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Evaluation of Resonance Parameters in Resolved and Unresolved Resonance Region for ^{233}U

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ABSTRACT

The single level Breit Wigner resonance parameters are evaluated for ^{233}U in the resolved resonance region starting from the area analysis data reported by Nizamuddin and Blons.

The statistical mean resonance parameters for ^{233}U in the unresolved resonance region are evaluated by simultaneous and consistent adjustment of mean fission width and p and s wave strength functions. Our evaluated mean resonance parameters reproduce well the total and the partial neutron induced reaction cross sections given in ENDF/B-IV file in the unresolved resonance for ^{233}U.

EVALUATION OF RESONANCE PARAMETERS IN RESOLVED AND UNRESOLVED RESONANCE REGION FOR ^{233}U.

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1. INTRODUCTION

We recommend in this note a complete set of resolved and unresolved resonance parameters for use in fast reactor design calculations. No unresolved parameters are available in the ENDF/B-IV file (1). In the resolved resonance regions since the fast reactor cross section processing code RAMBHA (2) developed at RRC can process only the single level Breit Wigner (SLBW) data, we present in this note the SLBW parameters for ^{233}U in the resolved resonance region and the mean resonance parameters in the unresolved resonance region. These parameters are proposed to be placed in the appropriate format in the RRC data file (2) (RRCDF) which is compatible with the code RAMBHA (2).

2. EVALUATION OF SLBW PARAMETERS FOR ^{233}U.

At present, we are satisfied with single level Breit Wigner representation of cross sections in the resolved resonance region for the following reasons (3).

1) In fast power reactors, the neutron flux is relatively less in the lower energy region 0-100 eV which is the resolved resonance region for ^{233}U.

2) In a typical 500 MWe fast breeder reactor fuelled with this isotope, the resolved resonance region contributes less than about 5% to the Doppler effect contributed by ^{233}U isotope.

3) Doppler broadening formulations are relatively simpler with the use of this formalism.

Several resolved resonance data sets are available in SLBW formalism in the literature [4-14]. We effect considerable simplification in our evaluation by selecting only one recent set of data based on completeness for our purpose.

We have selected the recent work by Nizamuddin and Blons [4]. These authors have reported measurements of the fission cross section of ^{233}U at liquid nitrogen temperature between 6 and 124 eV and analysed the results by a single level formalism. They presented the values of E_0, Γ and $\sigma_0 \Gamma_f$ These parameters were shown to represent their measured cross section quite well provided that, in addition to the 136 well resolved resonances, 33 broad levels were added in the vicinity of some of the highly asymmetric resonances. For the well resolved resonances they derived the fission widths Γ_f using a constant value of radiation width

$$\Gamma_\gamma = \langle \Gamma_\gamma \rangle = 0.039 \text{ eV}$$

They also report [4] that a χ^2 distribution with $\nu = 3$ degrees-of-freedom matches well the observed fission width distribution.

Table 1 gives the values of k, E_0, Γ_k, $(\sigma_{0_k} \Gamma_{f_k})$ and Γ_{fk} as reported by Nizamuddin and Blons [4] in the first five columns.

From the values given in Table 1, our aim is to deduce the following parameters.

$$E_0, \quad \Gamma_n, \quad \Gamma_\gamma, \quad \Gamma_f \quad \text{and} \quad g$$

for all resonances. E_0 and Γ_f are already given for all the well resolved resonances in Table 1. Γ_γ is assumed to be the same for all resonances and taken to be 39 meV. The value of $(g\Gamma_n)$ is deduced from the equation:

$$g\Gamma_n = \frac{(\sigma_0 \Gamma_f)}{\Gamma_f} \cdot \frac{\Gamma}{(4\pi \lambda^2)}$$

The spin assignments are now to be made for the resonances. The spins for the resonances are not known from ref. 4 and can be found in principle by looking for the validity of the conservation relations such as

$$\Gamma = \frac{g\Gamma_n}{g_{assigned}} + \Gamma_\gamma + \Gamma_f$$

and

$$\Gamma_\gamma = \Gamma - \Gamma_f - \frac{(g\Gamma_n)}{g_{assigned}} > 0$$

It is found that both values of J, J=2 or 3 are acceptable in view of the large uncertainties in the individual partial widths and also because

$$\Gamma_n << \Gamma_f$$

The BNL document (5) gives J=2 for some resonances. In our evaluation, for all the resonances we assign J=2 and thus

$$g = \frac{2J+1}{2(2I+1)} = \frac{5}{12}$$

for ^{233}U. This completes the evaluation for the real resolved levels.

