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PULSED NEUTRON FACILITY BASED ON AN ELECTRON LINAC*

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Abstract - The Pohang Neutron Facility based on an electron linac was constructed in order to construct the infrastructure for nuclear data production in Korea. It consists of a 100-MeV electron linac, a water-cooled Ta target, and an 11-m time-of-flight path. We measured the time-of-flight path length, the neutron energy spectra for different water levels inside the moderator, and the neutron total cross sections of polyethylene and copper by the transmission method.

INTRODUCTION

The nuclear data project as one of the nation-wide nuclear R&D programs was launched by the Korea Atomic Energy Research Institute (KAERI). Its main goals are to establish a nuclear data system, to construct the infrastructure for the nuclear data productions and evaluations, and to develop a highly reliable nuclear data system. We completed construction of a pulsed neutron facility, the Pohang Neutron Facility (PNF), based on an electron linac on December 1999. It consists of a 100-MeV electron linac, a water-cooled Ta target, and an 11-m time-of-flight (TOF) path.

The characteristics of PNF are described in the next section. The neutron TOF spectra measurements in order to measure the flight path length and determine the water level in the water moderator are presented. The measured total cross sections of polyethylene and copper are presented and compared with the evaluated data in ENDF/B-VI.

POHANG NEUTRON FACILITY

The Pohang Neutron Facility (PNF) consists of an electron linac, a water-cooled Ta target, and an 11-m long TOF path. The electron linac consists of a thermionic RF-gun, an alpha magnet, four quadrupole magnets, two SLAC-type accelerating sections, a quadrupole triplet, and a beam-analyzing magnet. A 2-m long drift space is added between the first and the second accelerating section to insert an energy compensation magnet or a beam transport magnet for other research. The overall length of the linac is about 15 m. The beam energy is 75 MeV, and the measured beam currents at the entrance of the first accelerating structure and at the end of the linac are 100 mA and 40 mA, respectively. The length of electron beam pulses is 1.5 μs, and the pulse repetition rate is 12 Hz. The diameter of electron beam is about 20 mm at the beam profile monitor in front of the target. The measured energy spread is about 1~3 %. The energy spread was reduced by

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adjustment of the RF phase for the RF-gun and by optimization of the magnetic field for the alpha magnet.

A water-cooled Ta target was designed by the Electron Gamma Shower simulation code, EGS4 [1]. The Ta target was composed of ten Ta sheets, 49 mm in diameter and 74 mm in total length [2]. There was 1.5-mm water gap between Ta sheets in order to cool the target effectively. The target housing was made of 0.5-mm thick titanium. The calculated conversion ratio from a 100-MeV electron to neutrons was 0.032 obtained by using the EGS4. According to this result, the neutron yields per kW beam power are 2.0×10^{12} n/sec, which is about 2.5% lower than the calculated value based on the Swanson's formula, $1.21\times10^{11}\ Z^{0.66}$, where Z is the atomic number of the target material and the electron energy is above 40 MeV [3].

Since we have to utilize the space and infrastructures at PAL, an 11 m long TOF path and a detector room were constructed vertically to the electron linac. The TOF tubes were made by stainless steel with two different diameters of 15 and 20 cm.

MEASUREMENT OF NEUTRON TIME-OF-FLIGHT SPECTRA

1. Experimental Arrangement

The experimental setup for the neutron TOF spectrum measurement is shown in Fig. 1. The target is located at a position where the electron beam hits the target center, and the target is aligned vertically with the center of the TOF tube. This target was set at the center of a water moderator made by using an aluminum cylinder with a thickness of 0.5 cm, a diameter of 30 cm and a height of 30 cm. A Pb block, 20 cm × 20 cm in area by 10 cm in thickness, was placed at the entrance of 15 cm diameter TOF tube to reduce the gamma flash generated by the electron burst from the target and scattered high-energy neutrons. In addition, a 0.5-cm thick Pb plate was attached in front of the TOF tube. There is 1.8 m thick concrete between the target room and the detector room. The sample was placed at the midpoint of the TOF path.

As a neutron detector, we used a ^{6}Li-ZnS (Ag) scintillator BC702 with a diameter of 12.5 cm and a thickness of 1.5 cm mounted on an EMI-93090 photomultiplier. It was located at a distance of 10.8 m the photoneutron target. The neutron detector was shielded by lead bricks and borated polyethylene plates.

In order to monitor the neutron intensity during the experiment, a BF3 proportional counter with a diameter of 1.6 cm and a length of 5.8 cm was placed in the target room at a distance of about 6 m from the target. The BF3 counter was inserted in a polyethylene sphere with a diameter of 30.5 cm and surrounded by borated polyethylene with a thickness of 5 cm and Pb bricks with a thickness of 10 cm to shield thermal neutrons generated from the moderator and walls inside the target room and to protect gamma flash generated by the electron burst from the target.

During the experiment, the electron linac was operated with a repetition rate of 12 Hz, a pulse width of 1.5 μs, a peak current of 30 mA, and electron energy of 60 MeV.

