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EVALUATION OF THE UNRESOLVED RESONANCE RANGE OF U-238

F. H. Fröhner

Kernforschungszentrum Karlsruhe

Institut für Neutronenphysik und Reaktortechnik

D-7500 Karlsruhe, West Germany

Send correspondence to

Dr. F.H. Froehner

Kernforschungszentrum Karlsruhe, INR

Postfach 3640

D-7500 Karlsruhe, West Germany

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2 tables

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ABSTRACT

The state of the JEF-2 evaluation of ^{238}U+n cross sections in the region of unresolved resonances (about 10-300 keV) is reported with special emphasis on recent progress in theory (rigorous expressions for resonance-averaged cross sections with arbitrary level overlap) which permits reliable model-aided evaluation and parametrization by simultaneous fits to total, capture and inelastic cross section data. Formalized inclusion of information from resolved resonances via Bayes' theorem has helped to remove past discrepancies between resolved and unresolved parameters, and has improved resonance statistics. Comparison with the latest ENDF/B-VI (pointwise) evaluations of the capture and the total cross section shows agreement within 1-3 % .

INTRODUCTION

^{238}U cross sections for neutron-induced reactions have, since the very beginning of nuclear technology, always been among the nuclear data requested with top priority and with the highest accuracies. As the present status in the resolved resonance region has recently been reviewed[1] the present paper will concentrate on the unresolved resonance region, and in particular on the evaluation for JEF-2 between about 10 keV and 300 keV which is in progress at Karlsruhe, in collaboration with groups at Harwell and Cadarache. The main reactions in this range are radiative capture, elastic scattering and inelastic scattering (with thresholds at 45, 149 and 310 keV corresponding to excitation of ^{238}U levels with spin-parity 2+, 4+ and 6+). There is also a minute, technologically unimportant amount of subthreshold fission wich can be neglected in the present context. Capture and scattering cross sections are mostly needed for fast-reactor applications, e. g. transport calculations, determination of k_{eff} , breeding ratios, Doppler and void coefficients, while accurate total cross sections are indispensable for consistent data evaluation including optical-model and Hauser-Feshbach calculations. Typical accuracies requested for resonance-averaged (infinite-dilution) cross sections by reactor physicists[2] and evaluators are

1-2 % for the total cross section,

1-3 % for radiative capture,

5-10 % for elastic and inelastic scattering.

For most applications these cross sections must be multiplied by self-shielding factors which describe the dependence of reaction rates on temperature and material composition, given the unobserved but very real resonance structure. The input for self-shielding calculations are level-statistical parameters (neutron and photon strength functions) which must be obtained from resolved resonances (for s-wave reactions) and from Hauser-Feshbach fits to resonance-averaged cross section data (for p-, d-,... wave reactions). The accuracies requested for self-shielding factors are 1 % (and 5 % for their temperature derivatives).[3]

Before anything close to these target accuracies could be achieved, a number of major problems had to be overcome. Many of them are purely experimental. Neutron capture cross sections are usually measured by detection of the prompt capture gamma rays with large liquid scintillators, energy-weighted scintillation (Maier-Leibnitz) detectors or energy-proportional (Moxon-Rae) detectors. With all these detectors there are difficulties because of the natural radioactivity of uranium samples and especially because of the soft capture gamma ray spectrum related to the small neutron separation energy, 4.81 MeV, of the compound nucleus ^{239}U.[4] More generally, there are principal open questions about the functioning of these detectors, especially about the weight functions for Maier-Leibnitz detectors.[5] In scattering experiments it is difficult to separate the elastic and the inelastic components for individual residual excitations and to integrate correctly over angles.

Data reduction in the unresolved resonance region is complicated by the resonance structure of the cross sections. Transmission data must be corrected for self-shielding. Capture and scattering data require additional corrections for multiple scattering. All these corrections depend on level statistics in a complicated way and must usually be calculated by Monte Carlo methods based on level statistics,[6,7] or determined expementally from data taken with different sample thicknesses by extrapolation to zero thickness.[8]

The difficulties are illustrated by the scatter of the data obtained in the unresolved region: For total cross sections the sample standard deviations are of the order 3-6 %, for capture 5-10 % (see Fig. 6), for inelastic scattering 10-20 %, and there appear to be serious systematic errors: total cross section data seem to be biased towards low values, capture and scattering data towards high values, mainly because of missing or inadequate self-shielding and multiple scattering corrections. Despite all this, progress during the last two decades has been such that the ^{238}U(n,γ) cross section has acquired the status of a secondary standard.

