3 Average Neutron Resonance Parameters

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Summary

Required parameters for statistical model calculations are neutron strength functions, average radiative widths and average spacing of resonances. These parameters are generally obtained from the analysis of parameter sets for the resolved resonances. The fact that the experimental resolution and sensitivity are limited in quality results in an incomplete (missing resonances) or distorted (errors on width determination) information on the resonance parameters. That is why the average widths and resonance spacings cannot be directly deduced from available resonance sequences, and they should always be estimated with account of missing resonances. Various methods for statistical analysis of missing resonances were developed, and most of them were applied for evaluation of average resonance parameters during RIPL project. Advantages and shortcomings of such methods are briefly discussed below for the purpose to obtain some objective estimation for an accuracy of recommended parameters.

For the RIPL Starter File the resonance parameters evaluated by Obninsk group are chosen as recommended ones mainly due a more reliable estimation of parameter uncertainities. These parameters are included into the **obninsk.dat** file. Alternative parameters evaluated by Beijing group are given in *beijing.dat* file, and average resonance parameters evaluated by Minsk group for the actinides are given in *minsk.dat* file.

3.1 Introduction

Before describing statistical methods for resonance analysis we would like to point out that statistical methods of resonance analysis are effective only when applied to pure resonance samples. Therefore, results of analysis become less and less accurate with the sample deficiencies.

Cases of pure resonance sample are pretty rare. In order to overcome this difficulty, one adopts different statistical analysis methods as well as sampling criteria in order to identify for each set of resonances a reduced sample where missing resonances and/or distortion are reduced. Getting average resonance parameters consists therefore of an iterative procedure where one tries to reach convergence of results from different methods of analysis. The spread of values obtained using different statistics is meaningful as uncertainty affecting results. Anyway, even such iterative procedure of statistical resonance analysis is not sufficient to guarantee the absolute value of parameters in many cases, and is to be validated by use of supplementary information like e.g. capture cross sections and radiative widths wherever possible. The formats of data are explained in the corresponding **readme** files.

3.2 Evaluation Methods

The neutron strength functions for a given orbital angular momentum l are defined by the relation

$$S_l = \frac{< g\Gamma_n^l >}{(2l+1)D_l} = \frac{1}{(2l+1)\Delta E}\sum_r g_r\Gamma_{nr}^l, \tag{3.1}$$

where the summation is performed over N resonances in the energy interval ΔE, $g_r = (2J_r+1)/2(2I_0+1)$ is the statistical weight factor that depends on the angular momentum J_r of a resonance and the spin I_0 of the target nucleus; Γ^l_{nr} are the reduced neutron widths of resonances, and D_l is the average resonance spacing, defined as

$$D_l = \Delta E/(N-1). \tag{3.2}$$

The reliable identification of s- and p-wave resonances is the most important for an accurate evaluation of average parameters. If such identification is available the neutron strength functions can be evaluated rather simply from the linear approximation of the cumulative sum of the products $g_r\Gamma^l_{nr}$. A departure from linearity may indicate the missing of resonances. The relative error of the evaluation can be defined from the relation

$$\frac{\delta S_l}{S_l} = \sqrt{2/N}, \tag{3.3}$$

which is based on an asymptotic estimation for the variance of the sum of neutron widths distributed in accordance with the Porter-Thomas law [3.1].

As dominant contributions to the sum in Eq. (3.1) give resonances with a large neutron width the missing of some weak resonances or admixture of p-wave resonances has a rather small effect on evaluation of strength functions for s-neutrons. The situation is not so favorable for p-neutrons, strength function of which can be strongly distorted by any admixture of incorrectly identified s-wave resonances. It is the main reason that for many nuclei the relative accuracy of p-wave strength functions is much lower than for s-wave ones.

For a rather full set of resonances the relative statistical error of the resonance spacing evaluation can be determined by the relation

$$\frac{\delta D_l}{D_l} = \frac{0.45\sqrt{\ln N + 2.18}}{N} \approx \frac{1}{N}, \tag{3.4}$$

which was obtained by Dayson and Mehta for the Gaussian orthogonal ensemble [3.2]. It is obvious that a missing of some resonances in a analyzed set results in a mistake that essentially exceeds the statistical one. So the estimation of missing resonances is a crucial problem for an accurate evaluation of the average resonance spacings. Another problem in resonance analysis arises in the separation of p-waves by s-waves. This is also crucial in order to be able to treat pure samples.

Three categories of methods were developed for the statistical account of missing or erroneously identified resonances: *i)* the methods exploiting the statistics of level spacings, *ii)* the methods based on the fit of the reduced neutron width distribution by a Porter-Thomas law, *iii)* the methods using combined simulation of the level and width statistics. Advantages and weaknesses of various methods have been broadly discussed in Refs. [3.3–3.8]. Some new developments connected the third class of methods were proposed recently too [3.9–3.12].

The simplest method of resonance analysis, often used even nowadays, is the staircase plot of the cumulative number $N(E)$ of resonances as a function of energy. It is usually assumed that at low energy range there are no missing resonances, and a linear approximation of this part of the plot gives a direct estimation of D_l. Some variety of this method is the approach based on the Δ_3 statistics given by Dayson and Mehta [3.2]. The best fit of $N(E)$ is searched by the least squares procedure of the parameter

$$\Delta = \min\left[\frac{1}{\Delta E}\int_0^{\Delta E}[N(E) - AE - B]^2 \mathrm{d}E\right]. \tag{3.5}$$

For a compete set of levels the value and variance of this parameter are defined by the relations:

$$\Delta_3 =< \Delta >= \frac{1}{\pi^2}(\ln N - 0.0687), \qquad \sigma = \frac{1}{\pi^2}\sqrt{\frac{4\pi^2}{45} + \frac{7}{24}} = 0.11. \tag{3.6}$$

Absence of levels or presence of spurious levels from another sequences obviously increases Δ_3. Therefore, if the fitted value of Δ satisfies the condition $\Delta_3 - \sigma < \Delta < \Delta_3 + \sigma$, the analyzed set of resonances may be considered as a pure and complete set. Unfortunately the Δ_3 statistics does not give any recipe to correct a bad set of resonance parameters. Besides in practice one finds that the Δ_3 test criteria are often satisfied for samples that are known to be neither pure nor complete [3.6, 3.8].

In contrast to the spacing distribution the neutron width distribution is only slightly affected by missing or spurious weak resonances. The upper part of the Porter-Thomas distribution, corresponding to the strong resonances, can be regarded as virtually unperturbed. A number of resonances that have reduced neutron width above a given value should be described by the function

$$N(\Gamma) = N_0 \int_{\Gamma/\overline{\Gamma}}^{\infty} \frac{\exp(-x/2)\mathrm{d}x}{\sqrt{2\pi x}} = N_0 \left[1 - \mathrm{erf}\sqrt{\Gamma/2\overline{\Gamma}}\right]. \tag{3.7}$$

So by fitting the corresponding distribution of neutron widths with a maximum likelihood approach we can find both the average reduced neutron width and total number of resonances N_0 at considered energy interval. The versions of the method were developed too that take into account of energy variations of neutron width measurement threshold and some other experimental conditions [3.8, 3.9].

The methods of the third class try to account simultaneously of limitations imposed on estimation of a mean width and resonance spacing by the Wigner and Porter-Thomas laws. Simulations of the neutron cross section by the Monte-Carlo methods with an account of experimental resolution and other conditions are applied in most cases. Some analytical treatments that could replace Monte-Carlo simulation in some cases were discussed in Refs. [3.9].

