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STUDY ON CONSTRUCTION OF AN ADDITIONAL BEAMLINE FOR A COMPACT NEUTRON SOURCE USING A 30 MeV PROTON CYCLOTRON

Y. Kuriyama*, M. Hino, Y. Iwashita, R. Nakamura, H. Tanaka
Institute for Integrated Radiation and Nuclear Science, Kyoto University, Kumatori, Japan

Abstract

The Institute for Integrated Radiation and Nuclear Science, Kyoto University (KURNS) has been actively using neutrons extracted from the research reactor (KUR) for collaborative research. Since the operation of KUR is scheduled to be terminated in 2026 according to the current reactor operation plan, the development of a general-purpose neutron source using the 30 MeV proton cyclotron (HM-30) installed at KURNS for Boron Neutron Capture Therapy (BNCT) research has been discussed as an alternative neutron source. In this presentation, we report on the conceptual design of an additional beamline for a compact neutron source using this cyclotron.

INTRODUCTION

At the Institute for Integrated Radiation and Nuclear Science, Kyoto University (KURNS), a medium-sized neutron source, neutrons extracted from a research reactor (KUR) with a maximum thermal power of 5 MW has been actively used for joint use. However, due to the deadline for the return of spent fuel, the KUR is not expected to continue operation after 2026, so there is an urgent need to construct a neutron source to replace the KUR.

Since 2007, Kyoto University has been developing a Boron Neutron Capture Therapy (BNCT) system using a proton cyclotron (HM-30), an average beam current of 1 mA and extraction beam energy of 30 MeV [1]. This system consists of HM-30 and a target station that moderates neutrons generated from Be targets to an energy suitable for BNCT [2, 3].

In 2019, HM-30 was transferred to Kyoto University, therefore, the consideration to use HM-30 as a proton accelerator for the KUR alternative neutron source had been started. Figure 1 shows KUR, Kyoto University Critical Assembly (KUCA), and Innovation Research Laboratory (Innovelab).

Figure 1: Appearance of KUR, KUCA and Innovelab in KURNS.

* kuriyama.yasutoshi.6n@kyoto-u.ac.jp

ACCELERATORS INSTALLED IN INNOVELAB AT KURNS

Innovelab at KURNS is equipped with four ring accelerators and one linear accelerator. Among these accelerators, the 150MeV FFAG main-ring (MR) and its injector [4], the 11MeV linear accelerator (linac) and HM-30 are currently in operation.

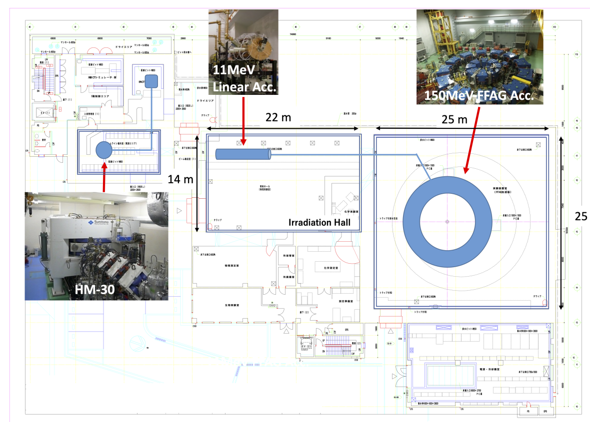

Figure 2: Layout of accelerators in Innovelab building at KURNS.

The Innovelab is divided into a medical building and an experimental building. HM-30 is located on the first floor of the medical building, and MR and linac are on the first floor of the experimental building. Figure 2 shows the layout of the accelerators in the Innovelab.

To make a room for a neutron generation target station in the irradiation hall (left-side of the experimental building), the linac has to move to the MR room (rigth side of the experimental building).

30MeV PROTON CYCLOTRON (HM-30) AT KURNS

30MeV proton cyclotron (HM-30), manufactured by Sumitomo Heavy Industories, had been installed for BNCT research in Innovbelab medical building in 2008. Figure 3 shows HM-30, and Table 1 shows the main specifications of the HM-30 [1].

For BNCT research, a 30 kW proton beam is extracted from the HM-30 and transported to the target station by 90-degree beam transport, as shown in Fig. 2.

