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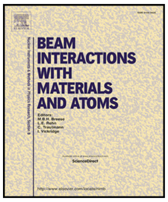

Overview of nuclear data production system at RAON

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ABSTRACT

Nuclear Data Production System (NDPS), a fast neutron facility for nuclear science and applications, was constructed at the Rare Isotope Accelerator complex for ON-line experiments (RAON) in Korea. NDPS is designed to provide both white and quasi-monoenergetic neutrons using 98 MeV deuteron and 20 – 83 MeV proton beams with thick graphite and thin lithium targets, respectively. Neutron energy is determined by employing the Time-Of-Flight (TOF) technique, along with a pulsed deuteron (or proton) beam with a repetition rate of less than 200 kHz. Fast neutrons are produced in the target room and are guided to the TOF room through a 4 m long neutron collimator consisting of iron and 5% borated polyethylene. The neutron beam is monitored using a parallel plate avalanche counter (PPAC) and a micro-mesh gaseous (MICROMEGAS) detector installed in the TOF room, so as to measure the energy and the position of neutrons.

1. Introduction

Neutron-induced reaction data play an important role in various fields, such as nuclear energy, medical applications, nuclear safeguards and nuclear astrophysics. Improvements of nuclear data are required as science and technology develop. Current neutron reaction data are still insufficient and inaccurate especially in the MeV energy region. High-energy neutron-induced reaction data are needed in a variety of applications such as accelerator-driven systems, radiation shielding, and fusion technologies.

RAON is a heavy ion accelerator facility that provides stable and rare isotope (RI) beams in Korea [1–5]. The RAON accelerator is designed to provide beams from proton to uranium over a wide energy range. Therefore, RAON can be utilized in various fields not only for pure science but also for applications.

Nuclear Data Production System (NDPS) [6,7] is one of the experimental facilities at RAON. NDPS provides neutron beams not only for nuclear data measurements but also for other applications. The installation of NDPS was completed along with the transport beamline from Super Conducting LINAC 3 (SCL3) to the NDPS facility in 2022. In this paper, the details of NDPS are described, together with the current status.

2. Nuclear Data Production System

NDPS is a fast neutron TOF facility that generates neutron beams up to 100 MeV by utilizing proton and deuteron beams from SCL3. For neutron TOF experiments, a fast chopper and a double gap buncher are installed at the low energy beam transport line (LEBT) in order to provide pulsed ion beams with a repetition rate less than 200 kHz and a bunch length less than 1 ns in FWHM [8]. Pulsed proton and deuteron beams are accelerated by SCL3 and delivered to NDPS through the SCL3-NDPS transport beamline.

NDPS has two experimental rooms separated by a 4 m long neutron collimator, as shown in Fig. 1. In the NDPS target room, ion beams are transported to the neutron production target chamber. Neutrons are generated in the target room and delivered to the TOF room through the neutron collimator. Neutron detectors and an experiment chamber are installed for the experiments in the TOF room. The neutron beam dump is located in the TOF room and the distance between the target and the beam dump is about 50 m. The specifications of NDPS are summarized in Table 1.

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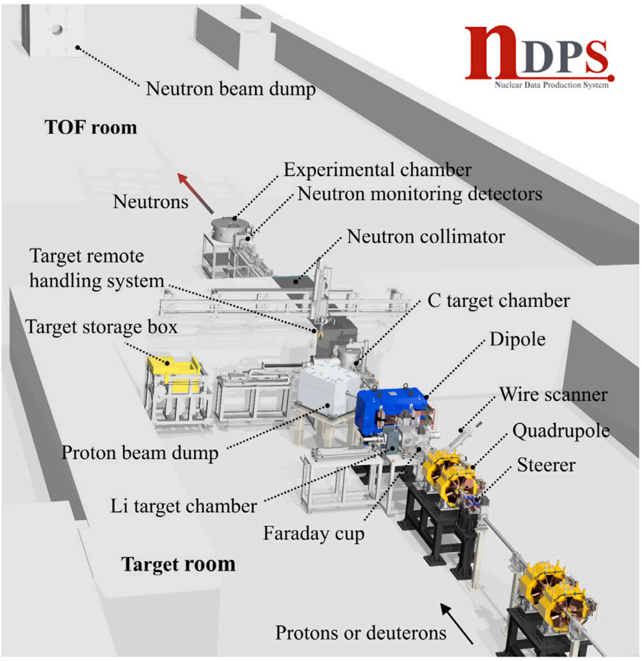

Fig. 1. Schematic view of NDPS.