On the basis of the resonance parameter analyses performed by different groups one conclusion should be stressed that none of the methods developed permits an unambiguous identification of missed or spurious resonances in a general case. A critical analysis of experimental conditions and of the approaches used to obtain individual resonance parameters is very important for many cases. The priority in average parameter evaluations should be given to the quality of the selected resonance set rather than to the total number of resonances included into consideration [3.9, 3.13]. Only for a rather small number of nuclei the accuracy of evaluated resonance spacings is better than 10%. The best examples of such nuclei are the isotopes U-235 and U-238 for which the relative errors of the recommended D_0 are better than 2%, and for the isotopes Pu-239, Pu-240 and Pu-242 such errors are about 5% [3.9, 3.11].

3.3 Files of Average Neutron Resonance Parameters

The complete tables of average resonance parameters have been provided to the NDS by Beijing, Bologna and Obninsk groups in the beginning of the RIPL project. They were obtained by each group on the basis of methods used for neutron data evaluations in the corresponding Centers.

Combined tables of average parameters for the resonance spacings D_0, the neutron strength function S_0 and the average radiative widths were prepared by the Bologna group. Obninsk group has compiled the tables to computer readable format errors. This results provided the

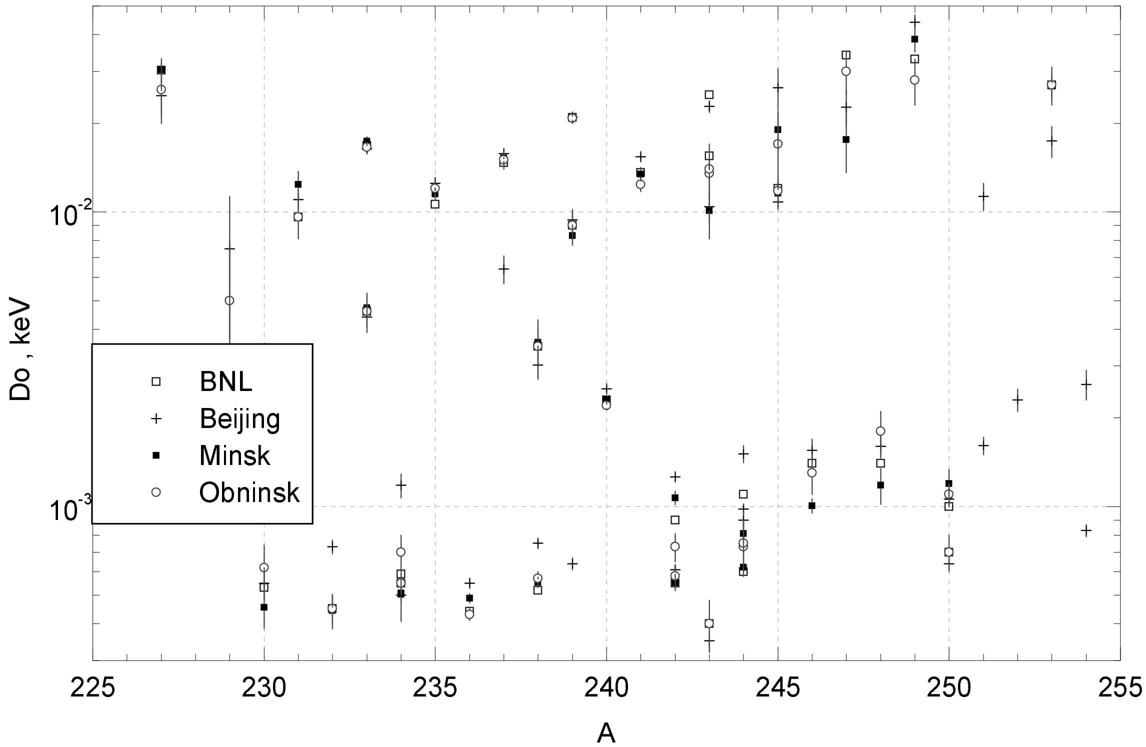

Figure 3.1: Average resonance spacings for actinides evaluated by Brookhaven (empty squares), Beijing (+) Obninsk (circles), and Minsk (full squares) groups.

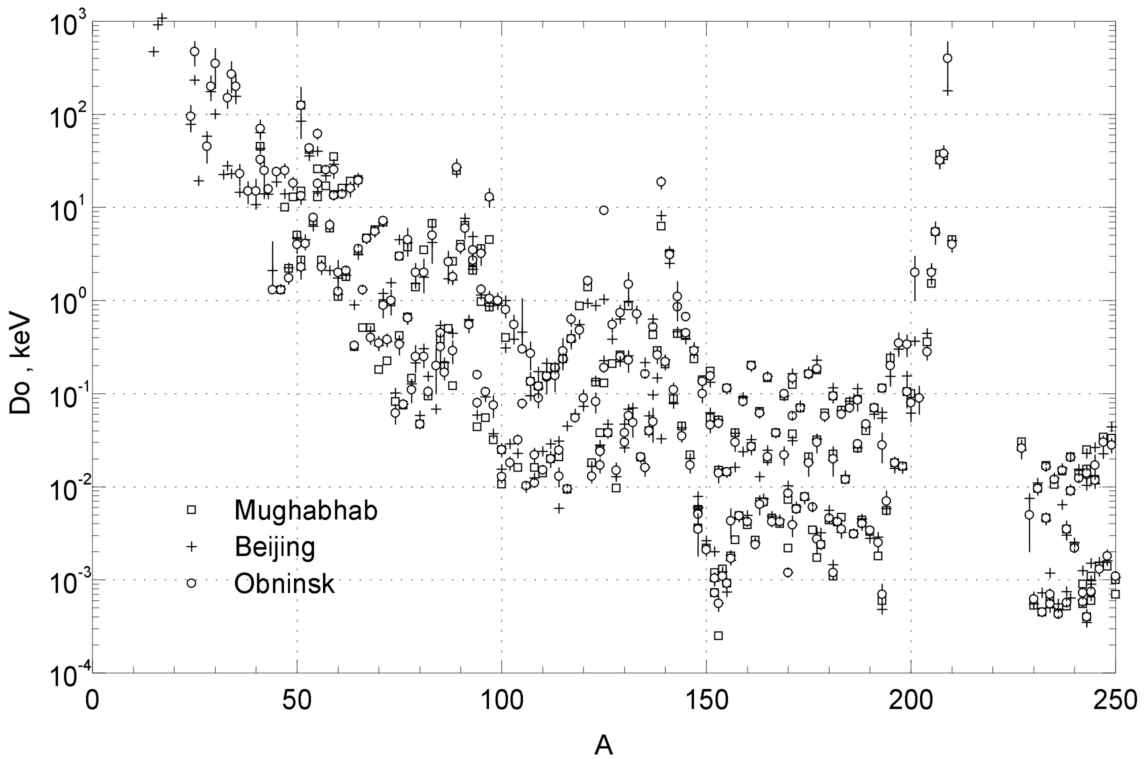

Figure 3.2: Average resonance spacings for full mass region evaluated by Brookhaven (squares), Beijing (+) and Obninsk (circles) groups. Uncertainties are shown for Obninsk evaluations only.

