Development and preliminary results of 30 MeV cyclotron-based neutron source at KAERI

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1. Introduction

Nuclear fusion is considered to be a next-generation clean and sustainable energy due to its inherent safety and abundant fuel resource. In this context, ITER has been built to resolve the scientific and technological issues that remained for the ignition at Cadarache in France since 2006, and Korea has joined this international project and contributed to its construction in parallel with the understanding of plasma physics through domestic KSTAR (Korea Super Conducting Tokamak Advanced Research) operation. Also, Korea has been developing a fusion energy roadmap to support engineering R&D, including materials, blankets, system engineering, licensing, codes and standards centered on fusion neutron source (FNS) promoting the development of fusion demonstration reactors and fusion reactors by refining the fusion energy roadmap. Various neutron sources are currently being considered, including a 40 MeV linear accelerator-based neutron source, an assembly of cyclotron-based neutron sources, a spherical tokamak-based neutron source, and so on.

As an organization that researches fusion energy with a focus on nuclear energy, the Nuclear Physics and Applied Research Division at KAERI is responsible for engineering research on plasma heating systems, and breeding blankets and plasma-facing components for nuclear fusion reactor development, as well as nuclear data production. We are promoting the development of neutron sources using our technologies, research utilization, and further industrial utilization. Following the success of the D-D compact neutron generator, the development of a 30 MeV cyclotron-based neutron source is imminent. In the present paper, we will briefly introduce the status of the division and the technologies behind it, followed by a brief overview of the development status and results of the 30 MeV cyclotron-based neutron source..

2. Status of 30MeV CANS development

Due to the neutron characteristics of its interaction with low atomic material, it has been used as a non-destructive testing method for such as an explosive, an ammunition, an aerospace compartment, etc., especially where X-ray imaging has limitations. So far, the research reactor, HANARO has provided the radiography (~10^{14} n/cm^2·s, 10^{18} n/s at reactor core), but the accessibility is decreasing due to the recently strengthened regulation and the limitation of the object size. The need for an on-site neutron source for radiography of industry and defence is increasing, therefore a new project was started in April 2020 to develop the neutron production over 10^{12} n/s considering the minimum neutron yield for radiography. The overall project scheme and concept of neutron source and radiography were introduced in Fig. 1. And it consists of the following Tasks;

(Task 1) Target-Moderator-Reflector-Shield (TMRS) system development.

(Task 2) On-site neutron radiography development and supply of stable proton beam. The well-established thermal neutron imaging technique will be used and compared with HANARO.

(Task 3) Comparison developed neutron radiography with X-ray ones with a company, in which more complex internal structure and feasibility/advantage of neutron image will be confirmed.

(Task 4) For produced neutron energy and spectrum, neutron flux will be measured at various locations in the laboratory including the specimen.

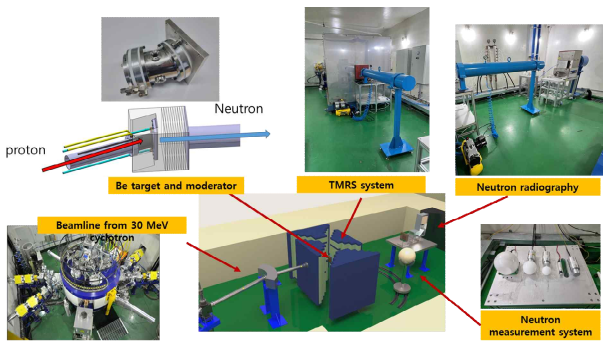

Fig. 1 Project scheme and concept of neutron source

For TMRS, the thickness of the Be target and the width of the water coolant were determined to be 5.5 mm and 4.5 mm, respectively, considering the maximum proton energy of 30 MeV and the depth of energy deposition to avoid blistering. To obtain the optimal neutron spectrum for radiography, high-density polyethylene (HDPE) moderators are used, varying in thickness from 5 cm to 30 cm, and the target-moderator assembly is designed and fabricated to be replaceable. The reflector and shield have a layered structure of HDPE, lead, and concrete mixed casemate combination as shown in Fig. 2, consisting of 48 cm of primary HDPE, 12 cm of lead, 25 cm of secondary HDPE, and 15 cm of concrete and steel shot casemate.

