The Cross Section Evaluation and Recommendation of ^{197}Au (n,2n)^{196}Au Reaction

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【abstract】 *The evaluation for ^{197}Au(n,2n)^{196}Au cross section was performed, the data of this reaction in the neutron energy range from threshold to 30 MeV were given, compared with the evaluation results by YUAN Hanrong et al., ZHAO Wenrong et al., Jose Martinez-Rico and YU Baosheng et al.. The agreement between different evaluations is good. However, the deviations are shown up for the data from ENDF/B-6 and JEF-2.2.*

Introduction

The ^{197}Au(n,2n)^{196}Au is one of the important dosimetry reaction. More than 40 measurements have been reported. Most of the experimental data were carried out by using the activation method and a few of them were carried out by using the large liquid scintillators.

The recent evaluations were reported by Yuan Hanrong[1] et al., ZHAO Wenrong[2] et al., Jose Martinez-Rico[3] and YU Baosheng[4] et al. The comparison among them are shown in Fig. 1. The agreement among the differential evaluations is good. However, the deviations are shown up in the energy region from 12 MeV to 20 MeV. The evaluation of Jose Martinez-Rico is not smooth from the threshold to 20 MeV, the data are lower in the range from 13 MeV to 15 MeV. The results of the evaluation are also compared with the ENDF/B-6 and JEF-2.2. The neutron energy extends to 30 MeV for ENDF/B-6, and the data are lower at the energy lower than 14 MeV, and higher in the energy range from 14 MeV to 20 MeV. For JEF-2.2, the data is larger in the energy range from 13 MeV to 16 MeV, and lower in the energy larger than 16 MeV.

The values of the different evaluations at the energy 14.7 MeV, YUAN Hanrong et al. is 2094±40 mb, ZHAO Wenrong et al., 2137±40mb, Jose Martinez-Rico, 2126±26mb, YU Baosheng et al. 2133±34 mb and T.B.Ryves[5] et al., 2127±26 mb, ENDF/B-6, 2187 mb. All evaluations were performed based on the experimental data before 1989.

In present work, we collected the new experimental data and re-evaluate the cross section of ^{197}Au(n, 2n)^{196}Au at the energy 14.7 MeV. And the cross section in the neutron energy range from threshold to 30 MeV was recommended.

1 The Evaluation of the Data at the Energy 14.7 MeV

In Table 1 are shown the measurements[6~35] for the cross section of ^{197}Au(n, 2n)^{196}Au at 14.7 MeV and their adjusted values. The R_1 is an adjusted factor for neutron energy according to the evaluation curve of T. B. Ryves[5], and R_2 is an adjusted factor for standard cross section and gamma branching, the standard cross section of ^{27}Al(n,α) reaction are taken from ENDF/B-6.

From Table 1, it can be seen that most of the data were measured relatively. The threshold energy of ^{197}Au(n,2n)^{196}Au reaction is 8.112 MeV, and the threshold energies of used as standard reactions ^{27}Al(n,α) is 3.248 MeV; ^{93}Nb(n,2n), 8.926 MeV; ^{75}As(n, 2n), 10.382 MeV; ^{56}Fe(n,p), 2.965 MeV; and

