Reference Fission Yield Data Evaluation of ^{79}Se etc.17 Fission Product Nuclides from ^{235}U Fission

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【**abstract**】*The reference fission yield data of ^{79}Se etc. 17 product nuclides from ^{235}U fission were evaluated based on available experimental data up to now. The data were processed with average code AVERAG and simultaneous evaluation code ZOTT. The evaluated data were compared with ENDF/B-6, JEF-2, JENDL-3 and CENDL/FY. The data were updated and improved.*

As reference fission yield data are used as standard and monitor, their accuracy and precision are very important, so they must be specially paid attention and evaluated. The relatively measured data should not be used in the evaluation as much as possible, because the standard could not be based on the other standards, which have not been approved to be reliable.

1 Experimental Data Evaluation.

The experimental data were retrieved from EXFOR Master Library and collected from the publications concerned. Altogether 102 entries (subentries, papers) were collected. The following data were abandoned:

(1) The quantity measured is not required;

(2) The data measured at the energy points are not required;

(3) Some thing is wrong in the measurement or data processing;

(4) The data are large discrepant with others and the measured method is not reliable or no information given in detail.

As a result, 32 papers were remained, which are listed in the Ref. [1~32]. All of these data were analyzed and evaluated in physics and made the necessary corrections and treatments:

(1) Standard corrections for Ref. [7,15,16, 31, 32] by using the reference data just evaluated by us;

(2) Decay data corrections for Ref.[28] by using the data taken from Table of Isotopes(eighth edition);

(3) Error adjusted or assigned for Refs. [2,3,6,9, 12~16, 18,20~25,29];

(4) Calculated the fission yield data from given ratio by using the reference data just evaluated by us for Refs. [12,25];

(5) Calculated the ratio from given relative data for Refs. [4,5] to avoid using other standard.

In addition, some things wrong were corrected for Ref. [32]. And also the data of some special nuclides in the above references were abandoned for the large differences with others. They are ^{79}Se (too large), ^{107}Pd (too small) in Ref. [19], ^{91}Zr (too large) in Ref. [22], ^{93,94}Rb (too small) in Ref. [28], ^{147}Pm (too large) in Ref. [31].

2 Data Processing

After the above analysis in physics and correction, the evaluated data with their adjusted errors were processed.

The all data with more than one set were averaged with weight by using code AVERAG[33]. Not only the weighted mean value but also the arithmetical mean value and reduced χ^2 were calculated. The weighted mean value is recommended and the latter two were used for reference and comparison. The averaged data are marked by letter “A” in Table 1, and also the data sets used for averaging were given in the Table.

The measured data together with the ratios relative to others were simultaneously evaluated by using code ZOTT[34]. The data concerned were divided into several groups, each group contain all data, which are correlative through the ratios, weather at numerator or at denominator. Concretely, they are four groups: ^{93,94,95}Rb; ^{99}Y, ^{99}Tc; ^{91,93}Zr and ^{105,107}Pd. The data evaluated simultaneously are marked by letter" S" in the Table 1.

If there are more than one set of absolute and ratio measurements, they were averaged first for each of them, and then evaluated simultaneously.

3 Result, Comparison and Recommendation

The evaluated results are presented in Table 1. The letter "T", "F" and "H" mean thermal energy spectrum, fission or fast reactor spectrum and around 14 MeV fast neutron respectively. The number under the "point" heading is the set number of the measured datum itself, and "+number" is the set number of the ratios at numerator, and "+number" is at denominator. There are only the data at thermal or thermal and fission spectrum for some nuclides, for there are no experimental data available. Also the data were collected for product nuclides ^{97}Br, ^{98m}Y, ^{134}Cs, ^{150}Sm and ^{155}Gd, but there are no any experimental data available at all. So there are no data given in Table 1 for them.

