Measurement of Energy Dependent Neutron Capture Cross Sections of ^{197}Au in Energy Region from 0.1 eV to 10 keV using a Lead Slowing-down Spectrometer

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요 약

본 연구는 교토대학 원자로실험소의 46-MeV전자선형가속기에서 발생된 전자선을 Ta표적에 충돌시켜 발생된 중성자를 이용하였다. 발생된 중성자는 납감속측정장치(LSDS:Lead Slowing-down Spectrometer))속에서 감속되었고 중성자비행시간법(TOF:Time-of-Flight)을 이용하여서 중성자에너지를 선별하여 ^{197}Au의 중성자포획단면적을 중성자에너지 0.1 eV에서 10 keV범위에 걸쳐 측정하였다. 발생된 중성자속을 측정하기 위하여 BF_3검출기속의 ^{10}B(n,ɣ)반응을 이용하였고 이것을 이용하여 중성자 반응 단면적을 상대적으로 얻었다. TOF방법으로 얻어진 결과는 1 eV에서의 결과(24.5 b)에 규격화되었다. 기존의 실험결과들과 평가결과들인 JENDL/D-99 Dosimetry File과 비교하였다.

중요단어: 중성자포획, 단면적, ^{197}Au, 납감속측정장치

Abstract

The neutron capture cross section of ^{197}Au has been measured relative to the ^{10}B(n,ɣ) standard cross section by the neutron time-of-flight(TOF) method using a 46-MeV electron linear accelerator(linac) at the Research Reactor Institute, Kyoto University(KURRI). In order to experimentally prove the result obtained, the supplementary cross section measurement has been made from 0.1 eV to 10 keV using the Kyoto University Lead slowing-down spectrometer (KULS) coupling to the linac. The relative measurement by the TOF method has been normalized to the reference value(24.5 b) at 1 eV.

The evaluated capture cross sections in JENDL/D-99 Dosimetry have been compared with the current measurements by the KULS experiments.

Key word: Neutron capture, Cross-section, ^{197}Au, Lead Slowing-down spectrometer

I. Introduction

The nuclear data is very useful for the nuclear physics, nuclearsynthesis, nuclear medicine and nuclear engineering. Futhermore, the nuclear cross section data of long-lived fission products (LLFPs) are of great importance for the assessment of reactor safety and the investigation of fuel-burn-up characteristics. In recent years, a great interest has been taken in the capture cross sections of LLFPs from the points of research and development of the nuclear transmutation technology[1]. Although the cross section of the ^{197}Au(n,ɣ) reaction has been measured by a few experimental groups in the keV region, no data has been reported below 100 eV, except for the data at the

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투고 일자: 2010년 09월 25일, 심사일자: 2010년 09월 30일, 수정 일자: 2010년 11월 16일, 게재 확정일자: 2010년 12월 13일

thermal neutron energy. The neutron capture cross section of ^{197}Au is very useful to obtaining the relative capture yield of the other nuclear material reaction experiment. Although the accurate neutron capture cross section is very important, these data are very poor in the energy region from 0.1 eV to 100 keV. The evaluated cross section of the ^{197}Au(n,ɣ) reaction has been compiled in JENDL/D-99.

Since a lead slowing-down spectrometer can give us an intense neutron flux/spectrum in the eV or resonance energy region, a good signal-to-noise ratio can be achieved in the cross section measurement using even radioactive materials[2]. However, the energy resolution of the spectrometer is poor and about 30 to 35% at full width at half maximum (FWHM)[2],[3]. Recently, the lead slowing-down spectrometer has been successfully applied to the cross section measurement[4].

