ACTIVITIES ON THE NUCLEAR DATA MEASUREMENT AT THE POHANG NEUTRON FACILITY BASED ON ELECTRON LINAC *

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Abstract

We report the present status of the Pohang Neutron Facility which consists of an electron linear accelerator, a water-cooled Ta target, and a 12-m time-of-flight path. We measured the neutron total cross-sections in the neutron energy range from 0.1 eV to few hundreds eV by using the neutron time-of-flight method. A ^{6}LiZnS(Ag) glass scintillator was used as a neutron detector. The neutron flight path from the water-cooled Ta target to the neutron detector was 12.1 m. The background level was determined by using notch-filters of Co, In, Ta, and Cd sheets. In order to reduce the gamma rays from bremsstrahlung and those from neutron capture, we employed a neutron-gamma separation system based on their different pulse shapes. The present measurements of Ta, Hf, Ag, and Mo samples are in general agreement with the evaluated data in ENDF/B-VI.

INTRODUCTION

The Pohang Neutron Facility (PNF) was proposed in 1997 and constructed at the Pohang Accelerator Laboratory on December 1998 [1]. It consists of a 65-MeV electron linac, water-cooled Ta neutron producing target, and a 12-m-long evacuated vertical flight tube leading to the detector location. 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. The overall length of the linac is about 15 m. As a photoneutron target, we choose a tantalum, which has advantages of high density (16.6 g/cm^3), high melting point (3,017^{o}C), and high resistant against the corrosion by cooling water. The characteristics of PNF are described elsewhere [2].

We report the measured neutron total cross-sections of natural Ta, Hf, Ag, and Mo in the neutron energy range between 0.1 eV and 100 eV by using the neutron time-of-flight (TOF) method at the PNF. The results were compared with other measurements and the evaluated data in ENDF/B-VI.

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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 standard subsystems: a thermionic RF-gun, an alpha magnet, four quadrupole magnets, two SLAC-type accelerating sections, a quadrupole triplet, and a beam-analyzing magnet. The overall length of the linac is about 15 m. The RF-gun is one cell cavity with a dispenser cathode of 6 mm diameter. The RF-gun produces electron beams of 1 MeV, 300 mA, and 1.5 μs [3]. The alpha magnet is used to match the longitudinal acceptance from the RF-gun to the first accelerating section. Electrons move along an alpha-shaped trajectory in the alpha magnet with the bend angle of 278.6^o. Four quadrupole magnets are used to focus the electron beam in the beam transport line from the thermionic RF-gun to the first accelerating section. The quadrupole triplet installed between the first and the second accelerating sections is used to focus the electron beam during the transport to the experimental beam line at the end of the linac.

A water-cooled Ta target was designed by the Electron Gamma Shower simulation code, EGS4 [4]. The Ta target was composed of ten Ta sheets, 49 mm in diameter and 74 mm in total length [5]. 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 yield per kW beam power for the electron energy above 40 MeV at the target was 2.0×10^{12} n/sec, which was 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 [6].

Since we have to utilize space and infrastructure at PAL, an 12 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.

EXPERIMENTAL PROCEDURE

The experimental arrangement and data acquisition system for the transmission measurements are described in elsewhere [2]. The target is located in the position where the electron beam hits its center. This target was set at the center of a cylindrical water moderator contained in an aluminum cylinder with a thickness of 0.5 cm, a diameter of 30 cm, and a height of 30 cm. The water level in the moderator was 3 cm above the target surface, which was decided based on a measurement of the thermal neutron flux. The neutron collimation system was mainly composed of H3BO3, Pb and Fe collimators, which were symmetrically tapered from a 10-cm diameter at the beginning to a 5-cm diameter in the middle position where the sample changer was located, to an 8-cm diameter at the end of guide tube where the neutron detector was placed. There was 1.8-m-thick concrete between the target and the detector room. The sample changer consists of a disc with 4 holes; each hole is 8 cm in diameter, which matches the hole of the collimator in the neutron beam line. The sample changer is controlled remotely by the CAMAC module. The distance between centers of two opposite holes is 31 cm. The transmission samples were placed at the midpoint of the flight path and were cycled into the neutron beam by using the sample changer with four positions. The physical parameters of the samples used in the total cross-section measurements are given in Table 1. A set of notch filters of Co, In, and Cd plates with thickness of 0.5 mm, 0.2 mm, and 0.5 mm, respectively, was also used for the background measurement and the energy calibration.

Table 1: Physical parameters of the sample.

Sample	Purity (%)	Size (cm^2)	Thickness (mm)	Weight (g)
Ta	99.7	10×10	0.45	16.60
Hf	99.9	5×5	0.5	16.44
Mo	99.9	π×3.1×3.1	3.0	94.00
Ag	99.98	10×10	0.5	53.04

The neutron detector was located at a distance of 10.81m from the photo-neutron target. A ^{6}Li-ZnS(Ag) scintillator BC702 from Bicron (Newbury, Ohio) with a diameter of 127 mm and a thickness of 15.9 mm mounted on an EMI-93090 photomultiplier was used as a detector for the neutron TOF spectrum measurement.

During the measurement, the electron linac was operated with a repetition rate of 10 Hz, a pulse width of 1.5 μs and the electron energy of 60~65 MeV. The peak current in the beam current monitor located at the end of the second accelerator section is above 50 mA, which is the same as that in the photo-neutron target.