The evaluated data were compared with existing evaluated data from ENDF/B-6, JEF-2.2, JENDL-3.2

Table 1 The evaluated reference fission yield by this work

Nuclide	E	Yield Y	Y Error	Point	Proce.	Reco.
34-Se-79	T	4.3900E-02	3.0000E-03	1		R
37-Rb-93	T	3.3914E+00	1.1804E-01	1+1	S	R
37-Rb-94	T	1.6726E+00	4.2809E-02	+1(B6)	S	R
37-Rb-95	T	7.2229E-01	2.1583E-02	1+(2)	S	R
39-Y-99	T	2.0482E+00	6.1049E-02	+1(B6)	S	(R)
40-ZR-91	T	5.9288E+00	4.3812E-02	5+1	AS	R
40-ZR-91	F	5.6600E+00	5.1089E-02	3	A	R
40-ZR-91	H	4.9100E+00	2.4513E-01	2	A	R
40-ZR-93	T	6.3470E+00	4.6309E-02	5+(1)	AS	R
40-ZR-93	F	6.1579E+00	5.3653E-02	3	A	R
40-ZR-93	H	5.0863E+00	2.7621E-01	2	A	R
43-Tc-99	T	6.0756E+00	6.1049E-02	3+(1)	AS	R
45-Rh-103	T	2.9667E+00	3.2215E-02	4	A	R
45-Rh-103	F	3.2100E+00	1.2840E-01	1		R
45-Rh-103	H	3.4930E+00	2.0960E-01	1		R
46-Pd-105	T	9.4645E-01	8.8925E-03	4+(1)	AS	R
46-Pd-105	F	1.1700E+00	1.3000E-01	1		R
46-Pd-105	H	1.7010E+00	1.0210E-01	1		N
46-Pd-107	T	1.4574E-01	1.3758E-03	2+1	AS	R
50-Sn-126	T	5.7213E-02	2.6396E-03	2	A	R
50-Sn-126	F	1.0000E-01	5.0000E-03	1		R
53-I-129	T	7.5145E-01	3.7840E-02	6	A	R
53-I-129	F	1.0900E+00	5.5000E-02	1		(R)
53-I-129	H	3.2630E+00	1.9580E-01	1		R
53-I-138	T	1.5356E+00	1.3112E-01	2	A	R
53-I-139	T	6.3139E-01	1.0900E-01	2	A	R
55-Cs-135	T	6.5311E+00	4.3430E-02	6	A	R
55-Cs-135	F	6.5240E+00	4.2048E-02	6	A	R
55-Cs-135	H	5.6990E+00	3.4190E-01	1		R
61-Pm-147	T	2.2440E+00	1.8227E-02	5	A	R
61-Pm-147	F	2.1807E+00	8.2012E-02	2	A	R
61-Pm-147	H	2.0220E+00	1.2130E-01	1		N

NOTE: E Neutron energy: T Thermal energy, F Fission or fast reactor spectrum, H Around 14 MeV.
POINT Data point been measured.
PRO Processed: A Averaged, S Simultaneously evaluated.
REC Recommendation: R Recommended, N Not recommended.

