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Optimization of moderator size of thermal and epithermal neutron source based on a compact accelerator for neutron imaging

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Abstract

A compact accelerator-driven neutron source has some advantages over a large accelerator facility in terms of accessibility and usability. Recently, the project to develop a non-destructive testing system for nuclear fuels by neutron imaging using a compact accelerator-driven neutron source has launched in Japan. In this project, the traditional neutron radiography and temperature imaging by neutron resonance absorption spectroscopy (N-RAS) have been studied. From the viewpoint of L/D, a high-brightness moderator is desirable for the neutron imaging. In this study, we investigated the dependence of moderator size on the source brightness and the pulse characteristics of the neutron by simulation calculations to design the moderator for imaging using thermal and epithermal neutrons. As a result, the optimal size of the moderator for the neutron imaging was 6~7 cm in the energy region from 5 meV to 100 eV.

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Keywords: Compact accelerator-driven neutron source; Neutron imaging; Moderator optimization; Pulse characteristics; Monte Carlo simulation

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1. Introduction

A neutron source based on a compact accelerator has some advantages over a large neutron facility in terms of accessibility and usability. One of the main objectives of a compact accelerator-driven neutron source is the neutron imaging. The neutron imaging includes the traditional neutron radiography and the energy-resolved neutron imaging, for example, the neutron resonance imaging based on neutron resonance absorption spectroscopy (N-RAS) (Kamiyama et al. 2005) and the Bragg-edge imaging (Sato et al. 2011). Recently, the Development of Non-Destructive Methods Adapted for Integrity test of Next generation nuclear fuels (N-DeMAIN) project has been launched in Japan. In the N-DeMAIN project, we have aimed to develop a non-destructive testing system for nuclear fuels using the neutron radiography and the N-RAS to obtain nuclide and temperature distribution in a real space at a compact accelerator-driven neutron source. Since the neutron resonance reaction occurs in the epithermal energy region, the epithermal neutron source is necessary to perform the N-RAS imaging. In addition, to perform the radiography for a bulk sample, thermal or higher energy neutron sources are suited for the neutron source dedicated for testing nuclear fuels. Therefore, we have aimed to develop the thermal and epithermal neutron source based on a compact accelerator for the neutron imaging in this project.

In this study, we optimized the moderator size of the thermal and epithermal neutron source by simulation calculations from a viewpoint of L/D. In the moderator design, the quantity of flux is usually used, however, we used the quantity of the brightness instead of the flux to develop the high spatial resolution moderator. At first, we investigated the dependence of the moderator size on the neutron brightness at the moderator surface because a high brightness neutron moderator can generate high L/D neutron beam. Since the neutron brightness decreases with increasing the moderator size, a smaller moderator has an advantage in terms of L/D (Hasemi et al. 2013). However, the pulse characteristics are also important for the N-RAS imaging. Therefore, we also estimated the influence of the moderator size on the pulse characteristics of the thermal and epithermal neutrons. From the results of these calculations, we decided the optimal moderator size for the thermal and epithermal neutron source based on a compact accelerator.

2. Calculation model and method

2.1. Calculation model

Fig. 1 shows the calculation model of Target-Moderator-Reflector assembly (TMRA). In this study, the slab alignment was chosen for simplicity. Among moderators, an ambient temperature moderator is most suited for the thermal and epithermal neutron source. We chose light water as a moderator material since light water is the suitable for thermal neutron imaging in terms of the brightness (Hasemi et al. 2012). The thickness of moderator was 4 cm, which gives maximum thermal neutron intensity (Hasemi et al. 2013). The side length of the moderator, L_m, varied from 4 cm to 16 cm. The target material was a lead cube of 4 cm on a side. The reflector material was beryllium and its thickness was 30 cm. The reflector thickness was not optimized but realistic value. To evaluate the influence of only L_m for the brightness, the thickness of the moderator and reflector were fixed.

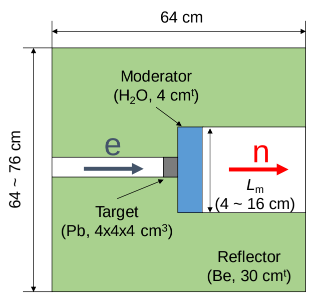

Fig. 1. Calculation model of TMRA.