Measurement of Neutron Production Cross Sections by High Energy Heavy Ions

H. Sato T. Kurosawa, H. Iwase, T. Nakamura
Cyclotron and Radioisotope Center,Tohoku University,Aoba,Aramaki,Aobaku,Sendai 980-8578,Japan
e-mail:hisaki@cyric.tohoku.ac.jp

N.Nakao
High Energy Accelerator Research Organization, Tsukuba, Ibaraki 305-0801, JAPAN

Y.Uwamino
Institute of Physical and Chemical Research, Hirosawa 2-1, Wako, Saitama, JAPAN

The double-differential cross section (DDX) of neutron production from thin C, Al, Cu, Pb targets bombarded by 135MeV/nucleon C ion were measured using the RIKEN Ring Cyclotron of the Institute of Physical and Chemical Research, Japan. The neutron energy spectra were obtained by using the time-of-flight method coupled with the ΔE-E counter telescope system. The ΔE counter of the NE102A plastic scintillator was used to discriminate charged particles from noncharged particles, neutrons and photons. The E counter of the NE213 liquid scintillator was used to measure the neutron energy spectra. The experimental spectra were compared with the calculation using the HIC and the QMD codes.

1. INTRODUCTION

Recently, the use of high-energy heavy ions have been increasing in various fields. To design the accelerator facility, it is important to protect workers from radiation, particularly penetrating neutrons produced by high energy heavy ions. There exist a few published data on the double-differential cross sections (DDX) of neutron production for 337 MeV/nucleon Ne ions on C, Al, Cu, U targets [1], but still very poor. In this work we present the double-differential cross sections (DDX) of neutron production from thin C, Al, Cu, Pb targets bombarded by 135MeV/nucleon C ion. These results will be useful as a benchmark experimental data to investigate the accuracy of high energy particle transport calculation code. Here, the measured spectra are compared with the calculation using the two heavy-ion Monte Carlo codes of internuclear-cascade and evaporation model (HIC) and the quantum molecular dynamics model (QMD).

2. EXPERIMENT

The measurements were carried out at the RIKEN Ring Cyclotron, the Institute of Physical and Chemical Research. A schematic view of the experimental set-up is shown in Fig.1. The NE213 liquid scintillator (12.7cm diameter by 12.7cm thick), which was designed to expand the dynamic range of output pulses for high energy neutron measurements, was used for E counter, and the NE102A plastic scintillator (15cm by 15cm square and 0.5cm thick) for ΔE counter was placed in front of the E counter to discriminate charged particles from noncharged particles, neutrons and photons. The target thicknesses are 1mm of C, 0.6mm of Al, 0.3mm of Cu, 0.3mm of Pb. The direction of incident beam was rotated around the target from 0 to 110 degrees through the beam swinger, for measuring the energy-angle distribution of neutrons produced from the target by the time-of-flight (TOF) method having the flight path of 847cm. In order to shield the spurious scattered neutrons, the neutrons from the target were introduced to the detector through the iron-concrete collimator of 120cm thickness. The measurements were carried out at 0°, 15°, 30°, 50°, 80° and 110°.