Now coming to the 33 "artifical resolved levels", we adopt the following procedure to evaluate the individual resonance parameters. For these "artificial levels" only Γ and $\sigma_0 \Gamma_f$ are given; We require to find Γ_γ, Γ_f and g. We assume $\langle \Gamma_\gamma \rangle$ to be 0.039 eV. The value of $\langle \Gamma_n \rangle$ from the Γ_n values of the well resolved 133 resonances is found to be:

$$\langle \Gamma_n \rangle = 0.1232E-02$$

An initial guess value of Γ_f is evaluated using the following conservations relation.

$$\Gamma_f \overset{guess}{=} \Gamma - \langle \Gamma_\gamma \rangle - \langle \Gamma_n \rangle$$

Using this guess value of Γ_f we obtain the value of Γ_f for the individual artifical resonances from the given values of Γ and $(\sigma_0 \Gamma_f)$ using the following relation :-

$$\Gamma_n = \frac{(\sigma_0 \Gamma_f)}{\Gamma_f^{\text{guess}}} \cdot \frac{\Gamma}{4\pi \lambda^2} \cdot \frac{12}{5}$$

Where g is taken to be 5/12. This Γ_n is used to re-evaluate Γ_f for the individual artificial resonance as follows :

$$\Gamma_f = \Gamma - \Gamma_n - 0.039$$

Thus we obtain through iteration using the basic conservation relations both Γ_f and Γ_n for the artificial resonances. The iteration is repeated until the Γ_n value converges to 95% certainty. The complete set Γ_n, Γ_γ, Γ_f, E_0 and g are tabulated in Table 1.

3. EVALUATION OF UNRESOLVED PARAMETERS FOR ^{233}U.

3.1 Review of the Earlier Publications : The unresolved resonance parameters as reported in the recent literature are complied with our comments below. The unresolved resonance region for our data set will cover the 0.101 to 40.93 KeV energy region for our purpose.

Average s-wave level spacing

Value (eV)	Year	Ref.	Comments
0.718 ± 0.35	1972	Guylassy (5)	Obtained from staircase plots. In all 53 resonances were considered. All data upto 39.37 eV was considered with fitting error of 7.2E-4 due to experimental uncertainties. This value is applicable to all J values. Data upto 62.27 eV containing 10 resonances for J=3 sping gave a value of $\langle D \rangle$ = 1.14 ± 0.5

0.71	1974	Nizamuddin & Blons [4]	Experimental value corresponding to the distribution of all the levels including the 33 somewhat broad (Γ > 500 meV) levels added in the vicinity of some of the highly asymmetric resonances for obtaining good representation of the measured cross sections. The distribution of well resolved (real) levels alone gives a somewhat higher value of 0.88 eV. The difference between these two values shows that certain closely spaced levels have been missed due to resolution effects. The energy range spanned was from 6 to 124 eV. Measurements were made at liquid nitrogen temperature to reduce Doppler broadening.
0.61 $\pm$ 0.07	1970	Kolar [6]	From the single level resonance parameters upto 30 eV comprising 45 spacings.
0.87	1967	Hennies [7]	Based on a value given by Michaudon.
$\langle D \rangle_{J=2} = 1.896$ $\langle D \rangle_{J=3} = 1.354$	1968	Boroughs et al [8]	Obtained by using as a guideline , the statistical average of the single level resonance parameters to fit the cross sections averaged over quarter lethargy energy groups. Energy range considered is from 61 eV to 100 keV.
0.56	1973	Reynolds and Steiglitz [9]	From analysis of the data for 76 resonances between 0.0 and 60.0 eV on the basis of Wigner distribution. The observed spacing is 0.79 eV which has been corrected for the missing levels.

