*PHYSOR 2002, Seoul, Korea, October 7-10, 2002*

# RE-EVALUATION OF THE $^{240}$PU CROSS SECTIONS IN THE UNRESOLVED RESONANCE ENERGY RANGE; SPECIAL CARE ON THE SUB-THRESHOLD FISSION CROSS SECTION.

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## ABSTRACT

This paper reviews the current status of the re-evaluation work performed at Cadarache on the $^{240}$Pu neutron cross sections in the so-called 'unresolved resonance energy range'. This study was the consequence of both the conclusions of the recent re-evaluation of the neutron cross sections in the resolved range and the trends given by the JEF-2.2 general purpose file validation. The work involves the calculation of average neutron cross sections by using Hauser-Feshbach theory and Moldauer prescription for overlapping resonances and a specific treatment for sub-threshold fission, respectively achieved by using the FITACS code coupled with an updated version of the AVXSF program. Posterior to this stage, the determination of a priori average parameter values was made by employing the ESTIMA code which fits the theoretical integral Porter-Thomas distribution on the cumulated number of experimental resonances after selection of the most confident s-wave resonances. These a priori average values: resonance spacing, $D_0 = (13.43 \pm 0.25)eV$; strength function, $S_0 = (1.064 \pm 0.125).10^{-4}$ must be compared to the corresponding values before purification of the resonance sample for p-waves contamination and missed small s-waves, being respectively: $D_0 = (12.06 \pm 0.60)eV, S_0 = (1.032 \pm 0.71).10^{-4}$, and to the posterior values resulting from a FITACS/AVXSF fit on the measured average cross sections in the unresolved range. The final values are $D_0 = (13.43 \pm 0.25)eV, S_0 = (1.102 \pm 0.052).10^{-4}$ and $S_1 = (1.842 \pm 0.083).10^{-4}$. This work leads to a much better agreement between the microscopic cross section measurements and the integral experiments in the so-called unresolved resonance energy range (5.7-40 keV). The upper boundary is currently chosen so as to do not take care to much about the inelastic cross section since the first inelastic threshold is at 43 keV. The average capture cross section has been decreased significantly (of about -12%) in this (5.7-40 keV) energy range consistently with the resolved resonance energy range and this is mainly achieved by reducing the value of the average capture widths such as $g\bar{\Gamma}_\gamma^0 = (30.7 \pm 2.5)$ meV and $g\bar{\Gamma}_\gamma^1 = (22.53 \pm 5)$ meV. Concerning the calculation of the average fission cross section performed in this work, this latter leads to an accurate physical calculation of the sub-threshold fission cross section which is adequate for the calculation of the other partial cross sections but is not well-suited for reproducing the none statistical fluctuations observed in the fission cross section of the $^{241}Pu$ fissioning nucleus. That explains why this work is still under progress for a finer description of the fission cross section.

## 1. INTRODUCTION

In 1995, following the conclusion of the JEF-2.2 validation studies[1], a re-evaluation work[2] on the $^{240}$Pu neutron cross sections up to 5.7 keV was performed. The experimental data base, used for the re-evaluation, differed from the JEF2.2 selected measurements mainly by the addition of two more recent transmission and fission measurements respectively by Harvey et al.[3], and Weston and Todd[4]. Moreover a careful re-examination of the old transmission measurement of Kolar and Böckhoff[5], after renormalisation and background subtraction, led to the determination of a set of resolved resonance parameters up to a higher energy (5.7 keV compared to 4 keV for JEF2.2). This 1995 study[2] concluded that the average capture cross section of JEF2.2 is 20 % too high in the energy range 200-5000 eV because the JEF2.2 (and also JENDL3.2) file is based on the average experimental capture data of Weston and Todd[6] which have to be renormalised. Moreover, these average capture data were disregarded by Weston himself for the evaluation of ENDF/B-VI[7] but surprisingly only in the lowest resonant range ($E < 5.7$ keV). As far as the average fission cross section is concerned, the JEF2.2 value had to be decreased by 30 % in the energy range 1.5 to 5700 eV and the 1995 analysis is in agreement with the ENDF/B-VI.5 and JENDL3.2 files. Assuring the consistency between the new resolved region and the old unresolved range was the motivation for re-evaluating also the JEF2.2 cross sections in the energy range above 5700 eV. Unfortunately none of the existing evaluated average cross sections, from the two other main files (ENDF/B-VI.5 or JENDL3.2), could be used to supersede the unresolved JEF2.2 values for inclusion in the JEFF3 file mainly because they were based on a too large value of the average capture cross section.

## 2. PRIOR AVERAGE PARAMETER VALUES FOR REVISING THE CROSS SECTIONS

Although a very comprehensive task was performed in 1995[2] on this newly resolved resonance energy range (0-5.7 keV), an even more accurate calculation of the average parameters has been performed using an updated version of the ESTIMA code[8] in order to take account of the experimentally missed small resonances and of the contamination by p- wave resonances. The 1995 study has shown that a large number of small resonances were missed beyond 2750 eV because of the instrumental energy resolution (see figure 1). In this context, two parallel studies of the statistical properties of the widths from the results obtained in the resolved resonance energy range have been carried out. The first one has covered the overall energy range (0-5.7keV) whereas the second one was restricted to energies below 2750 eV.