Table 1 ^{197}Au(n, 2n)^{196}Au experimental data

No.	Year	Author	E_n/MeV	σ_0/mb	$\Delta\sigma$/mb	Monitor	σ_0/mb (for Monitor)	R_1	R_2	σ/mb	Neutron source	METHOD	Detector	error	note
1	1969	R.C.BARRALL	14.6±0.2	2070	200	^{27}Al(n, α)		1.001		2072.	(D-T) T(d,n)	Activation	NaI(Tl)	200	√
2	1972	A.K.HANKLA	14.4±0.4	1986.	150.	^{27}Al(n, α)	151±18	1.003	0.7815	1556.	(D-T) T(D,N)	Activation	GE(LI)		×
3	1972	D.R.NETHAWAY	14.72	2149.		^{27}Al(n, α)	117.0±0.8	0.997	0.9658	2069.	(D-T)			200	√
4	1977	L.R.VEESER	14.7±0.15	2064.	125.0	H(n,n)H		1.000		2062.	(D-T)	Capture gamrays detected	Liquid Scintillator		×
5	1975	B.P.BAYHURST	14.10±0.05 14.89±0.05	2213. 2116.	94. 89.	^{27}Al(n, α)	122.0 107.0	1.006 0.9981	0.9959 1.0374	2217 2190	(D-T)	Activation	NAI(TL)	221 89	√ √
6	1960	H.A.TEWES	14.5	2080.		H(n,n)H		1.001		2082	(D-D)	Activation	Recoilo proton counter telescope		×
7	1961	R.J.PRESTWOOD	14.81	2356.	118.	^{238}U(n,f)	145.1±7.3	0.9990		2354	(D-T) T(D,N)	Activation			×
8	1987	L.R.GREENWOOD	14.50 14.65 14.80	2151. 2154. 2171.	33. 33. 33.	^{93}Nb(n,2n)	463±18	1.001 1.0004 0.9990	0.9905 0.9905 0.9905	2132 2134 2128		Activation	GELI	33 33 33	√ √ √
9	1975	J.FREHAUT	14.76±0.065	1935.	155.	^{238}U(n,f)	1216	0.9994		1934	(D-D)		Liquid Scintillator		×
10	1975	A.PAULSEN	14.4 ±0.44 14.6 ±0.32 14.8 ±0.34	1870. 1880 1890	105. 105. 105.	H(n,n)H		1.003 1.001 0.9990		1876 1881 1888	c T(D,N)		GELI		× × ×
11	1972	S.M.QAIM	14.7±0.3	2209.	253.	^{75}As(n,2n)	970±80	1.000		2209	(D-T)	Activation	GELI	253	√
12	1972	D.S.MATHER	14.3	2578.	177.	^{238}U(n,f)	1169±230	1.004		2588	(D-T)		Scintillator		×
13	1968	W.DILG	14.7±0.15	2320	150.	^{27}Al(n, α)	111.5±1.7	1.000	1.018	2361	(D-T)	Activation	NAI(TL)		×
14	1978	P.ANDERSSON	14.9±0.2	2295	116	H(n,n)H		0.9980		2290	(D-T)	Activation	GELI		×