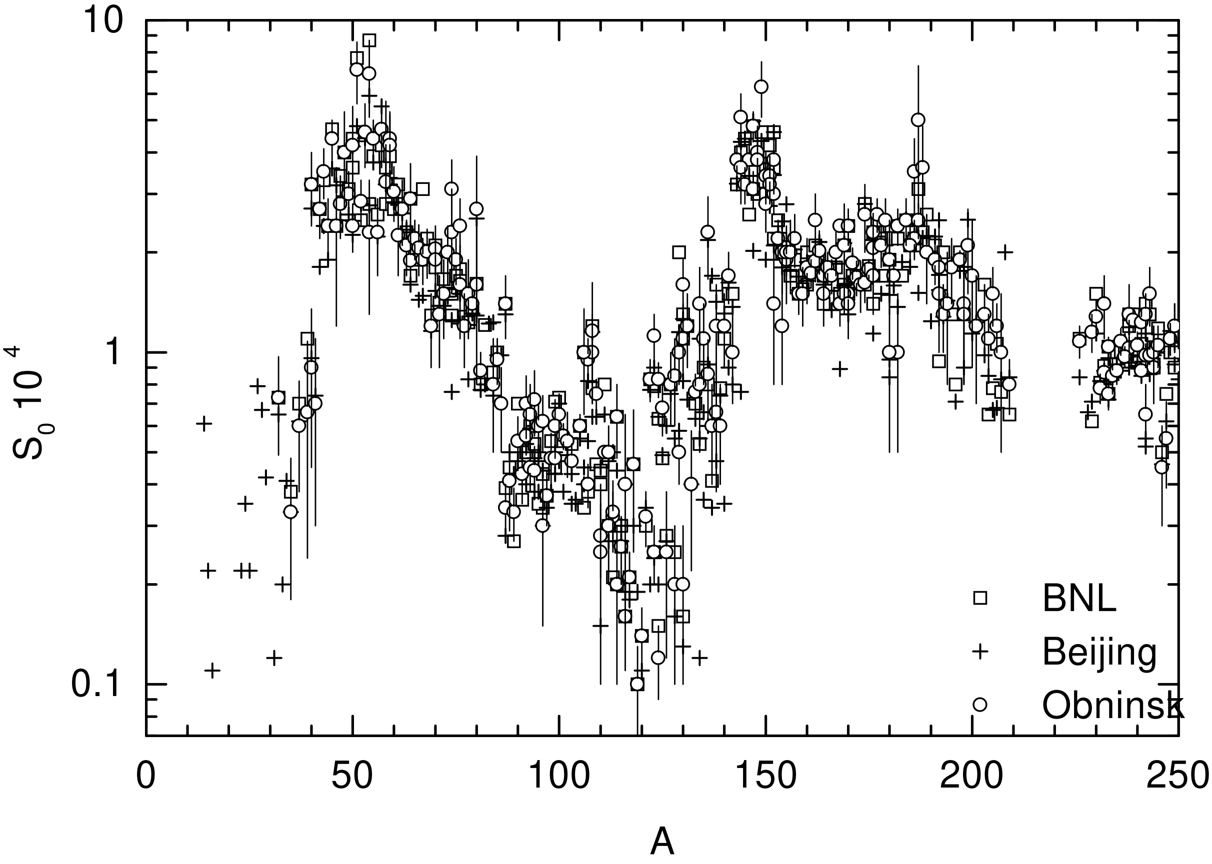

Figure 3.3: The s-wave neutron strength functions evaluated by BNL (squares), Beijing (+) and Obninsk (circles) groups. Uncertainties are shown for Obninsk evaluations only.

basis for detailed comparison and discussion of evaluated average parameters carried out by means of frequent consultations between Obninsk and Bologna.

Many discrepancies were found and the reasons for such discrepancies were traced. After the analysis of the available files, namely from Bologna, Obninsk and Beijing, meetings were held between Bologna and Obninsk groups where statistical methods of resonance analysis were carefully discussed in order to clarify the meaning of errors as well as the meaning of the different quantities. To better understand the nature of discrepancies, a restricted number of nuclei have been analyzed more carefully on the basis of methods used in Bologna and Obninsk. This has clarified the different philosophies adopted as well as the significance of the quoted quantities. In particular Obninsk group spends more attention to the limitation of energy interval on which the resonance parameters are analyzed and complements the statistical estimation of errors with some experience guesses about associated methodical errors. Bologna group approach is more formal and conservative in the sense that all information available about resonances is involved in the statistical analysis. The quoted uncertainties in this case represent the intrinsic limit and deficiency of the statistical sample, and they are in general larger than those obtained for the other confidence limit estimates.

After consideration of existing discrepancies Obninsk took care of the re-analysis of 80% of nuclei and new tables of the evaluated neutron strength functions and resonance spacings were prepared. For heavy actinides a new analysis of average resonance parameters was performed also by Minsk group.

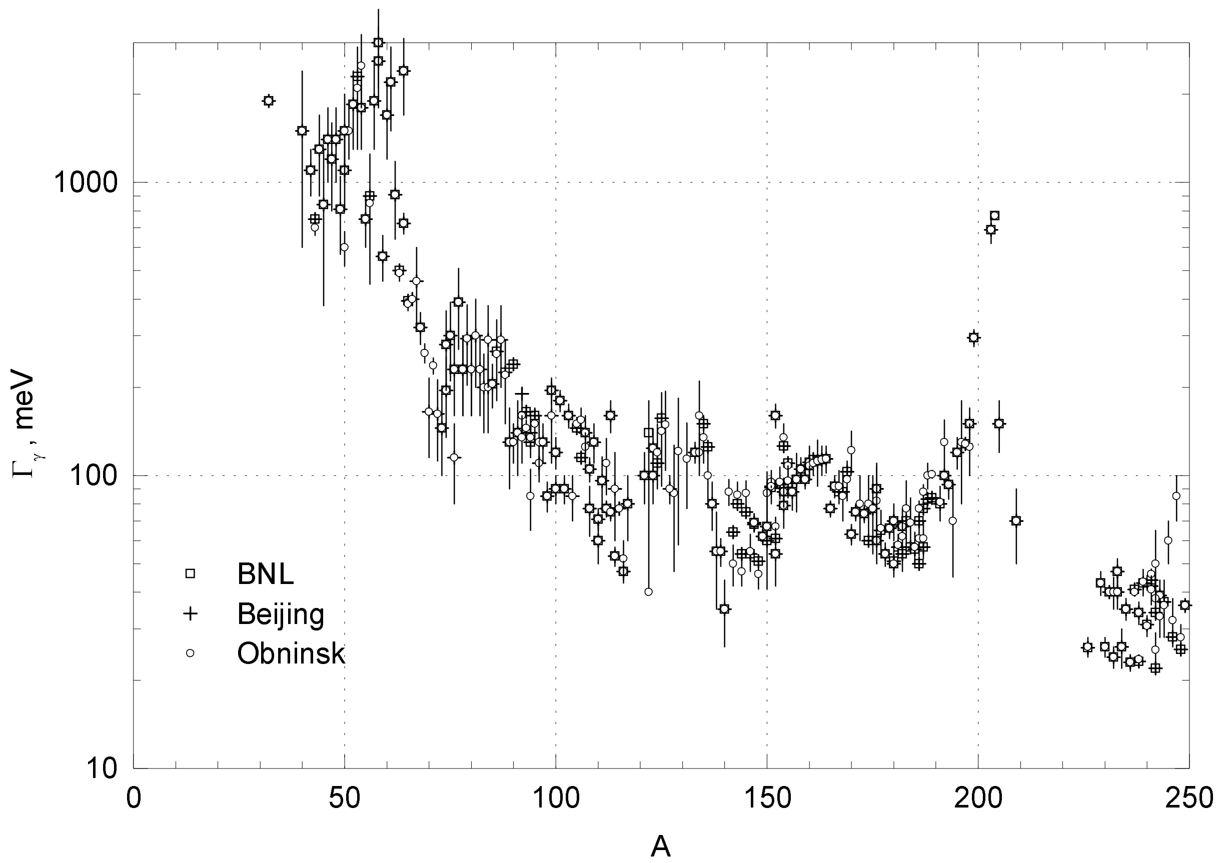

Figure 3.4: Average radiative widths evaluated by Beijing (+) and Obninsk (circles) groups.