2. Data Acquisition System

The block diagram of the data acquisition system is also shown in Fig. 1. The TOF signal from signal from a ^{6}Li-ZnS(Ag) scintillator was connected to an amplifier system (ORTEC-113 pre-amplifier and ORTEC-571 amplifier). The amplifier output was then fed as a discriminator (Disc.) input, whose output was used as a stop signal of a 150 MHz time-digitizer (Turbo MCS). The lower threshold level of the discriminator was set to 30 mV. The Turbo MCS was operated as a 16384-channel time analyzer. The channel width of the time analyzer was set to 0.5 (s. The 12 Hz trigger signal (RF Trigger) for the modulator of the electron linac was connected to an ORTEC-550 single channel analyzer (SCA), the output signal was used as the start signal for the Turbo MCS. The Turbo MCS is connected to a personal computer. The data were collected, stored and analyzed on this computer.

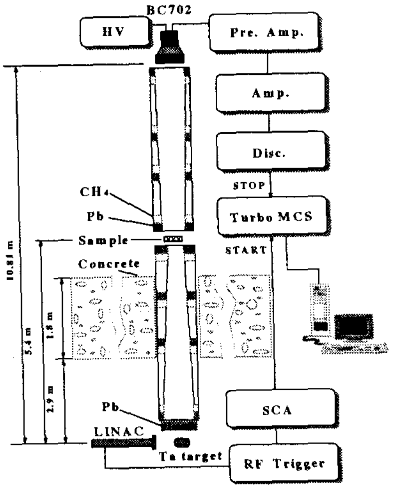

Fig. 1. Experimental setup and a block diagram for data acquisition.

3. Data Taking and Analysis

In order to determine the time of flight path length for our facility, we used neutron TOF spectra for Sm, Ta, W, and Ag sample runs. A Cd filter of 0.5 mm in thickness was used to suppress thermal neutrons. The samples were placed at the midpoint of the flight path. The resonance energy E and the channel number I are used to find the flight path length L in the following equation by the method of least squares fitting.

$$I=\frac{72.3\times L}{\Delta t\times\sqrt{E}}+\frac{\tau}{\Delta t} \qquad (1)$$

In the above equation, Δt is the channel width of the time digitizer and was set to 0.5μs.

The delay time τ is the time difference between the start signal from the RF trigger and the real zero time. The flight path length L is determined from the fitting. As shown in Fig. 2, the results of the fit are: L=10.81$\pm$0.02 m and τ=0.87μs.

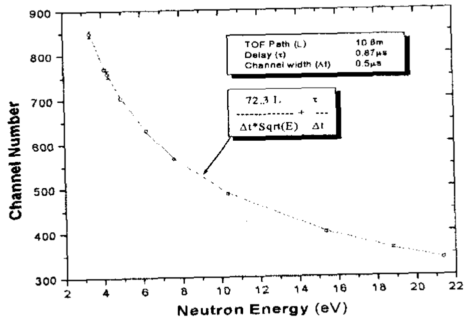

Fig. 2. A fit of the flight path length to resonance energies

In order to investigate the neutron energy spectra for the different water levels inside the moderator, we used three water levels: G2 corresponds to 0 cm water level above the target in which water is around the target but no water above the target. G3 is the geometry with a water level of 5 cm above the target surface. Geometry G4 is a full of water in the moderator, which corresponds to 11 cm water level from the target surface.

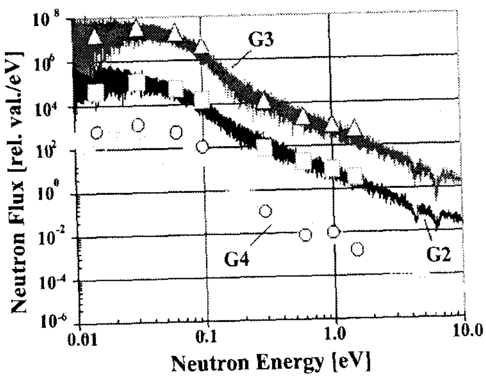

Fig. 3. Measured and calculated neutron spectra for three geometries

The measured neutron spectra for three geometries were shown in Fig. 3 compared with those of the MCNP calculations. In this Fig., the neutron flux for G3 (G4) geometry was multiplied with a factor 10 (0.1) for better visualization. The points (quadrates, triangles, and circles are for G2, G3, and G4 geometry, respectively) represent the result of the MCNP calculation. The experimental and calculated data were well agreed within the experimental uncertainty.

The neutron total cross sections of polyethylene and copper were measured in the neutron energy region between 0.01 eV and 100 eV based on the neutron transmission measurement by using the TOF method. The dimensions of a polyethylene and a copper are 1 mm and 0.2 mm thick metallic plates with 10cm x 10cm area, respectively. In addition to the transmission samples, a set of notch filters such as Co (130 eV), Ag (16.3 and 5.2 eV), In (1.46 eV), and Cd (<0.4 eV) was used for the energy calibration and the background measurement. We measured data with two different channel widths of the time analyzer, i.e., a 5 (sec for the lower energy region (<2 eV) and a 1 (sec for the higher energy region (>0.6 eV).

