Measurement of Neutron Energy Spectra of 345 MeV/u ^{238}U Incidence on a Copper Target

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Thick target neutron yields produced by 345 MeV/u ^{238}U incidence on a copper target were measured at 45° and 90° with time-of-flight method. The experimental results were compared with those calculated using JAERI Quantum Molecular Dynamics (JQMD) model followed by Generalized Evaporation Model implemented in PHITS. It was demonstrated that JQMD model underestimate measured data.

1 Introduction

Radioactive Isotope Beam Factory (RIBF) at RIKEN is an accelerator facility[1]. RIBF has an ability of accelerating heavy ions (e.g. Ca, Kr, Xe, U) up to 345 MeV/u through superconducting ring cyclotron (SRC). It is in progress to conduct a lot of researches with the utilization of Radioactive Isotope (RI) beams which are generated by reactions between primary beams and RI generating targets. A number of neutrons are produced at the target and a beam dump. Therefore, areas around the target and the beam dump is a high dose rate region.

Radiation shielding around the high dose rate area was basically designed by the Moyer model[2]. As a source term of the model, neutron thick target yield (TTY) by 345 MeV/u ^{238}U beam is essential. There is an available data of TTY for 1 GeV/u ^{238}U incidence on iron measured at Gesellschaft für Schwerionenforschun (GSI)[3]. Neutron energy spectra for forward directions were measured in the study. As RIBF is located in underground, measured data for side directions are of great importance. There is no measured data of TTY from 345 MeV/u ^{238}U incidence on copper, which is beam dump material at RIBF.

Particle transport code PHITS[4] has been recently applied for radiation shielding design. Measured data for examining accuracy of physics models in the code is not sufficient. Experimental data of neutron TTY is highly desired for verifying neutron emissions to optimize radiation shielding design.

In this study, neutron TTYs at 45° and 90° were measured from 345 MeV/u ^{238}U incidence on copper. Simulation TTYs are calculated by JAERI Quantum Molecular Dynamics (JQMD)[5] model followed by Generalized Evaporation Model[6] implemented in PHITS. These TTYs are compared to validate how accurate the physics model is.

2 Experiment

The experiment was carried out at Zero Degree Spectrometer of RIBF. Experimental arrangement is illustrated in Figure 1.

The incident energy of ^{238}U beam was 345 MeV/u. Beam intensity was about 10^6 pps. As radio frequency (RF) of SRC was 18.5 MHz, the beam pulse came every 54 ns. A copper target was positioned at the F10 chamber. A 10 mm thickness of the target was longer than the range of about 3.3 mm.

Neutrons produced in the target were measured with NE213 liquid organic scintillators. The neutron detectors were located at 45° and 90° from the beam axis. Both the diameter and length of the detectors were 12.7 cm. Flight path lengths from the target to each neutron detector were 4 m as shown in Fig. 1. Kinetic energies of detected neutrons were determined by inverse time-of-flight (TOF) method[7].

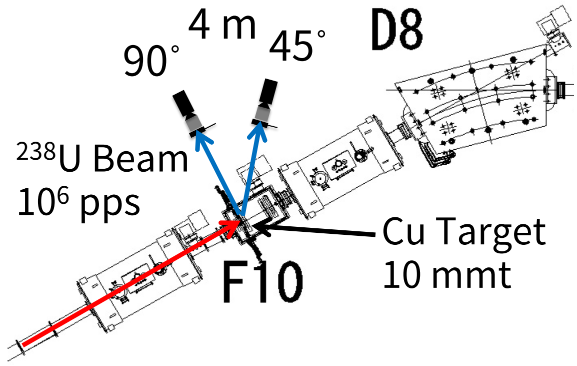

Figure 1 Illustration of experimental setup for the TOF measurement. 345 MeV/u ^{238}U beam irradiated a copper target. Neutron and veto detectors were located at 45° and 90° from a beam axis. Both flight path lengths were 4.0 m.

Start and stop signals came from neutron detectors and RF signal of SRC, respectively. Energies of neutrons overlapped with preceding beam pulse were less than 17.6 MeV. Threshold level was set to 12.3 MeVee which was two times higher than the Compton edge of 6.13 MeV γ-ray from ^{244}Cm-^{13}C. This was corresponded to the maximum light output of 18.4 MeV neutron. These low energy neutrons were automatically removed in data analysis because their pulse heights were smaller than the bias level. To eliminate charged particle events from total events, a NE102A plastic scintillator of 2 mm in thickness (veto detector) was used in front of each neutron detector.