The resonance spacings evaluated by Beijing, Minsk and Obninsk groups for actinides are shown in Fig. 3.1. The results of all groups demonstrate a rather good agreement for most cases where data are available for more than 30 resonances. The quoted uncertainties of Obninsk, as a rule, are higher than the uncertainties given by Beijing and Minsk groups. This difference of uncertainties mainly connected with the reduction of energy interval that used Obninsk group to improve quality of analyzed statistical samples. Taking into account the big difference between uncertainties obtained for various methods of resonance spacing estimation, the uncertainties of Obninsk group seem more reliable than Beijing or Minsk ones.

Evaluations of the resonance spacings for full mass range are shown in Fig. 3.2. The last Obninsk evaluations for some nuclei are based on more recent experimental data than included in Mughabghab compilations [3.14, 3.15] analyzed by Beijing group. As an alternative set is included into the RIPL Starter File the average resonance spacings evaluated by Beijing group [3.17]. The recent compilation of the resonance spacings published in Ref. [3.16] and based on evaluations of different authors is also included into the *iljinov_gc.dat* file which is placed in Segment 5 of the Starter File as more related to the nuclear level density parameters.

The results of new evaluations of Beijing and Obninsk groups for the s-wave neutron strength functions are shown in Fig. 3.3 in comparison with old BNL evaluations. There are no essential differences between the two evaluations for most nuclei. Uncertainties of Obninsk group are a little higher again because to some extent they take account of sample quality effects in addition to pure statistical errors.

The results of the radiative width evaluations obtained by Beijing and Obninsk groups are very close (Fig. 3.4). The uncertainties estimated by Obninsk group seem reasonable for Beijing group too. So Obninsk evaluations should be taken as recommended for the RIPL Starter File.

3.4 Conclusions and Recommendations

All recent evaluations of average neutron resonance parameters are available in the computer readable format in the RIPL Starter File. The **obninsk.dat** is recommended file, and *beijing.dat* and *minsk.dat* contain useful alternative values of the parameters. In addition, *iljinov_gc.dat* (see Chapter 5.1, p. 74, Fig. 5.3) contains recent compilation of D_0 from Troitsk, Russia. Difference of parameters obtained by different groups reflects the systematic uncertainity of parameter estimation caused by the evaluation methods used.

Obninsk evaluations of average resonance parameters seem preferable as recommended ones for most nuclei due more reliable estimation of parameter uncertainties.

Table 3.1: Table of recommended average parameters of the s-wave neutron resonances (file **obninsk.dat**).

Z and A are the element and mass numbers of the compound nucleus, I_0 is the spin of the target nucleus, Bn is the neutron binding energy, Nr is the number of resonances included in the analysis, D_0 and δD_0 are the evaluated resonance spacing and its uncertainty, S_0 and δS_0 are the neutron strength function and its uncertainty, Γ_γ and $\delta\Gamma_\gamma$ are the average radiative width and its uncertainity. The references relate to the works in which the resonance spacings and neutron strength functions were evaluated, the average radiative widths are mainly taken from Ref. [3.13].

Z	Sy	A	I_0	Bn MeV	Nr	D_0 keV	δD_0 keV	S_0 10^{-4}	δS_0 10^{-4}	Ref	Γ_γ meV	$\delta\Gamma_\gamma$ meV
11	Na	24	1.5	6.959	3	9.50E+01	3.00E+01			[3.18]		
12	Mg	25	0	7.330	4	4.70E+02	1.40E+02			[3.18]		
13	Al	28	2.5	7.725	7	4.50E+01	1.50E+01			[3.18]		
14	Si	29	0	8.474	5	2.00E+02	6.00E+01			[3.18]		
14	Si	30	0.5	10.610	5	3.50E+02	1.60E+02			[3.19]		
16	S	33	0	8.641	41	1.50E+02	3.50E+01	0.73	0.24	[3.18]	1900	
16	S	34	1.5	11.416	7	2.70E+02	1.00E+02			[3.18]		
16	S	35	0	6.985	3	2.00E+02	7.00E+01			[3.18]		
17	Cl	36	1.5	8.580	10	2.30E+01	6.00E+00	0.33	0.15	[3.20]		
17	Cl	38	1.5	6.108	14	1.50E+01	4.00E+00	0.60	0.22	[3.20]		
18	Ar	41	0	6.098	7	7.02E+01	1.70E+01	0.90	0.45	[3.21]		
19	K	40	1.5	7.799	7	1.50E+01	5.00E+00	0.66	0.42	[3.18]		
19	K	42	1.5	7.533	5	2.50E+01	1.00E+01	0.70	0.40	[3.20]		
20	Ca	41	0	8.362	31	3.26E+01	4.30E+00	3.20	0.80	[3.21]	1500	1000
20	Ca	43	0	7.932	27	1.58E+01	2.10E+00	2.70	0.50	[3.21]	1100	200
20	Ca	44	3.5	11.132	23	1.30E+00	3.00E+00	3.50	0.60	[3.20]	750	40
20	Ca	45	0	7.414	21	2.41E+01	3.20E+00	2.40	0.50	[3.21]	1300	400
21	Sc	46	3.5	8.760	74	1.30E+00	1.00E-01	4.40	0.60	[3.20]	840	460
22	Ti	47	0	8.877	12	2.50E+01	4.40E+00	2.40	1.20	[3.21]	1400	400
22	Ti	48	2.5	11.627	40	1.75E+00	2.50E-01	2.80	0.60	[3.20]	1200	400
22	Ti	49	0	8.142	16	1.83E+01	2.90E+00	4.00	1.30	[3.21]	1400	400
22	Ti	50	3.5	10.939	35	4.00E+00	8.00E-01	3.00	0.50	[3.20]	810	240
22	Ti	51	0	6.371	3	1.25E+02	7.00E+01			[3.14]	1100	300
23	V	51	6	11.051	16	2.30E+00	6.00E-01	4.20	1.30	[3.20]	600	80
23	V	52	3.5	7.310	48	4.10E+00	6.00E-01	7.10	1.50	[3.20]	1500	300
24	Cr	51	0	9.261	41	1.33E+01	1.30E+00	2.40	0.40	[3.21]	1500	500
24	Cr	53	0	7.939	23	4.34E+01	4.37E+00	2.85	0.45	[3.22]	1850	550
24	Cr	54	1.5	9.719	34	7.80E+00	8.00E-01	4.60	1.00	[3.22]	2100	800
24	Cr	55	0	6.246	15	6.20E+01	8.00E+00	2.30	1.00	[3.22]	2500	700
25	Mn	56	2.5	7.270	52	2.30E+00	4.00E-01	4.40	0.60	[3.20]	750	150
26	Fe	55	0	9.297	52	1.80E+01	2.40E+00	6.90	1.80	[3.21]	1800	500
26	Fe	57	0	7.646	41	2.54E+01	2.20E+00	2.30	0.60	[3.23]	920	410
26	Fe	58	0.5	10.044	22	6.50E+00	1.00E+00	4.70	1.10	[3.20]	1900	600
26	Fe	59	0	6.581	12	2.54E+01	4.90E+00	4.40	1.30	[3.21]	3000	900
27	Co	60	3.5	7.491	96	1.25E+00	1.50E-01	4.40	0.80	[3.20]	560	100

