

FACILITY FOR MEV DEGREE NEUTRON CAPTURE CROSS SECTION AT KIGAM *

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Abstract

KIGAM neutron facility is being designed and installed for measuring MeV neutron capture cross sections. Now the continuous neutrons with energies from 1MeV to 2 MeV and with total flux of about 10^8 neutrons/sec are ready. Bunched neutron beam and detecting system of prompt gamma and neutron flux is under construction to obtain neutron capture cross sections within 5% error for structure of a new reactor.

INTRODUCTION

Neutron capture cross section is very important factor to design a high burn up core, and to study incineration of minor actinides such as Am, Cm, and higher product with a fast reactor. And recently fast (above keV) neutron capture cross section has been extensively studied from both view points of nuclear astrophysics[1] and nuclear physics[2], Especially MeV neutron capture cross section is very important data in estimating the production yields of elements heavier than Fe in stellar nucleosynthesis and of intermediate-heavy nuclei ($A > 7$) in homogeneous big-bang models. However the experimental cross section data were poor both in quality and in quantity because the much sample is difficult to prepare and the background of scattered neutrons is very high. To obtain the accurate neutron capture cross sections for several materials, the KIGAM neutron facility such as neutron bunching system and the detecting system of prompt gamma ray with high efficiency has been designed and added to the previous beam line. The status of KIGAM neutron facility will be reported.

KIGAM NEUTRON FACILITY

Accelerator

KIGAM accelerator (NEC-5SDH2) is 1.7 MV tandem type with both RF source and SNICS. KIGAM uses mainly ${}^3\text{T}(p,n){}^3\text{He}$ reaction as a neutron generating reaction. The average beam current of proton with 3.4 MeV is about 10 uA. The proton energy stability is within 2 keV at all ranges of proton acceleration energy.

Bunching system and RF amplifier

KIGAM bunching system was based on the sweeping and double bunching techniques [3] by RF field to remove the delayed gamma-ray and to find out neutron energy. Deflector for sweeping beams consists of two parallel plate electrodes with respective to beam direction

and is applied by 4 MHz RF field vertical to beam direction. Otherwise bunching electrode consists of three stage electrodes with cylindrical shape. The frequency of the applied electric field to these electrodes is 8 MHz with parallel direction to beam direction. Fig.1 shows the inside of KIGAM bunching system. The length from the rear edge of deflector to slit is 286 mm, the longer distance is, the less the applied RF voltage is. The length of second electrode at bunching system is the transit length for a half period of 8 MHz, The einzel lens may be used to focus the incident beam, it is effective to increase the beam duty factor and time specification of bunched beam. The specification of neutron bunching beam is designed to be that the repetition rate is 8 MHz, the width is about 2 ns, and duty factor is about 20 %.



Figure 1: Bunching system of KIGAM.

Also the electronics is designed in the method of applying a high voltage with MHz both to deflector electrode and to bunching system electrode, synchronically. To obtain a high voltage of RF field, Two RF amplifiers, such as driver amplifier and main RF amplifier, are needed. A main RF amplifier is designed as a type of push-pull linear amplifier with 300 W CW across the 2 MHz and 30 MHz band. One of the Motorola's high power transistors developed for single-sideband is used. In driver amplifier, plastic RF power transistor is feathered with a total power gain of about 25 dB. By our simulation result, the required maximum voltages on each electrode are about 2 kV. So we need to change the high power of RF field to the high voltage, which is performed by coil. The amplification ratio of RF voltage is 30 times larger than that of before amplification. Also LCR resonance must be prepared at between bunching system second electrode and coil to transport the maximum RF power. Now impedance matching between the electrode and coil is under works by a variable condenser and a network analyzer.

45° bending magnet

A 45° bending magnet of C type to guide the charged particle beam to a new neutron experimental room has been designed and fabricated. The maximum field of this magnet is 1.2 T, which can bend the incident beams such as proton and deuteron 45° to the original beam

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direction. Also power supply for 45° bending magnet was fabricated and tested. This power supply is remotely controlled by our encoded program. We saw the good linearity of magnetic field to the applied current at the installed bending magnet. The transit ratio of proton beam to neutron chamber is 98 %, when the current of neutron chamber is compared with that after main magnet.

Neutron chamber

A chamber to install a neutron target is needed. The chamber was fabricated by Cu with thickness of 1 mm. This chamber also has the cooling system for neutron target. Its coolant is Freon. The time pick off detector will be positioned in this chamber.