The background neutrons scattered from the floor were measured by using an iron shadow bar of 1 m long, which was installed between the F10 chamber and each neutron detector.

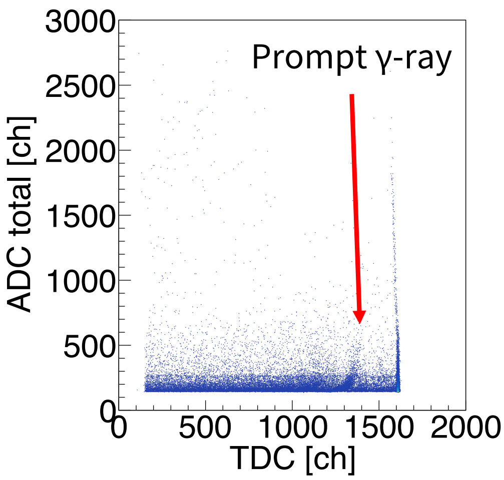

Figure 2 TDC-ADC two-dimensional plot for NE213 scintillator at 90°. Prompt γ-ray appears at roughly 1400 ch. Available time difference of neutrons and prompt γ-ray was less than 34 ns.

3 Analysis

Neutron energy spectra was derived from the flight time and data of pulse height distribution of neutron detectors[7]. Neutron events were identified with the use of two gate integration method[8]. After neutron events were extracted, kinetic energies of the neutrons were obtained from time difference between the neutrons and prompt γ-rays. The time difference was written to a computer of data acquisition as shown in Figure 2. Neutron detection efficiency was calculated by SCINFUL-QMD code[9][10]. Finally, measured data were converted into neutron production TTYs.

4 Results and Discussion

The measured data of neutron TTYs were compared with JQMD model implemented in PHITS ver.3.10. The measured and calculated neutron TTYs for 345 MeV/u ^{238}U bombardment on copper are shown in Figure 3. Only statistical error in the measured data was included in Fig. 3.

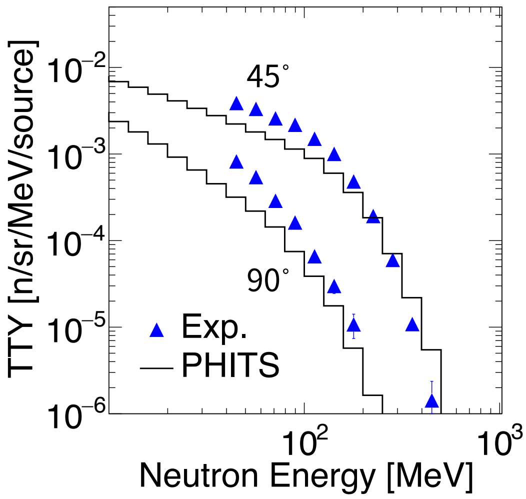

Figure 3 Neutron TTYs from 345 MeV/u ^{238}U incidence on copper. Blue triangles and black solid lines represent the experimental data, the results of PHITS calculation using JQMD ver.1.0 model, respectively.

Integral of the experimental and calculated energy spectra above 40 MeV is shown in Table 1. According to Table 1, the number of produced neutrons for PHITS was 0.61 of that of our experimental data at 45°. The ratio for 90° was roughly to be 0.44.

Table 1 Angular distribution of neutron production integrating neutron energy spectrum above 40 MeV. Only statistical errors were considered.

	45° [n/sr/source]	90° [n/sr/source]
Exp.	$(2.8 \pm 0.0014) \times 10^{-1}$	$(2.7 \pm 0.0049) \times 10^{-2}$
PHITS	$(1.7 \pm 0.011) \times 10^{-1}$	$(1.2 \pm 0.070) \times 10^{-2}$

5 Conclusion

Neutron TTYs at 45° and 90° were measured from 345 MeV/u ^{238}U incidence on a copper target with TOF method. PHITS underestimate the measured data. The experimental data will be useful for the estimation of the source term.

6 Acknowledgement

This experiment was performed at RI Beam Factory operated by RIKEN Nishina Center and CNS, the University of Tokyo. The PHITS calculation were performed using the supercomputer system of RIKEN.

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