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Neutron capture cross-section measurement for the $^{186}W(n,\gamma)^{187}W$ reaction at 0.0536 eV energy

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Abstract

The thermal neutron-induced activation cross section for the $^{186}W(n,\gamma)^{187}W$ reaction was measured at 0.0536 eV neutron energy using TRIGA Mark-II research reactor, Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh. The $^{197}Au(n,\gamma)^{198}Au$ monitor reaction induced in a high-purity gold foil was used to determine the effective neutron beam intensity. The activities induced in sample and monitor foils were measured nondestructively by a high-resolution HPGe γ-ray detector. The present experimental cross-section value is the first one at 0.0536 eV. The obtained new cross section that amounts to 26.6 ± 1.6 b is 2% higher than the recently reported data in ENDF/B-VII and 5% lower than that of JENDL-3.3.

Keywords: Reactor; Thermal neutron; 0.0536 eV energy; Cross section; Activation technique

1. Introduction

Tungsten is a structural material used in various parts of fusion reactors. Nuclear reactors have been considered promising as long-lived heat sources for light-weight space powder systems. To meet the requirements of compactness and high-temperature operation, tungsten has been suggested for use both as a fuel-element material and as a shielding material. To evaluate the merits of tungsten for these applications, accurate and complete nuclear data are required, particularly for neutron capture cross sections (Shook and Bogart, 1968). Because of the large temperature difference between reactor start-up and operation, the energy dependence of the capture cross section must be known over an appreciable energy interval. Particularly, the thermal neutron-induced activation cross section for the $^{186}W(n,\gamma)^{187}W$ reaction is of great importance not only for design and development of nuclear reactors, but also for the activation analysis and other theoretical and experimental studies concerning the interaction of neutrons with tungsten. Up to now, the capture cross sections have been measured with various neutron sources, based on reactors, Van-de-Graaff accelerators and electron linear accelerators.

A number of authors have reported that the cross section for this reaction at 0.0253 eV neutron energy and a large discrepancy is present among them. In most of these studies, thermal neutron cross sections were determined experimentally by the activation method using cadmium ratios of the investigated material and a reference material (monitor), for which usually gold is employed. Karadag and Yucel (2004) reported the thermal neutron cross section for the $^{186}W(n,\gamma)^{187}W$ reaction, which was measured by the activation method using the $^{55}Mn(n,\gamma)^{56}Mn$ reaction as a single comparator, where the irradiation was performed in an isotropic neutron field of the ^{241}Am–Be neutron sources. In these studies, neutron beams with broad spectrum (thermal, epithermal and fast energies) were used for irradiation of target.

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The present work was undertaken to measure the cross sections of the $^{186}W(n,\gamma)^{187}W$ reaction only in the interaction of monoenergetic thermal neutrons at 0.0536 eV with natural tungsten using the 3 MW TRIGA Mark-II research reactor at the Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh. To achieve 0.0536 neutron energy, it must have to arrange a special facility with monochromator outside the reactor. The activation technique can be employed to obtain capture cross sections, because the decay scheme of the product nucleus is known and its states with suitable half-life are present. The results were compared with the available reported experimental data and evaluated data of ENDF/B-VII (2007) and JENDL-3.3 (2002).

2. Experimental technique

2.1. Neutron source

The neutrons used in this experiment were generated in TRIGA Mark-II reactor at the Atomic Energy Research Establishment, Dhaka, Bangladesh. The TRIGA is a research reactor having a maximum continuous thermal power output of 3 MW. The experimental facilities around TRIGA reactor include four neutron beam tubes, namely tangential, piercing, radial-1 and radial-2 beam port. In the present experiment, the piercing beam port was utilized. The neutrons coming out of the reactor through this beam port are of various wavelengths. They have been monochromatized before sending them on the target for experiment. This can very effectively be done using a suitable single crystal of Cu(2 0 0). A schematic diagram of the arrangement for monochromatization of reactor neutrons and the experimental setup are shown in Fig. 1. The reactor neutrons (thermal and epithermal) of piercing beam port are coming through a collimator with sufficient shielding to the monochromator, which is also surrounded with enough shielding as shown in Fig. 1. The monochromatic neutrons escape through another collimator to target for irradiation. A monochromatic neutron beam of wavelength $\lambda = 1.236$ Å obtained by Bragg reflection from a Cu (2 0 0) monochromator was used for irradiation of target materials. The corresponding neutron energy at this wavelength is 0.0536 eV.