## 2.1 PURIFIED S- WAVE RESONANCES SAMPLE

The distribution of the experimental reduced neutron widths for both a given orbital momentum (l) and a given resonance spin (j) follows a one degree of freedom $\chi^2$ distribution, also called Porter-Thomas distribution. According to the latter distribution, the probability for a p-wave resonance to have a $g\Gamma_n^1$ greater than $10 \times g\bar{\Gamma}_n^1$ is less than 0.16%. This criterion combined with the Bayesian estimation of the l and j quantum numbers from a known $g\Gamma_n$ value has made possible the selection in the evaluated resonance sample[2] of the most probable s-wave resonances. Figure 2 shows in the energy range (0-2.75 keV) the application of this latter approach for assigning confidently the s- wave resonances.

## 2.2 MISSING LEVELS

Table I: s- wave average resonance parameters corrected (this work) and uncorrected[2] for missing levels and p- waves contamination.

| S-waves | resonance sample (number of resonances) | $g\bar{\Gamma}_n^0(meV)$ | $D_0^{J=1/2}(eV)$ | $S_0(10^{-4})$ |
|---|---|---|---|---|
| Uncorrected (0-5.7 keV) | 425 | | | |
| Corrected (0-5.7 keV) | 282 | $1.42 \pm 0.14$ | $14.00 \pm 0.25$ | $1.014 \pm 0.099$ |
| Uncorrected (0-2.75 keV) | 231 | $1.245 \pm 0.15$ | $12.06 \pm 0.60$ | $1.032 \pm 0.071$ |
| Corrected (0-2.75 keV) | 159 | $1.429 \pm 0.17$ | $13.43 \pm 0.25$ | $1.064 \pm 0.125$ |

Since the weakest levels (in terms of $g\Gamma_n^0$) tend to get lost in the experimental background and according to the distribution of Porter-Thomas which shows that they are the most frequent ones, a missing level correction must be applied to the widths distribution. Due to the fact that the resonance spacing distribution, which should follow a Wigner law, is distorted everywhere by missing levels whereas the Porter-Thomas distribution is only modified for small neutron width values, a study of the integral Porter-Thomas distribution was carried out from the confident s- wave resonances sample in the two energy ranges (0-5.7 keV) and (0-2.75 keV). For each threshold value applied to the reduced neutron width, the code ESTIMA estimates, by using the maximum likelihood method, the average reduced neutron width and the number of resonances which should be really observed in the energy range investigated. Finally the best estimate of the average reduced neutron width is found when the result of the fit becomes independent of the threshold. The s- wave average parameters corrected and uncorrected for missing resonances are given in the Table I. The resonance sample reported in study[2] which was including 425 resonances is significantly reduced by the confident spin assignment procedure and the p-waves purification to 282 resonances (see column 'resonance sample' in Table I). Standard deviations mentioned include both the fitting and sampling errors. Even if the results in the entire and restricted resolved regions are compatible, it seems more reliable to choose the average values obtained in the restricted energy range (0-2.75 keV) since the number of remaining resonances is still statistically representative. Figure 3 shows in the restricted energy range (0-2.75 keV) the theoretical Porter-Thomas integral distribution fitted on the cumulated number of resonances observed versus energy.

## 3. AVERAGE CROSS SECTIONS ADJUSTMENT

### 3.1 TOTAL CROSS SECTION ADJUSTMENT

From the experimental data collected in the unresolved range and the prior (new) estimate of the average parameters, the calculated average total cross section was fitted with the Bayesian code FITACS[9] which employs Hauser-Feshbach theory and Moldauer prescription for overlapping resonances. In the lowest part of the unresolved range (5.7-100 keV), the two sets of experimental data of Gwin[10] and Käppeler et al.[11] disagree strongly in shape and magnitude. The fit of the average total cross section has made possible the selection of the best set of experimental data (see figure 4). No conclusive reasons were found to explain the reason of the bad quality of the data of Käppeler et al. (13 percent departure from the expected total cross section value at 27.7 keV) since the major uncertainty contribution during their experiment was the background subtraction estimated at 3 percent. Although no indication is mentioned about the application of a shelf-shielding correction on the Käppeler et al. data, this possible missing smooth correction on the effective average total cross section will still increase the value of the cross section (+1.26 percent for a neutron energy of 27.7 keV).

Clearly the two disagreeing sets of experimental data were responsible for the differences between on the one hand JEF2.2 and JENDL3.2 (in agreement with each other) and on the other hand ENDF/B-VI.5; this latter evaluated file giving finally the closest curve with regard to the final solution as far as the total cross section is concerned. Table II shows the average resonance parameters set extracted from the fit on the experimental average total cross sections. The uncertainties given reflect only the statistical uncertainties on the experimental data and the quality of this adjustment.