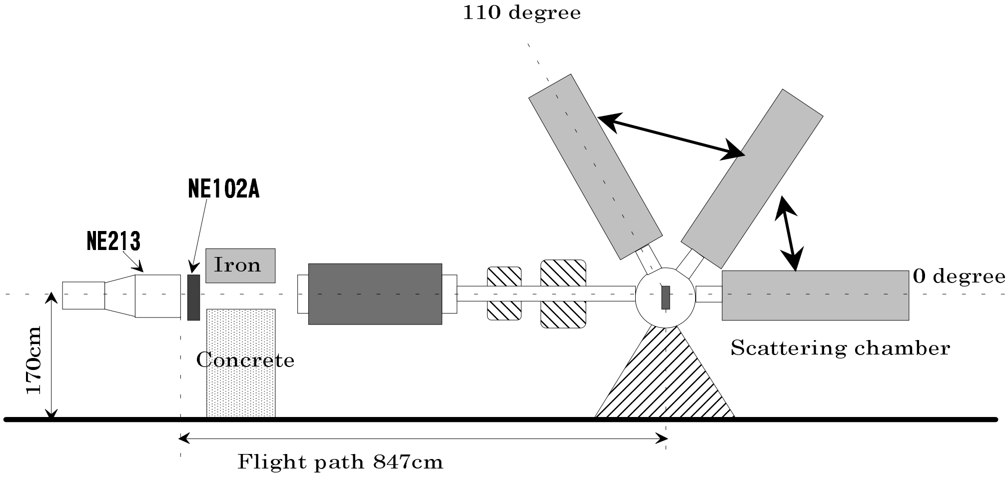

Fig.1 Schematic view of the experimental set-up

3. RESULTS AND DISCUSSIONS

We obtained neutron energy spectra for C,Al,Cu, and Pb targets bombarded by 135 MeV/nucleon C ion. These experimental results were compared with the calculation using the HIC [2] and the QMD [3] codes. Figs.2-5 show the experimental and calculated double differential cross sections of neutron production from C, Al, Cu, and Pb targets, respectively. Neutron energy spectra measured in the forward direction have a peak near the projectile energy per nucleon. This peak is due to a knock-on process in which a neutron is knocked out by the direct collision between the target nucleon and the projectile nucleon. This peak becomes more prominent in the forward direction and for a lighter target, since the momentum transfer from projectile to target nuclei is higher for lighter nucleus than for heavier nucleus [4]. The high energy end of neutrons in the forward direction reaches about 300-400MeV. This influences the Fermi motion of a nucleon in a nucleus. The neutron spectra have another two components based on cascade-preequilibrium emission process and evaporation-equilibrium emission process. At small angles, knock-on process is dominant, and at large angles, evaporation process is dominant. Two calculations of HIC and QMD show a tendency to underestimate the high energy neutron components beyond the peak at all angles. The HIC overestimates the peak, while the QMD underestimates the peak. At large angles, the calculated spectra become in good agreement with the measured spectra. In general, the QMD gives better agreement with the experimental results, especially for heavy target, than the HIC.

4. CONCULUSIONS

We measured double-differential cross sections of neutron production from thin C, Al, Cu, Pb targets bombarded by 135 MeV/u C ion. The experimental spectra were compared with the calculation using the HIC and the QMD codes. The calculated spectra tend to underestimate the high energy neutron region. At large angles, the calculated spectra, particularly the QMD, are in rather good agreement with the measured spectra. These experimental results will be useful as the benchmark data for investigating the accuracy of high energy particle transport calculation code.

References

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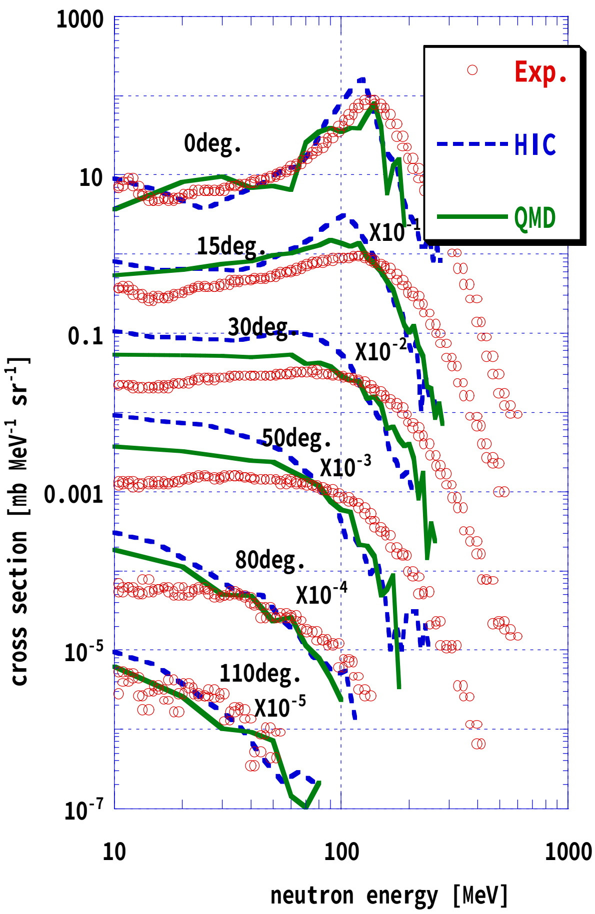