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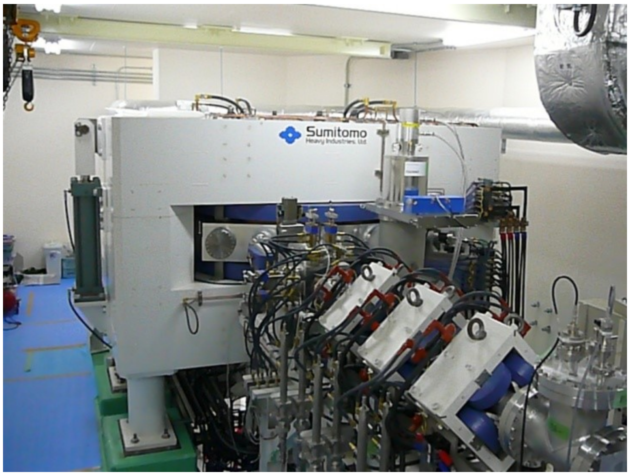

Figure 3: HM-30 in Innovelab.

Table 1: Specifications of HM-30

Particle	H^-
Injection Energy	30 keV
Extraction Energy	30 MeV
RF Frequency	73.1 MHz (h=4)
RF Voltage	200 kV/turn
Extraction Scheme	Foil
Extraction Beam Current	1 mA (DC)
Machine Size	W×D×H:3×1.6×1.7 m

ADDITIONAL BEAM TRANSPORT FOR GENERAL PURPOSE ACCELERATOR BASED NEUTRON SOURCE

The target station for the general purpose accelerator based neutron source is being considered for installation in the irradiation hall in the Innovelab experimental building. Figure 4 shows the additional beam transport (BT2) under consideration in blue. The distance from the HM-30 extraction point to the neutron producing target is roughly 15~20 m.

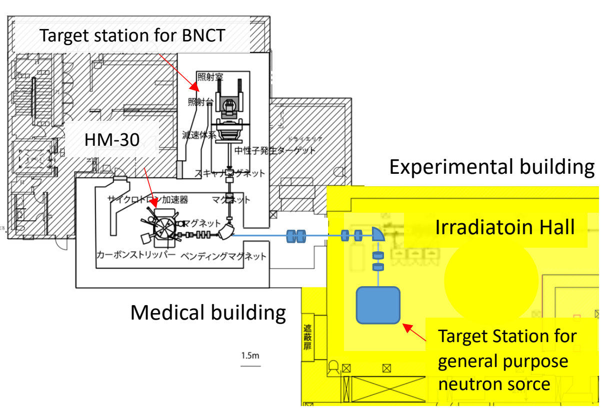

Figure 4: Additional beam transport for accelerator based neutron source. Blue objects indicate component of additional beam transport.

Construction of a Calculation System Using G4beamline

In order to perform beam transport calculations for the BT2 design, a calculation system using G4beamline (g4bl) [5] was developed. Figure 5 shows a 3D diagram of the calculation system constructed by g4bl.

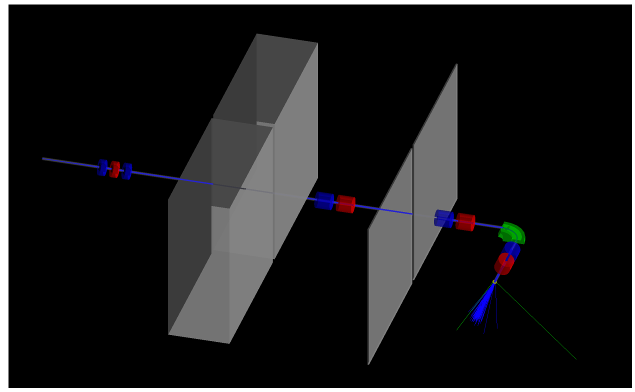

Figure 5: Computation geometry of additional beam transport for accelerator drive neutron source using G4beamline. Green object indicates bending magnet and blue and red objects indicate focus and defocus quadruople magnets, respectively. Be target is located at the endpoint.

The beam transport calculations for the HM-30 extraction beam are tentatively performed assuming gaussian distribution and Eq. (1) as the initial beam parameters.

$$\begin{aligned} \sigma_x &= \sigma_y = 3\text{mm} \\ \sigma_{x'} &= \sigma_y' = 1\text{mrad} \\ \Delta P &= 1\% \end{aligned} \quad (1)$$

Figure 6 shows the initial beam size and the beam size calculated by g4bl at the neutron generation target located about 19 m from the HM-30 extraction position.

Figure 7 shows the beam size along beam transport, starting from the HM-30 extraction position.

The inner diameter of the beam pipe to be used for the additional beam transport will be 100 mm in diameter. Therefore, the beam size during beam transport must be kept under ±50 mm. Taking into account the heat load on the target, the beam size should be about the same as the target size.

ESTIMATION OF NEUTRON GENERATION BY PHITS

Neutron Generation Targets

From the BNCT study, a 5.5 mm thick Be target is planned to be used as the neutron generation target. 5.5 mm thickness allows the proton range to be longer than the target thickness, so that the incident protons do not stop in the target but are injected into the cooling water. This will suppress the occurrence of blistering phenomena.