Table 2 Some typical examples for comparison of this work with others

NUCLIDE	LIBRARY	YIELD Y	ERR(%)	DIF(%)	YIELD Y	ERR(%)	DIF(%)	YIELD Y	ERR(%)	DIF(%)
40-ZR- 91	THIS WORK	5.9288E+00	0.74		5.6600E+00	0.90		4.9100E+00	4.99	
40-ZR- 91	ENDF/B-6	5.8278E+00	0.70	1.70	5.7334E+00	0.70	-1.30	4.8227E+00	4.00	1.78
40-ZR- 91	JEF-2	5.8800E+00	8.46	0.82	5.3922E+00	13.37	4.73	4.6336E+00	8.81	5.63
40-ZR- 91	JENDL-3	5.9187E+00	0.00	0.17	5.6549E+00	0.00	0.09	4.8924E+00	0.00	0.36
40-ZR- 91	CENDL-FY	5.8762E+00	2.04	0.89	5.6500E+00	1.33	0.18	5.0083E+00	69.51	-2.00
40-ZR- 93	THIS WORK	6.3470E+00	0.73		6.1579E+00	0.87		5.0863E+00	5.43	
40-ZR- 93	ENDF/B-6	6.3463E+00	0.70	0.01	6.2540E+00	0.70	-1.56	5.1932E+00	6.00	-2.10
40-ZR- 93	JEF-2	6.3206E+00	2.90	0.42	5.8791E+00	5.85	4.53	5.1759E+00	11.62	-1.76
40-ZR- 93	JENDL-3	6.3902E+00	0.00	-0.68	6.1394E+00	0.00	0.30	5.2958E+00	0.00	-4.12
40-ZR- 93	CENDL-FY	6.3548E+00	2.42	-0.12	6.1358E+00	0.89	0.36	5.6994E+00	93.82	-12.05
45-Rh-103	THIS WORK	2.9667E+00	1.09		3.2100E+00	4.00		3.4930E+00	6.00	
45-Rh-103	ENDF/B-6	3.0309E+00	1.00	-2.17	3.2439E+00	1.40	-1.06	3.2048E+00	2.80	8.25
45-Rh-103	JEF-2	3.0237E+00	4.07	-1.92	3.2851E+00	10.10	-2.34	3.3855E+00	3.04	3.08
45-Rh-103	JENDL-3	3.0274E+00	0.00	-2.05	3.2749E+00	0.00	-2.02	3.2180E+00	0.00	7.87
45-Rh-103	CENDL-FY	3.2209E+00	16.36	-8.57	3.1865E+00	102.17	0.73	3.1847E+00	100.36	8.83
46-Pd-105	THIS WORK	9.4645E-01	0.94		1.1700E+00	11.11		1.7010E+00	6.00	
46-Pd-105	ENDF/B-6	9.6416E-01	1.40	-1.87	1.1963E+00	2.80	-2.25	1.8721E+00	4.00	-10.06
46-Pd-105	JEF-2	9.5770E-01	6.82	-1.19	1.2810E+00	14.13	-9.49	1.8310E+00	6.76	-7.64
46-Pd-105	JENDL-3	9.6384E-01	0.00	-1.84	1.2048E+00	0.00	-2.98	1.8861E+00	0.00	-10.88
46-Pd-105	CENDL-FY	9.6888E-01	2.05	-2.37	1.4404E+00	91.23	-23.11	1.8683E+00	100.37	-9.84
53- I-129	THIS WORK	7.5145E-01	5.04		1.0900E+00	5.05		3.2630E+00	6.00	
53- I-129	ENDF/B-6	5.4335E-01	1.00	27.69	8.3516E-01	4.00	23.38	3.3746E+00	8.00	-3.42
53- I-129	JEF-2	7.8234E-01	4.01	-4.11	1.1739E+00	26.79	-7.70	2.4260E+00	33.16	25.65
53- I-129	JENDL-3	7.1785E-01	0.00	4.47	8.2731E-01	0.00	24.10	3.3557E+00	0.00	-2.84
53- I-129	CENDL-FY	8.7909E-01	15.94	-16.99	1.1598E+00	12.30	-6.40	3.5533E+00	100.37	-8.90
53- I-139	THIS WORK	6.3139E-01	17.26							
53- I-139	ENDF/B-6	7.7756E-01	8.00	-23.15						
53- I-139	JEF-2	6.2688E-01	34.03	0.71						
53- I-139	JENDL-3	9.8141E-01	0.00	-55.44						
53- I-139	CENDL-FY	8.4390E-01	30.88	-33.66						
55-Cs-135	THIS WORK	6.5311E+00	0.66		6.5240E+00	0.64		5.6990E+00	6.00	
55-Cs-135	ENDF/B-6	6.5390E+00	64.00	-0.12	6.6013E+00	64.00	-1.18	5.7288E+00	64.00	-0.52
55-Cs-135	JEF-2	6.5803E+00	2.23	-0.75	6.3696E+00	3.68	2.37	5.7721E+00	10.41	-1.28
55-Cs-135	JENDL-3	6.5337E+00	0.00	-0.04	6.5711E+00	0.00	-0.72	5.9116E+00	0.00	-3.73
55-Cs-135	CENDL-FY	6.5300E+00	0.35	0.02	6.3696E+00	1.73	2.37	5.4936E+00	79.67	3.60
61-Pm-147	THIS WORK	2.2440E+00	0.81		2.1807E+00	3.76		2.0220E+00	6.00	
61-Pm-147	ENDF/B-6	2.2467E+00	1.00	-0.12	2.1389E+00	1.00	1.92	1.6232E+00	2.80	19.72
61-Pm-147	JEF-2	2.2665E+00	8.36	-1.00	2.1367E+00	13.88	2.02	1.6392E+00	9.62	18.93
61-Pm-147	JENDL-3	2.2534E+00	0.00	-0.42	2.0961E+00	0.00	3.88	1.6266E+00	0.00	19.56
61-Pm-147	CENDL-FY	2.3606E+00	5.99	-5.20	1.9044E+00	111.88	12.67	1.6302E+00	100.34	19.38