Fig.2 Neutron energy spectrum for C

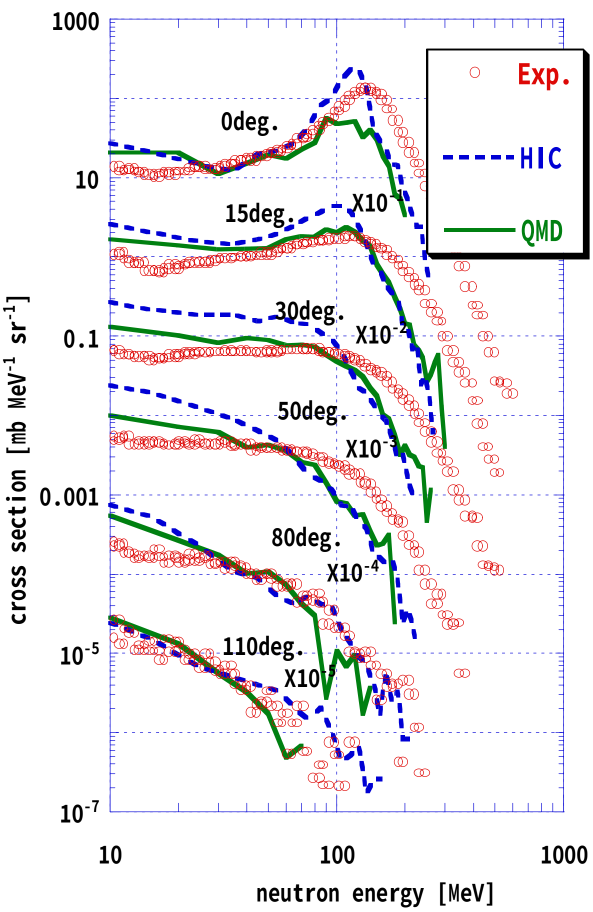

Fig.3 Neutron energy spectrum for Al

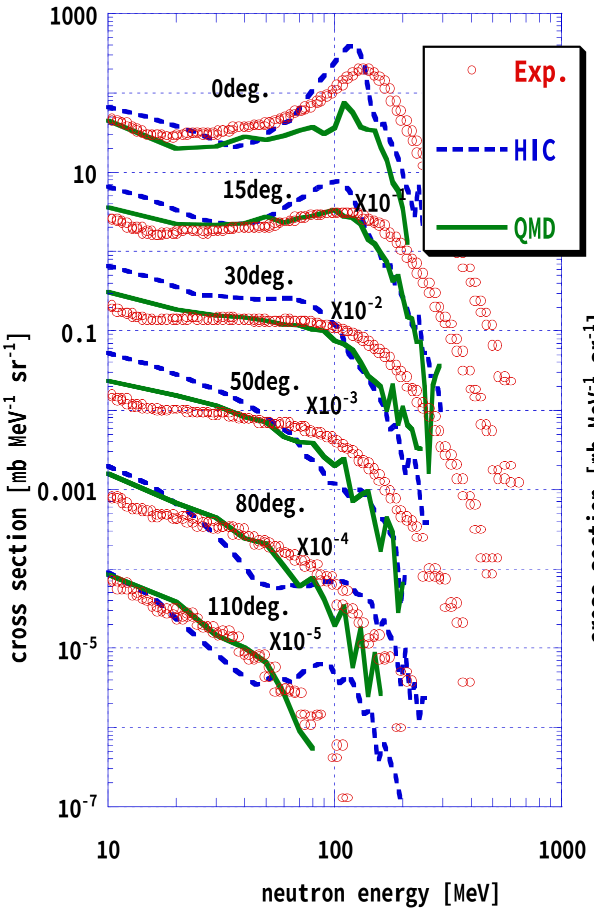

Fig.4 Neutron energy spectrum for Cu

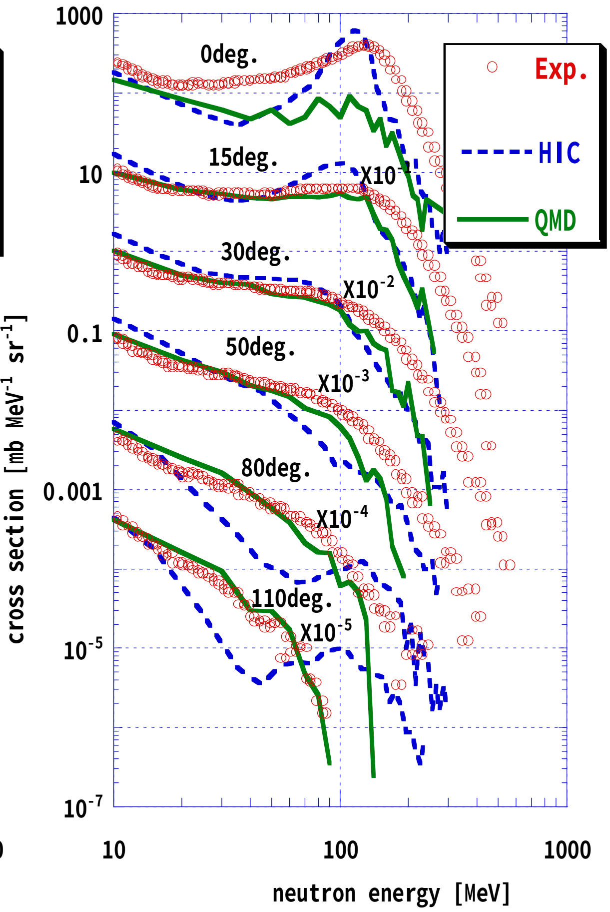

Fig.5 Neutron energy spectrum for Pb