0.62	1968	Bergen[10]	Sixty eight levels were considered from 20 eV through 63 eV. The spacing was derived from the least squares line drawn through the data. Actually the slight curvature of the level spacing plot suggests that levels may have been overlooked due to experimental resolution and Doppler broadening effects.

Average p wave level spacing

Value (eV)	Year	Ref.	Comments
3.16 ; for J=1 1.896; for J=2 1.354; for J=3 1.0053;for J=4	1968	Borough[8]	It is assumed that all levels are equally likely to be excited. Thus, the number of levels excited depends only on the statistical factor. The energy range considered is from 61 eV to 100 keV. Parameters were chosen to fit the quarter lethargy average cross sections.

Average radiation width $\langle \Gamma_\gamma \rangle$

Value (meV)	Year	Ref.	Comments
39.0	1974	Nizamuddin[4]	Computed from a formula given by Cameron by combining the data with that of Kolar et al (Ref. 6)
54.0	1967	Hennies[7]	The average value results from an unweighted average of the Γ_γ values for the 31 resolved levels upto an energy of 37 eV taken from BNL-325 report.
39.4	1968	Borough[8]	Evaluated
40.0	1973	Reynolds[9]	The observed capture width is 45 meV which has been corrected for the 30% levels missed.

48.44	1965	BNL-325[11]	Calculated from 31 resolved resonances using simple averaging.
45.0	1966	Bergen[10]	Evaluated.
47.0	1972	Guylassy[5]	Obtained from the analysis of 25 resonances. Uncertainty generated by finite sample size is 11 meV.
45.0	1970	Kikuchi[15]	From Channel Theory.

Average fission width $\langle \Gamma_f \rangle$

Value (eV)	Year	Ref.	Comments
0.372	1974	Nizamuddin[4]	Calculated from their values of total widths by assuming the radiation width computed with theoretical formulae. It was of course assumed that Γ_n is negligible. Distribution of these widths compares favourably with the χ^2 distribution with $\nu = 3$ degrees of freedom and this $\langle \Gamma_f \rangle$. Energy range from 6 eV to 124 eV is considered in the analysis.
0.314	1965	BNL-325[11]	Calculated from 31 resolved resonances using simple averaging.
0.3413	1968	Bergen[10]	Evaluated with single level analysis. The multilevel analysis gives a value of 379 meV.
0.389	1965	Nifenecker[12]	Evaluated.
0.382	1968	Boroughs[8]	The value is at 1 keV; Obtained by fitting the quarter lethargy energy group average cross sections in the energy range from 61 electron Volts.

			to 100 keV. $\langle \Gamma_f \rangle^{\ell=0}$ is the same for both J=2 and J=3. The values are given as a function of energy from 0.07 keV to 100 keV in a tabular form.
0.569	1973	Reynolds[9]	The distribution of fission widths agrees well with χ^2 distribution with 3 degrees of freedom. However, the statistics on the distribution of values are not good enough to allow it to be resolved into two different distributions for J=2 and J=3 sequences.
0.372	1972	Guylassy[5]	Obtained from the analysis of 85 resonances. Uncertainty generated by finite sample size is 23 meV.

Average fission width for p wave sequences

Value (eV)	Year	Ref.	Comments
$\langle \Gamma_f \rangle^{(J=1)} = 0.10058$	1968	Boroughs[8]	Fission widths for p waves were obtained from the formula $$\langle \Gamma_f \rangle^{(J)} = \frac{\langle D \rangle^{(J)}}{\pi}$$ The spacing for the p wave resonances was calculated from the above mentioned equation using the s wave values.
$\langle \Gamma_f \rangle^{(J=2)} = 0.6058$			
$\langle \Gamma_f \rangle^{(J=3)} = 0.431$			
$\langle \Gamma_f \rangle^{(J=4)} = 0.3352$			

The s wave strength function

Value (eV)	Year	Ref.	Comments
(10^{-4} units)			
2.25 ± 0.55	1970	Kolar[6]	46 levels up to 30 eV are considered and are taken to be all s wave levels.

