^{57}Fe(n,α)^{54}Cr cross sections in the MeV region

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Abstract

Cross sections of the ^{57}Fe(n,α)^{54}Cr reaction are measured for the first time at neutron energies of 5.0, 5.5, 6.0 and 6.5 MeV using a double-section gridded ionization chamber and two back-to-back ^{57}Fe samples. Experiments were performed at the 4.5 MV Van de Graaff Accelerator of Peking University. Monoenergetic neutrons were produced through the ^{2}H(d,n)^{3}He reaction with a deuterium gas target. Foreground and background were measured in separate runs. An ^{238}U sample and a BF_3 long counter were utilized for absolute neutron flux calibration and for neutron flux normalization, respectively. Present results are compared with TALYS code predictions and existing evaluations.

1. Introduction

The cross sections of neutron induced reactions are important for both engineering applications and modification of nuclear model calculations. Iron is one of the most important construct materials, therefore accurate neutron cross section data for isotopes of iron are demanded. Evaluation data exist for iron isotopes in almost all evaluated nuclear data libraries such as ENDF/B, JEFF, JENDL, BROND, and CENDL. However, for the ^{57}Fe(n,α)^{54}Cr reaction, there is no measurement data up to know. The abundance of the ^{57}Fe is only 2.119 %, and the residual nuclei of the ^{57}Fe(n,α)^{54}Cr reaction is stable so the commonly used activation method is unavailable. Although different evaluated libraries predict that cross sections for this reaction increase rapidly with the neutron energy in the MeV region, there are large differences as several times exist among them. So measurements are demanded to clarify the discrepancies and to determine the trends of the excitation function.

In the present work, enriched ^{57}Fe metal foil samples are prepared using the press method. With a double section gridded ionization chamber, the ^{57}Fe(n,α)^{54}Cr reaction cross sections are measured at E_n = 5.0, 5.5, 6.0 and 6.5 MeV for the first time.

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2. Details of measurements

Measurements were performed at the Van de Graaff accelerator of Peking University. Experimental setups are composed of three parts: the neutron source, the α-particle detector, and the neutron flux monitor as shown in Fig. 1.

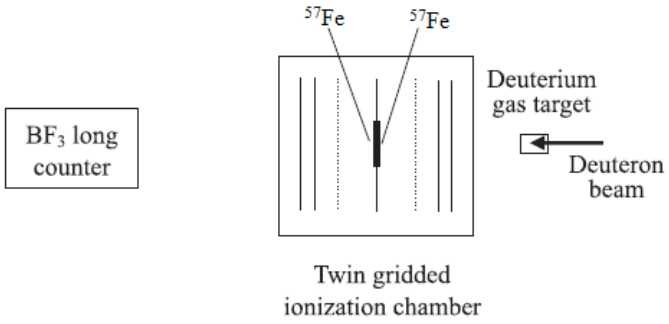

Fig.1. Setup of the experiment.

Neutrons were produced through the $^{2}H(d,n)^{3}He$ reaction using a deuterium gas target. The cylindrical gas cell, 2.0cm in length and 0.9 cm in diameter, was separated from the vacuum tube of the accelerator using a molybdenum foil of 5.0 μm in thickness. During the experiment the gas pressure was ~3 atm. The beam current was about 3.0 μA and the energies of produced neutrons were 5.0, 5.5, 6.0 and 6.5MeV, with energy spreads of 0.38, 0.33, 0.27 and 0.24 MeV, respectively.

The α-particle detector is a twin-gridded ionization chamber and its structure can be found in Ref. [1]. In this experiment, the distances for cathode-grid, grid-anode, and anode-shield were 61.0, 15.0 and 9.0 mm，respectively. The working gas of the ionization chamber was a mixture of Kr+2.82%CO_2 with a pressure of 1.0 atm. In this condition, the α-particle emitted from the ^{57}Fe sample was fully stopped before reaching the grid. High voltages applied to the cathode, grid, and anode were -1500, 0, and +750 respectively, allowing complete collection of electrons from the α-particle ionization.

A sample changer was set in the common cathode of the ionization chamber with five sample positions and two back-to-back samples can be placed at each of them. Specific description of the sample changer can be found in Ref. [2]. Forward and backward ^{57}Fe samples were set back-to-back at the first position of the sample changer. The ^{57}Fe samples were prepared using press method with enriched ^{57}Fe metal and then they were attached to tantalum backings. Data of the samples are listed in Table I. A ^{238}U film sample described in Table I was placed at the second position of the sample changer in the chamber to determine the absolute neutron flux by detecting the fission fragments. Two tantalum sheets were set back-to-back at the third position of the sample changer for background measurement. At the fourth position of the sample changer were double compound α-sources for system adjustment.

Neutron flux monitor is a BF_3 long counter. The axis of the BF_3 long counter and the normal line of the electrodes of the ionization chamber were at 0º to the neutron beam line. The distance from the cathode of the chamber to the center of the deuterium gas target was

16.3cm and that from the front side of the counter to the center of the gas target was 272 cm.

