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EVALUATION OF ^{56}Fe (n,p) ^{56}Mn CROSS SECTION

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Abstract: The experimental data for ^{56}Fe (n,p) ^{56}Mn cross section in the neutron energy region up to 20 MeV have been collected and evaluated. The selected data were treated by using the least square method. The trend of the excitation curve was used to adjust the experimental data in the 14 MeV region to 14.7 MeV and the evaluated cross section of 108.7±1.0 mb for 14.7 MeV neutrons was used to normalize the evaluated values of the excitation curve. The evaluated values of the excitation curve are higher than those of ENDF/B-V by about 4-10% in the 7-10 MeV energy region and by about 2-5% in the 11-19 MeV energy region.

(cross section, evaluation, ^{56}Fe(n,p) ^{56}Mn reaction, E_n = 4.0-20.0 MeV)

Introduction

The cross section of ^{56}Fe(n,p) ^{56}Mn reaction is frequently used as a reference cross section to measure fast neutron fluence rates and many other cross sections. The measurement and evaluation of this cross section have been taken seriously all along. Since nineteen fifties, a lot of measurements have been completed and the evaluations have also been reported from time to time. In the last ten years, in other words, after completing the relevant evaluation[1] for ENDF/B-V, a series of new experimental data[2-19] were published. It makes the reevaluation of ^{56}Fe(n,p) cross section a still more meaninful work. In addition, it should be noted here that the ^{56}Fe(n,p) cross section was not accepted as a standard cross section at the 1984 IAEA-OECD/NEANDC Advisory Group Meeting on Nuclear Standard and Reference Data held in Geel because the standard cross section of ^{27}Al (n,α) reaction is already available in the same energy region. Nevertheless, an evaluation of ^{56}Fe(n,p) cross section was strongly recommended because of its advantage over ^{27}Al(n,α) reaction with respect to the higher specific activity[20].

Data Status

The measurements of ^{56}Fe(n,p) cross section could be put into two categories on the basis of incident neutron energies. The first one is the measurements in the 3-12 MeV neutron energy region. In this neutron energy region the P-T and D-D reactions were generally used as neutron source and, comparatively speaking, few experimental works were carried out. In recent ten years only Nemilov[13] reported their experimental results which are in agreement with those of Santry[21] and higher than those of Smith[22] and Grundl[23] by about 10% in the 7.5-9.5 MeV neutron energy region. The second one is the measurements in the 12-20 MeV neutron energy region, in which the T-D reaction was used as neutron source. An enormous number of measurements were carried out in this region and most of them were the measurements carried out at one neutron energy point around 14 MeV. Although some of the values reported in the recent years differed greatly each other, the results of some precise measurements, such as the experimental results of Kudo[4], Ryves[15] and Li[17] etc., are close or agree good enough to each others. It make a favorable condition for reevaluation of the $^{56}Fe(n,p)$ ^{56}Mn cross section. The experimental results around 14 MeV completed in recent ten years are listed in Table 1.

Table 1. Cross Sections around 14 MeV Measured in Recent Ten Years

Author (Year)	Ref.	E_n,MeV	σ, mb	Monitor & Detector
Liu (1988)	2	14.6	110.7±1.9	$^{27}Al(n,\alpha)$ ^{24}Na etc.; Ge(Li)
Meadows (1987)	3	14.74	109.9±6.9	$^{238}U(n,f)$; Ge(Li)
Kudo (1985)	4	14.6	110.0±1.5	Proton recoil telescope;4πβ counter
Garlea (1985)	5	14.75	125.8±5.9	$^{235}U(n,f)$; Ge(Li)
Deak (1984)	6	14.71	91.3±7.3	$^{27}Al(n,\alpha)$ ^{24}Na; Ge(Li)
Pepelnik (1984)	7	14.7	111.0±5.5	
Antov (1983)	8	14.54	110.9±2.8	$^{27}Al(n,\alpha)$ ^{24}Na; Ge(Li)
Garlea (1983)	9	14.75	113.2±5.1	$^{235}U(n,f)$; Ge(Li)
Phan (1983)	10	14.8	118.7±12	$^{27}Al(n,\alpha)$ ^{24}Na; Ge(Li)
Kudo (1982)	11	14.6	110.9±1.4	Associated particle; 4πβ-γ
Viennot (1982)	12	14.73	104 ±6	$^{27}Al(n,\alpha)$ ^{24}Na, $^{27}Al(n,p)$ ^{27}Mg;Ge(Li)
Sharma (1979)	14	14.7	98.5±4.0	
Ryves (1979)	15	14.65	108.2±2.7	Proton recoil telescope; 4πβcounter
Sothras (1978)	16	14.8	96 ±8	$^{27}Al(n,p)$ ^{27}Mg; Ge(Li)
Li (1978)	17	14.61	108.0±2.7	Associated particle; NaI(Tl)
Kudo (1977)	18	14.8	107.1±3.1	Associated particle; 4πβ-γ
Molla (1977)	19	14.7	98.0±7	$^{27}Al(n,\alpha)$ ^{24}Na; Ge(Li)

