^{239}Pu NEUTRON CROSS-SECTIONS IN THE RESOLVED-RESONANCE REGION

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ABSTRACT

The authors have determined the multi-level parameters for description of the total and fission cross-sections for ^{239}Pu in the resolved-resonance region up to 500 eV. A method has been developed for the construction of the elastic scattering and radiative capture resonance cross-sections using these parameters. The group-averaged cross-sections for experimental and evaluated data have been calculated in the energy region considered.

Multi-level analysis of the total and fission cross-sections

While there is a large volume of experimental data on the energy structure of the ^{239}Pu neutron cross-sections in the resonance region, only a few of the available data sets can be used in practice in the problem of multi-level parametrization of this structure. Here, apart from good experimental resolution in a relatively wide energy range, we also need a high accuracy of cross-section measurements, especially in the region of the interference minima, which are important particularly for multi-level description of the fission cross-section energy structure. To represent the ^{239}Pu resonance cross-sections, the evaluated data libraries at present generally use the measurement results of Blons, Derrien and Gwin [1-6] with subsequent corrections on the basis of the new data for the energy-averaged cross-sections [7-9]. These data in the region below 500 eV, where the resonances can be regarded as satisfactorily resolved, are analysed in the present paper.

The multi-level description of the cross-sections for fissionable nuclei, especially ^{239}Pu, was performed in several studies using various scheme of the resonance reaction theory [10]. Thus, the formalism of the R-matrix theory was used for this purpose in Refs [11-15] and the so-called Adler-Adler scheme - a simplified version of S-matrix parametrization - in Refs [16-19]. The present study also uses the Adler-Adler scheme to determine the consistent set of the corresponding resonance parameters for the combined analysis of the total and fission cross-sections in the whole region of resolved levels up to 500 eV. The resonance cross-sections constructed with

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the parameters found by us reproduce all the observed characteristics of the cross-section energy structure in the region considered [20].

To describe the energy dependence of the cross-sections in the resolved region, we use the general expression for collision matrix elements $S^J(E)$ with the given value of total moment J and parity:

$$S^J_{nc}(E) = exp(-i\varphi_n)\left(\delta_{nc} + i \sum_k \frac{\Gamma^{1/2}_{kn}\Gamma^{1/2}_{kc}}{E_k - E}\right) exp(-i\varphi_c) . \qquad (1)$$

The complex parameters $E_k = \mu_k - i\nu_k$ and $\Gamma^{1/2}_{kc}$ are assumed to be independent of energy, except for $\Gamma_{kn} \simeq \sqrt{E}$ [10, 16]. The total and fission cross-sections are expressed in terms of the elements of the S^J-matrix;

$$\sigma(E) = 2\pi \lambda^2 \sum_J g_J \left[1 - Re\, S^J_{nn}(E)\right] ;$$

$$\sigma_f(E) = \pi\lambda^2 \sum_J g_J \sum_{c(f)} \left| S^J_{nc}(E)\right|^2 , \qquad (2)$$

where g_J is the spin factor and the sum over c(f) takes into account the possibility of several channels for the fission process [10]. Substituting expression (1) into (2) and considering the effective resonance broadening due to the thermal motion of the nuclei of the medium and the finiteness of the experimental resolution, we arrive at the well-known Adler-Adler formulae for the multi-level representation of the observed resonance cross-sections [10, 16]:

$$\sigma(E) = \sigma_p + \pi\lambda^2 \sqrt{E} \sum_k \left[\frac{G^T_k}{\nu_k}\psi\left(\frac{\mu_k - E}{\nu_k}, \frac{\nu_k}{\Delta}\right) - \frac{H^T_k}{\nu_k}\chi\left(\frac{\mu_k - E}{\nu_k}, \frac{\nu_k}{\Delta}\right)\right] ; \qquad (3)$$