II. Experiment and Measurement

We have also made a supplementary measurement of the ^{197}Au(n,ɣ) cross section by the Kyoto University Lead slowing-down Spectrometer (KULS)[4] using an Ar-gas proportional counter for the capture gamma-ray measurement. Lead is one of the very heavy elements in the elements table. When neutrons come in the lead with several MeV energy, most of the nuclear reaction is the elastic-scattering with high quantity cross-section. The capture cross section measurement has been carried out by the neutron TOF method using a 46-MeV linac at the KURRI. The experimental arrangement is shown in Fig. 1. A lead slowing-down spectrometer has been in stalled in coupling to a 46-MeV linac at KURRI. This linace-driven KULS is composed of 1600 lead blocks(each size:10 x 10 x 20 cm3, purity: 99.9%) and the blocks are piled up to make a cube of 1.5 x 1.5 x 1.5 m3 (about 40 tons in weight) without any structural materials, as shown Fig. 1. The KULS is covered with cadmium sheets of 0.5 mm thickness for shielding against low-energy neutrons scattered from the surroundings. At the center of the KULS, an aire-cooled photoneutron target of tantalum is set to generated uplsed fast neutrons. One of the experimental holes in the KULS is covered with 10 to 15 cm thickness bismuth layers to shield a detector from hight-energy capture gamma rays produced by the Pb(n,ɣ) reaction in the spectrometer.

We have employed the ^{10}B(n,α) standard cross section to obtain the relative neutron flux/spectrum in the resonance energy region. The BF_3 counter was inserted into a lead hole of the KULS to monitor the neutron intensity during the experiment. The BF_3 counter was of a cylindrical type, 50 mm in effective length, 12 mm in diameter, and with a gas pressure of 1 atom and hight voltage bias of 1100 V. In the relative cross-section measurement with the BF_3 counter are replaced with the counting rate of the counter and the ^{10}B(n,α) reaction cross section. Natural gold sample was made of metal plate (Au, chemical purity of gold: 99.99%) of 0.63 g, which was sized 1.8 x 1.8 cm2, 0.1 cm in thickness.

We have employed a coincidence method between the Ar-gas proportional counter detectors to reduce the background counts, although an anti- coincidence method has been applied to the B measurement with the BF3 counter. Through the amplifiers and the discriminators, signals from the detectors were fed into a time digitizer, which was started by the linac electron burst. The discrimination level was set at about 200 keV to detect the gamma rays from the ^{197}Au sample. Two sets of 4096 channels with a 0.5µs channel-width were allotted to the Ar-gas proportional counter detectors and a BF_3 proportional counter as a neutron intensity monitor during the experiment. These signals were stored in a data-acquisition system for each measurement. The linac was operated with a repetition rate of 50 Hz, a pulse width of 3µs, a peak current of 0.4 A and an electron energy of 30 MeV.

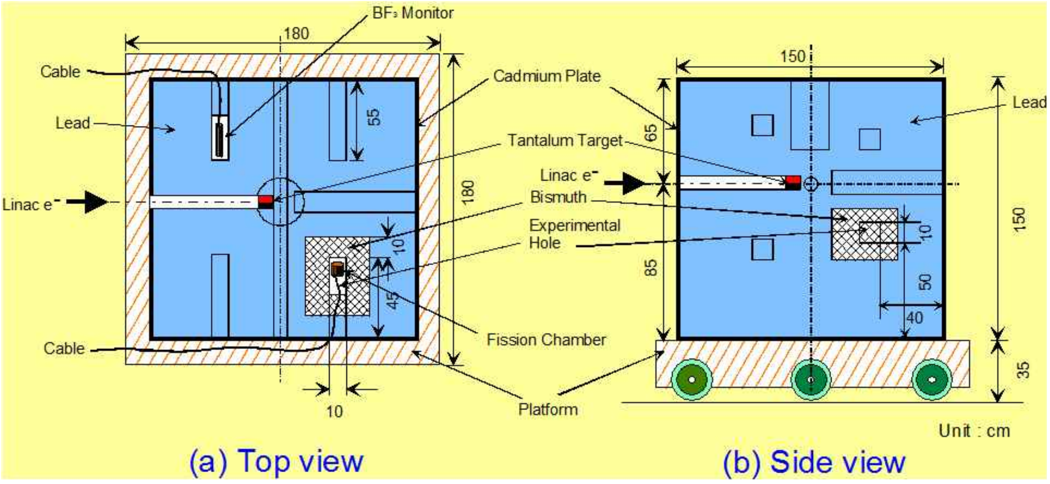

Fig. 1. Experimental arrangement for the linac time-of-flight method and cross sectional view of the KULS:(a) Top view and (b) Side view.