Table II: posterior average resonance parameters

| Orbital Angular Momentum ($\hbar$ ) | Strength function (1/10000) | Distant-level parameter ($R_c^\infty$) | Mean level spacing (eV) | Effective Radius (fm) |
|---|---|---|---|---|
| 0 | 1.102±0.052 | 0.034±0.011 | 13.43 | 9.10 |
| 1 | 1.842±0.083 | 0.284±0.028 | | |
| 2 | 1.030±0.121 | 0.046±0.027 | | |
| 3 | 2.022±0.135 | 0.126±0.092 | | |

## 3.2 PARTIAL CROSS SECTIONS ADJUSTMENT

Unfortunately the shape of the $^{240}$Pu fission cross section is incompatible with the single-humped fission barrier model available in the FITACS code and since the partial cross sections are inter-connected through the total transmission coefficient, the quest of a specific program for treating the sub-threshold fission was required.

The calculation of the fission cross section was finally achieved with the AVXSF program of LYNN[14] including a double-humped fission barrier with moderately weak coupling between the class-II states and the normal compound nuclear (class-I) resonances. Due to the large number of parameters involved in the calculation of the sub-threshold fission cross section, no fitting method was actually possible and thus a trial-error procedure was adopted. The program AVXSF, written at the end of the seventies, was designed for the old-fashioned computers and thus had to be largely updated during this work.

Since the program AVXSF uses some approximations in the calculation of both neutron and photon channel transmission coefficients, an iterative procedure which involves the two codes FITACS and AVXSF, was set up.

### 3.2.1 CAPTURE CROSS SECTION ADJUSTMENT

By reference to the very large amount of work on the validation of the JEF2.2 general purpose file[15], it appears that among the set of experimental capture data available (Weston and Todd[6], Wisshak and Käppeler[16] and Hockenbury et al.[17]) none of them were acceptable in magnitude; even the most satisfactory one (Weston and Todd) being too high of about (7±8) percent on average in the energy range (5.7-1000 keV). Since the conclusion of the recent 1995 re-evaluation of the resolved range was also to decrease the average capture cross section (20 % too high in the energy range 200-5000 eV), a significant decrease of the average capture cross section in the present work was unavoidable. Keeping the most adequate capture data set (Weston and Todd) but renormalised, a fit of the capture width of the s-, p- and d- waves was performed starting from the previously fitted neutron channel average parameters and from the fission channel parameters determined in parallel (see next section). In order to keep reasonable the fitted value of the s-wave radiative capture width, a renormalisation factor of only $-12\%$ was applied to the Weston and Todd capture measurement. Table III presents the chosen prior and the fitted posterior values for the various average capture widths involved in this work. Figure 5 plots the calculated average capture cross section after adjustment on the renormalised Weston and Todd measurement; fit performed in the energy range 1250- 95000 eV. This figure exhibits the strangeness of the ENDF/B-VI.5 calculation which does not trust in the Weston and Todd capture measurement as far as the resolved range is concerned but believes in this same experiment whenever the energy is larger than 4 keV.

Table III: Prior and posterior values for the average capture widths

| | $g\bar{\Gamma}^0_\gamma(meV)$ | $g\bar{\Gamma}^1_\gamma(meV)$ | $g\bar{\Gamma}^2_\gamma(meV)$ |
|---|---|---|---|
| Prior | $31.92 \pm 1.6$ | $31.92 \pm 10.$ | $31.92 \pm 10.$ |
| Posterior | $30.7 \pm 2.5$ | $22.53 \pm 5.$ | $30.7^*$ |

* Due to the conception of the FITACS code, the average capture width of the d- wave resonances is not a fitting parameter and is driven by the s- waves average capture width.

### 3.2.2 FISSION CROSS SECTION ADJUSTMENT

**SUB-THRESHOLD FISSION TREATMENT** For a typical actinide, the calculation of the deformation energy from the Strutinsky procedure[18] ends up in a double-humped fission barrier. The existence of both a second minimum in the deformation energy and some excited states in this second well (so-called class-II states) is responsible for some marked structure in the fission cross section. The nature of these states is crucial for the understanding and for the reproduction of the fission cross section. In the case of an even (proton number) - even (neutron number) fissioning nucleus, the prediction of the excited states in the second well is easier relatively to even-odd, odd-even or odd-odd fissioning nuclei since only collective states are involved at low energy. In the case of the fissioning $^{241}$Pu, in addition of collective states one lists many excitations of single particle character as well. Usually one distinguishes between the vibrational resonances (in the elongation axis) and the other types of collectives levels or single particle excitations. And thus shows up the two parts of the problem: the coupling in the second well of the vibrational levels to these intrinsic excitations and finally the coupling of the resulting class-II states with the normal compound nuclear (class-I) states in the primary well. The fissioning $^{241}$Pu is one of the remarkable isotope which exhibits a sub-threshold fission cross section modulated by a marked structure. Identified as the manifestation of the class-II resonances, these structures have been observed by several authors. In particular the high quality fission cross section measurement carried out by Auchamphaugh and Weston[19] has revealed about 22 clusters of class I resonances below 10 keV; which led to a mean class II level spacing of (450± 50)eV. Between these clusters, the fission cross section exhibits hardly any fission. Several options are available in the AVXSF code for calculating the fission cross section. A particularly useful one was used for calculating the average fission cross section at sub-barrier excitation energies assuming a moderately weak coupling between the class-II and the class-I states, and assuming a strong damping of the vibrational levels of the secondary well into the intrinsic class-II states. Under these hypotheses, the value of the average fission cross section for a fixed compound nuclear state $J^\pi$ at a given energy is obtained from the product of the compound nucleus formation cross section $\sigma^{J^\pi}_{n,(CN)}$ by the probability $P_f$ for the compound nucleus to fission as shown in formula (1) hereafter:

$$\sigma_{nf}^{J\pi} = \sigma_{n,(CN)}^{J\pi} P_f = \pi \lambda\!\!\!^{-2} g_J T_{I(n)} \{1 + \{\frac{T_I}{T_{(f)}}\}^2 + \frac{2T_I}{T_{(f)}} coth\{\frac{T_A + T_B}{2}\}\}^{-1/2} \quad (1)$$

with

$T_{I(n)}$ being the entrance neutron transmission coefficient for the class-I states extracted from the FITACS code[9],

$T_I$ being the total transmission channel over all radiation, elastic and inelastic channels; all of them extracted from the FITACS program,

$T_{(f)}$ being the statistical fission transmission coefficient which assumes a neutron energy much higher than the two barriers,

$T_A$ and $T_B$ being the sum of Hill-Wheeler transmission coefficients over each transition states respectively for the inner (A) and outer (B) barriers.

At this point, the statistical distribution of the class-II and the class-I compound states must be taken into account with a class-II and a class-I fluctuation factor respectively $\mathcal{S}_{\rm II}$ and Int$\mathcal{S}_{nf}$ such as

$$\mathcal{S}_{II} \simeq \frac{2}{\pi} \quad (2)$$

$$\mathrm{Int}\mathcal{S}_{nf} = \sqrt{\frac{W^2 + U}{\pi^2}} \int_{-\infty}^{\infty} \frac{d\epsilon}{\epsilon^2 + W^2 + 2\sqrt{U(\epsilon^2 + W^2)} + U} \quad (3)$$

where W and U are defined as: $W = \frac{T_A + T_B}{2}$ and $U = \frac{T_A T_B}{T_I}$

Although the class-I fluctuation factor had been calculated exactly in the past[20], this quantity was recalculated by a monte carlo technique (hit or miss) and tabulated versus $W/\sqrt{U}$ for this work since the code AVXSF was applying a simple step-like function which was chosen to be equal to the asymptotic value (0.6) or equal to 1 when the statistical fluctuations in the fission cross section vanish. The exact calculation is shown on figure 6. The use of a step-like function was generating some artificial discontinuities on the full average fission cross section which were visible on the fine energy mesh employed during this work.

At the fission transmission coefficient across the outer barrier B, the contribution $T_{II(\gamma f)}$ of the delayed fission must be added. The delayed fission comes from the fraction $b_f$ of gamma decay into the second well which leads to fission:

$$T_{II(\gamma f)} = T_{II(\gamma)} b_f = \frac{2\pi \bar{\Gamma}_{II(\gamma)}}{D_{II}} b_f \quad (4)$$

The full fission cross section observed is finally the sum over all the contributing excited states.

$$\sigma_{nf} = \sum_{J^\pi} \sum_{s=|I-\frac{1}{2}|}^{s=I+\frac{1}{2}} \sum_{l=|J-s|}^{l=J+s} \mathrm{Int}\mathcal{S}_{nf}\sigma_{nf}^{J^\pi}\mathcal{S}_{II} \tag{5}$$

**MAIN FISSION PARAMETERS USED IN THIS WORK** The aim of this paragraph is to give only an overview of the parameters used in this work for calculating the average fission cross section since the number of parameters involved is large.

Many sets of fission parameters are available in the literature which are reported for instance in the Bjornholm and Lynn's review[20], in the Wagemans'book [21] or in some libraries such as the Reference Input Parameter Library[22]. Finally the parameters of Vladuca et al.[23] were the basis of this work since they set up an exhaustive set of 54 transition states at the two barriers and since their parameters are in agreement with those of Bjornholm and Lynn as shown in Table IV.

Table IV: Main fission parameters given by Bjornholm and Lynn, and Vladuca et al.

| | $V_A(MeV)$ | $\hbar\omega_A(MeV)$ | $V_B(MeV)$ | $\hbar\omega_B(MeV)$ |
|---|---|---|---|---|
| Bjornholm and Lynn [20] | $6.1 \pm 0.2$ | 0.80 | $5.4 \pm 0.2$ | 0.52 |
| Vladuca et al.[23] | 6.065 | 0.81 | 5.21 | 0.52 |

The branching ratio ($b_f$) of the shape isomer is calculated from the experimental values reported in reference[24] available for the fission and radiative half-lives of the shape isomer such as:
$b_f = \frac{T^{\gamma}_{1/2}}{T^{f}_{1/2}+T^{\gamma}_{1/2}}$ which gives $b_f \simeq 0.91$;

The calculation of the contribution of the delayed fission $T_{II(\gamma f)}$ requires an estimate of $\bar{\Gamma}_{II(\gamma)}$. Following reference [20], a value of the order of 19 meV is expected for a typical odd-A fissioning nucleus.