and CENDL/FY. Some typical results are presented in Table 2. The relative errors are given for each set of data (there is no error given for JENDL-3.2, so all of them are zero) and the differences (relative to present evaluated data) of this work with other evaluated data are also given. It can be seen that the most of our new evaluated data are consistent with all of the others within the error bar, which shows that all of these evaluated data are in good agreement with each other. But there are some exceptions:

(1) There are larger differences of present data with CENDL/FY for nuclides ^{93}Rb(T), ^{93}Zr(H), ^{105}Pd(F), ^{147}Pm(F), but the present data are consistent with others. It is shown that there may be some problems for CENDL/FY data, and besides the errors of CENDL/FY data are very large for these nuclides (except for 93Rb(T)). The same situation is for ^{129}I(T) with ENDF/B-6 and for ^{129}I(H) with JEF-2.2.

(2) There are larger differences between present data with CENDL/FY and JENDL-3.2 for nuclides ^{95}Rb(T) and ^{99}Y(T), with ENDF/B-6 and JENDL-3.2 for ^{129}I(F), with ENDF/B-6, JENDL-3.2 and CENDL/FY for ^{139}I(T). The reliability of this kind of data should be analyzed concretely and carefully. For ^{99}Y(T) and ^{129}I(F), there is only one set of measured data, not so reliable, so the data are recommended only as reference (marked in Table 1 by "(R)"). For ^{95}Rb(T), there are three sets of independent measured data, including two sets of ratios relative to ^{93,94}Rb(T) and the data of ^{93,94}Rb(T) are in good agreement with others, the data can be recommended. For ^{139}I(T), there are two sets of measured data and there are large differences with three sets of other evaluated data, it seems that they are divided into two groups, more attention should be paid to it and more measurements are expected to clarify the discrepancy.

(3) For ^{105}Pd(H) and ^{147}Pm(H), there is large discrepancy with all of others and in the same direction (the former small and the latter large). There is only one set of measured data for them, and possibly there is a systematical error. The data could not be recommended.

The error comparison of this work with others is given in Table 3. The number in the table is the data sets, whose relative errors are in the given region (including the up limit, for example 1%~2% means $1\%<\Delta Y\leq 2\%$). It can be seen that at thermal energy point, the error ΔY_{half}, less than which of the data set number is half, is 2% for this work and ENDF/B-6, is 9% for JEF2.2 and CENDL/FY. About one third of the error is less than 1% for this work and ENDF/B-6. At fission spectrum, ΔY_{half} is 3% for this work, 4% for ENDF/B-6, and 20% for JEF-2.2. For CENDL/FY, two third of the errors are larger than 20%. At around 14 MeV fast neutron energy point, ΔY_{half} is 10% for ENDF/B-6, 15% for JEF-2.2. All of the errors are less than 9%(4%~6%, 6%~9% each half) for this work and almost all of them are larger than 20% for CENDL/FY. It can be concluded that comparing with JEF-2.2 and CENDL/FY, the error of this work is considerably reduced especially at fission spectrum and fast energy point. Comparing with ENDF/B-6, the error of this work is at the same level at thermal energy point and fission spectrum, and is improved at fast neutron energy point.