$$\sigma_f(E) = \pi\lambda^2 \sqrt{E} \sum_k \left[\frac{G^F_k}{\nu_k}\psi\left(\frac{\mu_k - E}{\nu_k}, \frac{\nu_k}{\Delta}\right) - \frac{H^F_k}{\nu_k}\chi\left(\frac{\mu_k - E}{\nu_k}, \frac{\nu_k}{\Delta}\right)\right] . \qquad (4)$$

here

$$\sigma_p = 4\pi\lambda^2 \sin^2\varphi_n - \qquad (5)$$

is the potential cross-section (phases φ_n are assumed to be independent of J); ψ and χ are the resonance form functions taking into account averaging over the Gauss distribution: $\Delta^2 = \Delta^2_R + \Delta^2_T$, where Δ_R is the width (dispersion) of the experimental resolution function and Δ_T the Doppler width [10]. The parameters in the analysis of experimental data are the values of μ_k and ν_k common to all cross-sections of the given element and also

$$G^T_k - iH^T_k = 2g_J exp(-2i\varphi_n)\Gamma_{kn}/\sqrt{E} ; \qquad (6)$$

$$G^F_k - iH^F_k = \frac{2g_J}{\sqrt{E}} \sum_{c(f)} \sum_{k'(J)} (\Gamma_{kn}\Gamma^*_{k'n}\Gamma_{kc}\Gamma^*_{k'c})^{1/2}/(E^*_{k'} - E_k) , \qquad (7)$$

The sum over k'(J) relates here to resonances of one spin and parity value (in the case of ^{239}Pu, s-wave resonances with J equal to 1 and 0 correspond to the resolved region).

In order to determine the parameters of the scheme from the experimental data on the ^{239}Pu resonance cross-sections, we constructed a program of linear search with subsequent broadening of the energy region used in the analysis of Ref.[21]. As a result, we could obtain the consistent set of parameters μ_k, G_k^T, H_k^T, H_k^F, ν_k (Table 1), which enables us

Table 1. Parameters of the combined multi-level analysis of the ^{239}Pu cross-sections.