One may ask whether theory can help. The answer is yes, of course, but there are consistency problems caused by the hybrid nature of the theory describing resonance-averaged data: It is well known that average total cross sections can be calculated either from an optical-model potential or as averages over resonances based on the statistical model of compound-nuclear levels. For resonance-averaged partial cross sections there must be a similar link between the optical model and level statistics, but its exact form and in particular a rigorous expression for the so-called width fluctuation (Dresner) factors, remained unknown until quite recently. When this hybrid theory (Hauser-Feshbach theory with width fluctuations) was applied to ^{238}U average cross section data it seemed as if the resulting photon strength functions differed significantly from those obtained from resolved resonances. In the following paragraphs we shall report how some of these difficulties were overcome.

DATA BASE

It is not possible to go into the details of the data base used for the JEF-2 evaluation but the main features can be given. Concerning total cross sections our task was greatly facilitated by the careful pointwise (model-free) evaluation of total cross section data above 44 keV, with due account of self-shielding corrections, which was reported by Smith et al.[9] in 1982. Together with data below 44 keV, notably those of Uttley et al.[10], Byoun et al.[11], Kononov et al.[12] and the more recent results of Tsubone et al.[13], this was the main input until early in 1988 when an updated ANL evaluation[14] became available for energies above 45 keV. All these data are in good agreement and define the average total cross section to the requested accuracy of about 1 %, at least above 45 keV.

The capture data base corresponded roughly to the more recent (post-1966) measurements found in the extensive compilation Ref. 15 where many relative data are already renormalized to ENDF/B-V standard cross sections. One addition were the lead slowing-down-time data of Stavissky et al.[16] which nicely define the average capture cross section shape from 31 keV downwards well into the resolved resonance region. Another valuable addition was the recent measurement of Kazakov et al.[17] It spans a wide range (4 to 460 keV) with good resolution, with black-resonance calibration at 6.67 eV and flux shape determination by means of ^{7}Li(n,t) and ^{10}B(n,α) standard cross sections from ENDF/B-V. Slight modifications in reference cross sections as compared to ENDF/B-V were applied to the whole capture data base of 27 sets.

Concerning inelastic scattering data the situation has significantly improved during the last decade. Highly accurate point measurements with filtered beams were reported by Winters et al.[18] (at 82 keV, with 5 % uncertainty) and by Murzin et al.[19] (around 144 keV, with 3 % uncertainty). The latter agrees well with a somewhat less accurate (10 %) value measured by Tsang and Brugger[20]. Another datum is due to Smith[21] (around 600 keV, with 3 % uncertainty). These data points dominate the inelastic-scattering data base due to their small uncertainties.

Additional input consisted of average parameters for s-wave levels estimated from resolved resonance parameters: A mean level spacing (including missing level corrections) of 21.5 ± 1.5 eV and a strength function of $(1.15 \pm .12) \cdot 10^{-4}$ had been determined from the resolved resonance parameters in KEDAK-4[22] and from those newly obtained for JEF-2 at Harwell.[1] An average radiation width of 23.5 ± 1.0 meV looked compatible with KEDAK-4, with the preliminary JEF-2 set and also with the recommendation of Poortmans et al.[23] The corresponding quantities for p-, d- and f- wave resonances were calculated from a spherical optical-model potential fitted to ^{238}U total and scattering cross section data below 15 MeV.[24] Higher-order partial waves can be neglected in the energy range of interest.

THEORY-AIDED EVALUATION IN THE UNRESOLVED RESONANCE REGION

The role of nuclear theory in the evaluation of cross section data is twofold. First it provides smooth curves where data show spurious fluctuations due to experimental effects; the resulting uncertainties are usually well below the scatter of the data. Secondly, theory permits simultaneous, physically meaningful description of all observations - transmission, scattering and capture data in the unresolved region, resonance statistics in the resolved region - in terms of few parameters such as neutron and photon strength functions or the equivalent optical model transmission coefficients. Since Hauser-Feshbach theory (with width fluctuations) relates resonance-averaged cross sections for all reaction channels in much the same way as R-matrix theory does for resonance cross sections, a coherent evaluation of all information provides powerful constraints and reduces uncertainties drastically. It is standard practice to extract resolved resonance parameters (level energies, partial widths for all open channels) and their uncertainties from simultaneous R-matrix fits to all available experimental results - high-resolution transmission, capture, fission data etc. - in the resolved resonance region. Similarly one can employ resonance-averaged R-matrix theory, i. e. Hauser-Feshbach theory with width fluctuations, in the unresolved resonance region to find best estimates of average resonance parameters (mean level spacing, average partial widths) and their uncertainties from simultaneous fits to all available resonance-averaged cross section data.

