height spectrum of the prototype and typical detector for the neutrons were similar. For the 2.2 MeV gamma-ray background generated by the water moderator of the KURNS-LINAC, the pulse height spectrum of the prototype detector was shifted to the left. From the present results, we confirmed that the prototype detector was less sensitive to high energy gamma-rays than the typical detector. For the data acquisition (DAQ) system, the analog electrical signals from the detector were digitized by the high-speed flash analog to digital converter (ADC). In the off-line, the moving average and baseline correction were carried out for the digitized signals, and the threshold was set to pick up the neutron signals.

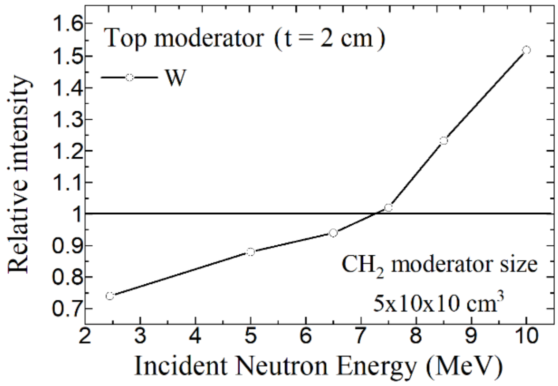

Figure 1. Relative intensity at L = 0.5 m. The intensity at the top moderator thickness t = 2 cm is compared to the intensity without the top moderator.

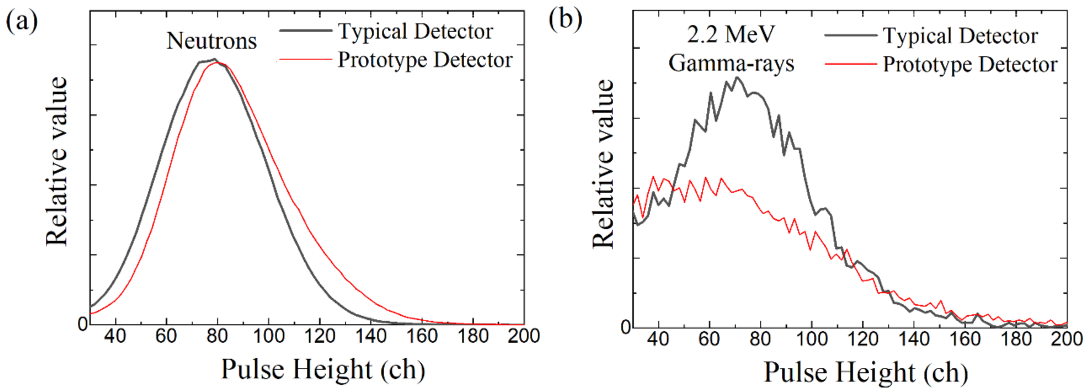

Figure 2. Pulse height spectra of the prototype and typical detector for the neutrons (a) and 2.2 MeV gamma-ray backgrounds at KURNS-LINAC (b).

DEMONSTRATION EXPERIMENT

To demonstrate the feasibility of NRTA using the LDNS, the preliminary neutron transmission experiment was carried out using the Laser for Fast Ignition Experiment (LFEX) [20] at Osaka University. In present experiment, we used the laser-driven epithermal neutron source developed by the Nuclear Photonics (NP) group at Osaka University. The 0.2 mm thick indium (In) sheet was used as the measurement sample. The neutron flight distance was about 3.6 m. After the off-line data processing, the signals having a suitable charge integral were selected as the neutron signals, and the selected signals were converted to a neutron TOF spectrum. The results of the obtained TOF spectrum is shown in **Figure 3**. As shown in **Figure 3**, we observed the resonance peaks of ^{115}In (1.46 eV) from the transmitted neutron TOF spectrum through In.

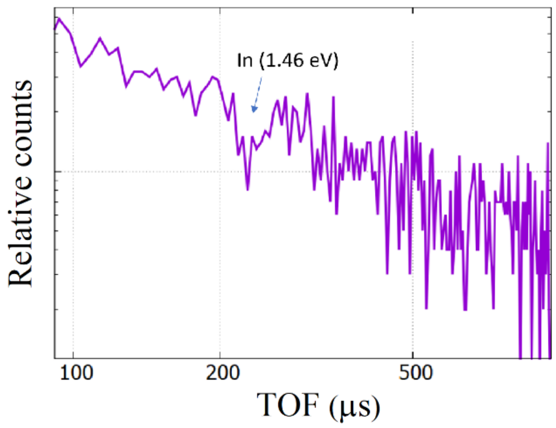

Figure 3. Preliminary result of transmitted neutron TOF spectrum through In using the LDNS.

SUMMARY

In order to apply the LDNS to the compact NRTA system, we have been carried out the technology development studies of the neutron moderator, detector, and DAQ system. In the demonstration experiment using the LDNS, we observed the resonance peaks of In from the transmitted neutron TOF spectrum through In.

Another neutron transmission experiment using the LFEX laser is planned to do for the first experimental demonstration of NRTA using the LDNS. In this experiment, a newly developed neutron detector with a higher detection efficiency to the neutrons with a low gamma sensitivity and a newly designed neutron generation and moderation system for the optimized production of the epithermal neutrons will be applied.

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