μ, eV	$G^T \cdot 10^6$, $eV^{1/2}$	$G^F \cdot 10^6$, $eV^{1/2}$	$H^T \cdot 10^6$, $eV^{1/2}$	$H^F \cdot 10^6$, $eV^{1/2}$	ν, MeV	J
-0,260	0,0	0,0	41,454	31.960	100,0	0
0,260	10,340	3,595	0,0	0,0	100.0	0
0,299	214,292	129,318	6,072	3,458	47.1	1
1,580	50,107	22.188	57,415	20,490	2250.0	0
7,807	414,603	230,186	-7,488	-6,594	42.9	1
10,920	830,202	623.722	50,632	51,270	88,9	1
11,880	418,144	164,613	-32,102	-33,351	33.1	1
14,301	258,094	161,463	-32,148	-37,153	53.2	1
14,661	736,000	325,263	50,260	39,075	36.4	1
15,417	282,151	253,136	-17,961	-25,966	404,6	0
17,633	638,244	290,233	1,877	-5,705	38.2	1
22,239	815,360	477,964	22,730	11,524	52.4	1
23,880	28,235	14,379	-4,255	-4,616	45.8	1
26,230	448,817	225,867	2,595	-4,404	43.0	1
27,236	39,225	4,699	2,150	-0,267	24.5	1
32,289	72,670	52,741	2,051	1,990	83.0	0
35,426	58,293	6,110	0,057	-0,107	19.4	1
41,375	884,634	71,400	33,879	6,636	22.5	1
41,626	299,937	139,449	-12,252	-8,862	50,6	1
44,436	1345,951	120,529	37,864	-2,660	25,8	1
47,559	369,974	324,595	26,475	15,687	140,6	0
49,648	240,744	239,689	19,544	11,758	366,5	0
50,037	629,376	138,103	10,879	-4,730	26,8	1
52,536	2000,650	270,773	71,993	4,660	28.8	1
55,580	305,015	115,950	-0,403	-14,768	28,5	1
57,415	1492,228	1372,241	622,323	522,352	465,9	0
59,155	902,246	655,852	30,723	-2,483	69,3	1
63,031	113,379	71,339	0,065	-1,884	49,4	1
63,603	977,862	948,770	-1180,160	-948,770	3510,9	0
65,454	715,369	538,243	210,550	318,910	195,6	0
65,704	1666,989	593,210	195.543	-22,514	33,6	1
74,028	560,493	263,456	-71,893	-82,425	38,9	1
74,901	3414,305		231,817	102,635	93,0	1
78,940	10,632	0,22	2,283	-0,369	62,6	1
81,129	255,698	199,741	398,051	399,482	835,4	0
82,663	56,367	3,380	1,155	-2,870	24,4	1
85,424	2832,952	2592,610	-344,838	-470,815	1165,0	0
85,488	1239,922	236,121	40,291	-18,186	38,2	1
90,722	1746,850	269,058	86,667	-6,340	30,1	1
92,969	100,498	9,284	-1,110	-6,841	20,7	1
95,374	296,672	88,270	27,172	-5,397	38,9	1
96,653	528,546	489,535	-115,832	-105,788	731,9	0
98,867	1538,524	1248,382	148,611	499,353	4652,0	0
103,012	228,421	47,755	10,271	-3,827	24,9	1
105,313	652,249	69,742	29,431	-1,963	29,9	1
106,687	1253,704	465,199	62,790	-30,667	36,4	1
110,415	63,145	26,277	2,044	-4,658	29,8	1
113,960	20,939	19,974	93,752	85,156	919,1	0
115,284	18,394	0,562	-19,604	-20,007	85,8	1
116,062	475,961	369,520	54,245	-7,643	122,2	0
118,840	2212,866	906,462	93,086	-46,784	40,8	1
119,221	61,349	30,132	-22,110	27,758	405,0	0
121,020	302,898	146,495	-7,022	-22,402	23,9	1
123,484	68,572	37,761	-0,356	-15,620	40,4	1
126,234	208,270	46,890	12,535	-1,894	19,8	1
127,569	62,813	17,917	-1,585	-8,640	18,5	1
132,037	1102,596	1064,689	-101,929	-238,700	1574,8	0
133,803	534,738	82,896	18,510	-3,487	22,2	1
135,230	1055,161	379,508	-672,458	-149,806	7505,9	0

Table 1. (continued)