Table 1
Specification of NDPS.

Beam ion	Proton, deuteron
Maximum beam energy	98 MeV (deuteron) 83 MeV (proton)
Maximum beam current	10 μA
Target	Graphite and lithium
Bunch length of pulsed beam	1 ns in FWHM
Repetition rate of pulsed beam	< 200 kHz
Flight length of neutron	5 – 50 m
Maximum neutron flux at 0° (at 5 m away from the target)	10^8 cm^{-2} s^{-1}

2.1. Neutron production target system

NDPS provides both white and quasi-monoenergetic neutrons, using 98 MeV deuteron and 20 – 83 MeV proton beams. White neutrons are generated by bombarding deuteron beams into a 30 mm thick graphite target located upstream of the neutron collimator. A target remote handling system is also installed to transport the graphite target after use to a 10 cm thick lead shield box, which is the interim storage.

A thin lithium target, which is located in the middle of the target room, can also be used to generate quasi-monoenergetic neutron beams when bombarded with an incident proton beam. Proton beams passing through the thin target are bent by a dipole magnet and stop at a proton beam dump.

Fig. 2 represents neutron yields calculated by using MCNPX code [9]. In particular, neutron production with deuteron beams is calculated with the more precise MCNPX extension code “McDeC” [10] developed by KIT because the McDeC reproduces the experimental data well for the neutron production with deuteron beams on a carbon target as reported in Ref. [11]. When 98 MeV deuteron beams bombard a graphite target, the neutron flux at 5 m from the target was calculated to be 10^8 cm^{-2} s^{-1} at 0° from the MCNPX + McDeC simulation results.

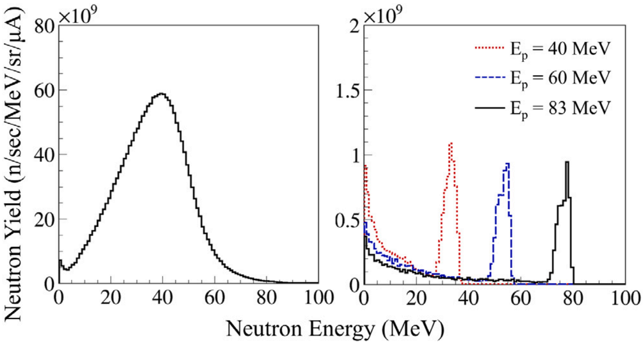

Fig. 2. Calculated neutron yields at 0° produced by (left) 98 MeV deuterons with a 30 mm thick graphite target, and (right) 40, 60, 83 MeV protons with a 5 mm thick lithium target.

2.2. Magnets

Four quadrupole magnets, two steering magnets, and a dipole magnet are installed in the target room for the transport of ion beams to the target. An H-type dipole magnet is installed downstream of the lithium target chamber to bend protons to a proton beam dump located at 30° to the beam axis. This also enables the installation of an additional beamline at 30° on the opposite side in the future.

2.3. Ion beam diagnostics

Four beam pick-up monitors, a wire scanner, a faraday cup, a fast faraday cup, and a capacitive pick-up monitor are installed in the target room. A capacitive pick-up monitor is installed upstream of the lithium target chamber to measure longitudinal bunch length and arrival time, which is important parameters for neutron TOF experiments. A wire scanner, a faraday cup, and a fast faraday cup are installed at the beam diagnostic chamber to measure the profile, current, longitudinal bunch length, and arrival time of ion beams.