Many sets of experimental average fission cross section data are available in the literature. For presenting the calculation performed in this work from the equations above, the calculated average fission cross section in the energy range [5.7 keV - 200 keV] is compared to some experimental fission data (which have been renormalised to the $^{235}U$ standard fission cross section value) as can be seen on figure 7. Although the AVXSF calculation includes a double-humped fission barrier and a representative coupling between the class-II and class-I states, this current modelisation of the class-II states gives only an average effect on the calculated fission cross section. From figure 7, one can see that these experimental data, even with a poor resolution, show a gross structure which can not be reproduced by such a formalism. Then another approach is under progress, which will be likely available at the time of the Physor 2002 conference, in order to take account of this gross structure and of the finer structure as well. Indeed in some other fission cross section measurements in the so-called 'unresolved energy range' above 5.7 keV such as in the Weston and Todd data[4], a very fine structure due to partially resolved class-I states appear in the envelope of the intrinsic class-II states. At higher energy the class-I states are no more resolved and the class-II states become badly resolved and thus only a gross structure show up in the fission cross section.

## CONCLUSIONS

A new $^{240}$Pu evaluation has been produced which yields a much better agreement between the microscopic cross section measurements and the integral experiments in the so-called unresolved resonance energy range (5.7-40 keV). In particular the average capture cross section has been decreased significantly in this energy range consistently with the resolved resonance energy range. Although the average fission cross section calculated in this work leads to an accurate physical calculation of the sub-threshold fission cross section which is adequate for the calculation of the other partial cross sections, it is not well-suited for reproducing the fluctuating fission cross section as observed in the $^{241}$Pu fissioning nucleus. Therefore the on-going work focuses on a finer description of the fission cross section. As far as the partial cross sections are concerned, their calculation is valid at a higher energy than 40 keV but nevertheless restricted by the appearance of both non-diagonal direct reaction terms and (n,$\gamma$ n') reactions not treated in FITACS. On the contrary the current fit of the average total cross section is correct over a wider energy range (5.7-1000 keV) since it is only limited by the long-range secular variation of the neutron strength functions which is neglected in FITACS.

## ACKNOWLEDGMENTS

Support of this work by Electricité de France is gratefully acknowledged. The author is deeply indebted to J.E. Lynn for making his code AVXSF available to him and for his help about its handling. Enlightening discussions with H. Derrien, F. Fröhner, E. Fort, O. Serot and A. Courcelle are appreciated.

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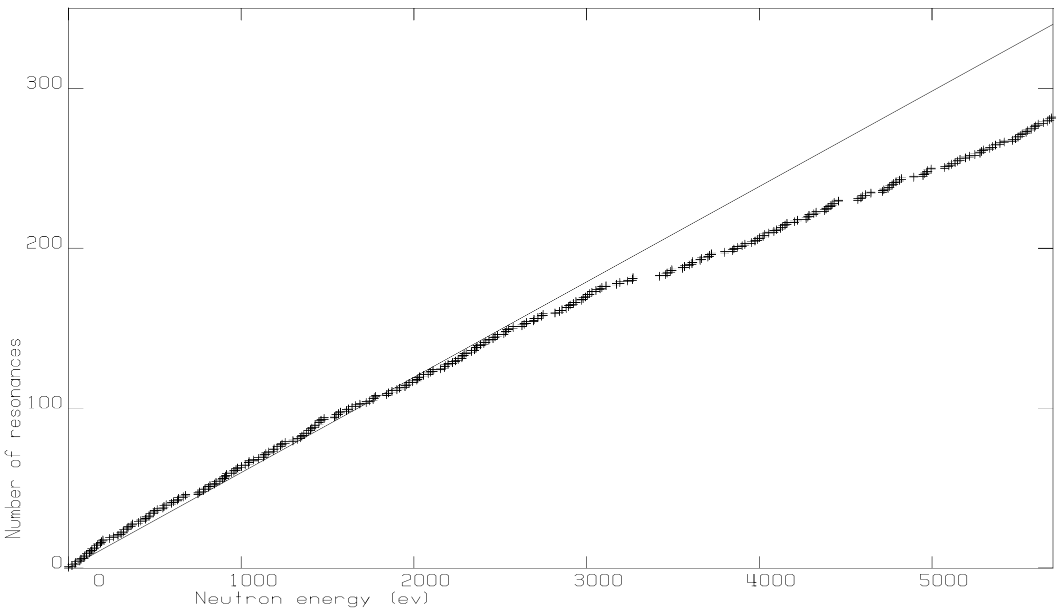


Fig. 1: Number of s-wave resonances (pluses) confidently assigned during this work from the evaluated resonance sample[2] in the 0- to 5.7 keV energy range as a function of E. On average, the variation of the number of resonances is linear up to about 2750 eV.