As we know, the present version of ENDF/B-V is recommended for the energy region from 11 to 20 MeV because the values of this ENDF/B-V evaluation are belived to be too low in the lower energy region[24]. It is not hard to find after investigating the experimental values reported in the recent ten years that comparing with the newer experimental data which have errors of less than 5%, the data of ENDF/B-V are too low in the higher energy region too. Li[17] measured the $^{56}Fe(n,p)$ cross section in the 12.8-18.3 MeV neutron energy region. The excitation curve was normalized to the absolute value of 108.0±2.7 mb at 14.61 MeV neutron energy, which was measured by using the associated particle method to determine the neutron flux with an accuracy of 1.2%. Their values of the cross section in this neutron energy region are higher than those of ENDF/B-V by about 2-4%. Ryves[15] measured the $^{56}Fe(n,p)$ cross section in the neutron energy region from 14.65 to 19.0 MeV, and the data obtained are higher than those of ENDF/B-V by about 3-8%. Recently, Kudo[4] reported his experimental results in the neutron energy region from 14.0 to 19.9 MeV. They were measured by the activation method, using a proton recoil telescope to determine the neutron fluence rate for all energies, and an associated α counting technique was also used at 14.0, 14.6 and 14.8 MeV to get the more precise values. The results agree closely with the measurements of Ryves between 14 and 16 MeV, but lie above their results in the higher energy region. That means, the results of Kudo show obviously and systematically higher values except at 19.9 MeV compared with those of ENDF/B-V. As for the results measured at one energy point around 14 MeV, almost all of the more precise measurements show higher values compared with that of ENDF/B-V too. For example, the experimental results given by Kudo[11], Antov[8] and Liu[2] are 110.9±1.4 mb at 14.6 MeV, 110.9±2.8 mb at 14.54 MeV and 110.7±1.9 mb at 14.6 MeV separately, and the value of ENDF/B-V at 14.6 MeV is only 105.0 mb.

Data Processing and Fitting

The data processing and fitting were carried out in three separate steps:

1. Curve fitting for the cross section data up to 20 MeV;
2. Processing of the cross section data at 14.7 MeV;
3. Normalization of the fitted curve.

A spline fit program for multiset data with knot optimization[25] was used to fit the excitation curve data. The experimental data for excitation function measurements given by Terrell[26], Santry[21], Liskien[27,28], Hemingway[29], Grundl[23], Smith[30,22], Mostafa[31], Li[17], Ryves[15], Nemilov[13], Viennot[12] and Kudo[11] were accepted as the input data. The weights of the data were taken on the basis of the experimental errors given by the authors, except those given the statistical errors only. A smooth fitted curve was obtained when the cubic spline fitting with a number of 11 of knots was applied.

As mentioned above, a large number of measurements were carried out at one neutron energy point around 14 MeV only. The cross section values are reducing along with the increase of incident neutron energy in this region and the various measurements were not always carried out at the same energy point. In order to make the evaluation of the cross section value at 14.7 MeV, seven experimental data, the data given by Robertson[32], Li[17], Ryves[15], Antov[8], Pepelnik[7], Kudo[4] and Liu[2] were selected and adjusted to the same neutron energy point, 14.7 MeV, according to the cross section trend given by the above-mentioned fitted curve, and a weighted average value was calculated. Similarly, the weights of the data were basically taken on the basis of the experimental errors given by the authors. An exception was that of work 2. The error given in it was enlarged to be ± 4.5 mb.

The weighted average of these results is

$$\sigma = 108.69 \pm 0.47 \text{ mb (external error)}$$

and

$$\sigma = 108.69 \pm 0.98 \text{ mb (internal error)}.$$

We take the internal error as the error of the recommended value. Thus the recommended value of the $^{56}Fe(n,p)\,^{56}Mn$ cross section at 14.7 MeV is

$$\sigma = 108.7 \pm 1.0 \text{ mb}$$

The fitted curve was then normalized to the evaluated value at 14.7 MeV, and the recommended values in the neutron energy region from 4.0 to 20.0 MeV were obtained. In Fig. 1, the present recommended values and ENDF/B-V values are plotted as curves and are supplemented by more recent experimental data which have errors of less than 5% and were not included in ENDF/B-V.

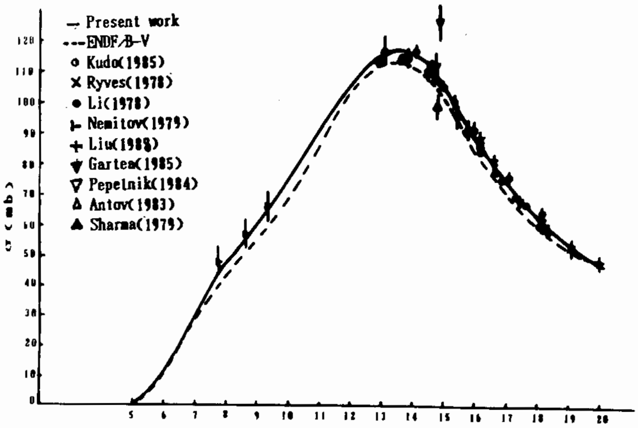

Fig.1 Results of this work compared with ENDF/B-V and recently measured data

Conclusion

It can be seen that our recommended values are systematically higher than those of ENDF/B-V by about 4-10% in the 7-10 MeV energy region and by about 2-5% in the 11-19 MeV energy region. They agree closely with the measurements of Ryves[15] and are in good agreement with the recent measurements of Kudo[4], Li[17] and Nemilov[13] within the limits of estimated errors. In the lower energy region scarcely any systematic deviations between the two evaluations can be seen.

As for the recommended value at 14.7 MeV, it is apparent in Table 2 that the recent evaluations all agree rather well with ours.

Table 2. Evaluated cross section data for 14.7 MeV neutrons

σ , mb	Reference
109.2±1.0	Ryves (1979)[33]
108.1±0.7	Hayes (1981)[34]
107.8±0.7	Winkler (1983)[35]
107.8±0.7	Ryves (1985)[36]
108.4±0.7	Liu (1988)[2]
108.7±1.0	Present work

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