28	Ni	59	0	8.999	61	1.34E+01	9.00E-01	3.26	0.59	[3.24]	2600	800
28	Ni	60	1.5	11.388	7	2.00E+00	7.00E-01	4.20	1.10	[3.20]	2200	700
28	Ni	61	0	7.820	58	1.38E+01	9.00E-01	3.05	0.57	[3.24]	1700	500
28	Ni	62	1.5	10.597	31	2.10E+00	1.50E-01	2.25	0.55	[3.20]	2200	700
28	Ni	63	0	6.838	29	1.60E+01	3.00E+00	2.70	0.60	[3.20]	910	270
28	Ni	65	0	6.097	28	1.96E+01	3.00E+00	2.90	0.80	[3.20]	2400	700
29	Cu	64	1.5	7.916	153	3.30E-01	4.00E-02	2.10	0.40	[3.20]	490	30
29	Cu	66	1.5	7.065	129	1.30E+00	1.10E-01	2.20	0.30	[3.20]	385	20
30	Zn	65	0	7.979	22	3.59E+00	1.60E-01	1.89	0.26	[3.25]	726	60
30	Zn	67	0	7.052	64	4.62E+00	5.50E-01	2.06	0.36	[3.25]	390	60
30	Zn	68	2.5	10.198	345	4.00E-01	6.00E-02	1.90	0.30	[3.20]	460	140
30	Zn	69	0	6.482	45	5.56E+00	4.30E-01	2.01	0.34	[3.25]	320	40
30	Zn	71	0	5.833	48	7.20E+00	8.00E-01	2.05	0.35	[3.25]		
31	Ga	70	1.5	7.654	19	3.50E-01	6.00E-02	1.20	0.30	[3.20]	262	25
31	Ga	72	1.5	6.521	14	3.80E-01	6.00E-02	1.30	0.40	[3.20]	237	20
32	Ge	71	0	7.416	21	8.90E-01	2.40E-01	1.90	0.30	[3.20]	165	50
32	Ge	73	0	6.783	14	1.00E+00	3.00E-01	1.50	0.40	[3.20]	162	50
32	Ge	74	4.5	10.199	35	6.20E-02	1.50E-02	2.00	0.40	[3.20]	195	45
32	Ge	75	0	6.506	8	3.00E+00	1.00E+00	2.30	0.80	[3.20]	195	60
32	Ge	77	0	6.073	8	4.50E+00	1.50E-00	1.60	0.50	[3.20]	115	35
33	As	76	1.5	7.326	243	7.70E-02	8.00E-03	1.90	0.30	[3.20]	300	90
34	Se	75	0	8.027	7	3.40E-01	8.00E-02	3.10	0.70	[3.20]	280	80
34	Se	77	0	7.418	15	6.50E-01	1.00E-01	2.40	0.50	[3.20]	230	60
34	Se	78	0.5	10.498	27	1.10E-01	3.00E-02	1.20	0.30	[3.20]	390	90
34	Se	79	0	6.963	16	2.00E+00	5.00E-01	1.50	0.40	[3.20]	230	60
34	Se	81	0	6.701	10	2.00E+00	8.00E-01	2.70	1.20	[3.20]	230	70
34	Se	83	0	5.818	4	5.00E+00	2.50E+00			[3.20]		
35	Br	80	1.5	7.892	111	4.70E-02	5.00E-03	1.40	0.15	[3.20]	293	90
35	Br	82	1.5	7.592	99	1.05E-01	1.50E-02	0.88	0.12	[3.20]	300	100
36	Kr	79	0	8.369	3	2.50E-01	8.00E-02			[3.20]		
36	Kr	81	0	7.874	4	2.50E-01	6.00E-02	1.60	0.80	[3.20]	230	60
36	Kr	84	4.5	10.519	4	2.00E-01	1.00E-01			[3.20]	210	60
36	Kr	85	0	7.118	3	4.50E-01	1.70E-01			[3.20]		
37	Rb	86	2.5	8.651	63	1.70E-01	3.00E-02	0.95	0.15	[3.20]	205	35
37	Rb	88	1.5	6.079	14	1.80E+00	3.00E-01	1.40	0.30	[3.20]		
38	Sr	85	0	8.529	9	3.20E-01	1.20E-01	0.80	0.30	[3.20]	290	90
38	Sr	87	0	8.428	24	2.60E+00	8.00E-01	0.70	0.20	[3.20]	260	80
38	Sr	88	4.5	11.112	50	2.90E-01	8.00E-02	0.34	0.06	[3.20]	290	90
38	Sr	89	0	6.366	8	2.70E+01	6.00E+00	0.41	0.12	[3.20]	220	70
39	Y	90	0.5	6.856	66	3.70E+00	4.00E-01	0.33	0.06	[3.20]	130	40
40	Zr	91	0	7.194	28	6.00E+00	1.40E+00	0.54	0.10	[3.20]	130	20
40	Zr	92	2.5	8.635	30	5.50E-01	1.00E-01	0.43	0.08	[3.20]	140	40
40	Zr	93	0	6.734	31	3.50E+00	8.00E-01	0.70	0.15	[3.20]	135	25
40	Zr	94	2.5	8.219	114	1.60E-01	1.50E-02	0.65	0.15	[3.20]		
40	Zr	95	0	6.462	17	3.20E+00	8.00E-01	0.72	0.16	[3.20]	85	20
40	Zr	97	0	5.579	8	1.30E+01	3.00E+00	0.30	0.15	[3.20]	130	
41	Nb	94	4.5	7.229	79	8.00E-02	1.00E-02	0.45	0.07	[3.20]	145	10
42	Mo	93	0	8.067	14	2.70E+00	5.00E-01	0.56	0.07	[3.20]	160	20
42	Mo	95	0	7.367	12	1.32E+00	1.80E-01	0.44	0.08	[3.20]	135	20

