NUCLEAR DATA MEASUREMENTS WITH A PULSED NEUTRON FACILITY BASED ON AN ELECTRON LINAC†

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Abstract

We report the activities by using the pulsed neutron facility which consists of an electron linear accelerator, a water-cooled Ta target with a water moderator, and a 12 m time-of-flight path. It can be possible to measure the neutron total cross-sections in the neutron energy range from 0.01 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 total cross-sections of Nb are in general agreement with the evaluated data in ENDF/B-VII. We also report the isomeric yield ratios for isomeric pairs produced from photo-nuclear reactions by using the bremsstrahlung photons from the electron linac.

INTRODUCTION

Electron linear accelerators (linac) are being used throughout the world in a variety of important applications. Pulsed neutrons based on an electron linac are effective for measuring energy-dependent cross sections with high resolution by using the neutron time-of-flight (TOF) method covering the energy range from thermal to a few tens of MeV neutrons. The Pohang Neutron Facility (PNF) based on a 100-MeV electron linac was proposed in 1997 and constructed at the Pohang Accelerator Laboratory (PAL) on December 1998 [1]. Its main goal is to construct the infrastructure for the nuclear data production in Korea.

Recently, the PNF has been used for measuring the cross-sections of neutron-nucleus reactions [2] and photo-nucleus reactions [3].

POHANG NEUTRON FACILITY

The PNF consists of an electron linac, a water-cooled Ta target, and a ~12-m-long TOF path. The characteristics of the facility are described elsewhere [4]. The beam energy of the electron linac is varied from 75 MeV to 50 MeV, and the beam currents at the end of linac are in between 100 mA and 30 mA. The length of electron beam pulse is 1-2 μs, and the pulse repetition rate is 10 Hz.

A Ta target was designed and constructed for the neutron production by way of bremsstrahlung under high power electron beams [5]. The Ta target was composed of ten Ta sheets, 49 mm in diameter and 74 mm in total length. 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 estimated neutron yield per kW of beam power at the neutron target was about 10^{12} n/sec.

The neutron guide tubes were constructed of 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 in the middle position where the sample 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.

During the experiment, the electron linac was operated with a repetition rate of 10 Hz, a pulse width of 1.0 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 almost is the same as that in the target.

NEUTRON TOF EXPERIMENT

Experimental Arrangement

The experimental arrangement for the neutron total cross-section measurements by using the neutron TOF method, which is similar to the previous one [6], is shown in Fig. 1. The target is located at a position where the electron beam hits its center. To reduce the gamma flash generated by the electron burst in the target, the target is placed in 5.5 cm away from the center of the neutron guide to the backward direction. This target was set in the 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 by

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the measurement of thermal neutron flux and also compared with the Monte Carlo simulation [5].

A high purity (99.99%) natural niobium metallic plate with a diameter of 80.11±0.01 mm and the thickness of 15.04±0.03 mm, was placed at the midpoint of the flight path. A set of notch filters of Co, In, and Cd plates with 0.5, 0.2, and 0.5 mm in thickness respectively, was used for the background measurement and the energy calibration.

The neutron detector was located at a distance of 12.06±0.02 m from the photo-neutron target. A ^{6}Li-ZnS(Ag) scintillator BC702 from Bicron (Newbury, Ohio) with a diameter of 125 mm and a thickness of 16 mm mounted on an EMI-93090 photomultiplier was used as a detector for the neutron TOF spectrum measurement. This scintillator consists of a matrix of a lithium compound enriched to 95% ^{6}Li dispersed in a fine ZnS(Ag) phosphor powder.