μ, eV	$G^T \cdot 10^6$, eV I/2	$G^F \cdot 10^6$, eV I/2	$H^T \cdot 10^6$, eV I/2	$H^F \cdot 10^6$, eV I/2	ν, MeV	J
I36,788	4I0,I32	279,598	I0,999	-3I,8II	50,3	I
I39,2I3	6,320	2,996	5,I35	0,999	25,0	I
I42,56I	372,204	242,I85	-8,405	-26,500	40,5	I
I43,476	508,I34	222,585	52,049	-3,239	42,0	I
I46,I36	I42,303	7I,500	52,I88	6I,I62	406,I	0
I46,266	650,I92	I07,874	7I,286	-27,690	I5,0	I
I48,293	42,9I5	24,470	-9,543	-20,200	47,2	I
I48,929	292,252	I59,793	-I03,458	26,965	2402,4	0
I49,453	I65,72I	6I,33I	I6,506	-I5,3I0	26,2	I
I56,989	208,3I0	I73,355	97,770	-92,532	80,4	0
I57,095	II88,507	599,223	-2I,580	46,766	442,6	0
I62,070	I3,630	2,650	-5,3I6	-I0,245	75,0	I
I64,566	3076,663	3I9,585	I90,575	-I4,709	40,8	I
I65,400	903,623	574,255	-290,I38	79,896	8836,3	0
I67,I36	68I,940	385,750	29,29I	-34,049	49,2	I
I70,532	70,762	57,526	-I5,050	0,282	I00,0	0
I7I,I00	237,479	94,866	-7,234	-II2,354	I500,0	0
I76,008	232,770	95,944	I2,430	-4,509	37,2	I
I77,252	380,248	53,809	22,398	-0,052	2I,4	I
I78,935	I33,438	35,279	7,033	I,274	25,I	I
I83,673	I73,243	63,I90	II,528	-I,255	20,0	I
I85,I32	742,568	544,294	-49,505	-83,7I7	I0II,0	0
I88,3I3	68,354	20,4I8	0,652	0,852	29,3	I
I90,665	I70,560	46,8I0	I3,438	3,995	26,3	I
I95,359	2020,036	I677,826	I78,2I7	99,27I	24I,5	0
I96,7I9	427,629	I62,895	55,I00	I9,705	40,4	I
I99,443	968,62I	523,756	43,033	-0,432	63,I	I
203,380	I44,977	6,872	I02,762	28,I69	46,I	I
203,964	2208,579	I697,9I9	-I24,I0I	-I49,806	275,4	0
207,4I3	676,5I4	75,326	44,263	-2,785	I5,6	I
207,880	I44,2I7	93,25I	-II4,844	-85,307	I000,0	0
2II,063	323,339	299,6I2	I83,027	I70,578	II54,9	0
2I3,235	38,633	I9,705	2I,069	I0,477	I04,3	0
2I6,582	620,049	86,743	27,964	-5,994	33,6	I
2I9,55I	305,I25	I00,204	-29,604	-I7,499	I5,0	I
220,273	797,542	207,043	-8,579	-23,243	59,3	I
223,2I6	304,975	37,923	2,752	-2,742	I5,7	I
224,930	I42,677	35,859	I0,406	9,473	I7,5	I
227,770	I308,645	9I8,809	46,334	99,87I	4500,0	0
227,940	I62,I89	67,825	I2,578	8,2I7	33,5	I
23I,433	I089,052	II7,7I0	97,968	9,7I4	23,2	I
232,588	24,720	22,I95	I8,I75	I4,38I	24,7	I
234,357	909,505	I83,572	80,982	0,I83	35,2	I
239,090	492,II6	I03,74I	27,288	-I0,I24	32,0	I
240,650	323,762	254,669	-265,443	-I84,942	4078,5	0
242,922	603,007	36I,628	44,873	I,6I9	58,2	I
247,637	I24,322	87,623	-33,352	-II,060	257,4	0
248,90I	I336,733	I37,637	79,992	II,2II	40,2	I
25I,272	2479,667	383,373	I80,962	-2,267	47,9	I
254,644	265,924	II6,3I2	9,I9I	5,874	42,I	I
256,I5I	56I,266	I5I,094	56,995	I9,687	5I,9	I
259,040	3,I62	3,I26	-8,466	-25,920	242,0	0
262,4I0	3708,40I	337I,56I	66,986	4,632	35I4,7	0
262,748	23I,9II	50,39I	57,06I	23,959	46,7	I
269,I50	I33,592	55,590	7,93I	I,I86	73,3	0
269,589	365,756	I64,232	27,802	6,967	30,5	I
272,686	238I,697	889,886	II3,980	-6I,892	6I,2	I
274,840	I2I3,695	II49,870	35I,354	227,I33	630,2	0
275,63I	I950,245	946,435	I06,3I5	-I9,II5	73,5	I
277,270	343,058	I59,793	456,694	483,000	2650,0	0
279,609	668,058	285,427	53,I39	-I,I33	43,3	0
282,970	2I79,I24	223,384	I73,084	-I6,473	42,7	I
288,040	895,686	769,570	94,448	38,435	3500,0	0
292,4II	33I,724	I58,439	I0,45I	-20,753	63,9	0
296,538	28I,033	III,00I	I4,979	-2,223	52,0	I
298,655	846,3I4	253,40I	79,983	I4,666	44,9	I
30I,888	I537,87I	70I,985	I22,368	-24,662	58,6	I
308,3I6	279,I29	22I,80I	-29,583	-37,89I	97,7	0
309,068	II2I,458	324,33I	I40,592	56,II6	47,4	I
3II,228	68,9I2	34,665	0,732	9,729	40I,0	0
3I3,692	I087,I6I	I87,798	89,560	I,52I	39,9	I
3I6,729	428,225	I59,II3	46,I09	-0,937	59,9	I
32I,850	326,689	325,577	-I7,502	I06,909	4406,9	0
323,447	I569,544	369,287	92,275	I,024	84,0	0
325,38I	679,309	25I,202	53,42I	-2,260	65,4	I

