Measurements of Total Cross Sections of Ta and Hf at Pohang Neutron Facility

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The Pohang Neutron Facility, which consists of an electron linear accelerator, a water-cooled Ta target with a water moderator, and a time-of-flight path with an 11 m length has been operated since 2000. We report the neutron total cross-section measurements of Ta and Hf samples in the neutron energy region from 0.01 eV to 100 eV by the neutron time-of-flight method at Pohang Neutron Facility. A ^{6}Li-ZnS(Ag) scintillator with a diameter of 12.5 cm and a thickness of 1.5 cm has been used as a neutron detector. The background level has been determined by using notch-filters of Co, Ta, and Cd sheets. In order to reduce the gamma rays from a Bremsstrahlung and that from a neutron capture, we have employed a neutron-gamma separation system based on their different pulse shape. The measured total cross-sections of Ta and Hf samples are compared with the previous ones and the evaluated data in ENDF/B-VI. The resonance parameters for Hf isotopes have been extracted from the transmission data by using the SAMMY code and compared with the previous ones.

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1. 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 100-MeV electron linac, water-cooled Ta neutron producing target, and an 11-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. The characteristics of PNF are described elsewhere [2].

We report the measured total cross-sections of natural Hf and Ta in the neutron energy range between 0.1 eV and 100 eV by using the neutron TOF method at the PNF. The measured results have been compared with other measurements and the evaluated data in ENDF/B-VI. The resonance parameters for Hf isotopes were determined from the fitting of transmission data by using the Multilevel R-Matrix code SAMMY [3].

2. Experimental Arrangement

The experimental arrangement and data acquisition system for the transmission measurements is described in elsewhere [2]. The target is located in the position where the electron beam hits its center. The target was composed of ten Ta plates with a diameter of 4.9 cm and an effective thickness of 7.4 cm. 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 guide tubes were constructed by stainless steel with two different diameters, 15 cm and 20 cm, and were placed perpendicularly to the electron beam. The neutron collimation system was mainly composed of H_3BO_3, 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 samples used in the experiment.

Sample	Purity (%)	Size (cm^2)	Thickness (mm)	Weight (g)
Ta	99.9	10×10	4	37.95
Hf	99.98	5×5	0.5	19.30

The neutron detector was located at a distance of 10.81 m 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 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.

3. 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. The total data taking times for Hf and Ta were 8.5 and 21.75 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:

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

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.

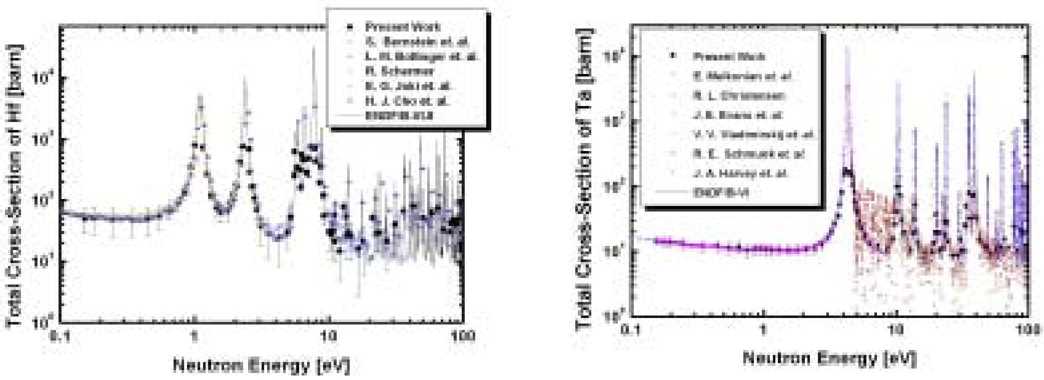

FIGURE 1. Comparison of the experimental total cross-sections of (a) Hf and (b) Ta with the other experiments and the evaluated one from ENDF/B-VI in the

The total cross-sections of natural Hf and Ta 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.

4. Results and Discussion

The present measurements for the neutron total cross-sections of Hf and Ta are compared with the previous data measured by other groups [4,5] and the evaluated data in ENDF/B-VI [6]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.

There are many resonance peaks in the neutron total cross-sections for Hf and Ta. In order to get the resonance parameters of each resonance peak, we fit the transmission data with the SAMMY code [3]. Resolution function $R(E, E')$ used in this calculation is the convolution of Gaussian and exponential function. We determined the resonance parameters for Hf samples form the SAMMY fitting. In Fig. 2, the measured total cross section of natural Hf in the neutron energy range from 0.1 eV to 15 eV was compared with the SAMMY fitting results. The SAMMY prediction of total cross section and the present data are in good agreement with each other with $\chi^2/N=0.33$.

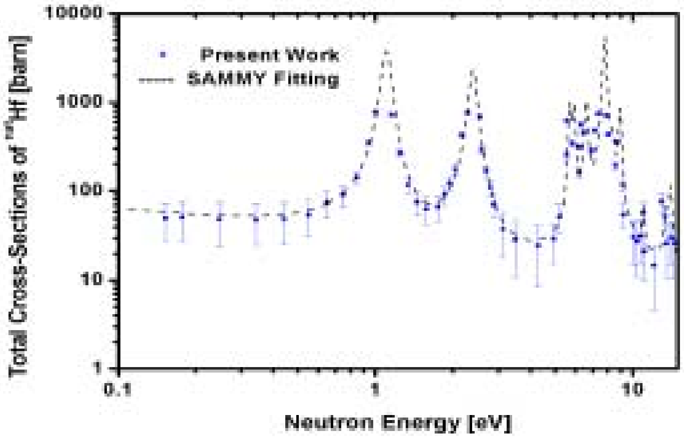

FIGURE 2. Comparison of the measured total cross sections of natural Hf with the predicted ones from the SAMMY fitting.

5. Conclusion

The Pohang Neutron Facility was constructed as a pulsed neutron facility based on an electron linac for producing nuclear data in Korea. It consists of an electron linac, a water cooled Ta target, and an 11-m long TOF path.

The neutron total cross-section of natural Hf and Ta have been measured in the neutron energy region from 0.1 eV to 100 eV by using a ^{6}Li-ZnS(Ag) scintillator and the neutron TOF method at the Pohang Neutron Facility. The present results are in good agreement with the evaluated data in ENDF/B-VI and the previous measurements. The resonance parameters of Hf isotopes have been determined by fitting the transmission data with the SAMMY code.

Acknowledgments

This work is partly supported through the Long-term Nuclear R&D program of the Korea Atomic Energy Research Institute and through the Science Research Center (SRC) program of the Institute of

High Energy Physics, Kyungpook National University. This research was also supported by Kyungpook National University Research Fund, 2004.

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