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Properties of neutron beam at the J-PARC/MLF BL04

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ABSTRACT

The neutron beam line 04 (BL04) at the J-PARC/MLF has been constructed to measure neutron capture cross-sections for minor actinides and long-lived fission products. For this purpose, BL04 was designed to provide a high-intensity and well-collimated neutron beam over a wide energy range. To examine the performance of BL04, energy spectra, spatial distributions, and pulse shapes have been measured. The energy spectra are almost in agreement with the simulation predictions in shape and absolute intensity. The measured spatial distributions agree with those of the collimator-system design. The energy resolutions of measured pulses are consistent with those of the simulation calculation of JSNS.

1. Introduction

The innovative reactor systems such as a fast reactor and an accelerator driven system are one of the secure energy sources in a long term. They have been planned to be used for transmutation of long-lived fission products and minor actinides. However, neutron cross-section data of minor actinides and long-lived fission products needed for the design of these systems are not accurate enough since their available amount is very small and/or they include not a little amount of impurity elements. A high intensity neutron source is required to perform the neutron cross-section measurements for the small amount of samples and high impurity rate samples. In order to measure the neutron capture cross-sections of these nuclei with a high accuracy, we have constructed a neutron beam line at JSNS (Japan spallation neutron source) of the Material and Life Science Experimental Facility (MLF) [1] of the Japan Proton Accelerator Research Complex (J-PARC), where the most intense pulsed neutron-beam in the world is expected in the future.

We have measured spatial distributions, energy spectra, and pulse structures of neutrons emitted from the moderator used for the capture cross-section measurements.

Here, we describe such neutronic performances of the beam line as a fundamental data for the cross section measurements.

2. Method for capture cross section measurements

We use the intense pulsed-neutron beam and the 4πGe spectrometer. This beam is provided by the coupled moderator, of which the neutron intensity is highest in the three moderators of JSNS. The 4πGe spectrometer has a high energy-resolution for the gamma ray measurements. These characteristics enable us to measure neutron capture cross-section data accurately. In case of small amount samples due to the high radioactivity and also due to the available amount, the intense beam provides us data with enough statistics. For the samples including unavoidable isotopic nuclei, cross-sections of intended nuclei could be distinguished using gamma rays peculiar to them.

To perform such measurements we need to decrease the background neutron level as low as possible. To suppress the background it is required to make a well defined beam at the sample position. We have designed the beam line collimation system and the insertion devices to fulfil this requirement.

3. Structure of BL04 and collimator system

The instrument for the capture cross section measurements is constructed at beam line No. 4 (BL04). The length from the moderator to the end of the beam line shield is about 35 m. The neutron beam, which is provided by the coupled moderator, goes through the T0 chopper, the filter instrument, and the double disk chopper before getting to the sample position. These instruments have been set in the region of about L=13 m to L=15 m. Hereafter, L means a distance from the moderator. The T0 chopper suppresses the background at the sample position by cutting the high-energy neutrons. Figure 1 is an example of neutron TOF spectra measured at L=21.5 m. The region of high-energy neutrons around TOF=0 msec and the two regions of low-energy neutrons are cut off by the rotor of the T0 chopper. The spectral intensity around time 0 has not reached 0, since around this time region the effect of the frame overlap still exists. Therefore, after correction of the frame overlap the intensity become 0. The maximum rotation frequency is 100 Hz and neutrons with energy higher than 18.6 eV are cut at 100 Hz. Neutrons with energy higher than 18.6 eV are also available by shifting the phase of the rotation. The filter instrument can insert filters of manganese, cobalt, indium, silver cadmium, lead, and

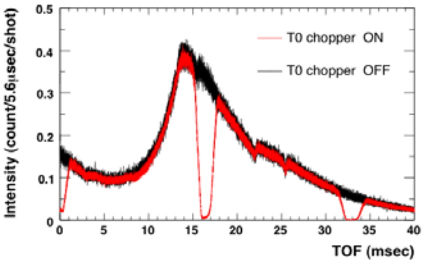

Fig. 1 TOF spectra of neutron at 21.5 m with and without the T0 chopper. The rotation frequency of the T0 chopper is 50 Hz.