0.8±0.2	1964	Nordheim[13]	Quoted from a survey by Garrison (1963).
0.306	1965	BNL 325[11]	Derived from the average observed level spacing and $2g\Gamma_n$ assuming g = 0.5.
2.14	1965	Nifenecker[12]	Evaluated.
1.1	1970	Kikuchi[15]	From Channel
0.95 to 1.15 (0.07<E <100 keV)	1968	Boroughs[8]	Unresolved resonance para meters were obtained by using the statistical average of the single level resonance para meters in the resolved resonance range with the requirement that the best fit to the experi mentally observed σ_f and σ_c values in the energy range 61 eV to 100 eV had to be obtained. It is however not expected that the recommended unresolved parameters will accurately predict the scattering cross sections.
$1.3^{+0.90}_{-0.39}$	1971	Ryabov[14]	Method of maximum likehood is used. The error is due mainly to the finite sample size.
0.89	1973	Reynolds[9]	Obtained from the slope of the plot of a sum of the reduced neturon widths as a function of energy. The assumption here is that the strength functions are equal for each of the spin states.
2.31	1968	Bergen[10]	Obtained by single level fit in in the resolved resonance energy region.
0.991	1972	Guylassy[5]	Number of resonance analysed is 30. Uncertainty due to finite sample size is of the order of 0.26.

The p wave strength function

Value	Year	Ref.	Comments
1.5	1968	Boroughs [8]	Same as for the s wave strength function.
1.42	1970	Kikuchi [15]	From Channel Theory.

Having complied the unresolved resonance parameters which were available with us, we note that there are wide discrepancies in the mean resonance data reported in the literature.

3.2 Present Evaluation of Unresolved Resonance Data

We present below our evaluation of a mean resonance data set that reproduces well the total and partial reaction cross sections given in ENDF/B-IV file.

Starting from the pointwise energy versus cross section data given in ENDF/B-IV file[1], we calculate the following average cross sections.

$$\langle \sigma_x \rangle = \frac{\int_{E_{g+1}}^{E_g} \sigma_x(E)\,dE}{\int_{E_{g+1}}^{E_g} dE} = \frac{\int_{E_{g+1}}^{E_g} \sigma_x(E)\,dE}{\Delta E_g}$$

where x stands for any one of the following processes: capture, fission, elastic, total. The subscript g denotes the energy group bounded by the energies E_g and E_{g+1} and ΔE_g is the width of of the energy group g. These calculations were done by invoking an option in the RAMBHA code[2]. The unresolved resonance data set

$$\left\{ S_{\ell,J},\ \langle \Gamma_x \rangle^{(\ell,J)},\ R,\ \langle D \rangle^{(\ell,J)} \right\}$$

must reproduce the above cross sections (total as well as partial) satisfactorily: Now,

$$\langle \sigma_x \rangle = \sum_{(\ell,J)} \frac{2\pi^2 \lambda\!\!\!^{-2} \left\langle \frac{\Gamma_n \Gamma_x}{\Gamma} \right\rangle_{(\ell,J)}}{\langle D \rangle^{(\ell,J)}}$$

and

$$\langle \sigma_t \rangle = \sigma_p + \sum_x \langle \sigma_x \rangle$$

where the symbols have their usual meanings (16,17,18).

To start the adjustment process, we input to ADDJA[16] the quantities

$\langle \sigma_x \rangle (\bar{E})$ and $\bar{E}$ where x refers to the partial and total cross sections.

For each value of $\bar{E}$ the following quantities are input

$$\nu_f^{(\ell,J)} = 3 \qquad \text{(Ref. 4)}$$

$$\nu_n^{(\ell,J)} = 2 \quad \text{for } \ell = 1,\ J=2,3$$

$$= 1 \quad \text{for all other } \ell \text{ and } J$$

$$\langle \Gamma_\gamma \rangle^{(\ell,J)} = 0.039 \text{ for all } \ell \text{ and } J. \text{ (Ref. 4)}$$

$$\langle D \rangle^{\ell=0,\ J=2} = 1.723 \text{ eV} = \langle D \rangle^{\ell=1,\ J=2}$$

$$\langle D \rangle^{\ell=0,\ J=3} = 1.231 \text{ eV} = \langle D \rangle^{\ell=1,\ J=3}$$

$$\langle D \rangle^{\ell=1,\ J=3} = 2.872 \text{ eV} \qquad \langle D \rangle^{\ell=1,\ J=4} = 0.9572 \text{ eV}$$

