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RAON neutron science facility design for measuring neutron-induced cross-section

Jae Cheon Kim[1,a], Jae Bum Son[2], Gi Dong Kim[1], Mitja Majerle[3], and Yong-Kyun Kim[1,2]

[1] *Rare Isotope Science Project, Institute for Basic Science, Daejeon 305-811, Republic of Korea*
[2] *Department of Nuclear Engineering, Hanyang University, Seoul 133-791, Republic of Korea*
[3] *Karlsruhe Institute of Technology, Eggenstein-leopoldshafen 76344, Germany*

Abstract. A heavy-ion accelerator complex called RAON is currently under development in Korea. The neutron science facility (NSF) is a part of RAON to produce white and mono-energetic neutrons covering the 10-90 MeV energy range with high-intensity. Deuterons and protons with ≤ 53 MeV and ≤ 88 MeV, respectively, accelerated by superconducting linac are delivered to the neutron target to produce fast neutrons. Pulsed beam intense is up to more than $\sim 20\mu A$ enough for measurements of neutron-induced reactions at the neutron time-of-flight (n-TOF) facility. Be and C target are used to produce white neutrons and Li target is used for mono-energetic neutrons. Basically, two neutron beam lines at 0° and 30° will be constructed by using neutron collimator. In NSF, the time projection counter (TPC) is employed to measure fission cross-section with ~few % uncertainty.

1 Introduction

An accelerator complex called RAON plans to provide the first primary beam into the neutron science facility (NSF) for producing fast neutrons covering the 10-90 MeV energy range with high-intensity in early 2018. Deuterons and protons with ≤ 53 MeV and ≤ 88 MeV, respectively, accelerated by superconducting driver linac (SCL1) will be delivered to the neutron target to produce fast neutrons. Pulsed beam intense is up to ~20μA enough for measurements of neutron-induced cross-sections. The proton and deuteron beam frequency are variable from 1 MHz to 1 kHz while linac primary beam frequency is 81.25 MHz. The beam width is ~10 ns. In order to maximize the effectiveness and availability of RAON, NSF will be located in the area of Low Energy Experimental Facility after driver linac of SCL1 as shown in Figure 1.

For neutron time-of-flight (n-TOF) in NSF, basically, two neutron beam lines will be available at 0° and 30°. More flexible collimators will be studied to use various beam energies. Fission (n,f), inelastic scattering (n,n′γ), and neutron multiplicity (n,xn) are known to play an dominant role in over ~10 MeV energy region. The design of next generation nuclear power plants and advanced accelerated-driven sub-critical systems highly depends on the accuracy of the libraries on neutron-induced reactions in this energy region.

[a] e-mail: jaecheon@ibs.re.kr

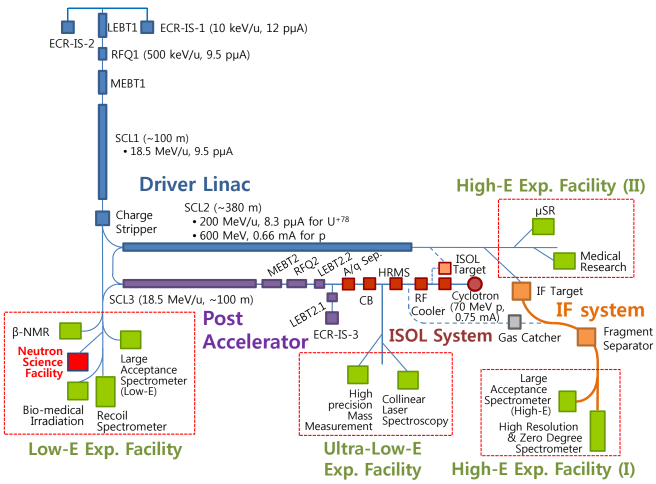

Figure 1. The schematic view of RAON and the potential location of neutron science facility at RAON.

2 Target and Beam Line

The building of NSF is divided into the two main sectors such as target and TOF hall. For production of white and mono-energetic neutrons, target system will be located before and after clearing magnet in target hall as shown in Figure 2 (left). For neutron time-of-flight, two flight paths of 5 m and 20 m will be considered, respectively.

