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# Measurement of energy spectra and spatial distributions of neutron beams provided by the ANNRI beamline for capture cross-section measurements at the J-PARC/MLF

K. Kino [a,*], M. Furusaka [a], F. Hiraga [a], T. Kamiyama [a], Y. Kiyanagi [a], K. Furutaka [b], S. Goko [b,1], H. Harada [b], M. Harada [b], T. Kai [b], A. Kimura [b], T. Kin [b], F. Kitatani [b], M. Koizumi [b], F. Maekawa [b], S. Meigo [b], S. Nakamura [b], M. Ooi [b], M. Ohta [b,2], M. Oshima [b], Y. Toh [b], M. Igashira [c], T. Katabuchi [c], M. Mizumoto [c]

[a] *Graduate School of Engineering, Hokkaido University, Kita 13 Nishi 8, Kita-ku, Sapporo 060-8628, Japan*
[b] *Japan Atomic Energy Agency, 2-4 Shirakata Shirane, Tokai, Naka, Ibaraki 319-1195, Japan*
[c] *Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology, O-okayama, Meguro-ku, Tokyo 152-8550, Japan*

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ABSTRACT

We measured the energy spectra and spatial distributions of the neutron beam of Accurate Neutron-Nucleus Reaction Measurement Instrument (ANNRI) at the Japan Proton Accelerator Research Complex/Materials and Life Science Experimental Facility (J-PARC/MLF). Our research team designed and built ANNRI to measure nuclear data with high precision. The measurements of the neutron beam were performed on three types of beams provided by ANNRI in the neutron energy range from 1.5 meV to 10 keV. The energy spectra show a typical feature of para-hydrogen moderator, and the absolute intensities almost agree with predictions based on both a simulation calculation of the Japan Spallation Neutron Source (JSNS) and a neutron transmission calculation of the beamline. The available neutron intensities at 21.5 m are $7.5\times10^5$, $1.6\times10^4$, and $1.1\times10^5$ n/cm$^2$/s in the energy ranges 1.5–25 meV, 0.9–1.1 eV, and 0.9–1.1 keV, respectively, under the 17.5 kW JSNS operation. The measured spatial distributions of the beams formed by three different collimators are consistent with those expected from the collimator-system design of the beamline. The beam sizes in FWHM are about 29, 14, and 11 mm for the three different beam collimators. The edges of the spatial distributions are relatively sharp, enabling us to measure the nuclear data successfully.



## 1. Introduction

The development of technologies used in treating minor actinides (MAs) and long-lived fission products (LLFPs) in nuclear waste are important for the environment. Innovative reactor systems such as a fast reactor and an accelerator driven system are expected to reduce their radio toxicity by reusing MAs as a nuclear fuel and transmuting MAs and LLFPs to less radioactive isotopes or stable nuclei. However, the present cross-section data of some MAs are still not accurate enough [1]. For LLFPs, scarcity and inconsistency of experimental cross-section data are pointed out [2]. In recent years, n_TOF at CERN [3] and DANCE at LANSCE [4] have been providing cross-section data on MAs and LLFPs using pulsed neutron beams from spallation neutron sources.

However, accurate neutron-capture data of some MAs and LLFPs are difficult to obtain because sample amounts are limited by high radioactivity and/or isotopic contamination in samples cannot be avoided. Solutions to this problem include the use of a neutron beam with intensity several orders of magnitude higher than those ever used at other facilities, and a gamma-ray detector that has high energy resolution and a large solid angle for gamma rays from the neutron-capture reaction. With the intense neutron beam and high detection efficiency, data are expected to be statistically accurate enough even for small samples. For samples whose isotopes are contaminated, we could provide reliable data on intended isotopes by distinguishing them using gamma rays peculiar to them.

Therefore, we decided to build a beamline [5] at the Japan Spallation Neutron Source (JSNS) [6], which became operational in June 2008 and which is one of the most intense pulsed neutron sources in the world. To detect gamma rays, we employed an upgraded 4πGe spectrometer system that had been in use at the time-of-flight neutron beamline at the electron LINAC of the Kyoto

* Corresponding author. Present address: High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan. Tel.: +81 29 284 4628; fax: +81 29 284 4899.
*E-mail address:* kkino@post.kek.jp (K. Kino).
[1] Present address: Graduate School of Engineering, Hokkaido University, Kita 13 Nishi 8, Kita-ku, Sapporo 060-8628, Japan
[2] Present address: Osaka University, Yamadaoka, Suita, Osaka 565-0871, Japan

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University Research Reactor Institute [7]. The solid angle has been increased and the data acquisition system has been made faster.

One of the key issues for successful measurement with the intense neutron beam and Ge spectrometer mentioned above is that the neutron beam has two characteristics: high intensity in a target area on the sample and a well-defined edge outside this area. Neutrons, which enter the Ge spectrometer directly or via scattering with materials outside the sample, become backgrounds through the neutron-capture reaction inside the Ge spectrometer. Therefore, we designed a beamline collimator system carefully using simulation calculations [8]. To assess the system's performance, we measured neutron energy spectra and spatial distributions at the sample position of the Ge spectrometer. In this paper we report the measured results and discuss them in comparison to designed values obtained by simulation.

## 2. The ANNRI facility

### *2.1. The ANNRI beamline*

At JSNS, a 3 GeV proton beam is bombarded on the mercury target at a repetition of 25 Hz. Neutrons generated by the spallation reaction in the mercury target are slowed down in the three types of moderators located above and below the mercury target. Neutron beams are extracted from the moderators and provided to 23 beamlines [9].