Neutron experimental room

The neutron experimental room was fabricated to decrease the number of the room scattered neutron. The size of this room is 600 cm (vertical) x 550 cm (horizontal) x 400 cm (height). The shielding system of neutron and gamma ray in this room has not been yet fabricated.

Prompt gamma ray measurement system

Neutron capture cross section is hard data to measure, because the reaction rate and the quantity of sample are very small. So the high efficiency gamma-ray detector must be prepared. The main detector is a NaI(Tl) with 3 inch by 3 inch. A main detector will be positioned at 125° with proton beam direction, which is easy to calculate the neutron cross sections, because angle dependence for cross section can be ignored.

Also Compton suppression technique and time of flight technique are applied to the prompt gamma-ray measurement system, in order not only to remove background gamma ray, but to get off the delayed gamma ray and distinguish the neutron energy. The prompt gamma ray after neutron capture cross section is measured by a main detector with Compton suppressor and shields of W and high purity Pb. A high density polyethylene and Cd sheets with thickness of 2 mm are used as the shield for the scattered neutrons. The Li-6 glass scintillation detector with 2 inch by 0.4 inch will be used for neutron flux monitor. The detecting system for prompt gamma ray and neutron monitor is shown in Fig. 2. The two dimensional data, such as energy spectra of neutron and the corresponding energy spectra of gamma ray are obtained by a main detector. Neutron energy is identified by measuring a flight time between the sample and neutron target. In our system, this is very short. So it may be very difficult to distinguish the neutron energy by TOF because the neutron energy spread by Ti thickness of TiT target is comparatively large.

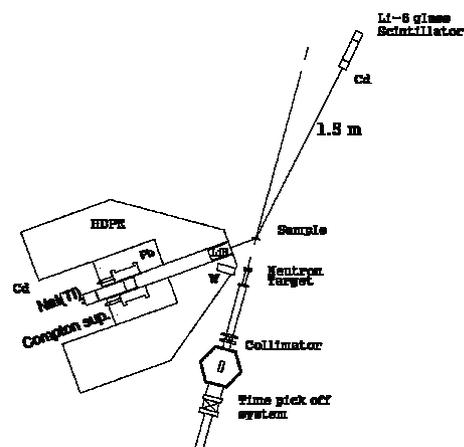


Figure 2: Measurement system for prompt gamma ray and neutron monitor.

TiT target

A TiT thin film, provided by SODERN in France, was used mainly as neutron generating target. The substrate of this target was Cu with a thickness of 1.2 mm. The quantity and quality analysis for neutron target was performed by He-RBS, proton-RBS, and CI-ERD-TOF. The quantity of tritium was 3.6×10^{15} particles/cm² and atomic fraction of nitrogen to oxygen was 0.2 to 0.8. However, the depth accessible by ERD-TOF was about a few thousand Å. The bulk of the TiT target could not be analyzed completely, So proton and helium RBS was performed again using the analyzed atomic fraction of nitrogen to oxygen determined via ERD-TOF. The areal density of tritium, 3.8×10^{18} particles/cm², was almost the same as the value obtained by He-RBS. That of He RBS is in good agreement with that of ERD-TOF. However the thickness of Ti was obtained to be 1.4×10^{19} particles/cm², which is different from the data referred by the target-producing company [4].

Specification of continuous neutron beam

Owing to the absence of the low lying nuclear level in ³He, the high neutron energy could be produced by high proton energy [5]. Q-value of ³T(p,n)³He reaction is -0.76 MeV. The neutron energy corresponding to incident proton energy and scattering angle could be calculated by kinematics [6].

The energies of the generated neutrons were confirmed with 2,077 keV and 1,410 keV, 1,479 keV, 2,501 keV resonance states of ¹²C(n,tot) and ²⁸Si(n,tot) reaction respectively. These resonances were well known to have narrow widths such as about 10 keV [7-8]. The neutron pulse height spectra corresponding to incident proton energy were observed by 2" x 2" BC-501 at 0° with respect to beam direction and at 319 cm from TiT targets and pulse shape discrimination like Fig. 3. By extrapolation of the end point for pulse height spectrum, the Cut-off energy of neutron was confirmed to be about 0.78 MeV. The available maximum neutron energy was 2.6 MeV. Samples for these reactions were C with square type and Si film.