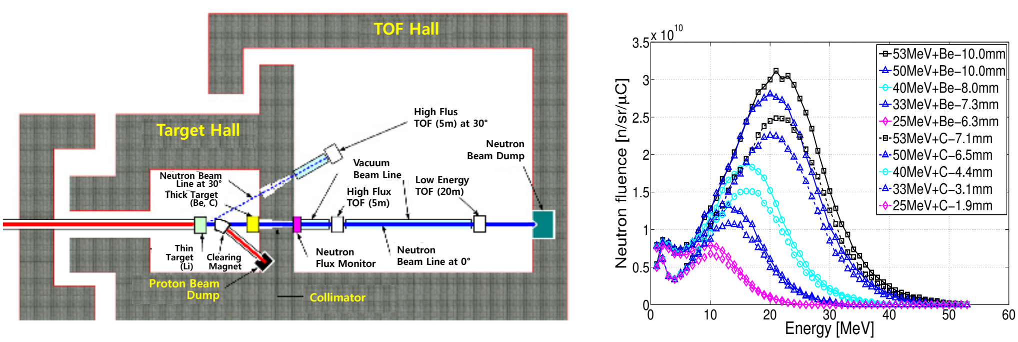

Figure 2. Conceptual design of neutron science facility (left) and neutron spectral fluence at 0° produced by bombardment of deuteron beams with thick Be and C target as a function of incident deuteron energies (right).

There are several main devices such as the target (Be, Li, and C) system, proton/neutron beam line, beam dump, vacuum system, 0° and 30° neutron collimator, radiation monitoring system, and several nuclear data measurement systems such as fission, inelastic, neutron multiplicity, and capture.

The neutron spectra produced by bombardment of deuteron and proton beams on target have been reproduced by Monte Carlo codes. From ≤ 88 MeV protons and ≤ 53 MeV deuterons, fast neutrons have energies almost as high as those of driver linac primary beams. Figure 2 (right) shows the neutron spectra at 0° as a function of incident deuteron energy simulated by McDeBe and McDeC codes considering the stripping and compound models for deuteron-Be and deuteron-C interactions [1] [2]. MCNPX calculations with built-in nuclear reaction models significantly disagree with available experimental data. Because traditional MCNPX code do not include the stripping and compound models for deuteron-nuclei interaction.

In NSF, thermal safety of target system should be examined carefully due to beryllium's toxicity. According to the repetition rate of 53 MeV deuterons, beam currents are 2.5 μA at 100 kHz and 24.6 μA at 1 MHz, respectively, Assuming rotation target, maximal power deposition becomes 0.13 kW and 1.3 kW, respectively. Figure 3 shows the geometry of rotating Be target irradiated by deuterons and their temperature distribution calculated by ANSYS code. As a result, the maximum temperature is 1062°C at 1.3 kW and it nearly approaches to the melting point of Be, 1278°C. For preventing oxidation of Be by the heating power of the primary beam, it is necessary to use suitable external cooling devices with the rotation target, additionally.

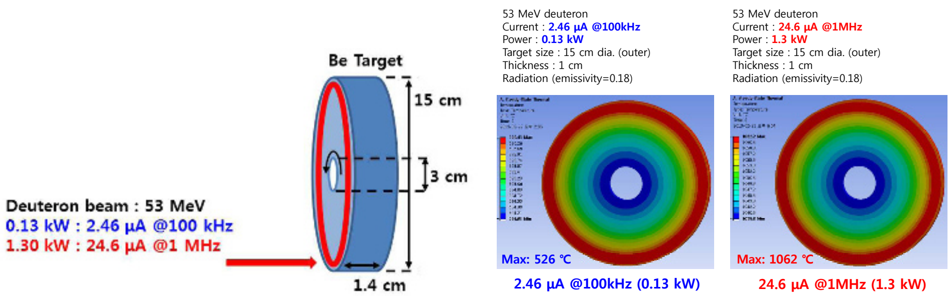

Figure 3. The geometry of the Be target (left) and their temperature distribution when the thermal power by primary beams is 0.13 kW and 1.3 kW (right).