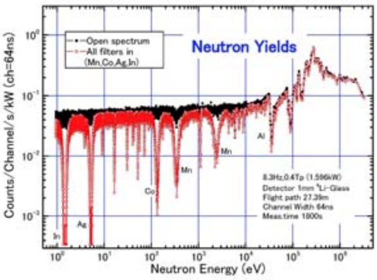

Fig. 2 Neutron energy spectra with and without the resonance filters.

aluminum in the beam line. The lead filter attenuates the gamma flash and the cadmium filter removes frame-overlap neutrons. The filters of manganese, cobalt, indium, silver, and aluminum, work as resonance filters. Figure 2 shows measured neutron spectra with the manganese, cobalt, indium, and silver filters, and without them. The resonances of 1.457 eV (indium), 5.19 eV (silver), 132 eV (cobalt), 336 eV (manganese), and so on can be used for estimating the background. The indium resonance indicates that the background level is extremely low. The double disk chopper consists of two rotating disks. Boron carbide is applied to area of 180 degrees of each disk. By rotation of these disks at 1500 rpm or 3000 rpm, neutrons of an intended energy range are selected and the background is reduced.

The 4πGe spectrometer is placed around 21.5 m from the moderator and consists of two cluster-type Ge spectrometers and eight coaxial-type spectrometers surrounding the sample at L=21.5 m. In addition to the Ge spectrometer a NaI spectrometer is placed at 27.5 m for providing supplemental cross-section data to verify the data obtained by the 4π Ge spectrometer.

Two superior characteristics of the neutron beam are needed for successful measurements. One is a high intensity at the sample position and the other is a well-defined edge outside the sample area. The former is necessary for obtaining high-statistical data. The latter is important for quality of data by suppressing the background. Therefore, we designed the collimator system of BL04 carefully by simulation calculations. [2] There are five collimators between the moderator and the L=21.5m sample position. In the area of L=7 m to L=18 m, the collimators have been designed so that the neutron beam does not hit the inner surface of the beam ducts. The collimator, which is called rotary collimator and placed just upstream of the sample position, defines the spatial distributions of the beams at the sample position. The main part of the rotary collimator is an iron cylinder of a 400-mm diameter and a 1700-mm length along the beam line. This cylinder has four holes of a 100-mm diameter along the beam line and one of holes can be set on the beam line by rotation. Insertion collimators have been inserted in these holes to form beam spots suitable for samples of different sizes at the sample position. The shapes of collimator holes of the insertion collimators have been designed so that the scattering of neutrons is suppressed. Three types of the insertion collimators have been prepared. The diameters of designed umbrae (penumbrae) of the beam are 22 mm (37 mm), 7 mm (22 mm), and 3 mm (18.5 mm).

4. Neutronic properties of the neutron beam

4.1. Energy spectra and spatial distributions

We measured energy spectra and spatial distributions of the neutron beam at the 21.5-m sample position by a position sensitive Li-glass scintillation detector, which was put on the beam line. This detector consists of 256 Li-6 glass scintillators of a 2.1×2.1-mm^2 area and a 1-mm thick, and a photo-multiplier tube (PMT, Hamamatsu H9500). By processing signals of the 256 anodes of the PMT individually, we obtained time-

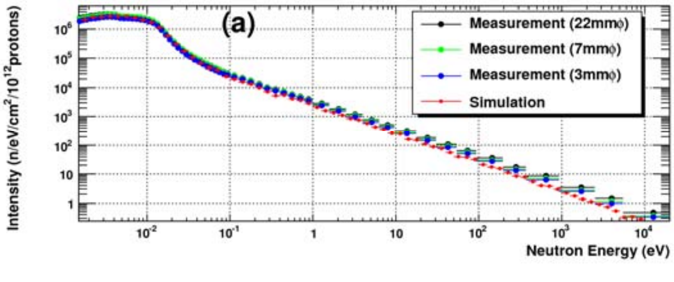

Fig. 3 Energy spectra at L=21.5 m.

of-flight (TOF) spectra and spatial distributions simultaneously. The neutron energy was calculated from the measured TOF value. The power of the proton beam was 17.5 kW and the repetition of the neutron beam was 25 Hz.