Table I. Description of samples

	Material	Isotopic abundance	Thickness ($\mu g/cm^2$)	Diameter (mm)	Backing
^{57}Fe sample	Enriched ^{57}Fe	95.9%	582.5[a] and 599.1[b]	45.0[a] and 41.0[b]	Ta sheet
^{238}U sample	$^{238}U_3O_8$	99.999%	493.6	45.0	Ta sheet

[a] Forward sample.
[b] Backward sample.

The data acquisition system can be found in Ref. [1]. Coincident events of cathode-anode signal were recorded for both forward and backward directions. For each energy point, the experimental process in turn is compound α-sources measurement for energy calibration, foreground measurement for expected α-events, background measurement, ^{238}U fission measurement to determine the neutron flux and α sources measurement again for stability checking of the data acquisition system. The beam durations for E_n = 5.0, 5.5, 6.0 and 6.5 MeV were about 10, 9.0, 8.5 and 8.5 h, respectively.

3. Results and discussions

Firstly, the cathode-anode two-dimensional spectrum from the crude experimental data was plotted in Fig. 2 for forward direction at E_n = 6.5 MeV. Counts between the 0 and 90 -deg lines represent the α events from the $^{57}Fe(n,\alpha)^{54}Cr$ reaction and the background from the (n, α) reaction of the working gas.

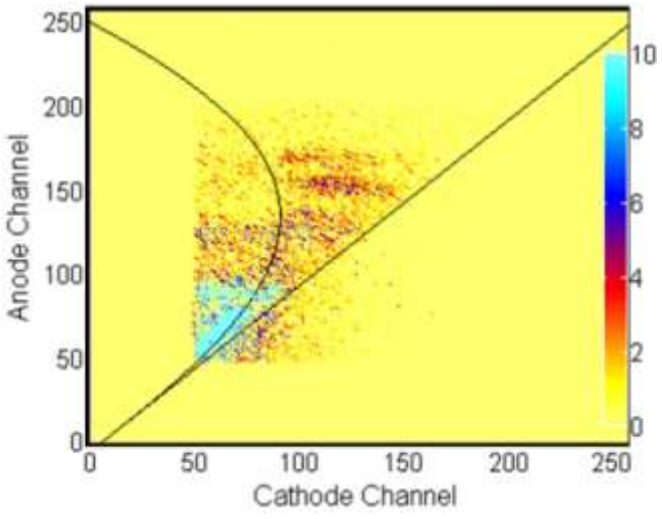

Fig.2. Two-dimensional spectrum of forward events at E_n=6.5MeV.

Then after projecting between the 0 and 90º lines the anode spectrum can be obtained as

is shown in Fig. 3. Particle peak of (n, α_0), (n, α_1), and (n, α_2) can be seen clearly, so the number of α-events for each peak can be obtained.

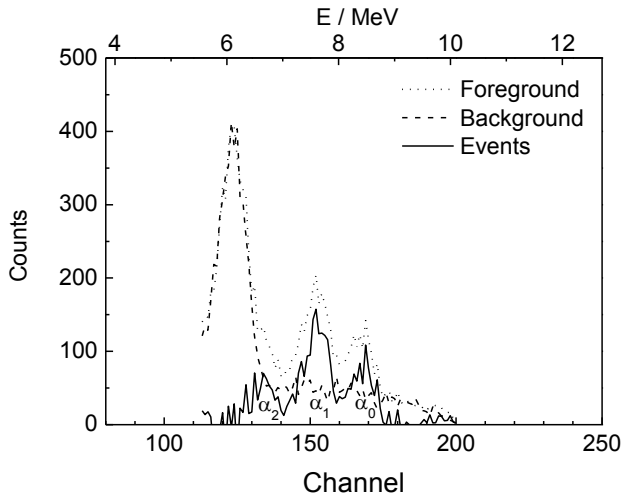

Fig.3. Anode spectrum from the Fig.2 between the 0 and 90 -deg lines.

The anode spectrum from the ^{238}U(n,f) reaction is shown in Fig.4, from which the fission count was obtained.

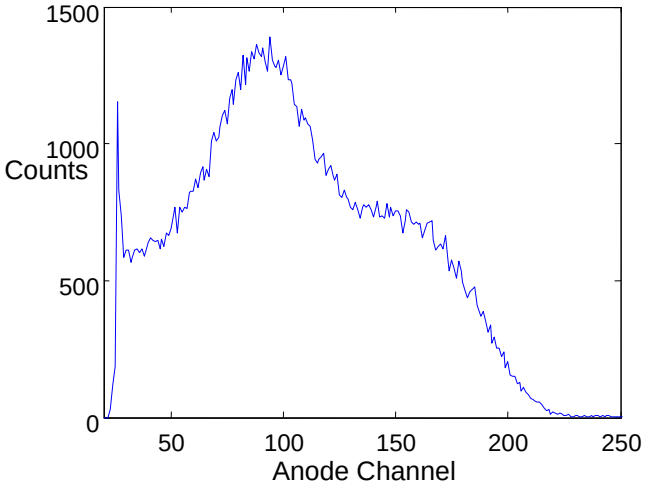

Fig. 4 Anode spectrum of the ^{238}U fission reaction at E_n = 6.5 MeV.