42	Mo	96	2.5	9.154	22	1.05E-01	1.00E-02	0.60	0.10	[3.20]	150	20
42	Mo	97	0	6.821	12	1.05E+00	2.00E-01	0.62	0.12	[3.20]	110	15
42	Mo	98	2.5	8.642	22	7.50E-02	2.00E-02	0.37	0.07	[3.20]	130	20
42	Mo	99	0	5.925	28	1.00E+00	2.00E-01	0.48	0.09	[3.20]	85	10
42	Mo	101	0	5.398	32	8.00E-01	1.50E-01	0.65	0.10	[3.20]	90	10
43	Tc	100	4.5	6.764	106	1.28E-02	1.80E-03	0.48	0.07	[3.20]	160	50
44	Ru	100	2.5	9.673	35	2.50E-02	4.00E-03	0.60	0.12	[3.20]	195	20
44	Ru	102	2.5	9.220	41	1.80E-02	3.00E-03	0.56	0.05	[3.20]	180	15
44	Ru	103	0	6.232	21	5.50E-01	1.50E-01	0.54	0.12	[3.8]	90	10
44	Ru	105	0	5.910	17	3.00E-01	7.50E-01			[3.8]	85	15
45	Rh	104	0.5	6.999	30	3.20E-02	4.00E-03	0.47	0.06	[3.20]	160	15
46	Pd	105	0	7.094	29	7.80E-02	9.00E-03			[3.31]		
46	Pd	106	2.5	9.562	193	1.03E-02	5.00E-04	0.60	0.05	[3.20]	150	8
46	Pd	107	0	6.538	29	2.70E-01	9.00E-02			[3.20]		
46	Pd	108	2.5	9.220	51	1.10E-02	9.00E-04	0.95	0.15	[3.20]	125	15
46	Pd	109	0	6.153	20	9.00E-02	2.00E-02	1.00	0.30	[3.20]	77	5
46	Pd	111	0	5.756	40	1.50E-01	5.00E-02	0.25	0.15	[3.20]	60	10
47	Ag	108	0.5	7.269	39	2.20E-02	4.00E-03	0.40	0.06	[3.20]	140	20
47	Ag	110	0.5	6.809	61	1.51E-02	1.40E-03	0.75	0.08	[3.20]	130	20
48	Cd	107	0	7.926	56	1.35E-01	3.50E-02	1.00	0.35	[3.26]	155	15
48	Cd	109	0	7.325	52	1.20E-01	3.00E-02	1.16	0.46	[3.26]	105	10
48	Cd	111	0	6.974	43	1.55E-01	2.00E-02	0.28	0.07	[3.26]	71	6
48	Cd	112	0.5	9.398	78	2.00E-02	4.00E-03	0.50		[3.26]	96	20
48	Cd	113	0	6.540	34	1.90E-01	2.50E-02	0.50	0.10	[3.26]	77	5
48	Cd	114	0.5	9.042	122	2.48E-02	2.60E-03	0.32	0.06	[3.27]	160	20
48	Cd	115	0	6.141	34	2.35E-01	3.50E-02	0.64	0.16	[3.26]	53	4
48	Cd	117	0	5.767	26	3.90E-01	9.00E-02	0.16	0.05	[3.26]	47	4
49	In	114	4.5	7.274	38	1.30E-02	3.00E-03	0.33	0.08	[3.20]	75	5
49	In	116	4.5	6.784	205	9.50E-03	5.00E-04	0.26	0.06	[3.20]	77	4
50	Sn	113	0	7.743	7	1.57E-01	5.20E-02	0.30	0.10	[3.28]	110	25
50	Sn	115	0	7.545	4	2.86E-01	1.06E-01	0.20	0.10	[3.28]	90	30
50	Sn	117	0	6.944	4	6.29E-01	9.80E-02	0.40	0.25	[3.28]	52	10
50	Sn	118	0.5	9.326	56	5.50E-02	5.00E-03	0.21	0.04	[3.28]	80	20
50	Sn	119	0	6.485	10	4.80E-01	9.00E-02	0.46	0.21	[3.28]		
50	Sn	120	0.5	9.106	16	9.00E-02	2.00E-02	0.10	0.03	[3.28]		
50	Sn	121	0	6.171	31	1.64E+00	2.00E-01	0.14	0.03	[3.29]		
50	Sn	125	0	5.732	32	9.30E+00	9.00E-01	0.12	0.03	[3.30]		
51	Sb	122	2.5	6.807	60	1.30E-02	2.00E-03	0.32	0.06	[3.20]	100	20
51	Sb	124	3.5	6.467	48	2.40E-02	3.00E-03	0.25	0.05	[3.20]	100	20
52	Te	123	0	6.935	22	8.20E-02	2.00E-02	0.83	0.12	[3.20]	140	40
52	Te	124	0.5	9.425	27	1.70E-02	3.00E-03	1.12	0.18	[3.20]	124	20
52	Te	125	0	6.570	36	1.90E-01	2.00E-02	0.83	0.10	[3.20]	120	30
52	Te	126	0.5	9.114	65	3.80E-02	5.00E-03	0.68	0.12	[3.20]	157	30
52	Te	127	0	6.290	15	5.50E-01	1.00E-01	0.25	0.13	[3.20]	149	45
52	Te	129	0	6.085	11	7.40E-01	1.50E-01	0.20	0.10	[3.20]	87	40
52	Te	131	0	5.929	22	1.50E+00	5.00E-01	0.20	0.10	[3.20]		
53	I	128	2.5	6.825	328	1.50E-02	3.00E-03	0.80	0.20	[3.20]	90	10
53	I	130	3.5	6.461	62	3.00E-02	3.00E-03	0.50	0.10	[3.20]		
54	Xe	129	0	6.909	10	2.50E-01	1.00E-03	0.85	0.25	[3.20]		