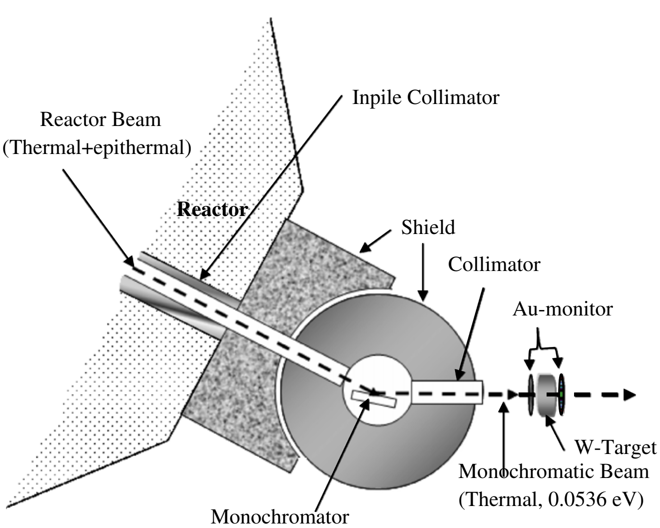

Fig. 1. A schematic view of the monochromatic system and experimental arrangement for irradiation.

2.2. Sample irradiation

A foil of tungsten (1.2 cm diameter × 200 μm thick; purity 99.99%) of natural isotopic composition: $^{180}W(0.12\pm0.01\%)$, $^{182}W(26.50\pm0.16\%)$, $^{183}W(14.31\pm0.04\%)$, $^{184}W(30.64\pm0.02\%)$, and $^{186}W(28.42\pm0.19\%)$ and thin gold foils (1.2 cm diameter × 25 μm thick; purity 99.99%) were irradiated with neutrons of 0.0536 eV energy for 5 h. Gold foils were used to measure the effective neutron flux using the $^{197}Au(n,\gamma)^{198}Au$ monitor reaction (68.5 ± 1.7 b at 0.0536 eV (Yamamoto et al., 1996; Pavlenko and Gnidak, 1975; Haddad et al., 1964)). Two gold foils of approximately same size and weight were attached at the front and back of the tungsten foil, respectively to check the difference in neutron beam intensity between entrance and exit of the target. To follow the effect of epithermal neutrons and fast neutrons, the cadmium-covered gold foil and bare aluminum foil were also irradiated.

2.3. Gamma-ray measurement and data analysis

The activities of the radioisotopes produced in the target and the monitor foils were measured nondestructively using high-purity germanium (HPGe) gamma-ray spectroscopy (Canberra, 15% relative efficiency, 1.8 keV resolution at 1332.5 keV of ^{60}Co) coupled with a digital gamma spectrometry system (ORTEC DSPEC jr ^{TM}) and Maestro data acquisition software. The spectrum analysis was done using the program GammaVision 5.0 (EG&G Ortec) and Hypermat PC software. Measurements were started about 10 h after the end of irradiation. Each sample was recounted three times, giving enough intervals to avoid disturbance by overlapping gamma-lines from undesired sources and to determine the experimental cross-section value with adequate precision and accuracy. The thickness of the material used in the present experiment was limited for the self-absorption of captured gamma rays in the sample. If this absorption becomes large, the fraction of the gamma rays escaping may become a function of the neutron capture cross section of the sample. This arises from the fact that a capture event occurring near the front face (which is more likely when the cross section is relatively high) can have an appreciably higher probability of being detected than one that originates in the interior due to the exponential nature of the gamma attenuation.

The efficiency versus energy curve of the HPGe gamma-ray detector for the counting distance was determined using the standard point sources, ^{133}Ba, ^{109}Cd, ^{22}Na, ^{60}Co, ^{57}Co, ^{54}Mn and ^{137}Cs. The neutron beam intensity was determined from the measured activities induced in gold