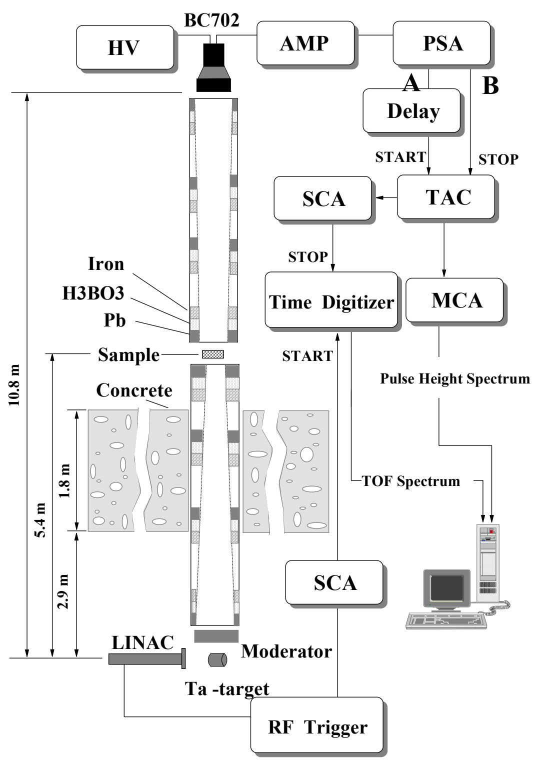

Figure 1: Experimental arrangement and a block diagram for data acquisition.

Data Taking and Analysis

The configuration of the data acquisition system used in this measurement is also shown in Fig. 1. The details of data acquisition system and data taking are described elsewhere [2]. In the transmission measurements, we have taken data with sample in (Nb sample) and out (open beam) periodically. Total data taking times for sample in and out are 35.83 hours. The neutron total cross section is determined by measuring the transmission of neutrons through the sample. The transmission rate of neutrons at 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:

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

$$T(E_i) = \frac{[I(E_i) - IB(E_i)]/M_I}{[O(E_i) - OB(E_i)]/M_O} \tag{2}$$

where N_j is the atomic density per cm^2 of j-th isotope in the sample. $I(E_i)$ and $O(E_i)$ are the foreground counts, $IB(E_i)$ and $OB(E_i)$ are the background counts, and M_I and M_O are monitor counts for sample in and out, respectively. In this measurement, we assumed the monitor counts to be equal during the experiment. The total cross-sections of the Nb sample as a function of neutron energy were obtained by using the Eq. (1). The statistical error can be determined from Eq. (1) assuming the monitor counters are equal during the measurements and found about 5%. The systematic uncertainties came from the following sources: the sample thickness (2.6%), and the dead time, the normalization, etc. (2%). Thus, the total systematic error of the present measurement is about 3.8 %. The measured total cross-sections are generally in good agreement with other existing data and with ENDF/B-VII.0 [7] and JENDL 3.3 [8] evaluated data assuming 300K for Doppler broadening, as shown in Fig. 2. The data measured by V.E. Pilcher et al. [9] are higher than the present results at energies from 29.2 to 299.7 eV. The present results are in general good agreement with those of K.K. Seth et al. [10] measured at the neutron energy regions from 47.1 to 166.9 eV.

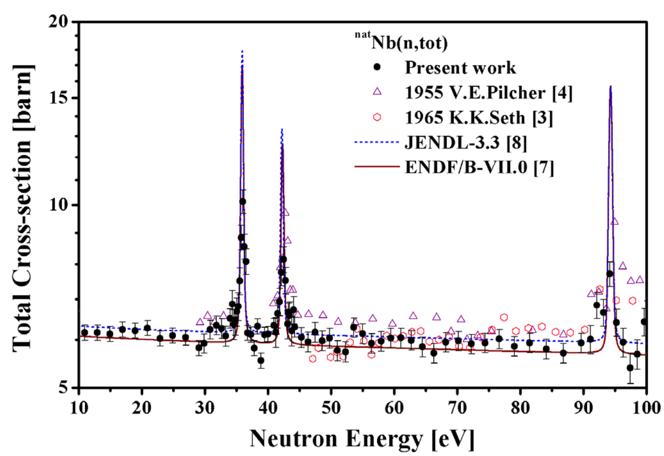

Figure 2: The measured total cross-sections of natural Nb compared with the existing measured data.