The data fitting itself is best done in such a way that a-priori information about the adjusted parameters is fully taken into account. This is possible with the generalized (Bayesian) least-squares technique which, in contrast to the customary "primitive" least-squares method, allows utilisation not only of a-priori values (as first guesses) but also of their estimated uncertainties.[25] It is an ideal tool for data evaluation because in Bayesian parameter estimation the old a-posteriori distribution of the parameters becomes the new a-priori distribution as soon as new data become available. This means one can fit in steps, data set by data set, without loosing the information gained in previous fits.

The ^{238}U average cross section data were fitted along these lines with the FITACS code[26] which employs Hauser-Feshbach theory. It calculates average total cross sections for a given entrance channel c (i. e. for given target spin, total and orbital angular momentum), with spin factor g_c, as

$$\bar{\sigma}_c = \pi \bar{\lambda}_c^2 g_c (1 - \mathrm{Re}\, \bar{S}_{cc}) \tag{1}$$

from the resonance-averaged collision function

$$\bar{S}_{cc} = e^{-2i\phi_c} \frac{1-\bar{R}_{cc} L_c^{0*}}{1-\bar{R}_{cc} L_c^{0}} \tag{2}$$

(which can be identified with the optical-model collision function) with

$$\bar{R}_{cc} = R_c^{\infty} + i\pi s_c \,, \tag{3}$$

where ϕ_c is the hard-sphere scattering phase, R_c^{∞} the distant-level parameter related to the effective radius, s_c the pole strength (proportional to the strength function) and otherwise conventional R-matrix notation is used. The corresponding transmission coefficient (for neutron channels) is

$$T_c = 1 - |\bar{S}_{cc}|^2 = \frac{4\pi P_c s_c}{|1-\bar{R}_{cc} L_c^0|^2} \,. \tag{4}$$

The transmission coefficients for photon and fission channels are taken as

$$T_\gamma = 2\pi \frac{\bar{\Gamma}_\gamma}{D_c} \,, \tag{5}$$

$$T_f = 2\pi \frac{\bar{\Gamma}_f}{D_c} \,. \tag{6}$$

The adjustable parameters are strength functions, distant-level parameters, average radiation widths (for E=0, parity-dependent) and average fission widths (for E=0, JΠ-dependent). The energy dependence of average radiation widths is calculated with the giant-dipole resonance model, that of fission widths with Hill-Wheeler fission barrier transmission coefficients, and that of the mean level spacing with the Gilbert-Cameron composite formula.[27] The mean spacing for s-wave levels (for E=0) is an input number from which mean spacings for other partial waves are generated with the Bethe formula (see e.g. ref. 26)

$$D_c^{-1} \propto \exp\left(-\frac{J^2}{2\sigma^2}\right) - \exp\left(-\frac{(J+1)^2}{2\sigma^2}\right) , \qquad (7)$$

where J is the level spin and σ the spin cutoff. (For J<<σ this gives the widely used approximation $D^{-1} \propto 2J+1$).

The relationship (1) between average total cross section and average S-matrix is exact. Such an exact relationship for average partial cross sections, in particular for the width fluctuation correction, was not available until recently, except in the limit of very small transmission coefficients, i. e. for well separated narrow resonances. Therefore heuristic prescriptions for arbitrary level overlap had to be inferred from Monte Carlo calculations based on the known laws of level statistics. Moldauer[28] proposed

$$\bar{\sigma}_{ab} = \sigma_{pa}\delta_{ab} + \pi\lambda\!\!\!^{-}{}_a^2 g_a \frac{T_a T_b}{T}\left(1+\frac{2}{\nu_a}\delta_{ab}\right)\int_0^\infty dx \prod_c \left(1+\frac{2T_c}{\nu_c T}\right)^{-\delta_{ac}-\delta_{bc}-\nu_c/2} , \qquad (8)$$

where σ_{pa} is the potential-scattering cross section for the entrance channel a and ν_c is an effective degree of freedom for the (generalized Porter-Thomas) distribution of the partial widths Γ_c, taken as

$$\nu_c = 1.78 + (T_c^{1.218} - 0.78)e^{-0.228T} , \quad T \equiv \sum_c T_c . \tag{9}$$

The first pair of parantheses in (8) causes elastic enhancement and the integral is the width fluctuation correction or Dresner factor: the whole expression is a modest generalisation of the known limit for well separated resonances. The obviously heuristic expression (9) approximates average cross sections calculated from resonance ladders that were obtained by Monte Carlo sampling of level energies and widths from the known distributions of the level-statistical model (Mehta-Dyson spacing distribution with level repulsion, Porter-Thomas width distribution[29]). The original version of FITACS used Moldauer's prescription, because in contrast to the HRTW prescription[30] it has the correct limiting behavior for small transmissions coefficients and for small numbers of open particle channels, i. e. for small energies.