Table 1. (continued)

μ, eV	$G^{T}\cdot 10^{6}$, eV$^{1/2}$	$G^{F}\cdot 10^{6}$, eV$^{1/2}$	$H^{T}\cdot 10^{6}$, eV$^{1/2}$	$H^{F}\cdot 10^{6}$, eV$^{1/2}$	ν, MeV	J
329,750	337,833	I92,732	-4I,404	-30,643	2I09,5	0
333,990	4I7,463	7I,703	36,020	8,396	4I,3	I
336,0I4	II39,586	262,749	83,993	2,320	45,4	I
338,037	6II,05I	I02,853	4I,524	-4,982	42,0	I
339,336	266,902	I05,494	I0,560	-6,492	59,2	0
343,266	II86,893	356,I27	97,85I	-I7,427	54,0	I
346,557	39I,278	3I6,354	40,55I	44,942	757,5	0
350,399	I592,396	630,963	I32,353	-22,2I7	59,3	I
352,9I5	305,720	96,456	20,029	-0,630	54,5	I
355,050	33,I84	I9,542	-6,347	-8,859	8I,3	0
357,970	256,I02	I9I,942	-I5I,272	-32,094	3000,0	0
360,II5	96,438	50,938	-7,8I2	-II,204	93,5	0
36I,380	26,896	I7,55I	-3,625	-5,55I	I07,2	0
366,I00	246,359	242,685	-296,442	-I30,503	2500,0	0
368,609	64,I85	24,968	-46,867	-I4,609	378,5	0
370,457	I8I,275	I4,24I	-2I,504	-I0,288	45,3	I
37I,820	I260,358	979,40I	-44,539	-I64,04I	2289,8	0
375,I09	204,I62	4I,003	24,646	6,634	38,7	0
377,I82	I76,68I	79,796	25,030	3,703	I02,4	0
378,072	74,899	I0,278	3I,576	I6,798	79,0	0
382,593	I9,250	4,994	-6,445	-2,760	I5,4	I
383,765	9II,057	I79,767	-37,266	-2,397	4298,2	0
384,35I	423,823	238,627	45,546	2,77I	65,6	I
389,595	I02,657	I9,853	I6,682	8,806	49,0	I
39I,605	7I,686	33,475	II,957	-0,999	76,3	0
394,543	466,683	24I,4I6	2I,I74	-29,45I	65,6	I
397,029	I67,68I	I08,59I	7,350	-I4,729	85,9	0
40I,250	I8I,453	39,948	-I26,897	-69,909	I000,0	0
40I,690	I322,665	994,248	I3I,938	-40,956	II0,0	I
404,320	I509,38I	827,773	2I2,4I5	-53,52I	77,5	I
404,900	323,35I	I79,844	I9,207	I39,908	I000,0	0
406,I40	II3,904	I5,439	67,224	3I,224	I60,0	0
407,027	45,I49	37,95I	38,328	0,999	I65,0	0
408,830	87,982	25,445	25,315	II,365	75,0	I
4I2,4I0	6I7,522	3I4,554	68,540	-I4,432	72,5	I