The present results are compared with TALYS-1.4 calculations as shown in Fig.5 and existing evaluations as shown in Fig.6. Good agreements are achieved for partial cross section between measurements and code predictions using default parameters. As seen in Fig. 6, there is large disagreement among different evaluated data libraries, both in magnitudes and in the trends [3].

Data of the present work are listed in Table II.

Table II. Measured cross section of the $^{57}Fe(n,\alpha)^{54}Cr$ reaction

E_n(MeV)	σ_{exp} (mb)			
	(n,α_0)	(n,α_1)	(n,α_2)	(n,α)
5.0	1.53±0.18	1.44±0.18		3.11±0.34
5.5	1.97±0.22	2.33±0.28		4.69±0.47
6.0	1.93±0.23	3.31±0.36	0.55±0.11	6.11±0.61
6.5	1.84±0.22	3.68±0.40	0.82±0.13	7.27±0.65

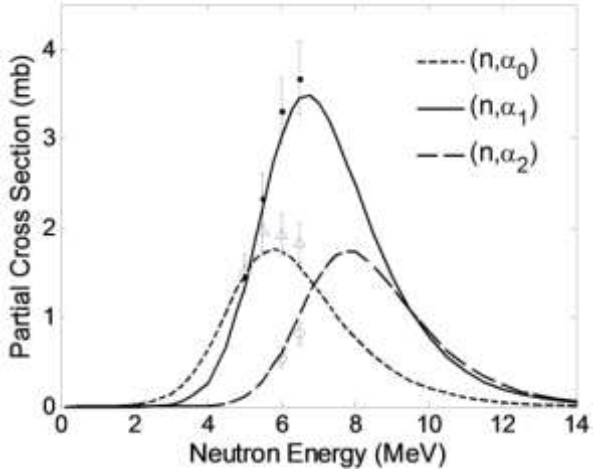

Fig.5. Present partial cross sections of $^{57}Fe(n,\alpha_0)$, (n,α_1) and (n,α_2) reactions compared with TALYS-1.4 code calculations.

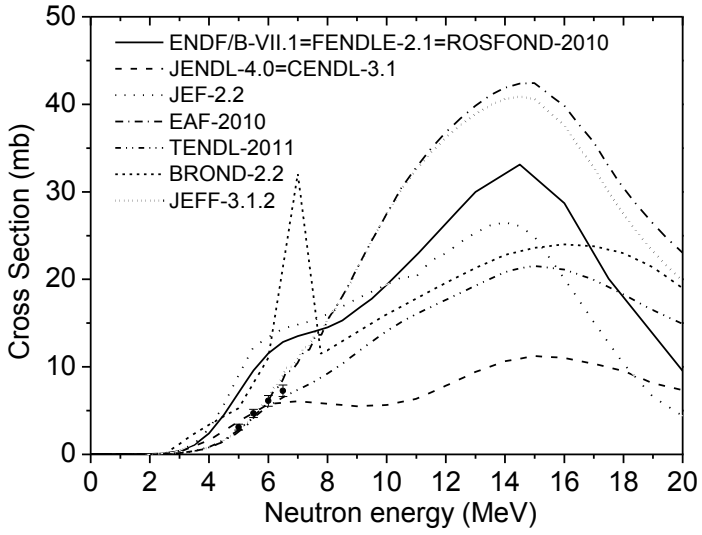

Fig.6. Present cross sections of the $^{57}Fe(n,\alpha)^{54}Cr$ reaction compared with existing evaluations.

4. Conclusions

In the present work ^{57}Fe(n,α_0)^{54}Cr and ^{57}Fe(n,α_1)^{54}Cr reaction cross sections are measured at E_n = 5.0, 5.5, 6.0 and 6.5 MeV, and ^{57}Fe(n,α_2)^{54}Cr reaction cross sections are measured at E_n = 6.0 and 6.5 MeV. Combined with TALYS code calculation, the ^{57}Fe(n,α)^{54}Cr reaction cross sections are obtained at the above four energy points. The present results are the first reported measurement for this reaction in the MeV neutron energy region. Good agreement is obtained between measurements and TALYS code calculation. The present results are preliminary and further check and measurements at higher neutron energies are needed.

Acknowledgements

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References

[1] G. Zhang, H. Wu, J. Zhang, J. Liu, J. Chen, Yu. M. Gledenov, M. V. Sedysheva, G. Khuukhenkhuu, and P. J. Szalanski, Eur. Phys. J A **43**, 1(2010)

[2] G. Zhang, Yu. M. Gledenov, G. Khuukhenkhuu, M. V. Sedysheva, et al, Physical Review C 82, 054619(2010)

[3] Evaluated Nuclear Data File (ENDF), database version of august 13, 2013 [https://www-nds.iaea.org/exfor/endf.htm]