After three decades of futile attempts to find rigorous expressions a breakthrough was achieved in 1985. Mello, Pereyra and Seligman[31] and independently Fröhner[32] found, by application of information theory and in particular by entropy maximization, the joint probability distributions of S-matrix and of R-matrix elements for given average S- and R-matrices, which yield simple expressions for average partial cross sections if few channels are open. Verbaarschot, Weidenmüller and Zirnbauer[33] succeeded in directly averaging the R-matrix expressions over the Gaussian Orthogonal Ensemble (GOE) of Hamiltonian matrices (which is tantamount to averaging over the Dyson-Mehta distribution of level positions and the Porter-Thomas distributions of all partial widths), using new mathematical tools from the many-body theory of disordered systems. Their result is useful also for many open channels: The average partial cross section, generally given by

$$\overline{\sigma}_{ab} = \pi\lambda\!\!\!^{-}{}_a^2 g_a \overline{|\delta_{ab}-S_{ab}|^2} , \tag{10}$$

is to be calculated with the GOE triple integral

$$\overline{|S_{ab}|^2} = |\overline{S}_{ab}|^2 + \frac{T_a T_b}{8}\int_0^\infty d\lambda_1 \int_0^\infty d\lambda_2 \int_0^1 d\lambda \, \frac{\lambda(1-\lambda)|\lambda_1-\lambda_2|}{\sqrt{\lambda_1(1+\lambda_1)\lambda_2(1+\lambda_2)}\,(\lambda+\lambda_1)^2(\lambda+\lambda_2)^2}$$
$$\cdot \prod_c \frac{1-T_c\lambda}{\sqrt{1+T_c\lambda_1}\,\sqrt{1+T_c\lambda_2}} \left\{\delta_{ab}(1-T_a)\left(\frac{\lambda_1}{1+T_a\lambda_1}+\frac{\lambda_2}{1+T_a\lambda_2}+\frac{2\lambda}{1-T_a\lambda}\right)^2\right.$$
$$\left. + (1+\delta_{ab})\left(\frac{\lambda_1(1+\lambda_1)}{(1+T_a\lambda_1)(1+T_b\lambda_1)}+\frac{\lambda_2(1+\lambda_2)}{(1+T_a\lambda_2)(1+T_b\lambda_2)}+\frac{2\lambda(1-\lambda)}{(1-T_a\lambda)(1-T_b\lambda)}\right)\right\} \tag{11}$$

(it was this quantity that had caused the trouble). Although the two solutions to the Hauser-Feshbach problem look utterly different, they yield practically the same numbers. A new version of the FITACS code uses the GOE triple integral.

An example for a simultaneous FITACS fit to transmission, capture and inelastic-scattering cross sections is given in Figs. 1-3. The cross section shapes are well reproduced, including the Wigner cusp in the capture cross section caused by rapidly increasing competition of inelastic scattering above 45 keV. Unfortunately these and similar fits to all the other data sets resulted in s-wave photon transmission coefficients that were about 9 % lower than the value implied by our a-priori radiation width of 23.5 meV and mean level spacing of 21.5 eV for s-wave levels. Recently the Harwell recommendation for the average radiation width for the resolved resonances was lowered to 23.0 meV.[1] This reduced the discrepancy to 7 % but did not remove it.

IMPROVED RESONANCE STATISTICS

We therefore decided to redetermine the mean level spacing from resolved resonance parameters. The main problem is that of missing levels: According to the Porter-Thomas distribution the most frequent resonances are those with the smallest neutron widths, i. e. those that are most difficult to find. As a consequence all experimental resonance parameter sets for actinides are affected by missing levels. There are basically two ways to estimate the missing fraction: (1) "Ladder" methods which use only the observed level energies, (2) more efficient methods which also utilize the neutron widths, inferring the missing fraction from the scarcity of small observed widths relative to the expected Porter-Thomas distribution. The second approach is implemented in the statistical resonance analysis code STARA-81 which is well tested: In a benchmark exercise organized by the NEA Data Bank[34] it was the only competitor estimating level densities correctly from realistic sets of resolved resonance parameters comparable to those of ^{238}U, thanks to its capability to cope not only with missing weak levels but also with unresolved multiplets.[35] Basically it yields a joint maximum-likelihood estimate of mean level spacing and neutron strength function for s-wave levels by comparing the observed reduced neutron widths with the Porter-

Thomas distribution, under the assumption of a very regular increase of level number with energy as predicted by the GOE model of compound-nuclear resonances. Reasonably clean s-wave samples are needed, however, incorrect s- or p-wave assignments falsify the results. This appeared to be the problem with previous analyses.