Cont. Table 1

No.	Year	Author	E_n/MeV	σ_0/mb	$\Delta\sigma$/mb	Monitor	σ_0/mb (for Monitor)	R_1	R_2	σ/mb	Neutron source	METHOD	Detector	error	note
15	1981	J.LAUREC	14.8±0.3	2010.	90.	^{27}Al(n, α)	112.0±0.2	0.9990	1.0089	2026	(D-T)	Activation	GELI	202	√
16	1981	T.B.RYVES	14.68±0.03	2170	67.	^{56}Fe(n,p)		1.0002	0.9940	2144	(D-T)	Activation	GELI	67	√
17	1984	Y.IKEDA	14.66	2120.	106.	^{27}Al(n, α)		1.0004		2121	(D-T)	Activation	GE-IN	106	√
18	1988	Y.IKEDA	14.71	1894.	97.	^{27}Al(n, α)	129.1±7.0	1.0000	0.8760	1659	(D-T)	Activation	GELI		×
20	1988	K.KOBAYASHI	14.05±0.07	2125.	79.	^{27}Al(n, α)	123±3.8	1.0060	1.0000	2137	(D-T)	Activation	GELI	79	√
21	1990	I.KIMURA	14.1	2125.	79.	^{27}Al(n, α)	123±3.8	1.0060	0.9878	2111		Activation		200	√
22	1972	D.MAOR	14.0	2200.	300.			1.007		2215		Activation	GELI	200	√
23	1989	LU HAN-LIN	14.6	2129.	95.	^{27}Al(n, α)	115.8±1.6	1.000	1.0000	2129	(D-T)	Activation	GELI	95	√
24	1982	J.CSIKAI	14.66	2087.	142.	^{27}Al(n, α)	122 (14.1)	1.0004	1.0000	2088	(D-T)	Activation	GELI	142	√
25	1982	A.REGGOUG	14.8	1990	50			0.9990		1988	(D-T)	Activation	GELI		×
26	1984	M.HERMAN	15±0.3	2025. 2148.	122. 137.	^{56}Fe(n,p)		0.9980		2021 2143	(D-T)	Activation	GELI	137	× √
27	1984	I.GARLEA	14.75	2071.	93.	^{238}U(n,f)	2021	0.9994		2070	(D-T)	Activation	GELI	200	√
28	1989	WANG XIUYUAN	14.67±0.24	2147.	114.	^{27}Al(n, α)	115.3±2.7	1.0003	1.0035	2155		Activation		114	√
29	1989	WANG XIUYUAN	14.63±0.15	2133	155	^{27}Al(n, α)	115.3±2.7	1.0006	1.0035	2142		Activation		155	√
30	1965	S.K. MANGAL	14.8	1720.	172.	^{27}Al(n,p)	230±35	0.9990		1712			Scintillator		×
31	1992	I.GARLEA	14.758±0.3	1896.	85.	^{93}Nb(n,2n)		0.9995		1895	(D-T)	Activation	GELI		×
32	1972	G.N.MASLOV	14.2±0.2	2243.	160.	^{65}Cu(n,2n)	920±20	1.0050	0.9964	2237		Activation	Scintillator	160	√
33	1972	D.R.NETHAWAY	14.43	2168	100.	^{27}Al(n,p)		1.0024	1.0074	2189				100	√
33	1997	A.A.FILATENKOV	14.67	2325.	120.	^{27}Al(n, α) ^{93}Nb(n,2n)	128.9±5.6	1.0004	0.9535	2225		Activation	Scintillator	222	√
34	1999	A.A.FILATENKOV	14.1	2220.	90.	^{27}Al(n, α) ^{93}Nb(n,2n)	128.9±5.6	1.0060	0.9535	2129		Activation	Scintillator	90	√
35	1989	T.B.RYVES	14.7	2127.	26.			1.0000		2127				26	√

^{65}Cu(n,2n), 11.399 MeV. For H(n,n)H reaction, the threshold energy is zero. The threshold energy of the standard reaction ^{93}Nb(n,2n) is closed to the reaction ^{197}Au(n, 2n)^{196}Au, the data using this standard should be in agreement with the true values of the reaction ^{197}Au(n,2n)^{196}Au. In contrary to the standard reaction H(n,n)H, the results maybe have large error, because the low energy neutron effect. We divide the data at around 14 MeV into four groups: relative measurements to reaction ^{27}Al(n,α), H(n,n)H, ^{238}U(n,f) and others. The result is shown in Fig. 2. It was found that the results with H(n,n)H reaction are much lower than other three groups, the systematic errors should be existed in these measurements, so the data were given up. Some of the data in other three group are abnegated since they are far away comparing with other experimental data. In Table 1, the data with "√" denotes the experimental data being adopted, and "×" denotes the data being given up.

The errors acting as weight were adjusted. In Table 1, if there are no errors given by the author, or the errors are lower than 5%~15% for NaI detector, 2%~10% for GeLi detector in the activation method, the errors are adjusted, they are listed in Table 1 at column "error". Then, the average value with weight for the cross section of ^{197}Au(n,2n)^{196}Au at 14.7 MeV using their adjusted data was got:

$$\sigma=2131\pm13 \text{ mb}$$

However, the error is just the called "internal error", only reflects the statistical one in the measurements, it should be adjusted. The scale factor method was adopted for present work