DATA TAKING AND ANALYSIS

Two different data acquisition systems were used for the neutron TOF spectra measurements: one for the NIM-based system and the other for the CAMAC-based system. The main purpose of the NIM-based system was neutron-gamma separation and the parallel accumulation of the neutron TOF spectra if necessary. The CAMAC-based system consists of a main data acquisition part and a control part of the sample changer. The 10-Hz RF trigger signal for the modulator of the electron linac was used as a start signal of the time digitizer. The details of data acquisition system are described in elsewhere [2].

The measurements were performed with two samples simultaneously. The two other positions of the sample changer were empty to collect the neutron TOF spectra without a sample (open beam). The positions of the samples were chosen in the following sequence: sample 1 – empty – sample 2 – empty. The exposition times for both sample 1 and sample 2 were 15 minutes (9000 pulses of PNF linac); for each empty position, it was 7.5 minutes. Thus, the durations for the samples were the same as those for the total open beam measurements. The interleaving sequence of free positions of the sample changer was chosen to minimize the influence of slow and/or/ small variation of the neutron beam intensity. If the beam intensity variations or its drift was fast and/or large, then these partial measurements were excluded from the total statistics. The total data taking times for Ta, Hf, Ag, and Mo were 21.75, 8.5, 65, and 48 hours, respectively, with the same times for the open beams.

We estimated the background level by using the resonance energies of the neutron TOF spectra of the notch-filters of Co, In and Cd. The magnitude of the background level was interpolated between the black resonances by using the fitting function, $F(I) = a + be^{-I/c}$, where *a*, *b,* and *c* are constants and *I* is the channel number of the time digitizer.

The neutron total cross-section is determined by measuring the transmission of neutrons through the sample. The transmission rate of neutrons at the *i*-th group energy E_i is defined as the fraction of incident neutrons passing through the sample compared to that in the open beam. Thus, the neutron total cross-section is related to the neutron transmission rate $T(E_i)$ as follows:

$$\sigma(E_i) = -\frac{1}{N}\ln T(E_i)$$

where N is the atomic density per cm^2 of the sample. Then, we have calculated the average total cross-sections for the same energy interval.

The total cross-sections of natural Hf , Ta, Ag, and Mo were obtained in the energy range from 0.1 eV to 100 eV by using the neutron TOF method as shown in Fig. 1. We only considered the statistical errors for the present measurements because the other sources of uncertainties, which include the detection efficiencies, the geometric factor for the sample, and the other systematic errors, are negligible.

RESULTS AND DISCUSSION

The present measurements for the neutron total cross-sections of Hf, Ta, Ag, and Mo are compared with the previous data measured by other groups [7, 8, 9, 10] and the evaluated data in ENDF/B-VI [11] as shown in Fig. 1. The present measurements without any corrections are generally in good agreement with other data and the evaluated ones in the energy range between 0.1 eV and 100 eV.

In addition to the measurements of neutron total cross-sections in the neutron energy range from thermal to several hundreds eV by using the neutron TOF method, we performed the activation measurements with photons produced by bremsstrahlung process and neutrons. We are also preparing gamma detectors with BGO crystals for the neutron capture cross-section measurement.

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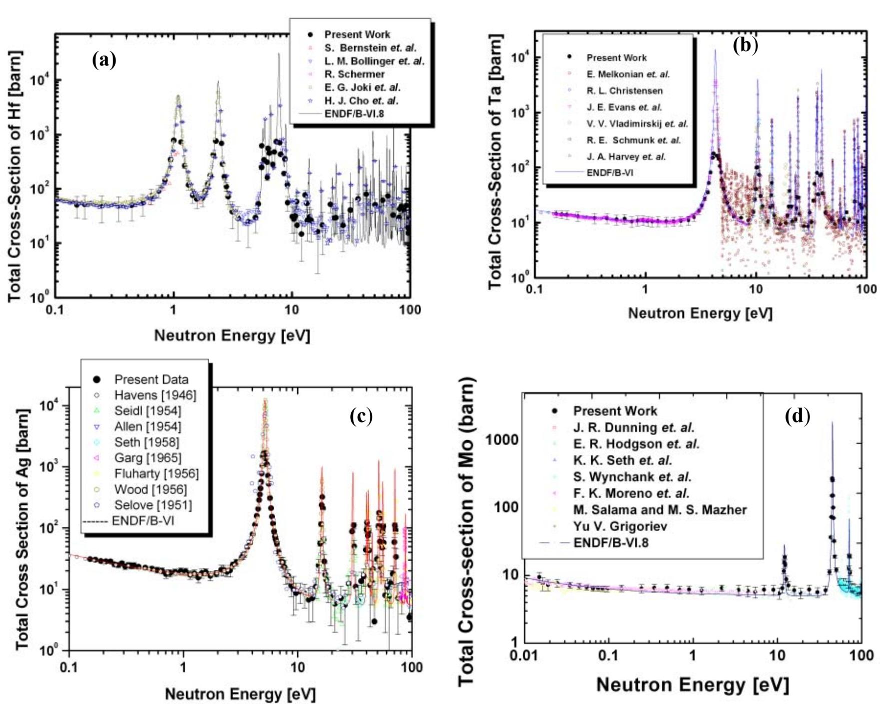

Figure 1: Comparison of the experimental total cross-sections of (a) Hf, (b) Ta, (c) Ag, and (d) Mo with the other experiments and the evaluated one from ENDF/B-VI in the neutron energy region between 0.01 and 100 eV.