Since the observed shapes of weak s-, p- and d-wave resonances are practically indistinguishable, their parities can only be assigned probabilistically. For the preliminary JEF-2 set of resolved resonance parameters[1] this had been done with Dyson's Δ_3 statistic (a straight-line fit to the number of levels plotted versus energy).[36] As already indicated such "ladder" methods which utilize only the level positions but not their widths are notorious for their unreliability in statistical resonance analysis.[37] This had already affected earlier analyses[35] for KEDAK-4 which had relied on similar parity assignments by Keyworth and Moore.[38] Therefore we analyzed the resolved resonance parameters from KEDAK-4 and from the present JEF-2 evaluation[1] a second time, but now ensuring highly pure s-wave samples by imposing an artificial threshold such that only resonances with more than 99 % s-wave probability (given their neutron widths and iterated estimates of strength functions and mean level spacings) were included. Typical results are shown in Figs. 4 and 5 and in Table I. The new estimates obtained up to 4 keV are perfectly consistent with the average radiation width and mean level spacing extracted from average cross section data. (At higher energies the relative strength of p-wave levels increases rapidly, and therefore also the threshold required to eliminate them. As a consequence the retained fraction of "99 % sure" s-wave levels becomes too small, i. e. the statistics too bad, for similarly accurate estimates.)

Table II shows the set of average resonance parameters for E = 0 from which JEF-2 point cross sections were calculated between 10 and 300 keV. The necessary extrapolation from E = 0 to higher energies was based on the spherical optical model of Ref. 24 and, for level spacings and radiation widths, on the Gilbert-Cameron composite level density formula.[27] and on the giant-dipole resonance model as given by Holmes et al.[33] The point data and the parameters may still be subject to some modification during the JEF-2 test phase, during which also the final uncertainties will be fixed.

SUMMARY

The present JEF-2 evaluation of ^{238}U in the unresolved resonance region, based on fits with modern Hauser-Feshbach theory to a large body of total, inelastic-scattering and capture cross section data, and on rigorous (Bayesian) inclusion of prior knowledge from resolved resonances and from optical-model fits at higher energies, agrees to within 1 % with the recent ANL model-free evaluation of the total cross section between 45 and 300 keV (and in fact up to 1 MeV). Agreement with the recent accurate inelastic-scattering data shown in Fig. 3 is also satisfactory in view of the experimental uncertainties (and of model uncertainties above 300 keV, see below). An initial disagreement with a preliminary ENDF/B-VI model-free evaluation of the capture cross section (shown in Fig. 6 as a thin solid line) has disappeared: The latest ENDF/B-VI standards evaluation of ^{238}U capture (solid dots in Fig. 6) agrees well over most of the range considered here. The small differences below 20 keV are not unexpected because of residual resonance effects in the data which Hauser-Feshbach calculations cannot reproduce: The Hauser-Feshbach curve represents the mean of the cross section distribution but does not contain information about fluctuations about the mean that are notable at low energies (see e. g. Ref. 40). Above 200 keV the latest ENDF points are still lower than the JEF-2 model curve but the difference is not really significant until about 300 keV where the model calculations are increasingly affected by uncertainties about level density behavior and direct reactions. These points are under study. Indications are that the range of our Hauser-Feshbach calculation can be extended considerably. The deduced average resonance parameters are fully consistent with resolved resonance parameters if due account is taken of dubious spin and parity assignments of weak resonances. It can therefore be expected that the average resonance parameters are adequate for calculation of self-shielding factors and for reproduction of self-indication data but this remains to be checked during the JEF-2 test phase (for a brief review of self-shielding benchmark calculations for JEF see Ref. 41).

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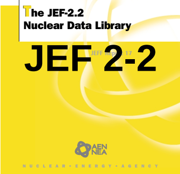

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TABLE I

Average Resonance Parameters, for E = 0 and ℓ = 0

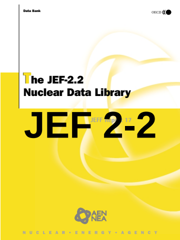
Energy Range (keV)	Strength Function (10^{-4})	Mean Level Spacing (eV)	Radiation Width (eV)	Included Level Fraction	Resonance Parameter Set
from statistical analysis of JEF-2 resolved resonance parameters (only resonances with more than 99 % s-wave probability included):					
0 - 1	0.95±0.25	22.7±1.6	[23.5]	0.84	KEDAK-4 (1979)
	0.96±0.26	22.7±1.6	[23.0]	0.84	JEF-2 (1988)
0 - 2	1.07±0.18	21.6±0.9	[23.5]	0.71	KEDAK-4 (1979)
	1.07±0.19	22.5±0.9	[23.0]	0.77	JEF-2 (1988)
0 - 3	1.14±0.16	23.2±0.8	[23.5]	0.73	KEDAK-4 (1979)
	1.20±0.18	23.4±0.6	[23.0]	0.78	JEF-2 (1988)
0 - 4	1.13±0.12	21.9±1.0	[23.5]	0.64	KEDAK-4 (1979)
	1.20±0.14	22.5±0.8	[23.0]	0.71	JEF-2 (1988)
from fits to transmission, inelastic and capture cross section data in the unresolved resonance region:					
4 - 310	0.98±0.05	23.0±0.6	22.6±0.4		