3 Measurement System and Radiation Protection

It is reported that neutron-induced reactions such as fission (n,f), inelastic scattering (n,n$'\gamma$), and neutron multiplicity (n, xn) are unknown or known with poor precision in higher energy range over ~10 MeV. NSF is well suited to produce fast neutrons with similar energies. Therefore, we will focus on measurement of fission, inelastic scattering, and neutron multiplicity reactions.

It is reported that uncertainties for fission cross-section libraries are 2-3% below 14 MeV and over 10% at higher energies. There are three dominating issues that contribute to the high uncertainty of fission cross-section in conventional detector such as fission chamber [3]. First, traditional fission chambers only measure deposited energy and cannot distinguish between a fission fragment, a neutron scatterer, and alpha decay. The most significant uncertainty of fission cross-section comes from this ambiguity. Second, the quantity of target material and the target thickness should be accurately determined by counting the spontaneous alphas. However, accurate determination of the target thickness is difficult due to several systematic errors such as uncertainties in the alpha counter calibration, averaging over variations across the full target and so on. Third, the use of ^{235}U reference that is the conventional method to measure the beam flux causes its own intrinsic statistical error in fission cross-section measurement.

Recently, many researchers have been paying attention to employment of a time projection chamber (TPC) for measuring fission cross-section. Because a TPC can measure charged particle trajectories in the active volume in three dimensions as well as energy deposition and overcome above three issues remarkably. In addition, a TPC can directly measure the neutron beam flux by ^{1}H(n,n′) reaction of drift gas ^{1}H. In order to measure fission cross-section with less than ~ few % uncertainty, the TPC will be employed for n-TOF detector system in NSF.

Since NSF will use fast neutrons up to ~90 MeV with high-intensity, radiation protection have to be performed faithfully for safety of workers. For radiation protection, there are two things to be considered. The first is immediate radiation dose caused by fast neutrons. The second is gamma-ray dose by secondary radiation from various substances (concrete, accessories of the experiment, etc.) activated by the fast neutrons. After operating accelerator, it is an element that gives constraints such as working and cooling time of the experimental facility. Figure 4 (left) shows the radiation dose as a function of shielding thickness when 53 MeV neutrons are incident on the wall. The concrete of 3 m thickness does not satisfy the annual dose limit of worker 5 μSv/h except considering an additional shielding such as iron in front of concrete. For evaluation of immediate radiation dose, 53 MeV deuterons whose beam current is 24.6 μA at 1 MHz are assumed to be incident on Be target and its neutron yield at each direction was calculated. Based on the basic layout in Figure 2, the external prompt dose rate by the neutron was calculated. Figure 4 (right) shows the ambient dose rate in the neutron facility.

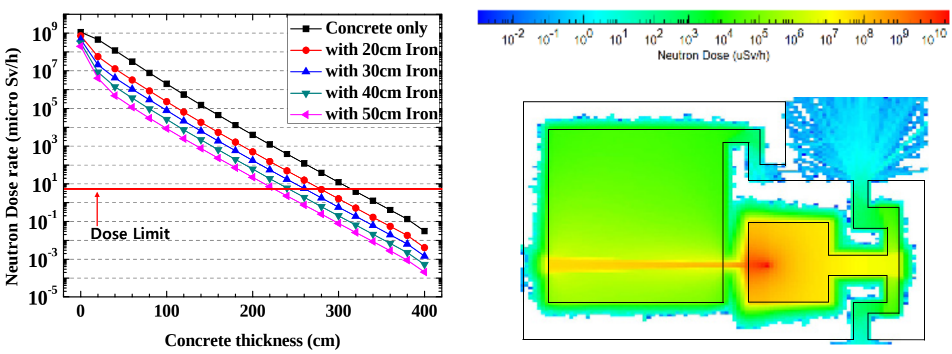

Figure 4. The neutron dose rate modulation depending on the thickness of radiation shielding (left) and the external prompt dose rate in the experimental facility occurred by the neutron beam during operation (right).

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