$$\varepsilon^2 = \frac{1}{N-1}\chi^2_{N-1}$$

Where ε denotes scale factor, N denotes the number of measurements and $\chi^2_{N\text{-}1}$ is χ square and equal to 217.0 based on the chosen measured data listed in Table 1. The adjusted error is 13 mb×ε, called "external error" and equal to 38 mb. So the evaluated value for the cross section of ^{197}Au(n, 2n)^{196}Au at neutron energy of 14.7 MeV is

$$\sigma=2131\pm38 \text{ mb}$$

Based on the late evaluation value, Yu Baosheng's, 2133±34 mb, the new measurement data after this evaluation have been collected, listed in Table 1 at column 21, 31,33, and 34 (from 1990 to 1997). According to the Bayesian method, the new evaluated value is

$$\sigma=2130.8\pm32.6 \text{ mb}$$

This result is in good agreement with our evaluated value.

2 The Recommendation for Cross Section

The data processing and fitting are carried out for present work in the following three steps:

(1) Curve fitting for the cross section data in the energy range from threshold to 30 MeV by using the least square method;

(2) Normalization of the obtained fitted curve to the evaluated cross section value at 14.7 MeV.

Fig. 3 gives the recommendation cross section of ^{197}Au(n, 2n)^{196}Au in the neutron energy range from 8.12 to 30 MeV. The recommendation results are compared with the measurements, YU Baosheng's evaluation and ENDF/B-6. It is clear that the recommended results are in agreement with the experimental data.

From Fig. 3, we found our recommendation is in good agreement with the measured data in the neutron energy range from 8.12 MeV to 30 MeV, and is lower than ENDF/B-6 in the energy range from 14.7 MeV to 30 MeV and YU Baosheng's evaluation in the energy range from 8.12 MeV to 14.7 MeV

Fig. 4 gives the comparison with the experimental data, YU Baosheng's evaluation and ENDF/B-6 in the neutron energy range of 14 to 15 MeV. It is clear that our results is very closed to YU Baosheng's evaluation and lower than ENDF/B-6, in good agreement with measurement data.

3 Summary

In present work, the results of evaluations reported by YUAN Hanrong et al. ZHAO Wenrong et al., Jose Martinez-Rico and YU Baosheng et al. are compared. The experimental data were collected, evaluated and adjusted for neutron energy, standard cross section, and gamma branching and the cross section of ^{197}Au(n, 2n)^{196}Au at the energy 14.7 MeV was evaluated, the evaluation value is 2131±38 mb. The recommendation cross section of ^{197}Au(n,2n)^{196}Au in the neutron energy range from 8.12 to 30 MeV and comparisons with measured data, ENDF/B-6 and YU Baosheng's evaluation, were carried out.