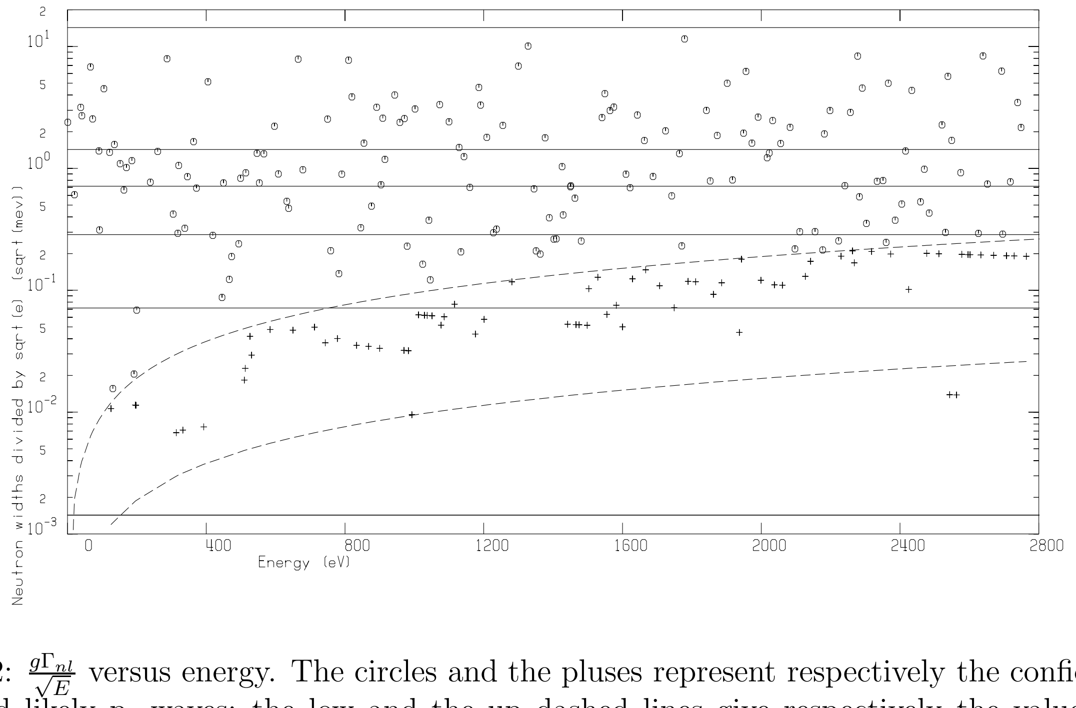


Fig. 2: $\frac{g\Gamma_{nl}}{\sqrt{E}}$ versus energy. The circles and the pluses represent respectively the confident s- and likely p- waves; the low and the up dashed lines give respectively the values of $g\bar{\Gamma}_{n1}/\sqrt{E}$ and $10 \times g\bar{\Gamma}_{n1}/\sqrt{E}$. The horizontal lines represent respectively from the top to the bottom $10 \times g\bar{\Gamma}^0_n$, $g\bar{\Gamma}^0_n$, $g\bar{\Gamma}^0_n/2$, $g\bar{\Gamma}^0_n/5$, $g\bar{\Gamma}^0_n/20$ and $g\bar{\Gamma}^0_n/1000$.

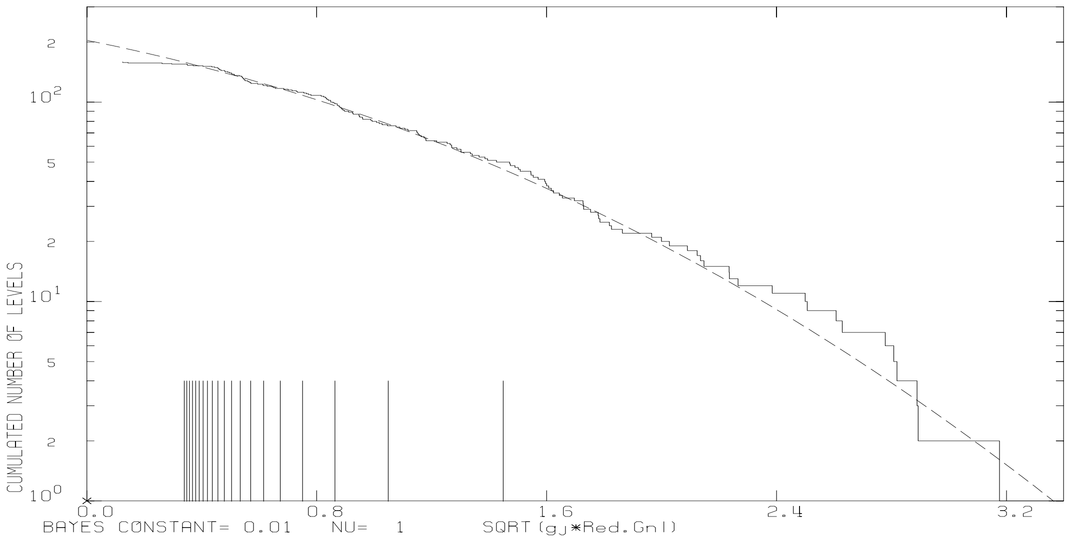


Fig. 3: Cumulated number of confident s- wave resonances versus $\sqrt{g\bar{\Gamma}_n^0}$ in the restricted energy range (0-2.75 keV). The dashed curve is the fitted Porter-Thomas integral distribution and the solid histogram represents the cumulated number of observed resonances. The various vertical bars are the successive thresholds applied to the reduced neutron width to overcome the instrumental resolution effect.