These values correspond to a $\bar{D}$ = 0.718 eV (J= all)

There are two s wave and 4 p wave sequences. These are characterised by

$$\ell = 0, \quad J = 2 \text{ and } 3$$

$$\ell = 1, \quad J = 1 \text{ to } 4$$

The ENDF/B-IV file gives for the nuclear radius a value of

$$(1.23\ (231.043)^{1/3} + 0.8\ ] . 10^{-1} = 0.834749 \text{ fm}.$$

It was found that this value of nuclear radius given in ENDF/B-IV file was too small so that the p and s wave strength functions were required to be adjusted much beyond their spread reported in the literature. Also, the scattering cross section could not be satisfactorily fitted. We found after some parametric studies using *ADDJA* code[16] that a value of R = 0.9 fm is acceptable to our evaluation.

With these values of R, $\langle \Gamma_\gamma \rangle^{(\ell,J)}$, $\langle D \rangle^{(\ell,J)}$, $\nu_f^{(\ell,J)}$ and $\nu_n^{(\ell,J)}$ we adjusted the following parameters:

$$\langle \Gamma_f \rangle^{(\ell,J)}, \quad S_1 \quad \text{and} \quad S_0$$

to obtain best fit to $\langle \sigma_f \rangle$, $\langle \sigma_t \rangle$ and $\langle \sigma_c \rangle$ The code ADDJA was used to do these adjustments. Obviously the adjusted quantities $\langle \Gamma_f \rangle^{(\ell,J)}$, and S_0 depend on $\overline{E}$. Care is taken to see that again these are not permitted to vary beyond the spread that exists in the literature. Thus S_1 was allowed to vary between 0.9 and 2.0 (in 10^{-4} units), S_0 between 0.9 and 1.3 (10^{-4} units). The $\langle \Gamma_f \rangle^{(\ell,J)}$ are assumed to have the following values as the initial guess

$$\langle \Gamma_f \rangle^{\ell=0, J=2} = 1.21 \text{ eV}$$

$$\langle \Gamma_f \rangle^{\ell=0, J=3} = 0.3813 \text{ eV}$$

$$\langle \Gamma_f \rangle^{\ell=1, J} = 0.6506 \text{ eV for } J = 1 \text{ to } 4$$

It is assumed that $\langle \Gamma_f \rangle^{\ell=1, J}$ is independent of J.

The $\langle \Gamma_f \rangle$ values are adjusted using the relation

$$\langle \Gamma_f \rangle^{i} = \epsilon \, . \, \langle \Gamma_f \rangle^{i-1} \, \frac{\langle \sigma_f \rangle^{c}}{\langle \sigma_f \rangle^{g}}$$

for each (ℓ, J).

Here ϵ is a constant parameter (which may be put to unity) meant to accelerate the convergence; i is the iteration index; $\langle \sigma_f \rangle^{c}$ is the calculated value and $\langle \sigma_f \rangle^{g}$ is the given value.

Once $\langle \Gamma_f \rangle^{(\ell,J)}$ values are obtained S_0 and S_1 are adjusted in a similar way to fit the total cross section within 1%. Wtih these, $\langle \sigma_f \rangle^{c}$ would have now changed. The values of $\langle \Gamma_f \rangle^{(\ell,J)}$ are again adjusted to fit $\langle \sigma_f \rangle$. This procedure is repeated till acceptable $\langle \sigma_f \rangle^{c}$, $\langle \sigma_c \rangle^{c}$ and $\langle \sigma_t \rangle^{c}$ values are calculated. In Table 3 we give both the $\langle \sigma_x \rangle^{g}$ values (those of ENDF/B-IV) and the values of $\langle \sigma_x \rangle^{c}$ obtained using the final unresolved resonance data set given in Table 2.

It is seen that the selected mean resonance data set given in Table 2 is able to satisfactorily fit $\langle \sigma_t \rangle$ to 1 % and other partial cross sections to about 3 to 5% on the average.

It must be stressed that the unresolved parameters are, to some extent, non unique, the non uniqueness arising from the choice among the mean resonance data sets, all such sets leading to the 'same' average cross sections within their quoted uncertainties[18].