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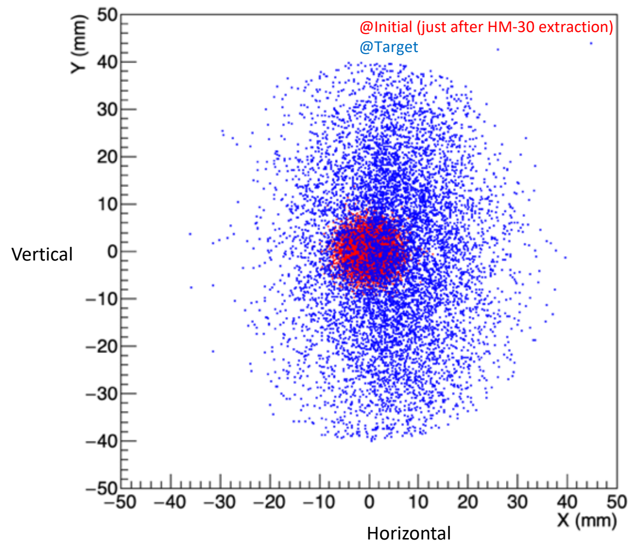

Figure 6: The comparison at initial condition (red dots) and after transport (blue dots) based on beam size using G4beamline.

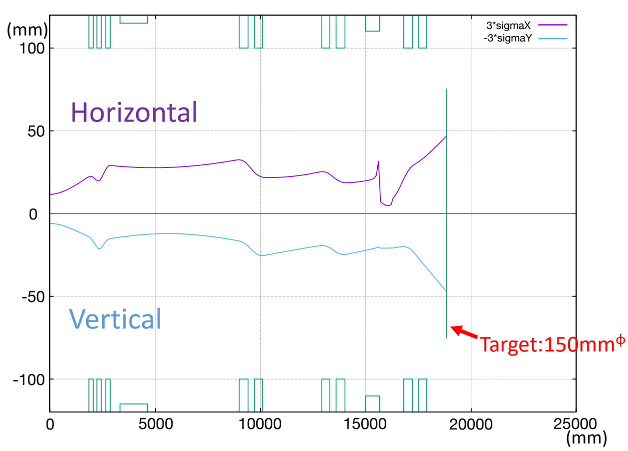

Figure 7: Beam tracking result of the additional beam transport (BT2) for general purpose accelerator neutron source using G4beamline.

Estimation of Neutron Generation

PHITS (ver. 3.04) [6] was used to estimate the amount of neutrons produced when a uniform circular 30 MeV proton beam of 120 mm diameter is injected into a 5.5 mm thick Be target. The results of the PHITS calculations are shown in Fig. 8.

Based on the PHITS calculations, assuming an average beam current of 1mA, the neutrons produced are expected to be 1.6E-2 neutrons/proton and the total neutrons produced are expected to be 1E14 neutrons/s.

SUMMARY AND FUTURE PLANS

Although the KUR has been actively used for joint use at KURNS, it is expected to be difficult to continue the operation of the KUR after 2026 due to the deadline for the return of spent fuel. Therefore, the development of a general-purpose neutron source using HM-30 has been discussed as an alternative neutron source. The conceptual design of the additional beam transport from HM-30 to the general purpose neutron generation target station has been carried out using g4bl. In addition, calculations using PHITS are being performed to estimate the neutron generation. Currently, we are at the stage of evaluation with tentative parameters, but we plan to perform beam transport calculations with more realistic beam parameters.

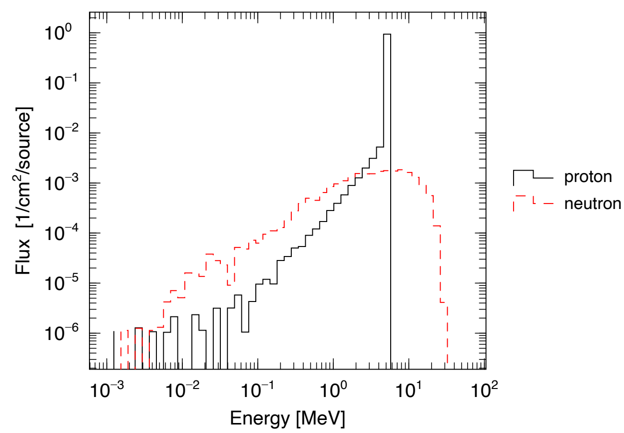

Figure 8: Calculated neutron and proton energy distribution from Be target using PHITS.

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