The total system for cross-section measurements is called "Accurate Neutron-Nucleus Reaction Measurement Instrument (ANNRI)". The ANNRI beamline is Beamline 04 (BL04) at JSNS. Fig. 1 shows the structure of ANNRI. ANNRI uses neutrons from a coupled moderator (140 mm in diameter and 120 mm in height) that provides the most intense neutron beam among the three moderators at JSNS. The neutron beam emitted from the moderator goes through the T0 chopper, neutron filter, double disk chopper, and rotary collimator instruments and the two experimental areas, and then is dumped into the beam stopper. Neutron intensity monitoring devices will be also installed in the beamline in the future.

The sample position of the Ge spectrometer is 21.5 m from the moderator and is in the experimental area 1. In addition to the Ge spectrometer, there is a NaI spectrometer at 27.9 m, which is in the experimental area 2. We use this spectrometer also for measuring accurate neutron-capture cross-sections. Data in the higher neutron energy region are expected to be obtained by virtue of this spectrometer's fast response. A reliable analysis is possible by the established pulse-height weighting technique [10] for this spectrometer; this will lead to supplemental data, which will help verifying the cross-section data obtained by the Ge spectrometer.

There are five collimators between the moderator and the 21.5 m sample position. The collimator holes become smaller as the collimators become closer to the 21.5 m sample position, so that neutrons from almost entire area open on BL04 ($100 \times 100$ mm$^2$) of the moderator surface can be utilized [8]. The most downstream collimator defines the spatial distribution of the neutron beam at the 21.5 m sample position. This is called a "rotary collimator" and has four collimator holes of different sizes. One of them can be selected by rotation [8]. Three collimator holes have been prepared for the 21.5 m sample position. They are designed to provide beams with diameters of 22, 7, and 3 mm to suit samples of different sizes. Due to a 1.18 m-long space between the downstream edge of the rotary collimator and the 21.5 m sample position, the penumbras are expected to be 37, 22, and 18.5 mm, corresponding to the 22, 7, and 3 mm umbrae, respectively.

The energy resolution of the neutron beam at the 21.5 m sample position depends on the moderator system and the proton-beam operation of JSNS. The proton beam usually consists of two bunches with a distance of 599 ns. The width of each bunch increases up to 185 ns depending on the JSNS power. At the present measurements, the proton beam consisted of one bunch of a 50 ns width. The energy resolution is less than about 1% in FWHM in the energy range of thermal energy to 10 keV. In the case of two bunches in the proton beam, the resolution deteriorates gradually above 10 eV as the neutron energy increases and reaches to about 10% at 10 keV [11].

### *2.2. Simulation of the ANNRI neutron beam*

We performed simulation calculations of the neutron source and the beamline transportation not only to compare the measured data with the simulation calculations but also to apply corrections to the measured data. The Monte-Carlo simulation code PHITS [12]

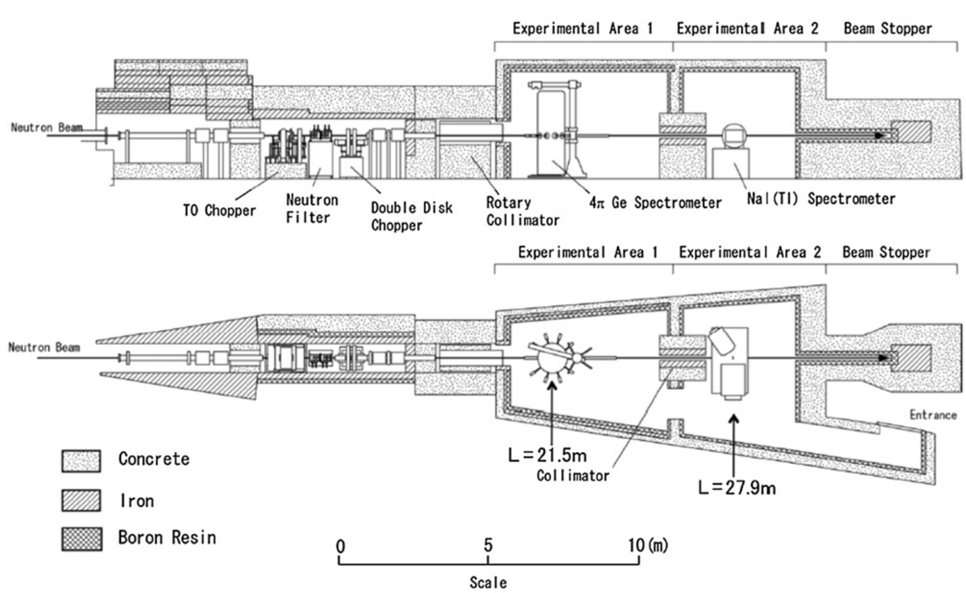


**Fig. 1.** Side and top views of ANNRI. The neutron beam emitted from the moderator goes through the T0 chopper, neutron filter, double disk chopper, and rotary collimator instruments and the two experimental areas, and then is dumped into the beam stopper. The sample positions for the Ge spectrometer and NaI spectrometer are 21.5 and 27.9 m from the moderator, respectively. The rotary collimator just upstream from the $L$=21.5 m sample position defines the spatial beam spots at 21.5 m.