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Table 1

Reported (Ref. 4) and Our Deduced Resonance Parameters

1	2	3	4	5	6	7	8 **
k	E_{ok} (eV)	Γ_k (meV)	$\sigma_{ok}\Gamma_{fk}$ (b. eV)	Γ_{fk} (meV)	LF *	Γ_{nk} (eV)	Γ_{fk} (meV)
1.	5.89	320	26	281	0	.159	---
2.	6.27	538	12	---	1	.074	499
3.	6.64	500	57	---	1	.375	461
4.	6.82	138	110	99	0	.954	---
5.	7.50	200	5	161	0	.043	---
6.	8.64	248	5	209	0	.047	---
7.	9.26	298	15	259	0	.146	---
8.	9.71	500	4	---	1	.038	461
9.	10.39	315	172	258	0	1.991	---
10.	10.86	1000	1	---	1	.010	961
11.	11.31	218	8	179	0	.101	---
12.	11.89	2000	129	---	1	1.428	1960
13.	12.79	309	122	254	0	1.732	---
14.	13.45	144	4	105	0	.067	---
15.	13.73	255	25	216	0	.370	---
16.	13.95	1000	15	---	1	.199	961
17.	14.22	490	2	---	1	.028	451
18.	15.33	122	30	92	0	.556	---
19.	15.47	255	34	---	1	.568	215
20.	15.82	200	6	---	1	.108	161
21.	16.20	426	66	387	0	1.074	---
22.	16.56	219	46	180	0	.846	---
23.	17.28	1500	22	---	1	.356	1461
24.	17.63	900	5	---	1	.084	861
25.	17.97	208	19	169	0	.383	---

Table 1 (Contd..)

1	2	3	4	5	6	7	8
26.	18.28	379	9	---	1	.167	340
27.	18.48	135	8	96	0	.190	---
28.	18.96	316	113	294	0	2.101	---
29.	19.63	2500	26	---	1	.473	2461
30.	20.59	364	44	325	0	.926	---
31.	21.58	2000	35	---	1	.703	1960
32.	21.86	254	54	215	0	1.272	---
33.	22.34	412	173	364	0	3.991	----
34.	22.90	692	30	653	0	.664	---
35.	23.75	453	28	414	0	.664	---
36.	24.30	1000	27	961	0	.623	---
37.	25.25	274	33	235	0	.886	---
38.	25.78	660	25	621	0	.625	---
39.	26.25	495	11	456	0	.286	---
40.	26.62	260	15	221	0	.429	---
41.	26.98	592	7	553	0	.184	---
42.	27.76	900	23	861	0	.609	---
43.	28.07	168	1	129	0	.033	---
44.	28.28	230	9	191	0	.280	---
45.	29.04	540	74	501	0	2.113	---
46.	29.58	112	4	73	0	.166	---
47.	30.35	396	6	357	0	.184	---
48.	30.72	261	23	224	0	.751	---
49.	31.33	325	11	286	0	.357	---
50.	31.69	600	18	---	1	.557	560
51.	32.01	217	32	178	0	1.139	---
52.	33.14	740	27	701	0	.862	---
53.	33.95	1300	67	1261	0	2.140	---
54.	34.51	647	42	599	0	1.428	---
55.	35.25	395	8	356	0	.285	---
56.	35.75	900	24	861	0	.818	---

Table 1 (Contd..)