The measured energy spectra are shown in Figure 3. These data were corrected for the detection efficiency of neutrons and the loss of neutrons by materials on the beam line between the moderator and the detector. The materials on the beam line are helium gas of 1.03 atmospheres, air of 1 atmosphere, and aluminium windows. Their thicknesses are 1500, 7100, and 14 mm, respectively. The contribution of the frame overlap has been subtracted from the measured data. The spectrum by a simulation calculation of JSNS is shown also. In the low energy region, the measured spectra show a shape expected from the simulation result for the coupled moderator of JSNS. In the epithermal energy region, the measured spectra are almost expressed by 1/E, which is consistent with the slowing-down process of neutrons in an infinite hydrogenous medium. From these results, it was found that the measured spectra almost agreed with the simulation calculation in shape and absolute intensity in the neutron energy range of 1.5 meV to 10 keV.

Figure 4 shows measured spatial distributions of the neutron beams formed by the rotally collimator. The inner and outer circles in each figure are the sizes of the umbra and penumbra of the collimator-system designed. The centers of these circles are set to the centers of gravity on the basis of the measured spatial distributions. One can see that the measured distributions are in agreement with the designed ones. The obtained values of these beam sizes in FWHM are about 29, 14, and 11 mm for the beams of 22, 7, and 3-mm diameters, respectively. These values are in good agreement with the values based on the simulation calculations of the neutron beam transportation. These results mean that the spatial distributions of the neutron beams have well-defined edges as expected from the collimator-system design.

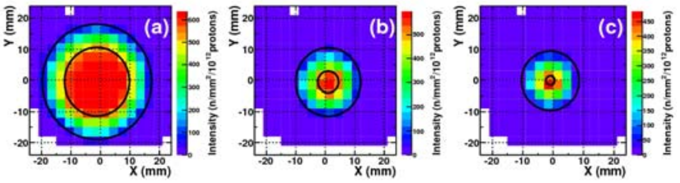

Fig. 4 Spatial distributions at L=21.5 m. (a) 22-mm beam (b) 7-mm beam (c) 3-mm beam.

4.2. Neutron pulses

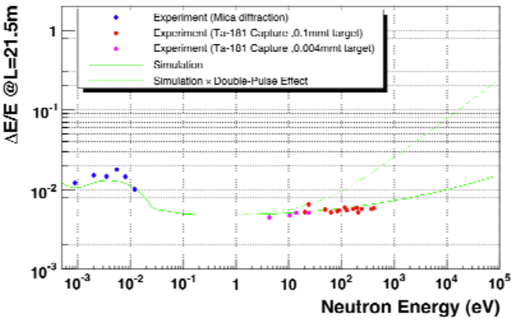

Fig. 5 Energy resolutions at L=21.5 m.

Neutron pulse characteristics of the beam emitted from the moderator are the important factor determining the energy resolution of the measurements. In order to measure pulses, two different methods were applied. One is the diffraction by a mica crystal in the thermal neutron energy region. A helium-3 proportional tube detected the diffracted neutrons to the 85 degrees Bragg angle. The pulse widths were obtained from the diffraction peaks in the measured TOF spectrum. The other is a method using the neutron capture reaction by a tantalum foil in the epi-thermal region. Plastic scintillators detected prompt gamma rays following the capture reaction. The pulse shapes were extracted from resonance peaks seen in the measured TOF spectra by taking into account the intrinsic resonance widths and thermal broadening. From the pulse shapes obtained by this procedure we calculated the energy resolutions as a function of the neutron energy, $\Delta E/E=2\Delta t/t$. Here, Δt is the full width at half maximum of the pulse shape and t is the flight time at L=21.5 m. The energy resolutions of the measured pulses are plotted in Figure 5 with the result of simulation calculations. The resolution is about 1% around thermal energy region, and around 0.5% up to about 1 keV. Proton delivery scheme is usually a double pulse with a time difference of about 600 ns although the data here was obtained in the case of the single pulse mode. Therefore, the effect of the double pulse on the energy resolution appears above about 10 eV as shown in the simulation results. This indicates that we need special method to deduce the real resonance cross section.

5. Summary

We confirmed the validity of the neutron beams provided by BL04 for the properties: energy spectra, spatial distributions, and pulses. These characteristics enable us to measure the capture cross sections of LLFPs and MAs and we have succeeded in obtaining the capture cross sections with the low background condition.

6. Acknowledgements

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7. References

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