2.4. The proton beam dump

A proton beam dump is installed at 30° from the beam line. The proton beam dump is made of copper and cooled by water. It is also designed to measure the beam current like a faraday cup. The proton beam dump is surrounded by 10 cm thick lead blocks for radiation shielding.

2.5. The neutron collimator

The neutrons produced from the target pass through a 4 m long neutron collimator and are delivered to the TOF room, where experiments are conducted. The neutron collimator is designed to reduce the background neutrons while maintaining neutron intensity. Ring-shaped iron and 5% borated polyethylene are arranged in layers in the beam direction inside a 4 m long beam pipe. The collimator is divided into four sections, each section having the same inner radius and spanning a length of 1 m. From the side adjacent to the target room, the initial section has an inner radius of 0.5 cm, which increases by 0.5 cm in diameter for every 1 m. On the opposite side, adjacent to the TOF room, the final section has an inner radius of 2 cm. The neutron beam size can be adjusted by replacing the collimator pieces inside the beam pipe. Further details of the neutron collimator for NDPS are described in [12].

Fig. 3. Photographs of (a) the target room, (b) the detectors in the TOF room, and (c) the neutron beam dump in the TOF room.

2.6. The neutron beam dump

Neutrons emitting from the neutron collimator travel 50 m in the TOF room and are stopped at the neutron beam dump. The neutron beam dump is a concrete block with a size of 3 m × 3 m × 4 m. It has an opening radius of 30 cm and a 2 m deep hole to minimize backscattering to the TOF room. The neutron beam dump is installed at the end of the TOF room for safety. The thickness of the neutron beam dump in the beam direction is determined to be 2.6 m, to maintain a dose rate of less than 0.25 μSv/h outside of the building, which is the dose limit for the public.

2.7. Neutron monitoring detectors

PPAC (Parallel Plate Avalanche Counter) and MICROM-EGAS (MICRO MEsh GAseous Structure) detectors are installed to monitor neutron flux and the neutron beam profile. These two detectors are appropriate for neutron TOF measurements due to the good timing resolution of about 1 ns for the MICROMEGAS detector [13] and less than 1 ns for the PPAC detector [14,15]. As a neutron converter, ^{232}Th is used because the ^{232}Th(n,f) reaction has large cross-sections for high-energy neutrons. The ^{232}Th converter is made by electro-deposition on an aluminum foil. The areal density of the electro-deposited ^{232}Th is about 300 μg/cm^2. The detection efficiency of the neutron detectors with the ^{232}Th converter was calculated as around 10^{-7} counts/neutrons with a GEANT4 simulation [16]. Additionally, EJ-301 liquid scintillators are also installed to measure neutron flux and validate the performance of the PPAC and MICROMEGAS detectors. Further details of the neutron monitoring detectors for NDPS are described in [17].

3. Status of NDPS

The main components of NDPS were installed along with a 65 m transport beamline from SCL3 in 2022. Fig. 3 shows photographs of NDPS after installation. Power cables, signal lines, pneumatic plumbings, and cooling pipes are also installed and connected to each device, together with the installation of cable trays. All the components of NDPS are controlled and monitored remotely from the NDPS control room in the basement of the TOF room. NDPS control system was developed using Siemens Programmable Logic Controllers (PLC) and Experimental Physics and Industrial Control System (EPICS).

The first beam commissioning and experiment are planned for 2024. In the early stage, a beam commissioning at NDPS will be performed with a proton beam. The neutron-induced fission reaction cross-section will be measured as the first experiment. A detector array, consisting of a microchannel plate detector and passivated implanted planar silicon detectors, is being developed for neutron-induced fission reaction experiments.

4. Summary

We have constructed a neutron TOF facility NDPS at RAON. NDPS will provide white and quasi-mono-energetic neutrons. Users can utilize the neutron beam in the energy range of less than 100 MeV. The maximum flight length of neutrons in the TOF room is about 50 m from the target.

The first NDPS beam commissioning with a proton beam is planned for 2024. At NDPS, nuclear data measurements with charged particles will also be planned in the future. We expect that NDPS will give an opportunity to perform experiments for nuclear physics and other applications as well as for nuclear data measurements.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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