1	2	3	4	5	6	7	8
57.	36.53	197	23	158	0	.956	---
58.	37.20	420	3	---	1	.112	381
59.	37.48	395	22	356	0	.835	---
60.	39.33	686	25	647	0	.951	---
61.	39.83	445	8	406	0	.319	---
62.	40.41	900	33	861	0	1.272	---
63.	41.03	175	9	136	0	.434	---
64.	41.79	392	1	353	0	.042	---
65.	42.09	592	4	553	0	.164	---
66.	42.62	209	20	152	0	1.069	---
67.	43.50	341	13	321	0	.548	---
68.	44.10	300	2	---	1	.093	261
69.	44.52	1060	28	1041	0	1.158	---
70.	45.25	138	1	---	1	.058	99
71.	45.45	150	1	111	0	.056	---
72.	46.10	192	11	153	0	.581	---
73.	46.53	245	2	206	0	.101	---
74.	47.22	507	27	468	0	1.260	---
75.	48.68	171	40	131	0	2.319	---
76.	49.10	516	14	477	0	.678	
77.	50.40	1100	25	1061	0	1.192	---
78.	51.00	500	3	461	0	.151	---
79.	51.85	150	1	111	0	.032	---
80.	52.10	280	2	241	0	.083	---
81.	53.03	240	12	201	0	.693	---
82.	53.32	360	12	321	0	.655	---
83.	53.94	230	4	---	1	.237	191
84.	54.05	500	36	461	0	1.926	---
85.	54.41	295	2	---	1	.114	256
86.	54.78	263	26	224	0	1.555	---
87.	55.20	490	3	---	1	.164	451

Table 1 (Contd..)

1	2	3	4	5	6	7	8
88.	55.95	860	60	821	0	3.208	---
89.	56.44	373	24	331	0	1.393	---
90.	56.88	1500	28	---	1	1.493	1460
91.	57.48	780	53	731	0	2.966	----
92.	58.18	1300	33	---	1	1.808	1259
93.	58.52	225	13	186	0	.840	---
94.	59.10	295	1	256	0	.062	---
95.	60.01	220	1	181	0	.040	---
96.	60.42	1700	4	---	1	.226	1661
97.	60.95	940	18	901	0	1.044	---
98.	61.38	400	31	361	0	1.924	---
99.	62.59	135	22	83	0	2.043	---
100.	63.49	1000	9	---	1	.543	960
101.	64.03	370	14	331	0	.914	---
102.	64.44	239	25	200	0	1.756	---
103.	65.09	238	10	199	0	.710	---
104.	65.49	630	9	591	0	.573	---
105.	66.56	770	12	731	0	.768	---
106.	67.30	940	7	901	0	.474	---
107.	67.98	333	8	294	0	.562	---
108.	69.23	1000	42	961	0	2.761	---
109.	70.19	533	34	487	0	2.383	---
110.	71.75	349	4	310	0	.295	---
111.	72.22	800	9	761	0	.623	---
112.	73.43	125	21	86	0	2.045	---
113.	74.03	510	78	471	0	5.705	---
114.	75.00	258	10	219	0	.806	---
115.	75.49	290	49	251	0	3.899	---
116.	76.77	872	9	833	0	.660	---
117.	78.18	570	31	531	0	2.374	---
118.	78.46	900	6	---	1	.449	861

Table 1 (Contd.)

1	2	3	4	5	6	7	8
119.	79.00	1200	11	---	1	.820	1160
120.	79.78	596	39	557	0	3.038	---
121.	81.47	1300	25	1261	0	1.916	---
122.	82.35	740	26	701	0	2.062	---
123.	82.78	135	24	96	0	2.549	---
124.	84.75	815	7	776	0	.568	---
125.	85.22	400	11	361	0	.948	---
126.	85.73	590	5	551	0	.419	---
127.	86.78	295	1	---	1	.091	256
128.	87.13	150	4	111	0	.430	---
129.	87.70	88		49	0	.014	---
130.	88.89	342	28	303	0	2.563	---
131.	89.76	558	8	519	0	.704	---
132.	90.55	253	89	214	0	8.693	---
133.	91.72	740	8	701	0	.707	---
134.	92.67	517	17	478	0	1.555	---
135.	93.25	590	5	---	1	.456	551
136.	93.77	104	14	65	0	1.916	---
137.	95.22	101	14	62	0	1.981	---
138.	96.42	1600	44	1561	0	3.968	---
139.	97.81	229	53	190	0	5.701	---
140.	98.58	315	23	276	0	2.361	---
141.	99.30	540	17	501	0	1.660	---
142.	99.95	540	32	501	0	3.145	---

* LF is a flag denoting whether the resonance is real (LF = 0) or artificial (LF = 1).