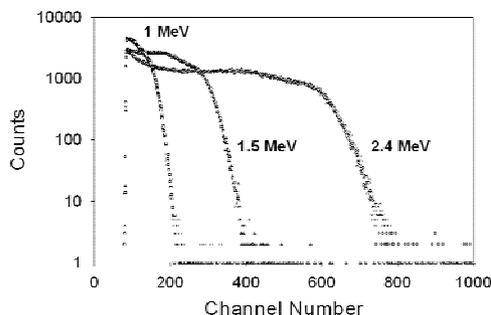


Figure 3: Neutron pulse height spectrum

Causes in neutron energy spread may be Ti thickness of TiT target, detector solid angle, and the stability of accelerating voltage. Because the variation of neutron energy spread at 0° with respect to beam direction is calculated to be small by kinematics [6], the neutron energy spread by the solid angle of detector can be negligible. As the variation of accelerating voltage is within 2 keV, the neutron energy spread by that can be also negligible. Neutron energy spreads by Ti thickness were calculated to be about 26 keVs in two resonances, such as the 2,077 keV resonance of $^{12}\text{C}(n,\text{tot})$ and the 2,501keV resonance of $^{28}\text{Si}(n,\text{tot})$, respectively, by calculating proton stopping power on thickness of Ti. Ti thickness was measured by ERD-TOF and RBS.

Also neutron energy spread by Ti thickness of TiT target could be directly measured by investigating excitation functions of $^{12}\text{C}(n,\text{tot})$ and $^{28}\text{Si}(n,\text{tot})$ reaction. Excitation functions of $^{12}\text{C}(n,\text{tot})$ and $^{28}\text{Si}(n,\text{tot})$ for four resonance states were shown in Fig. 4 as a function of the terminal voltage of accelerator. For two resonance states for the 2,077 keV of $^{12}\text{C}(n,\text{tot})$ and for the 2,501keV of $^{28}\text{Si}(n,\text{tot})$, the neutron energy spreads of 26 keV could be obtained if these peaks of Fig.4 would be fitted by Gaussian function and the resonance widths of neutron total scattering reactions would be removed off the each fitted widths .

This was almost same result of proton stopping power on thickness of Ti layer, which had been measured before by ERD-TOF and RBS.

Neutron flux was estimated by fast neutron activation method on ^{197}Au . Neutron flux was obtained from gamma ray(411keV) of ^{197}Hf , which was formed by the beta transition from ^{198}Au . ^{198}Au was obtained by $^{197}\text{Au}(n,\gamma)$ and neutron captured cross section of this reaction was well known [8]. The absolute efficiency of HP Ge detector was obtained to be a 0.0287 with error of 1.3 % at 411keV through the simulation of that for a sample with thickness of 3mm and diameter of 50 mm by MCNP code.

At the neutron energies of 1.408 MeV and 2.015 MeV, the neutron fluxes were 1.80×10^7 neutrons/sec/sr and 3.76

$\times 10^7$ neutrons/sec/sr with errors of about 4.2 %, respectively.

These data were in good agreements within 10 % to the results calculated by irradiation beam quantity, tritium areal density by ERD-TOF method and differential cross section of $^3\text{T}(p,n)^3\text{He}$ reaction by other experimental data [8].

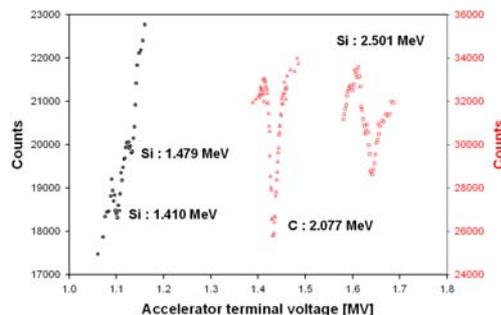


Figure 4: Resonances of $^{12}\text{C}(n,\text{tot})$ and $^{28}\text{Si}(n,\text{tot})$

SUMMARY

MeV neutron facility has been designed and fabricated by KIGAM. Continuous neutron beams with MeV energy were obtained by $^3\text{T}(p,n)^3\text{He}$ reaction to measure neutron capture and total cross section. Now bunched beams and a detecting system of prompt gamma ray are under construction to measure the accurate neutron capture reaction cross section for every material

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