Neutron capture cross section of ^{185}Re leading to ground and isomer states of ^{186}Re in the keV-neutron energy region

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Abstract. The neutron capture cross section of ^{185}Re was measured in the astrophysically important energy region. Measurements were made using a neutron beam from a ^{7}Li$(p,n)^{7}$Be neutron source with energies ranging from 3 to 90 keV. Two different experimental techniques, time-of-flight (TOF) and activation methods, were employed. In the TOF experiments, the total neutron capture cross section of ^{185}Re was determined by the pulse-height weighting technique. In the activation method, the partial capture cross section leading to the ground state of ^{186}Re was measured by detecting decay γ-rays from neutron activated samples. The present cross section values were compared with evaluated cross section data and previous measurements. The difference between the TOF and activation results was smaller than experimental uncertainties. This suggests that the production cross section of isomer states of ^{186}Re is very small.

1 Introduction

A Re/Os nucleo-cosmochronometer has been proposed to date a rapid neutron-capture process (r-process) in nucleosynthesis [1]. Rhenium-187 is primarily considered a pure r-process nuclide and has a long half-life of 43.5 Gyr. Thus, the ^{187}Re/^{187}Os abundance ratio changing with the ^{187}Re half-life can be a good chronometer for the r-process. However, slow neutron-capture process (s-process) through an isomer state of ^{186}Re ($T_{1/2}$ = 0.2 Myr) may contaminate the ^{187}Re/^{187}Os abundance ratio [2]. It is necessary to evaluate a contribution from ^{186m}Re created from the ^{185}Re$(n,\gamma)^{186m}$Re reaction.

In this work, we experimentally determined the total capture cross section of ^{185}Re by the time-of-flight (TOF) method, and the partial capture cross section leading to the ground state of ^{186}Re by the activation method. The production cross section of the isomer state of ^{186}Re is discussed from a difference between the two different technique measurements.

2 Experiments and Data Analysis

Experiments were performed at the Laboratory for Advanced Nuclear Energy at the Tokyo Institute of Technology. Incident neutrons were generated through the ^{7}Li$(p,n)^{7}$Be reaction by a pulsed proton beam from a Pelletron accelerator bombarding a lithium target. The incident neutron energy distributed from a few keV to 90 keV, determined by the TOF method.

For the TOF experiments to determine the total capture cross section of ^{185}Re, an isotopically enriched ^{185}Re sample (enrichment: 97.7%) in a physical form of metal powder was used. The sample weight was 0.2967 g. The sample powder was encased in a graphite container with an inner diameter of 10 mm. A gold sample (10 mm diam. and 2.15 g) was used as standard for cross section measurements. The flight length from the neutron source to the sample was 12 cm. Capture γ-rays from the sample were detected with an anti-Compton NaI(Tl) spectrometer in the TOF experiments. The details of the experimental method and the data analysis procedure can be found elsewhere[3]. The (n,γ) cross sections were obtained from the pulse height spectra by the pulse-height weighting technique[4]. The absolute cross sections were determined from the ratio of ^{185}Re to ^{197}Au yields and the JENDL-4.0 evaluated ^{197}Au(n,γ)^{198}Au cross section. Corrections for neutron self shielding, multiple scattering and impurities in the sample were made. The neutron capture cross section was derived in four energy regions: 15-25, 25-35, 35-55, and 55-90 keV.

In the activation experiments, a natural rhenium sample (^{185}Re: 37.4%, ^{187}Re: 62.6%) was used. Rhenium metal powder was pressed to form a pellet with a diameter of 10 mm. The weight of the sample was 0.2848 g. The rhenium sample was sandwiched between two gold samples with the same diameter and placed at a distance of 2 cm from the ^{7}Li$(p,n)^{7}$Be neutron source for irradiation. The gold samples were standard for determining the neutron capture cross section of ^{185}Re. After irradiation, γ-rays from the activated rhenium and gold samples were measured with a HP Ge detector that was well shielded from natural background γ-rays. Decay γ-rays of 136 keV (^{186}Re) and 412 keV (^{198}Au) were clearly observed but transitions from isomer states of ^{186}Re did not appear in the spectra due to much longer half-life than its ground state. The partial neutron capture cross section leading to

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the ground state of ^{186}Re were determined from measured activities.

3 Results

The results are plotted in Fig. 1. The present experimental results were compared with evaluated cross section [5] and previous experimental data [6]-[11]. For activation experimental results, the averaged cross section over the incident neutron energy distributing from 3 keV to 90 keV is plotted at 42 keV, the average incident neutron energy. To compare the TOF data with the activation average cross section, the averaged cross section was calculated from the present TOF data. The averaged cross section calculated from the TOF results was 1.22 ± 0.05 b while the activation experiments results in 1.29 ± 0.11 b. The difference between the two values is smaller than experimental uncertainties. This suggests that the isomer production cross section is smaller than the uncertainties.

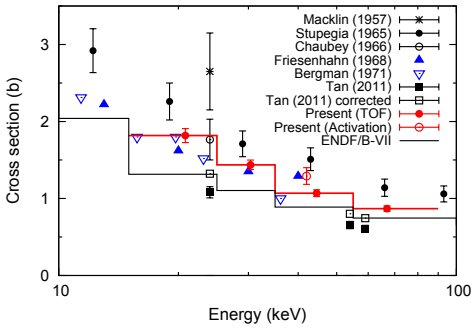

Figure 1. Neutron capture cross section of ^{185}Re.

4 Summary

We measured the neutron capture cross section of ^{185}Re in the keV energy region. To discuss the production cross section of astrophysically important ^{186}Re isomers, two different experimental techniques, time-of-flight and activation methods, were employed. In the TOF experiment, the total capture cross section of ^{185}Re was measured. On the other hand, using the activation method, the partial neutron capture cross section leading the ground state of ^{186}Re was determined. The difference between the two experimental cross sections was smaller than the experimental uncertainties. We conclude that the production cross section of ^{186}Re isomers is very small. In future work, we can reduce the experimental uncertainties, for example, uncertainty of the detection efficiency of the HP Ge detector in the activation measurement that can be improved with better standard γ-ray sources. Then, we can discuss more on astrophysical impact of our experimental results.

References

[1] D. D. Clayton, Nature, **224**, 56 (1969).
[2] T. Hayakawa, Astrophys. J., **628**, 533 (2005).
[3] S. Mizuno et al., J. Nucl. Sci. Technol., **36** 493 (1999).
[4] R. L. Macklin et al., Nucl Instrum Meth. Phys. Res., **91** 565 (1971).
[5] ENDF/B-VII.1 data file for ^{185}Re (MAT = 7525), evaluated by I. J. Thompson and N. C. Summers, (2011).
[6] R. L. Macklin et al., Phys. Rev., **107** 504 (1957).
[7] D. C. Stupegia et al., J. Nucl. Energ. Parts A/B., **19** 767 (1965).
[8] A. K. Chaubey and M. L. Sehgal, Phys. Rev., **22** 191 (1968).
[9] S. J. Friesenhahn, J. Nucl. Energ., **22** 191 (1968).
[10] A. A. Bergman et al., Neutron Phys. Conf., **1** 144 (1971).
[11] V. H. Tan et al., J. Korean Phys. Soc., **59** 1757 (2011).