4I5,780	228,999	37,934	I5,I65	-5,I60	76,0	I
4I7,720	I26,458	56,457	9,774	-25,467	I33,5	0
4I9,940	4I7,865	225,072	2I,374	-33,52I	69,5	I
425,700	II,079	2,497	I2,320	-I,725	7I,0	I
426,450	600,500	499,353	-3I3,370	-33I,570	3500,0	0
429,720	276,725	26I,II3	-0,7I0	-30,0I7	390,0	0
43I,370	588,787	5I8,783	-38,039	-33,438	I750,0	0
432,8I0	57,I24	20,063	43,0I9	36,675	I70,0	0
437,885	I8I,I26	44,723	-I2,400	-0,999	4I,6	I
438,964	2I7,983	33,423	-44,663	-I0,278	69,I	I
439,895	I75,720	29,96I	60,446	36,952	957,2	0
442,5I5	508,57I	406,5I3	75,II8	20,646	238,3	0
450,0II	75,508	47,I78	-33,090	-34,7I6	I25,3	0
45I,483	864,368	70,400	54,9I6	-8,5I4	55,I	I
455,736	9,90I	8,988	I889,750	II26,220	20I,5	0
455,764	I840,236	II78,472	-I863,532	-I292,055	320,0	0
457,497	588,666	499,353	-5,I84	-I2,284	2I5,8	0
458,906	352,704	I74,56I	68,I07	57,332	98,4	I
46I,454	237,534	I66,685	-I6,390	-3I,653	I99,9	0
462,509	74,004	52,809	89,626	63,245	302,I	0
468,34I	370,695	320,447	-43,263	-I26,399	I067,3	0
469,534	903,427	90I,83I	30I,955	359,534	2848,9	0
473,249	269,603	46,589	I0,4I6	-24,968	38,0	I
475,422	288,454	259,663	47,675	86,69I	389,6	0
477,050	I04,803	7,57I	34,003	47,938	I002,2	0
479,609	I3,564	9,987	-9,002	-I2,234	I27,4	0
484,30I	I73,I76	34,858	9,649	2,999	63,6	I
487,440	I27,087	I24,838	-44,78I	-80,590	I76,2	0
487,984	353,9I8	3I0,238	45,536	63,283	293,9	0
490,874	94I,324	684,II3	42,960	49,935	II48,9	0
494,263	334,I09	22I,658	I5,378	I2,753	97,4	I
495,794	48,980	5,789	6,I33	9,987	I02,3	0
500,677	25I,773	I39,8I9	2,578	8,533	60,8	I
502,994	7II,075	438,036	II3,969	72,282	98,3	I
506,I3I	I7,497	4,494	-I7,I00	-4,994	98,6	0
508,370	2,963	2,896	-28,790	28,348	346,3	0
509,890	3469,086	599,223	28I,464	-30,398	I30,7	0
5II,670	689,847	47I,675	-339,987	-257,939	I700,0	0
5I5,3I0	74,628	52,87I	-I8,I59	-I,0I4	24I,2	0