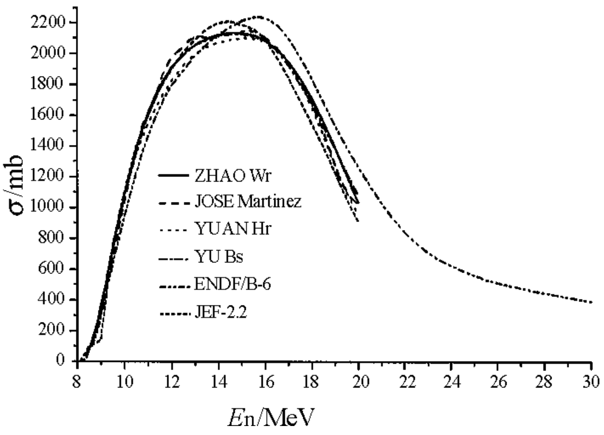

Fig.1 Comparison of the several differential evaluation results

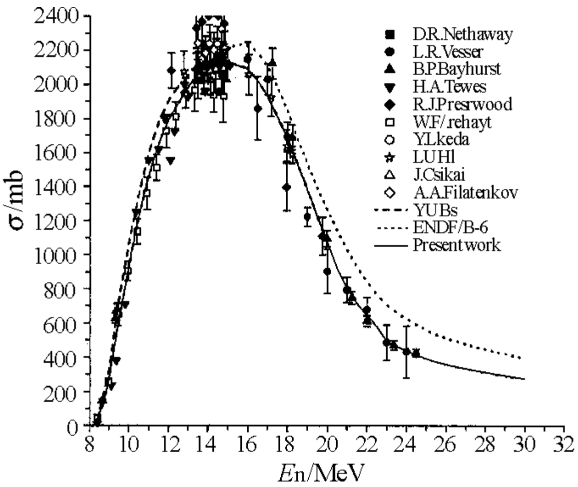

Fig.3 The recommendated cross section of ^{197}Au(n,2n)^{196}Au and the comparison with Yu Baosheng's evaluation and ENDF/B-6

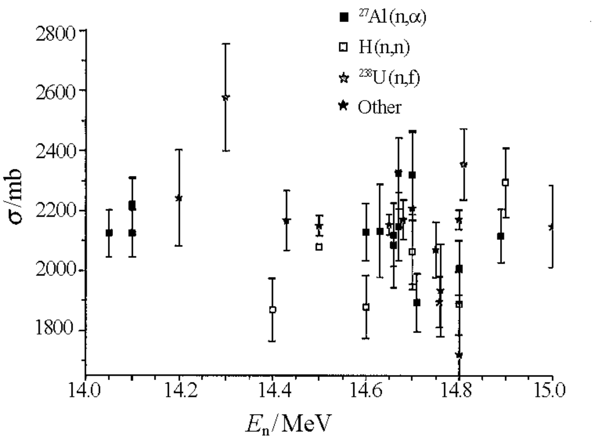

Fig. 2 Comparison of the four groups of experimental data with different standards

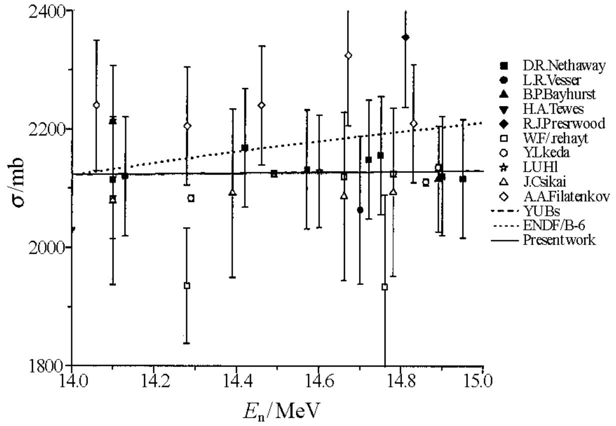

Fig.4 Comparison of cross section of ^{197}Au(n,2n)^{196}Au with experimental data, YU Baosheng's evaluation and ENDF/B-6 in the energy range of 14 to 15 MeV

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The Effect of the Decay Data on Activation Cross Section

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【abstract】 *The effect of the decay data on evaluation of activation cross section is investigated. Present work shows that these effects must be considered carefully when activation cross section is evaluated. Sometime they are main reason for causing the discrepancies among the experimental data.*

Introduction

The neutron activation cross sections are very useful in nuclear engineering applications especially in fission and fusion reactors, and nuclear physics studies. They are also used to confirm predictions of nuclear reaction theory. As developing of nuclear technology and nuclear engineering, more accurate evaluated data are required.

Up to now, a lot of neutron activation cross sections have been measured by activation method. And there are large discrepancies among some reactions.

There are many factors, which affects the accuracy of the experimental data. According to the principle of activation method, the decay data of product is one of the factors which will affect the measured data. In order to provide more reliable and accurate evaluated nuclear data, evaluation is necessary for decay data.

In this work, the effect of the decay data on activation cross section is investigated. Some examples are given to show these effects.

1 The Effect of Decay Data

According to the principle of activation method, the decay data of residual nucleus will affect the result of measured data. Usually the decay data include the half-life of the residual nucleus, γ branching ratio of the residual nucleus. On the other hand, the decay scheme of the product will play an important role in selecting the γ rays which were used to determine the radioactivity of the reaction products.