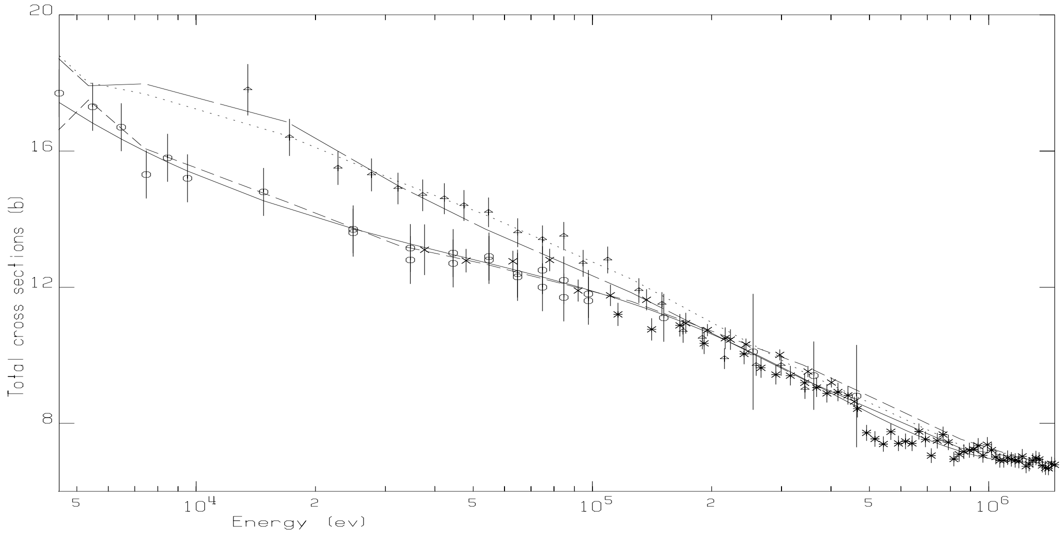


Fig. 4: Total average cross section fitted with FITACS (solid curve) on the experimental data of Gwin ([10],circles), Poenitz and Whalen ([12], crosses) and Smith et al.([13], stars) from the upper boundary of the resolved range (5.7 keV) up to 1 MeV; the data of Käppeler et al.([11], triangles) were not taken into account. The dots, the short and long dashes represent respectively the total cross sections calculated from the JEF2.2, ENDF/B-VI.5 and JENDL3.2 evaluated data files.

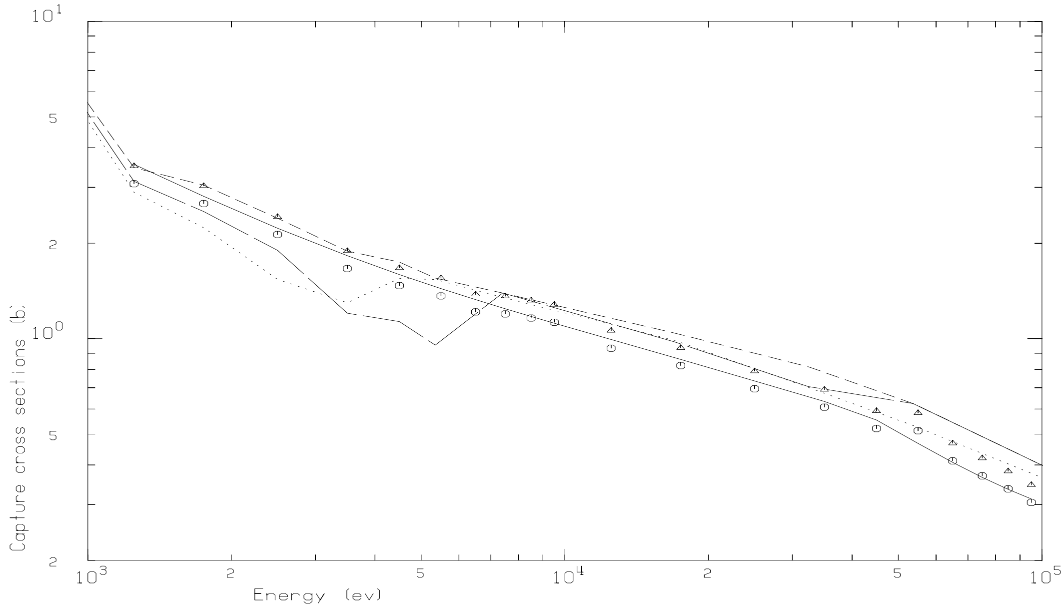


Fig. 5: Fitted average capture cross section (solid curve) on the renormalised Weston and Todd measurement ([6], circles). The short dashes and the dots plot respectively the calculated cross sections from JENDL3.2. and ENDF/B-VI.5. The long dashes represent the cross section calculated from the recent 1995 resolved range evaluation (i.e: below 5.7 keV) and JEF2.2 (above 5.7 keV). For recall the triangles show the Weston and Todd measurement before renormalisation.