54	Xe	130	0.5	9.254	69	3.80E-02	5.00E-03	1.00	0.20	[3.20]	120	60
54	Xe	131	0	6.618	11	2.30E-01	6.00E-02	1.10	0.30	[3.20]		
54	Xe	132	1.5	8.935	20	4.90E-02	1.50E-02	1.20	0.30	[3.20]	114	37
54	Xe	133	0	6.438	5	7.17E-01	1.55E-01	0.40	0.18	[3.31]		
55	Cs	134	3.5	6.891	107	2.10E-02	2.00E-03	0.76	0.10	[3.20]	120	10
55	Cs	135	4	8.827	7	1.60E-02	3.00E-03	0.80	0.30	[3.20]	160	40
56	Ba	131	0	7.494	39	5.80E-02	1.00E-02	1.60	0.30	[3.32]	100	30
56	Ba	135	0	6.973	35	1.63E-01	1.10E-02	1.40	0.40	[3.33]	78	27
56	Ba	136	3.5	9.107	28	4.00E-02	6.00E-03	1.10	0.30	[3.32]	135	25
56	Ba	137	0	6.900	18	5.22E-01	3.40E-02	0.86	0.23	[3.33]	86	28
56	Ba	138	1.5	8.611	44	2.60E-01	5.00E-02	0.60	0.20	[3.32]	80	15
56	Ba	139	0	4.723	11	1.87E+01	2.90E+00	0.66	0.28	[3.24]	55	20
57	La	139	5	8.778	10	3.20E-02	6.00E-03	1.20	0.40	[3.20]	95	25
57	La	140	3.5	5.160	88	2.20E-01	4.00E-02	0.60	0.20	[3.20]	55	6
58	Ce	137	0	7.481	9	5.00E-02	2.00E-02	2.30	0.64	[3.20]		
58	Ce	141	0	5.428	40	3.10E+00	5.00E-01	1.20	0.30	[3.20]	35	9
58	Ce	143	0	5.145	4	1.10E+00	5.00E-01			[3.20]		
59	Pr	142	2.5	5.843	107	1.10E-01	2.00E-02	1.70	0.30	[3.20]	88	9
60	Nd	143	0	6.123	26	8.60E-01	8.00E-02	1.00	0.30	[3.20]	50	8
60	Nd	144	3.5	7.817	57	3.50E-02	5.00E-03	3.80	0.40	[3.20]	86	9
60	Nd	145	0	5.755	20	4.50E-01	5.00E-02	5.10	0.90	[3.20]	47	5
60	Nd	146	3.5	7.564	114	1.70E-02	3.00E-03	3.20	0.40	[3.20]	87	9
60	Nd	147	0	5.292	31	2.90E-01	5.00E-02	3.80	0.60	[3.20]	55	8
60	Nd	148	2.5	7.333	7	3.50E-03	1.70E-03			[3.20]		
60	Nd	149	0	5.038	39	1.35E-01	2.00E-02	4.00	0.80	[3.20]	46	5
60	Nd	151	0	5.334	77	1.55E-01	2.00E-02	2.80	0.50	[3.20]	67	25
61	Pm	148	3.5	5.893	43	5.20E-03	1.20E-03	3.10	0.40	[3.20]	69	5
62	Sm	145	0	6.762	50	6.70E-01	6.00E-02	3.60	0.80	[3.34]	75	5
62	Sm	148	3.5	8.141	89	5.10E-03	5.00E-04	4.80	0.50	[3.32]	69	2
62	Sm	149	0	5.871	26	1.00E-01	2.00E-02	3.80	0.80	[3.32]		
62	Sm	150	3.5	7.985	86	2.10E-03	3.00E-04	6.30	1.20	[3.32]	62	2
62	Sm	151	0	5.598	11	4.60E-02	8.00E-03	3.40	0.60	[3.32]	87	16
62	Sm	152	2.5	8.257	62	1.04E-03	1.50E-04	3.40	0.50	[3.32]	95	4
62	Sm	153	0	5.867	41	4.80E-02	5.00E-03	3.00	0.40	[3.32]	67	5
62	Sm	155	0	5.807	22	1.14E-01	1.50E-02	2.00	0.50	[3.32]	79	13
63	Eu	152	2.5	6.307	90	7.30E-04	7.00E-05	3.20	0.40	[3.32]	92	12
63	Eu	153	3	8.550	17	5.60E-04	1.00E-04	1.40	0.60	[3.32]	160	25
63	Eu	154	2.5	6.441	70	1.10E-03	2.00E-04	2.20	0.30	[3.32]	95	12
63	Eu	155	3	8.152	19	9.20E-04	1.20E-04	1.20	0.40	[3.32]	135	25
63	Eu	156	2.5	6.338	7	4.30E-03	1.50E-03	1.90	0.50	[3.32]	96	18
64	Gd	153	0	6.246	17	1.40E-02	3.00E-03	3.80	0.80	[3.32]	54	12
64	Gd	155	0	6.435	47	1.45E-02	1.50E-03	2.00	0.40	[3.32]	88	10
64	Gd	156	1.5	8.536	92	1.70E-03	2.00E-04	2.00	0.30	[3.32]	108	10
64	Gd	157	0	6.359	33	3.00E-02	6.00E-03	2.00	0.50	[3.32]	88	12
64	Gd	158	1.5	7.938	56	4.90E-03	5.00E-04	2.20	0.40	[3.32]	97	22
64	Gd	159	0	5.942	60	8.20E-02	6.00E-03	1.50	0.20	[3.32]	105	10
64	Gd	161	0	5.635	38	2.00E-01	2.00E-02	1.80	0.40	[3.32]	111	15
65	Tb	160	1.5	6.375	201	4.20E-03	3.00E-04	1.50	0.30	[3.32]	97	7
66	Dy	161	0	6.453	34	2.70E-02	5.00E-03	2.00	0.36	[3.20]	108	10

66	Dy	162	2.5	8.196	53	2.40E-03	2.00E-04	1.73	0.17	[3.20]	112	10
66	Dy	163	0	6.271	72	6.20E-02	5.00E-03	1.88	0.25	[3.20]	112	20
66	Dy	164	2.5	7.658	60	6.80E-03	6.00E-04	2.02	0.30	[3.20]	113	13
66	Dy	165	0	5.716	48	1.50E-01	1.00E-02	1.70	0.25	[3.20]	114	14
67	Ho	166	3.5	6.243	150	4.20E-03	5.00E-04	1.80	0.20	[3.35]	77	5
68	Er	163	0	6.902	17	6.50E-03	1.50E-03	2.50	0.50	[3.32]		
68	Er	165	0	6.649	18	2.10E-02	4.00E-03	1.50	0.30	[3.32]		
68	Er	167	0	6.436	115	3.80E-02	3.00E-03	1.70	0.20	[3.32]	92	8
68	Er	168	3.5	7.771	124	4.20E-03	3.00E-04	2.00	0.30	[3.32]	92	12
68	Er	169	0	6.003	82	1.00E-01	1.00E-02	1.40	0.20	[3.32]	85	15
68	Er	171	0	5.681	41	1.47E-01	2.00E-02	1.50	0.20	[3.32]		
69	Tm	170	0.5	6.593	192	8.50E-03	7.00E-04	1.50	0.20	[3.32]	97	15
69	Tm	171	1	7.486	13	3.90E-03	1.00E-03	1.40	0.30	[3.32]	122	20
70	Yb	169	0	6.867	5	2.20E-02	5.00E-03	2.40	0.80	[3.20]	64	20
70	Yb	170	3.5	8.470	21	1.19E-03	1.00E-04	2.10	0.70	[3.20]	80	25
70	Yb	171	0	6.615	23	5.80E-02	2.60E-03	2.40	0.30	[3.20]	63	5
70	Yb	172	0.5	8.019	168	5.79E-03	4.80E-04	1.86	0.20	[3.20]	75	5
70	Yb	173	0	6.367	100	7.03E-02	2.60E-03	1.68	0.20	[3.20]	79	20
70	Yb	174	2.5	7.464	166	7.81E-03	9.30E-04	1.60	0.28	[3.20]	74	5
70	Yb	175	0	5.822	78	1.62E-01	1.80E-02	1.62	0.21	[3.20]	80	20
70	Yb	177	0	5.566	68	1.85E-01	1.90E-02	2.30	0.32	[3.20]	82	25
71	Lu	176	3.5	6.294	227	6.05E-03	1.50E-04	1.78	0.12	[3.32]	77	23
71	Lu	177	7	7.071	59	2.75E-03	8.50E-04	2.06	0.44	[3.32]	90	20
72	Hf	175	0	6.708	10	1.80E-02	5.00E-03	2.60	0.60	[3.32]		
72	Hf	177	0	6.381	39	3.00E-02	7.00E-03	1.70	0.40	[3.32]	60	10
72	Hf	178	3.5	7.625	94	2.40E-03	3.00E-04	2.60	0.30	[3.32]	66	10
72	Hf	179	0	6.100	48	5.70E-02	6.00E-03	2.10	0.30	[3.32]	54	5
72	Hf	180	4.5	7.387	70	4.60E-03	3.00E-04	2.50	0.40	[3.32]	66	5
72	Hf	181	0	5.696	14	9.40E-02	1.50E-02	1.90	0.60	[3.32]	50	5
73	Ta	181	1	7.576	60	1.20E-03	2.00E-04	1.90	0.30	[3.32]	51	3
73	Ta	182	3.5	6.063	418	4.20E-03	3.00E-04	1.70	0.20	[3.32]	57	3
73	Ta	183	5	6.934	9	3.50E-03	7.00E-04	1.00	0.50	[3.32]	67	3
74	W	181	0	6.680	5	2.00E-02	7.00E-03	1.00	0.50	[3.20]	70	15
74	W	183	0	6.190	47	6.00E-02	6.00E-03	2.30	0.30	[3.20]	62	15
74	W	184	0.5	7.411	59	1.20E-02	1.00E-03	1.90	0.30	[3.20]	77	12
74	W	185	0	5.755	31	7.00E-02	7.00E-03	2.80	0.40	[3.20]	69	17
74	W	187	0	5.466	32	8.50E-02	8.00E-03	2.10	0.40	[3.20]	61	8
75	Re	186	2.5	6.178	237	3.10E-03	3.00E-04	2.70	0.30	[3.20]	57	7
75	Re	188	2.5	5.871	174	4.10E-03	3.00E-04	2.50	0.30	[3.20]	61	9
76	Os	187	0	6.292	32	2.90E-02	3.00E-03	3.50	0.90	[3.36]	77	10
76	Os	188	0.5	7.989	25	4.00E-03	6.00E-04	5.00	2.30	[3.36]	88	5
76	Os	189	0	5.922	20	4.70E-02	6.00E-03	3.60	1.20	[3.36]	100	10
76	Os	190	1.5	7.792	21	3.40E-03	4.00E-04	2.00	0.60	[3.20]	100	10
76	Os	191	0	5.758	23	7.00E-02	1.00E-02			[3.20]		
76	Os	193	0	5.584	19	1.15E-01	1.00E-02			[3.20]		
77	Ir	192	1.5	6.199	41	2.50E-03	5.00E-04	1.90	0.30	[3.32]	81	11
77	Ir	193	4	7.772	11	7.00E-04	2.00E-04	1.50	0.50	[3.32]	100	20
77	Ir	194	1.5	6.066	34	7.00E-03	2.00E-03	1.30	0.30	[3.32]	93	10
78	Pt	193	0	6.255	9	2.80E-02	1.00E-02	1.80	0.60	[3.32]	80	30