Table 1. (continued)

μ, eV	$G^T \cdot 10^6$, eV$^{1/2}$	$G^F \cdot 10^6$, eV$^{1/2}$	$H^T \cdot 10^6$, eV$^{1/2}$	$H^F \cdot 10^6$, eV$^{1/2}$	ν, MeV	J
516,720	35,653	35,454	-3,159	1,997	160,9	0
518,130	72,807	17,940	-4,661	16,650	218,8	0
520,401	906,819	362,349	46,014	-38,381	83,2	0
524,360	2053,283	382,787	257,619	8,948	45,5	1
525,642	6139,813	4993,523	-351,683	-588,712	5583,2	0
526,150	33,011	9,987	36,569	85,822	47,2	1
527,530	34,663	9,987	31,493	51,007	33,9	1
530,730	3081,960	756,912	133,752	-200,268	77,2	0
596,859	119,267	113,829	541,737	285,164	1374,8	0
596,905	2017,571	1353,805	-1824,245	-635,841	7527,8	0

Table 2. Values of the average ^{239}Pu fission cross-sections in specific energy intervals.

Energy, eV	$\bar{\sigma}_f = \frac{1}{\Delta E}\int_{\Delta E} \sigma_f(E)dE$						
	Gwin, 1976 [3]	Gwin, 1984 [7]	Weston 1984, 1980 [8]	Wagemans, 1980 [9]	ENDF/B-IV*	Kon'shin, 1982 [5]*	Present work
6-9	60,7	59,6+0,6	-	60,6	60,9	61,4	59,8
9-12,6	137,5	140,1±1,3	-	138,4	139,7	135,9	137,5
12,6-20	73,4	70,7±0,7	-	73,8	73,9	66,7	72,5
20-24,7	47,7	46,2±0,6	-	47,5	47,7	43,9	46,6
50-100	56,96	-	56,56	57,4	56,9	60,75	55,7
100-200	17,96±0,04	-	17,98±0,03	18,9	18,4	19,22	18,7
200-300	17,90±0,05	-	17,23±0,04	17,9	17,7	17,69	17,9
300-400	8,48±0,03	-	8,064±0,022	—	—	9,43	9,1
0,0253	741,6	-	741,7	741,9	741,7	741,7	741,6

* Calculated from the file.

Table 3. Values of the average neutron radiative capture cross-sections for ^{239}Pu in specific energy intervals.

Energy, eV	$\bar{\sigma}_c = \frac{1}{\Delta E}\int_{\Delta E} \sigma_c(E)dE$			
	Gwin, 1976 [3]	ENDF/B-IV*	Kon'shin, 1982 [5]*	Present work
6-9	51,3	51,0	44,7	45,2
9-12,6	75,3	75,8	67,0	74,7
12,6-20	61,7	58,1	58,1	59,1
20-24,7	37,4	32,0	30,8	30,6
50-100	35,88	36,3	35,25	36,7
100-200	15,70	17,1	15,02	16,3
200-300	16,79	17,5	14,48	16,1
300-400	9,83	-	8,54	9,5
0,0253	271,3	270,2	271,3	271,3

* Calculated from the file.

Table 4.

Average vales of $\bar{\alpha}=\bar{\sigma}_c/\bar{\sigma}_f$ for ^{239}Pu in specific energy intervals

Energy, eV	$\bar{\alpha}=\bar{\sigma}_c/\bar{\sigma}_f$			
	Gwin, I976 [3]	ENDF/B-IV*	Kon'shin I982 [5]*	Present work
6-9	0,85	0,83	0,73	0,76
9-I2,6	0,55	0,54	0,49	0,54
I2,6-20	0,84	0,79	0,87	0,82
20-24,7	0,78	0,67	0,70	0,66
50-I00	0,63	0,64	0,58	0,66
I00-200	0.87±0,0I5	0,93	0,78	0,87
200-300	0,94±0,0I	0,99	0,82	0,90
300-400	I,I6±0,0I4	-	0,9I	I,04

* Calculated from file.

with the appropriate choice of Δ to reproduce by formulae (3) and (4) virtually all the observed characteristics of the energy dependence of σ(E) and of $\sigma_f(E)$ right up to 500 eV [20].

Parameters of the elastic scattering and radiative capture cross-sections

The analysis of the total cross-section (3) for a particular spin identification of resonance enables us to find not only parameters G_k^T and H_k^T but also neutron widths Γ_{kn} (6). Using these values, we can directly construct two more cross-sections determined by the diagonal elements of the S^J-matrix (1). These are the neutron absorption cross-sections

$$\sigma_a(E)=\pi\lambda^2\sum_J g_J\left[1-|S_{nn}^J(E)|^2\right]=$$
$$=\pi\lambda^2\sqrt{E}\sum_k\left[\frac{G_k^a}{\nu_k}\psi\left(\frac{\mu_k-E}{\nu_k},\frac{\nu_k}{\Delta}\right)-\frac{H_k^a}{\nu_k}\chi\left(\frac{\mu_k-E}{\nu_k},\frac{\nu_k}{\Delta}\right)\right], \quad (8)$$