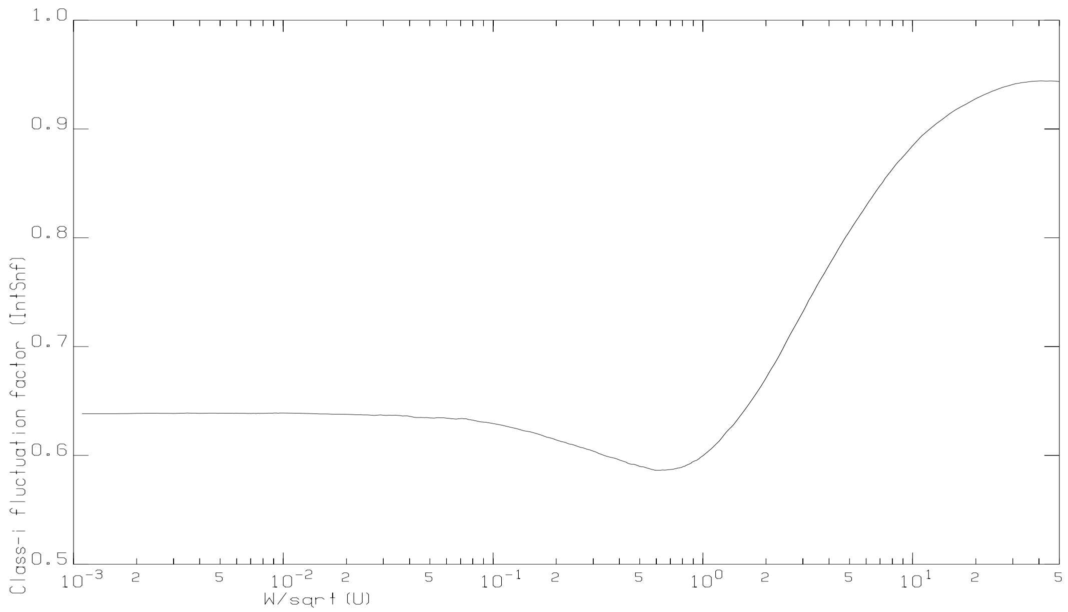


Fig. 6: The Class-I fluctuation factor I$nt\mathcal{S}_{nf}$ as a function of the ratio $W/\sqrt{U}$.

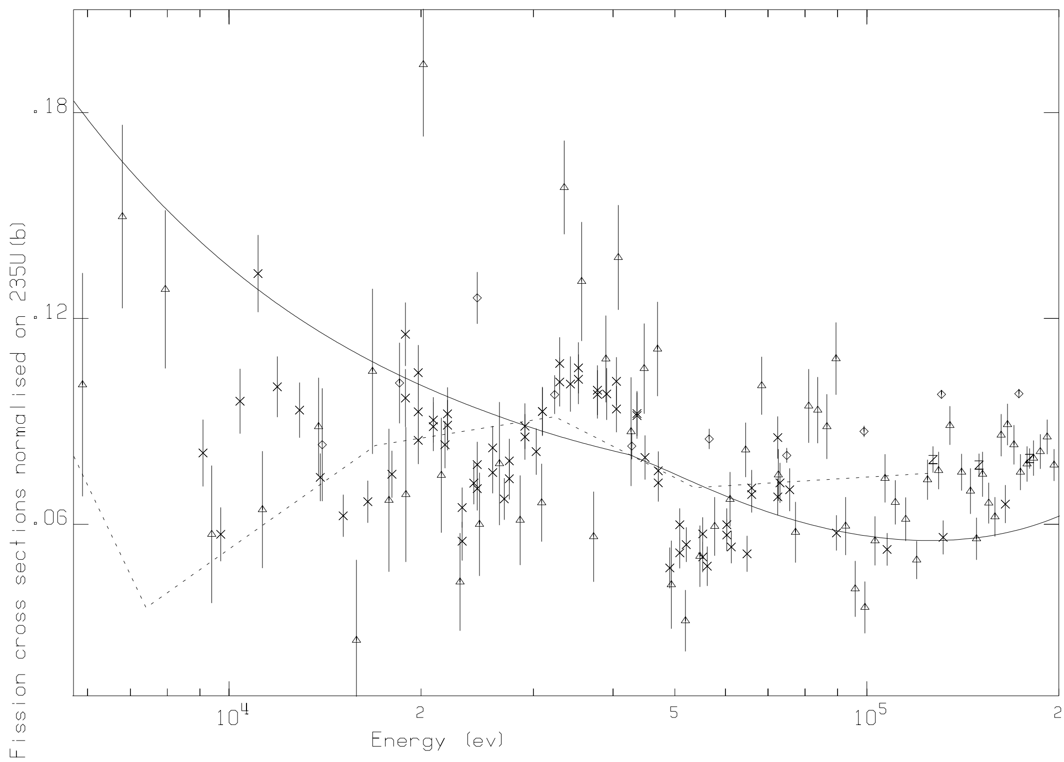


Fig. 7: Average fission cross section plotted versus energy. The solid curve represents the calculated average cross section (this work) assuming a moderately weak coupling between the class-II and the class-I states, and a strong damping of the vibrational levels of the secondary well into the intrinsic class-II resonances. The experimental data of Behrens[25], Wisshak and Käppeler[26], Gilboy and Knoll[27] and Kuprijanov et al.[28] are respectively symbolized by triangles, crosses, diamonds and z letters. The vertical bars give the experimental uncertainties. The short dashed line plots the JEF2.2 cross section for reference.