** For artificial resonances.

Table 2

Selected set of Unresolved Resonance Parameters

$\nu_f^{(\ell,J)}$ = 3 for all ℓ and J

$\nu_n^{(\ell,J)}$ = 2 for ℓ = 1; J = 2 and 3

$\nu_n^{(\ell,J)}$ = 1 for ℓ = o, J = 2 and 3 and for ℓ =1, J = 1 to 4

R = 0.9 fm

$\langle \Gamma_\gamma \rangle^{(\ell,J)}$ = 0.039 eV for all ℓ, J and E

$\langle D \rangle^{(\ell,J)}$ = 1.723 eV for (ℓ = 0 ; J = 2) and (ℓ = 1; J = 2)

= 1.231 eV for (ℓ = 0 ; J = 3) and (ℓ = 1; J = 3)

= 2.872 eV for (ℓ = 1; J = 1)

and g_J = (2J + 1) /12

$\overline{E}$	$S_0 \times 10^4$	$S_1 \times 10^4$	$\langle \Gamma_f \rangle^{(\ell,J)}$ (eV)		
			(ℓ = 0; J = 2)	(ℓ = 0; J = 3)	(ℓ = 1; J = 1 to 4)
188.63	0.94400	0.91700	1.0890	0.34300	0.58600
365.25	0.91579	0.90708	1.2100	0.38100	0.65060
602.195	0.91124	0.95442	1.4247	0.44884	0.76991
995.0	0.90744	0.97746	1.4997	0.472000	0.80622
1640.0	0.92848	0.91944	1.4997	0.47200	0.80622
2700.0	1.03580	0.95958	1.2858	0.40508	0.69123
4450.0	1.16390	0.98673	1.4247	0.44884	0.76591
7335.0	1.24010	0.99302	1.4247	0.44884	0.76591
12095.0	1.28430	0.97730	1.4240	0.44884	0.76591
19945.0	1.26520	0.94848	1.2215	0.38482	0.65667
32880.0	1.20000	1.03350	1.2100	0.38130	0.65060

Table 3

Calculated Cross Sections from the ENDF/B-IV File

Sl. No. **	Lower Limit (eV)	Upper Limit (eV)	Average $\bar{E}$ (eV)	$\langle\sigma_t\rangle$ (barns)	$\langle\sigma_{el}\rangle$ (barns)	$\langle\sigma_f\rangle$ (barns)	$\langle\sigma_c\rangle$ (barns)
11	24.83 + 3 [a]	40.930 + 3	32.88 +3	13.51 (13.71)	10.24 (10.64)	2.948 (2.754)	0.329 (0.320)
12	15.06 + 3	24.83 + 3	19.945+3	14.57 (14.48)	10.76 (10.70)	3.422 (3.381)	0.392 (0.397)
13	9.13 + 3	15.6 + 3	12.095+3	15.75 (15.49)	11.27 (10.68)	4.012 (4.35)	0.469 (0.457)
14	5.54 + 3	9.13 + 3	7.335+3	16.61 (16.55)	11.26 (10.67)	4.789 (5.31)	0.567 (0.568)
15	3.36 + 3	5.54 + 3	4.45 +3	17.63 (17.69)	11.20 (10.64)	5.752 (6.361)	0.686 (0.693)
16	2.04 + 3	3.36 + 3	2.7 + 3	18.58 (18.64)	10.76 (10.58)	6.982 (7.185)	0.837 (0.870)
17	1.24 + 3	2.04 + 3	1.64 + 3	19.71 (19.82)	9.73 (10.48)	9.070 (8.43)	0.897 (0.906)
18	749.68	1.24 + 3	0.995+3	22.12 (22.20)	10.10 (10.47)	10.94 (10.47)	1.080 (1.144)
19	454.71	749.68	602.195	25.51 (25.61)	10.55 (10.59)	13.40 (13.56)	1.559 (1.545)
20	275.79	454.71	365.25	29.96 (30.03)	11.02 (10.54)	16.70 (17.22)	2.241 (2.271)
21	101.46	275.79	188.63	38.4 (38.58)	11.75 (10.60)	23.19 (24.44)	3.526 (3.547)

The values of cross sections given in the brackets are those obtained using our selected mean resonance data set given in Table 2

** The Sl No. here corresponds to the energy group number as used in the 25 group calculations at RRC.

a Read 24.83 + 3 as 24.83 x 10^3