Proton beam irradiation tests were conducted in conjunction with the TMR fabrication to (1) confirm the proton beam stable withdrawal conditions (30 MeV, 0.1 mA) derived over 36 hours and (2) confirm proton beam transmittance of >75% on the Be target through beam optical alignment with the existing Al window. For neutron spectrum measurements, we developed a scintillator-based device (H3164/9111B series PMT with HDPE boner sphere) and unfolded it with MCNP 6.2 calculations to evaluate neutron yield.

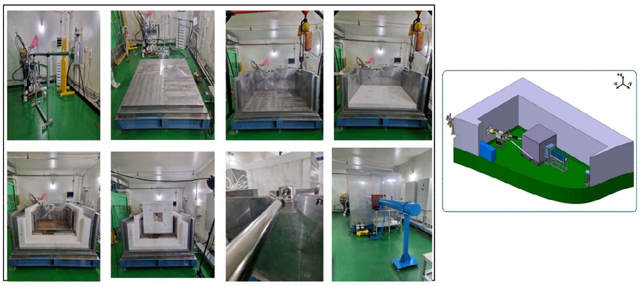

Fig. 2 Fabrication procedure of TMRS for neutron production

Initially using the Be target without HDPE moderators, neutron spectrum and yields were evaluated to be 2.6x10^{10} n/s and 1.6x10^{12} n/s at 1.2 μA and 10 μA (0.01 mA), respectively. Fig. 3 shows the measured and unfolded neutron spectrum at each current. Preliminary neutron images of the modulation transfer function (MRF) bar patterns were obtained at 30 MeV and 0.01 mA conditions, as shown in Fig. 4, with progressively more closely spaced bar patterns providing a more quantitative way to characterize the spatial resolution of the detector. Using this standard, the limiting resolution of this radiography is about 0.3 mm.

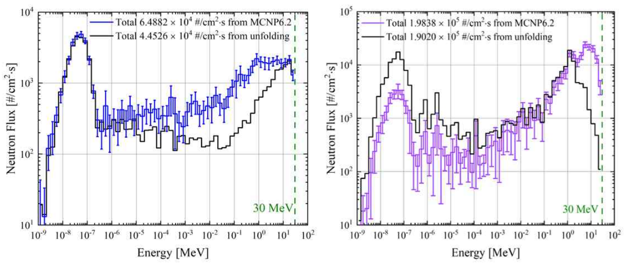

Fig. 3 Neutron spectrum results of 0.0012 mA (left) and 0.0100 mA (right) at 30 MeV

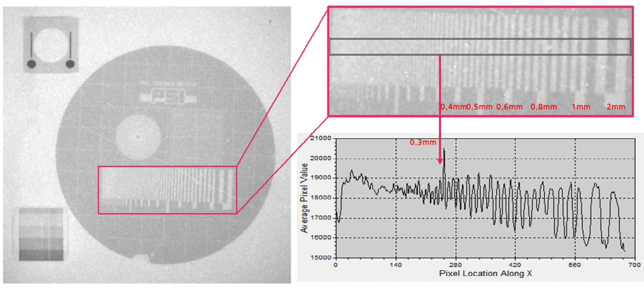

Fig. 4 Neutron image of the bar pattern to measure the MTF (left) and enlarged MTF bar and an intensity profile of the image (right)

4. Conclusions and Future works

KAERI has developed a variety of neutron generators and CANS according to the established neutron sources development plan, utilizing our over 40 years of research experience and technologies for fusion plasma heating and engineering. Recently, the 30 MeV cyclotron-based neutron source has developed starting in April 2020 and preliminary tests at 0.01 mA confirmed its performance of the more 10^{12} n/s with a neutron imaging resolution of 0.3 mm. In the near future, we will further confirm the neutron imaging by increasing the current which will enable industrial service.

ACKNOWLEDGMENTS

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