78	Pt	195	0	6.105	6	2.00E-01	8.00E-02	1.40	0.60	[3.32]	70	25
78	Pt	196	0.5	7.921	44	1.80E-02	3.00E-03	1.80	0.40	[3.32]	120	15
78	Pt	197	0	5.846	4	3.50E-01	1.00E-01			[3.32]		
78	Pt	199	0	5.571	4	3.40E-01	9.00E-02	1.40	0.60	[3.32]		
79	Au	198	1.5	6.512	151	1.65E-02	9.00E-04	1.90	0.12	[3.32]	128	6
80	Hg	199	0	6.664	5	1.05E-01	3.50E-02	1.30	0.50	[3.32]	150	20
80	Hg	200	0.5	8.028	9	8.00E-02	3.00E-02	2.10	0.60	[3.32]	295	20
80	Hg	201	0	6.230	4	2.00E+00	1.00E+00	1.70	0.80	[3.32]		
80	Hg	202	1.5	7.753	7	9.00E-02	3.00E-02	1.20	0.50	[3.32]		
81	Tl	204	0.5	6.656	48	2.80E-01	5.00E-02	1.30	0.30	[3.32]	690	70
81	Tl	206	0.5	6.503	10	5.50E+00	1.50E+00	1.50	0.30	[3.32]	1500	300
82	Pb	205	0	6.732	29	2.00E+00	5.00E-01	1.10	0.20	[3.32]	770	
82	Pb	207	0	6.738	22	3.20E+01	6.00E+00	1.20	0.20	[3.32]		
82	Pb	208	0.5	7.367	12	3.80E+01	8.00E+00	1.00	0.50	[3.32]		
82	Pb	209	0	3.937	2	1.00E+03				[3.32]		
83	Bi	210	4.5	4.604	42	4.00E+00	7.00E-01	0.80	0.15	[3.32]	70	20
88	Ra	227	0	4.561	33	2.60E-02	6.00E-03	1.08	0.12	[3.32]	26	3
90	Th	229	0	5.239	2	5.00E-03	3.00E-03			[3.32]		
90	Th	230	2.5	6.794	11	6.20E-04	1.20E-04	1.15	0.15	[3.32]	43	4
90	Th	231	0	5.117	20	9.60E-03	1.50E-03	1.28	0.15	[3.32]	26	2
90	Th	233	0	4.786	180	1.66E-02	6.00E-04	0.87	0.07	[3.32]	24	2
91	Pa	232	1.5	5.569	44	4.50E-04	5.00E-05	0.78	0.08	[3.32]	40	2
91	Pa	234	1.5	5.222	24	7.00E-04	1.00E-04	0.75	0.08	[3.32]	47	5
92	U	233	0	5.743	12	4.60E-03	7.00E-04	1.40	0.30	[3.32]		
92	U	234	2.5	6.845	160	5.50E-04	5.00E-05	1.04	0.07	[3.32]	40	5
92	U	235	0	5.297	115	1.20E-02	8.00E-04	0.85	0.10	[3.32]	26	4
92	U	236	3.5	6.545	200	4.30E-04	2.00E-05	0.88	0.08	[3.32]	35	3
92	U	237	0	5.125	161	1.50E-02	1.00E-03	1.08	0.10	[3.32]	23	2
92	U	238	0.5	6.153	27	3.50E-03	8.00E-04			[3.32]		
92	U	239	0	4.806	473	2.08E-02	3.00E-04	1.03	0.08	[3.32]	23.6	.8
93	Np	238	2.5	5.488	270	5.70E-04	3.00E-05	0.97	0.07	[3.32]	40.8	1.2
94	Pu	239	0	5.647	26	9.00E-03	1.00E-03	1.30	0.30	[3.32]	34.	3.0
94	Pu	240	0.5	6.533	258	2.20E-03	5.00E-05	1.25	0.10	[3.32]	43.3	4.5
94	Pu	241	0	5.241	173	1.24E-02	7.00E-04	1.05	0.10	[3.32]	30.7	2.5
94	Pu	242	0.5	6.310	123	7.30E-04	8.00E-05	1.23	0.13	[3.32]	40.8	4.6
94	Pu	243	0	5.033	77	1.35E-02	1.50E-03	0.98	0.08	[3.32]	25.4	3.7
94	Pu	245	0	4.698	14	1.70E-02	5.00E-03	0.90	0.20	[3.32]		
95	Am	242	2.5	5.539	190	5.80E-04	4.00E-05	0.88	0.06	[3.32]	46.0	2.0
95	Am	243	1	6.365	24	4.00E-04	8.00E-05	1.30	0.20	[3.32]		
95	Am	244	2.5	5.363	219	7.30E-04	6.00E-05	0.98	0.06	[3.32]	39.0	5.0
96	Cm	243	0	5.694	12	1.40E-02	3.00E-03	0.65	0.15	[3.32]	38.0	6.0
96	Cm	244	2.5	6.799	40	7.50E-04	1.50E-04	1.50	0.30	[3.32]	33.0	5.0
96	Cm	245	0	5.522	38	1.18E-02	1.20E-03	1.00	0.20	[3.32]	36.	8
96	Cm	246	0.5	6.455	38	1.30E-03	2.00E-04	1.05	0.15	[3.32]	60.	10
96	Cm	247	0	5.157	9	3.00E-02	5.00E-03	0.45	0.15	[3.32]	32.	6
96	Cm	248	4.5	6.211	34	1.80E-03	3.00E-04	0.55	0.16	[3.32]	85.	15
96	Cm	249	0	4.713	33	2.80E-02	5.00E-03	1.10	0.12	[3.32]	28.	3
97	Bk	250	3.5	4.962	33	1.10E-03	1.00E-04	1.20	0.20	[3.32]	36.	2
98	Cf	250	4.5	6.621	48	7.00E-04	1.00E-04	1.20	0.20	[3.32]		
98	Cf	253	0	4.805	30	2.70E-02	4.00E-03			[3.32]		

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