TABLE II

Average Resonance Parameters for E = 0

Used to Generate JEF-2 Test Data Between 10 and 300 keV

Orbital Angular Momentum ($\hbar$)	Neutron Strength Function (10^{-4})	Distant-Level Parameter	Average Radiation Width (eV)	Mean Level Spacing (eV)	Effective Radius (fm)
0	0.98	-0.12	22.6	23.0	9.43
1	2.01	0.19	22.7		
2	1.24	-0.06	22.6		
3	2.00	0.18	22.7		



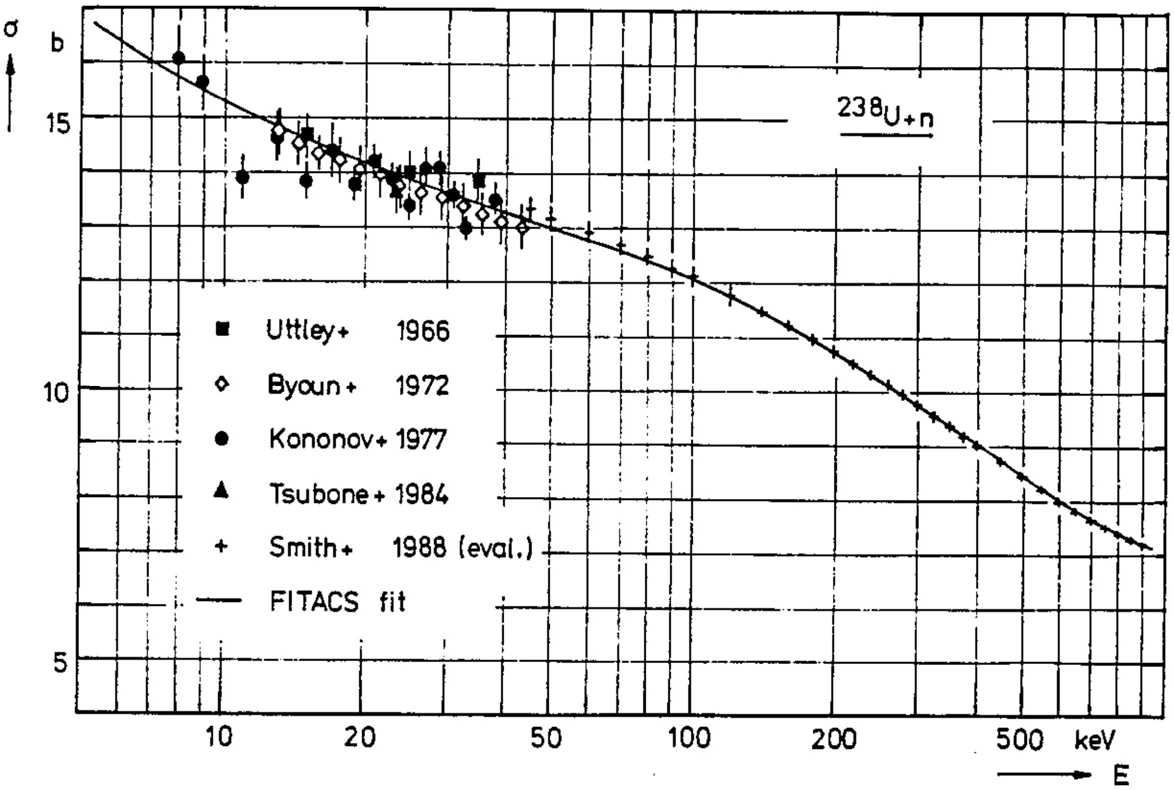


Fig. 1. Fit to ^{238}U data in the unresolved resonance region: total cross section (simultaneous with Figs. 2 and 3).