ISOMERIC YIELD RATIO

The bremsstrahlung photons of the end point energy 50-, 60-, 65-, and 70-MeV are produced from a 100-MeV electron linac. The bremsstrahlung is produced when a pulsed electron beam hit a 0.1-mm thin W-target with a size of 100 mm × 100 mm. The W-target is located at 18 cm from the beam exit window. The high-purity metallic foils of natural composition that made by the Nilaco Co. (Japan) were exposed to uncollimated bremsstrahlung photons of 50-, 60-, 65-, and 70-MeV. The activation foils were placed in air at 12 cm from the W target and they were positioned at zero degree with the direction of the electron beam. The time of sample irradiation is considered according to the half-lives of the reaction products. During the irradiation of samples, the electron linac was operated with a repetition rate of 15 Hz, a pulse width of 2.0 μs, and the average beam current of 23±2 mA, 31±3 mA, and 37±3 mA for 50-, 60-, and 70-MeV, respectively. The spectroscopic measurements of the studied nuclei from the activated foils were taken with a p-type coaxial CANBERRA high-purity germanium (HPGe) detector which is operated with GENIE2000 data acquisition software. The full peak efficiency was measured with standard radioactive source. The details of the detection efficiency measurement as a function of photon energy are given in [11].

In activation process, considering the production of nuclide of isomeric state and ground state at the same time of irradiation and internal transfer, we can derive the isomeric ratio *IR* from the measured gamma activities as follows:

$$IR = {}^{Y_m}\!\big/_{Y_g} \tag{3}$$

where $Y_{m(g)}$ is the yield of the isomeric- and the ground-state defined as

$$Y_i = N_0 \int_{E_{th}}^{E_{\gamma\max}} \sigma_i(E)\phi(E)dE \,. \tag{4}$$

N_0 is the number of target nuclei, $\sigma_i(E)$ is the energy dependent reaction cross-section and $\phi(E)$ is the shape of the bremsstrahlung spectrum. $E_{\gamma\max}$ and E_{th} are the maximum end point energy of bremsstrahlung and the reaction threshold, respectively.

The isomeric yield ratios of ^{44m,g}Sc from ^{nat}Ti are measured by the photo-activation method with the maximum bremsstrahlung energy ($E_{\gamma max}$) of 50-, 60-, and 70-MeV. The ^{44m,g}Sc isomeric pair were identified based on their characteristic γ-ray energies and half-lives. The nuclear reactions and decay data of the ^{44m,g}Sc are taken from [12]. According to the decay scheme given in [12], the isomeric state ^{44m}Sc (high spin state, 6^+) with a half-life of 58.6 h decays directly to the 3285.0 keV state of ^{44}Ca (6^+) by an electron capture reaction with a branching ratio of 1.20%. Meanwhile, 98.8% of the isomeric state decays to the unstable ground state ^{44g}Sc (low spin state, 2^+) by emitting a 271.13 keV γ-ray. The unstable ground state ^{44g}Sc (2^+) with a half-life of 3.927 h again decays to the 1157.03 keV energy level of ^{44}Ca (2^+) by both an electron capture and a β^+-process with a branching ratio of 98.95%. In this work, the activity of the isomeric state, ^{44m}Sc was determined by using the 271.13 keV γ-ray, and that of the unstable ground state radionuclide ^{44g}Sc was determined by using the γ-ray of 1157.03 keV. The interference and coincidence summing are taken in to account in analyzing data.

The measured isomeric yield ratios of 44m,gSc from natTi target are 0.083±0.012, 0.108±0.009, 0.120±0.030, and 0.129±0.012 for 50-, 60-, 65-, and 70-MeV, respectively. The increasing isomeric yield ratio indicates the increased transfer of angular momentum in the reaction process.

CONCLUSIONS

The Pohang Neutron Facility based on an electron linac was constructed for nuclear data production in Korea. In order to show the ability of PNF as the nuclear data production facility, the total cross section of natural Nb has been measured in the neutron energy region between 0.02 and 100 eV by using the neutron TOF method and a ^{6}Li-ZnS(Ag) scintillator as a neutron detector. The present measurement is in good agreement with other measurements and the evaluated data in ENDF/B-VII and JENDL 3.3. We also reported the isomeric yield ratios of ^{44m,g}Sc from ^{nat}Ti for 50-, 60-, 65-, and 70-MeV.

The pulsed neutron facility based on an electron linac can be a good user facility for nuclear data production and for basic science experiments using both neutrons and photons.

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