Table 3 The error comparison of the evaluated data with others

E_n	ERROR(%)	<1	1~2	2~3	3~4	4~6	6~9	9~12	12~15	15~20	>20
T	THIS WORK	6	2	3	1	2	2	0	0	1	0
	ENDF/B-6	7	1	3	1	0	4	0	0	0	1
	JEF-2.2	0	0	2	1	2	4	2	1	0	5
	CENDL/FY	1	1	4	0	2	0	3	1	3	2
F	THIS WORK	3	0	0	2	2	0	1	0	0	0
	ENDF/B-6	4	1	1	3	0	2	1	0	1	4
	JEF-2.2	0	0	0	1	1	0	1	4	1	9
	CENDL/FY	1	2	0	1	0	0	0	1	0	12
H	THIS WORK	0	0	0	0	4	3	0	0	0	0
	ENDF/B-6	0	0	3	1	2	2	1	0	0	8
	JEF-2.2	0	0	0	1	0	3	3	1	0	9
	CENDL/FY	0	0	0	0	0	0	0	0	1	16

References

[1] M.Shima, CJP,56,1340(7810)

[2] W.J.Maeck, ICP-1142(7809)

[3] H.Farrar, NP,34,367(62)

[4] H.Farrar, CJP,40,1017(62)

[5] P.L.Reeder, 75WASH,1,401(7503)

[6] L.R.Bunney, JIN,27,273(65)

[7] R.J.Meyer, ANL-6900,338(6406)

[8] B.R.Erdal, JIN,31,2993(6910)

[9] R.P.Larson,Private Communication (6912) (EXFOR 13249002)

[10] F.L.Lisman, NSE,42,191(70)

[11] J.W.Mandler, BAP,18,768(7306)

[12] M.M.fowler, JIN,36,1201(7406)

[13] W.J.Maeck, 75WASH,1,378(7503)

[14] G.Diiorio, NIM/B,147,487(7712)

[15] D.R.Wiles, CJP,31,419(53)

[16] J.A.Petruska, CJP,33,64095511)

[17] L.E.Glendenin, Private Communication (55) (EXFOR 13428002)

[18] W.J.Maeck, ENICO-1028(8002)|7.0+05|

[19] H.Wohlfarth, Private Communication (7612) (EXFOR 21054087)

[20] L.Kosh, RCA,29,61(81)

[21] B.C.Purkayast, CJC,34,293(56)

[22] H.Thierens, NIM,134,299(7604)

[23] R.Brissot, NP/A,255,461(7512)

[24] M.Rajagopalan, NSE,58,414(7512)

[25] M.Weis, Private Communication (8010) (EXFOR 21687004)

[26] J.P.Bocquet, NP/A,189,556(7207)

[27] D.C.Aumann, RCA,30,(1),19(82)

[28] G.Rudstam, RCA,49,155(90)

[29] C.K.Mathews, PR/C,15,344(7701)

[30] M.Shmid, IA-1345(7908)

[31] V.K.Gorshkov, AE,3,(7),11(5707)

[32] V.YA.Gabeskir, AE,43,59(77)

[33] LIU Tingjin, CNDP, 19, 103(1998)

[34] D.Muir, Nucl. Su. and Eng., 101, 88(1989)

Evaluation of Complete Neutron Data of n+^{241,242}Pu from 10^{-5} eV to 20 MeV

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【**abstract**】*A complete set of neutron nuclear data, including cross sections, angular distributions, secondary neutron spectra, of n+^{241,242}Pu from 10^{-5} eV to 20 MeV were evaluated based on available experimental data and theoretically calculated results. The data are given in ENDF/B-6 format.*

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1 Resonance Parameters and Evaluated Files

The resonance parameters and ν value were taken from ENDF/B-6 due to the boundary is higher than other nuclear data libraries. The resolved region resonance for ^{241}Pu is from 1.0^{-5} eV to 0.3 keV and the unresolved region is from 0.3 to 40.2 keV. For ^{242}Pu, the region of resolved resonance is from 0 to 986 eV and the unresolved one is from 986 eV to 10 keV.