The relation of capture yields for the ^{197}Au(n,ɣ) reaction and the ^{10}B(n,ɣ) reaction in the BF_3 counter is obtained by the following relations:

$$Y_X(E) = \frac{C_X(E)}{C_B(E)} \cdot Y_B(E) \quad \text{...} (1)$$

where the subscripts X and B are for the ^{197}Au and the neutron flux from the BF_3 counter, respectively. CX(E) and CB(E) are the counting rates at energy E for each sample. YB(E) is the energy dependent capture yield for the ^{10}B(n,ɣ) standard cross section. There is a following relation between the capture cross section σ(E) and the yield Y(E)

$$Y(E) = \left\{ 1 - \exp(-N \cdot \sigma_T(E) \cdot t) \right\} \frac{\sigma_C(E)}{\sigma_T(E) \cdot Fc(E)}, \quad \text{..} (2)$$

whereσC(E) andσT(E) are the neutron capture and the total cross sections, N and t are the atomic density and the thickness of the sample, and Fc(E) is a correction function for the neutron scattering and/or self-shielding in the sample. In the current data analysis, we have employed the Monte Carlo code MCNP[5] to derive the correction function Fc(E).

III. Results and Discussion

Making use of the Ar-gas proportional counter and the 46-MeV electron linac at KURRI, the capture cross section of ^{197}Au has been measured relative to that of the ^{10}B(n,ɣ) reaction in the BF_3 counter from 0.1 eV to 10 keV and the result has been normalized to the reference cross section value of 24.5 b at 0.1 eV in JENDL/D-99 file. The capture cross section of ^{197}Au(n,ɣ) reaction obtained by the KULS system with TOF method is presented in Fig. 2.

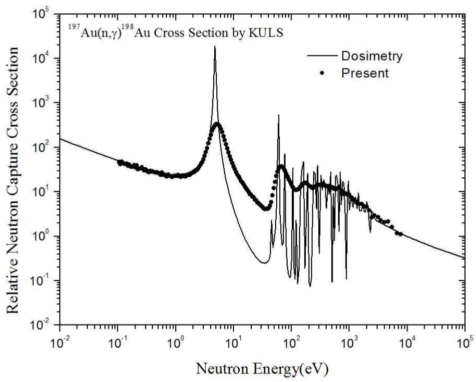

Fig. 2. Comparison of the current measurement and the experimental/ evaluated cross sections of the ^{197}Au(n,ɣ) reaction.

The experimental uncertainties, which are mainly due to the statistical ones, are from 0.3 to 5%. The KULS data have been normalized to the evaluated neutron capture data by integrating them in the relevant energy region. The data by the KULS are practically close to the energy-broadened TOF data, although slight discrepancies are found between the data in the resonance structure region. The discrepancies would be due to the fact that there may exist some problems in the resolution function to reproduce the KULS measurement.

The present result was compared the evaluated data JENDL/D-99 file. In the cross section minimum region between s-wave main resonance(about 5 eV region) and several tens eV resonances, the present data has large discrepancies because of the neutron energy resolution of KULS. Above the 1 keV energy region(continuum region) the present data seems good agree with the evaluated data JENDL/D-99 file.

Ⅳ. Conclusion

The neutron capture cross section of ^{197}Au has been measured relative to the 10B(n,ɣ) standard cross section by the neutron time-of-flight(TOF) method using a 46-MeV electron linear accelerator(linac) at the Research Reactor Institute, Kyoto University(KURRI). In order to experimentally prove the result obtained, the supplementary cross section measurement has been made from 0.1 eV to 10 keV using the Kyoto University Lead slowing-down spectrometer (KULS) coupling to the linac. The relative measurement by the TOF method has been normalized to the reference value(24.5 b) at 1 eV. The evaluated capture cross sections in JENDL/D-99 Dosimetry file have been compared with the current measurements by the KULS experiments. In the cross section minimum region between s-wave main resonance(about 5 eV region) and several tens eV resonances, the present data has large discrepancies because of the neutron energy resolution of KULS. Above the 1 keV energy region(continuum region) the present data seems in good agreement with the evaluated data JENDL/D-99 file.

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