The neutron total cross section can be obtained by measuring the transmission rate of the sample defined as

$$T(E_i) = \frac{S_{in}(E_i)}{S_{out}(E_i)}, \qquad (2)$$

where S_{in} and S_{out} are the number of normalized events subtracted by the backgrounds for the sample-in and the sample-out runs, respectively. The background was estimated by using the resonance peaks of In, Ag, Co, and Cd. The estimated background counts for each channel are less than 10% of the signal counts. In order to normalized the number of events for the sample-in and the sample-out runs, we used the neutron counts integrating TOF counts corresponding to the relevant energy region obtained by the ^{3}He proportional counter.

The neutron total cross section is determined from the measured transmission rate as follows:

$$\sigma(E_i) = -\left(\frac{1}{n}\right)\ln T(E_i) \qquad (3)$$

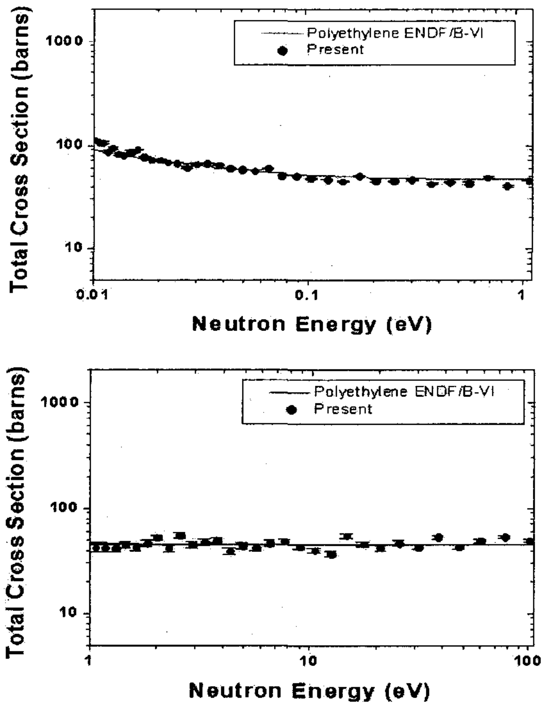

Fig. 4. Comparison of the total cross section of polyethylene with the measured data the evaluated data.

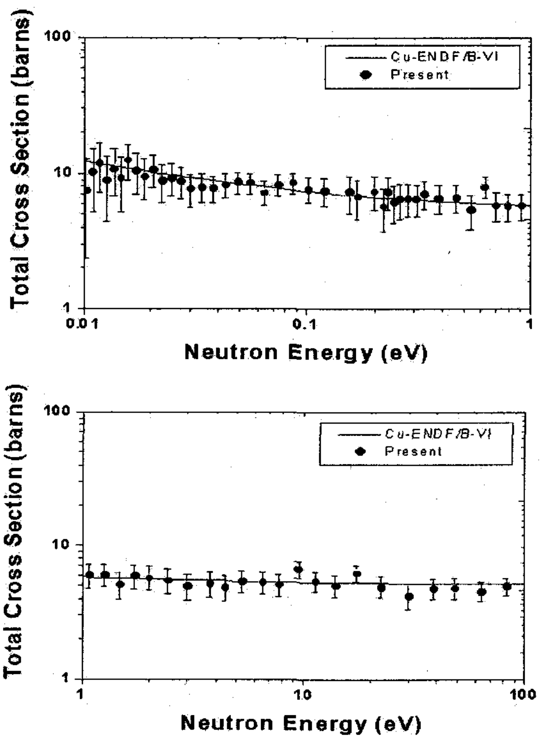

Fig. 5. Comparison of the total cross section of copper (Cu) with the measured data the evaluated data.

The neutron total cross sections for the samples of polyethylene and copper were determined in the energy region between 0.01 eV and 100 eV by using Eq. (3). The results obtained for each sample were summed up in every ΔU=0.1 lethargy width for the individual samples in order to obtain better statistics. The final results were compared with the evaluated data in the ENDF/B-VI in the Fig.s 4 and 5, respectively. The error bars shown in the Fig.s only indicate the statistical uncertainties estimated to be less than approximately 10% at all energy regions.

SUMMARY AND DISCUSSION

In order to construct infrastructures for nuclear data production, the Pohang Neutron Facility based on a 100-MeV electron linac was constructed in December 1999. The neutron energy spectra produced by the photoneutron target with a water moderator were measured with a ^{6}Li-ZnS(Ag) glass scintillator as a neutron detector with the neutron TOF method at 11 m flight path. As a neutron monitor, a BF_3 proportional counter was used. We measured the time-of-flight path length, the neutron TOF spectra for different water levels inside the moderator and compared experimental results with the MCNP calculations in order to maximize the thermal neutron flux. We also measured the neutron total cross sections of polyethylene and copper with the neutron transmission method at the PNF.

The PNF can be used as a user facility for the nuclear data production, the radiation hardness test of a detector, the radiation protection and dosimetry, and other radiation application.

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