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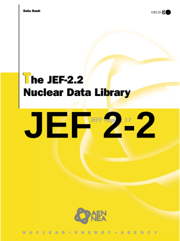

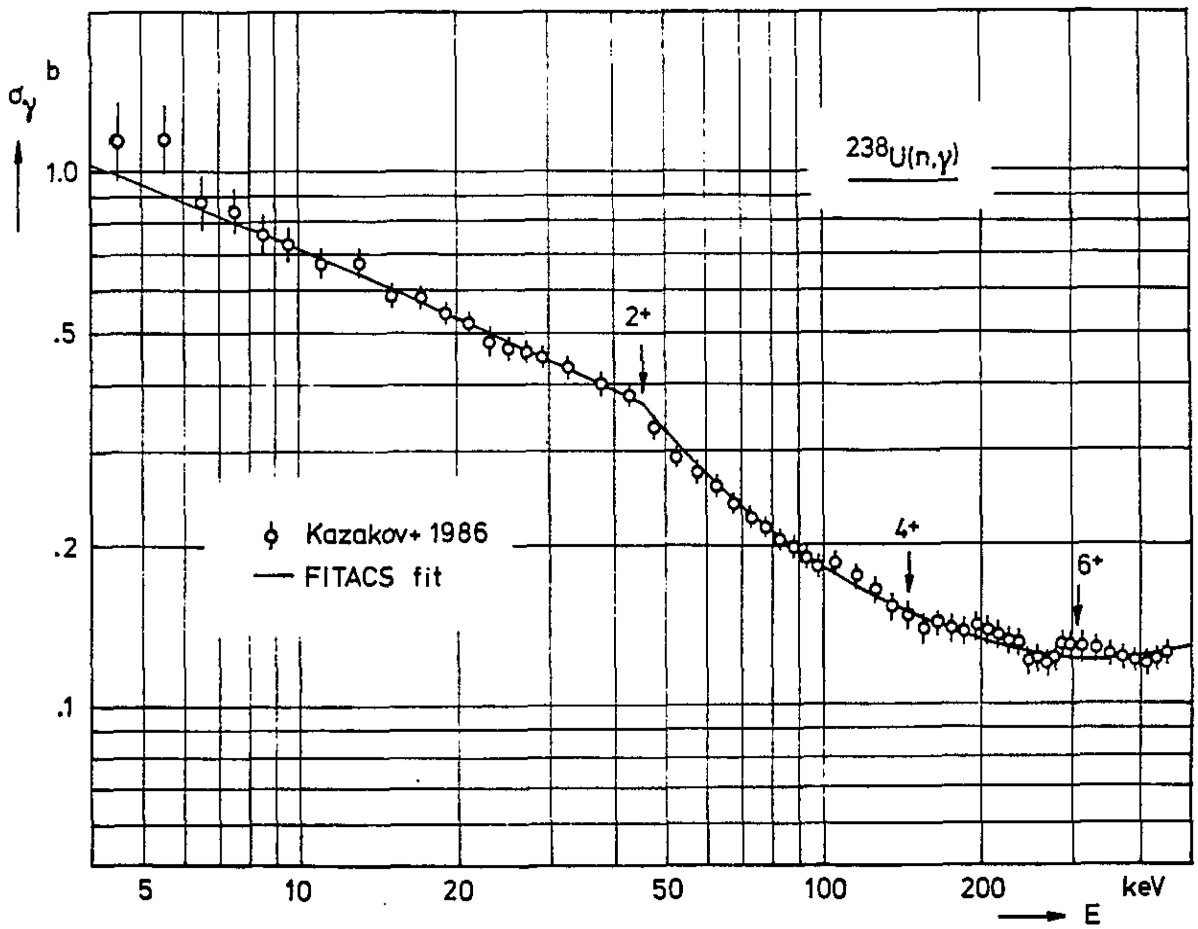

Fig. 2. Coherent fit to ^{238}U data in the unresolved resonance region: capture cross section (example, simultaneous with Figs. 1 and 3). The discontinuity (Wigner cusp) at 45 keV is due to competition by inelastic scattering above that energy. Inelastic thresholds are indicated by spin-parity characteristics of residual levels.