where

$$G_k^a-iH_k^a=(G_k^T-iH_k^T)\exp(2i\varphi_n)-$$
$$-i\frac{\sqrt{E}}{2g_J}\sum_{k'(J)}\frac{(G_k^T G_{k'}^T+H_k^T H_{k'}^T)-i(H_k^T G_{k'}^T-H_{k'}^T G_k^T)}{\mu_{k'}-\mu_k+i(\nu_k+\nu_{k'})} \quad (9)$$

and the elastic scattering cross-section

$$\sigma_n(E) = \sigma(E) - \sigma_a(E) \,. \tag{10}$$

Using the found values of parameters G_k^T and H_k^T (see Table 1) for each possible value of spins J, we can find the absorption cross-section parameters G_k^a and H_k^a (9) and construct cross-sections $\sigma_a(E)$ (8) for Δ corresponding to the measurement results given in Ref.[3].

For neutron elastic scattering cross-section $\sigma_n(E)$ (10) there are virtually no direct experimental data on energy dependence in the resonance region, and we give only the calculated dependence $\sigma_n(E)$ for T = 300 K. Thus, $\sigma_a(E)$ and $\sigma_n(E)$ obtained from the total cross-section parameters contain all the characteristic features of the resonance structure in the region under consideration, the errors of reproduction of these features being of the same order as in the case of the total cross-sections measured with the best resolution [19].

It is obvious that, constructing the absorption cross-section and having reliable fission cross-sections $\sigma_f(E)$, we can also determine the resonance dependence of the radiative captive cross-section with the corresponding accuracy:

$$\sigma_c(E) = \sigma_a(E) - \sigma_f(E) = \pi \lambda^2 \sqrt{E} \sum_K \left[\frac{G_K^c}{\nu_K} \psi\left(\frac{\mu_K - E}{\nu_K}, \frac{\nu_K}{\Delta}\right) - \frac{H_K^c}{\nu_K} \chi\left(\frac{\mu_K - E}{\nu_K}, \frac{\nu_K}{\Delta}\right) \right] \tag{11}$$

with $G_k^c = G_k^a - G_K^F$, $H_k^c = H_k^a - H_k^F$ [22, 23]. The available experimental data [3] agree qualitatively with the results of our calculation of $G_c(E)$ (11). It is important that in this method of construction there are possibilities of correcting the total and fission cross-section parameters (see Table 1) and of more reliably determining the resonance spins. The most interesting are the regions near some interference minima, where the use of not sufficiently accurate total and fission cross-section data may lead to a discrepancy of results for our scheme (11). This can serve as an indication of the nature of errors in experimental data.

<u>Comparison with integral data</u>

The fission cross-section resonance parameters given in Table 1 were normalized to the last evaluation of σ_f = 748.1 b for 0.0253 eV

(σ_c = 269.3 b) [24]. The group-averaged fission and neutron-radiative-capture cross-sections and $\bar{\alpha} = \bar{\sigma}_c/\bar{\sigma}_f$ were compared with the available experimental data [3, 7-9] and contemporary evaluations (Tables 2-4). Here the normalization of the fission cross-section was taken to be the same as in Ref.[3].

From a detailed and consistent analysis of the whole set of ^{239}Pu resonance cross-sections in the proposed multi-level parametrization scheme we can draw specific conclusions regarding the degree of accuracy and consistency of the available experimental data. The differences from experiment and also the possible inconsistency of the different experiments obviously point to the need for further studies on the cross-sections both in direct measurements and in measurements of transmissions and self-indication cross-sections for relatively thick samples [25]. By refining these data with broadening of the range of the target thicknesses used it will be possible to make a further correction of the resonance parameters (mainly H_k^F and H_k^T) sensitive to the minima in the cross-sections.

A unified approach to the description of all cross-sections in the resolved region involving the direct use of the property of unitarity of the S^J-matrix (1) gives a useful interrelationship between the parameters of the different cross-sections, which can be used ultimately to solve the problem of unambiguous description of the resonance cross-sections. The scheme can be applied to other fissionable nuclei with specific resonance spins.

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