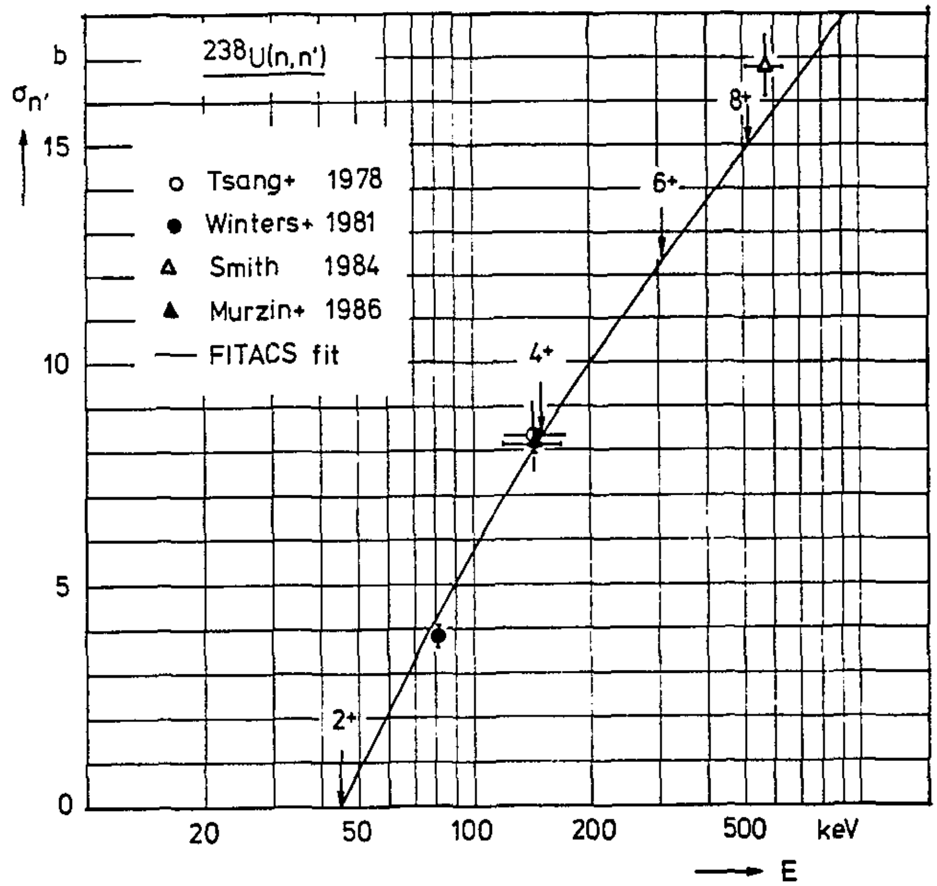

Fig. 3. Coherent fit to ^{238}U data in the unresolved resonance region: inelastic-scattering cross section (simultaneous with Figs. 1 and 2). Inelastic thresholds are indicated by spin-parity characteristics of residual levels.

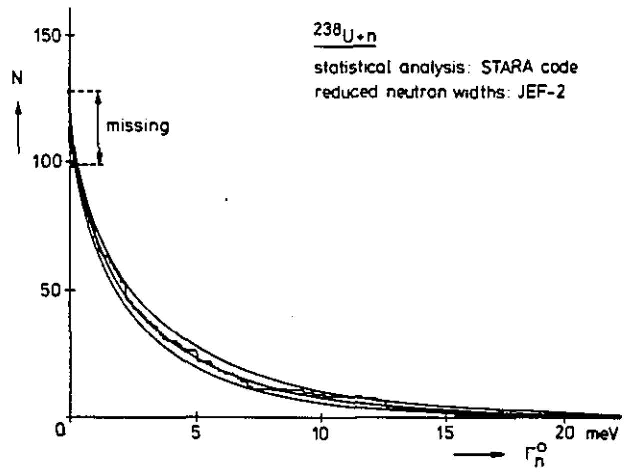

Fig. 4. Cumulative Porter-Thomas distribution resulting from statistical resonance analysis, 0 - 3 keV, s-wave. Histogram: reduced neutron widths from JEF-2 resolved resonance parameter set; solid lines: maximum-likelihood estimate with confidence band. Different intercepts with vertical axis of histogram and best-estimate curve indicate missing weak levels.

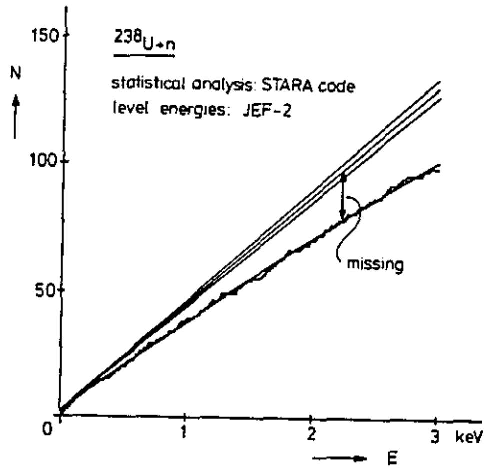

Fig. 5. Level number plot, statistical resonance analysis, 0 - 3 keV, s-wave. Stairstep curve: level energies from JEF-2 resolved resonance parameter set; solid lines: maximum-likelihood estimate with confidence band, corrected for missing levels. Missing levels are mainly those unobserved due to their weakness, a smaller fraction are those excluded because of uncertain spins and parities.

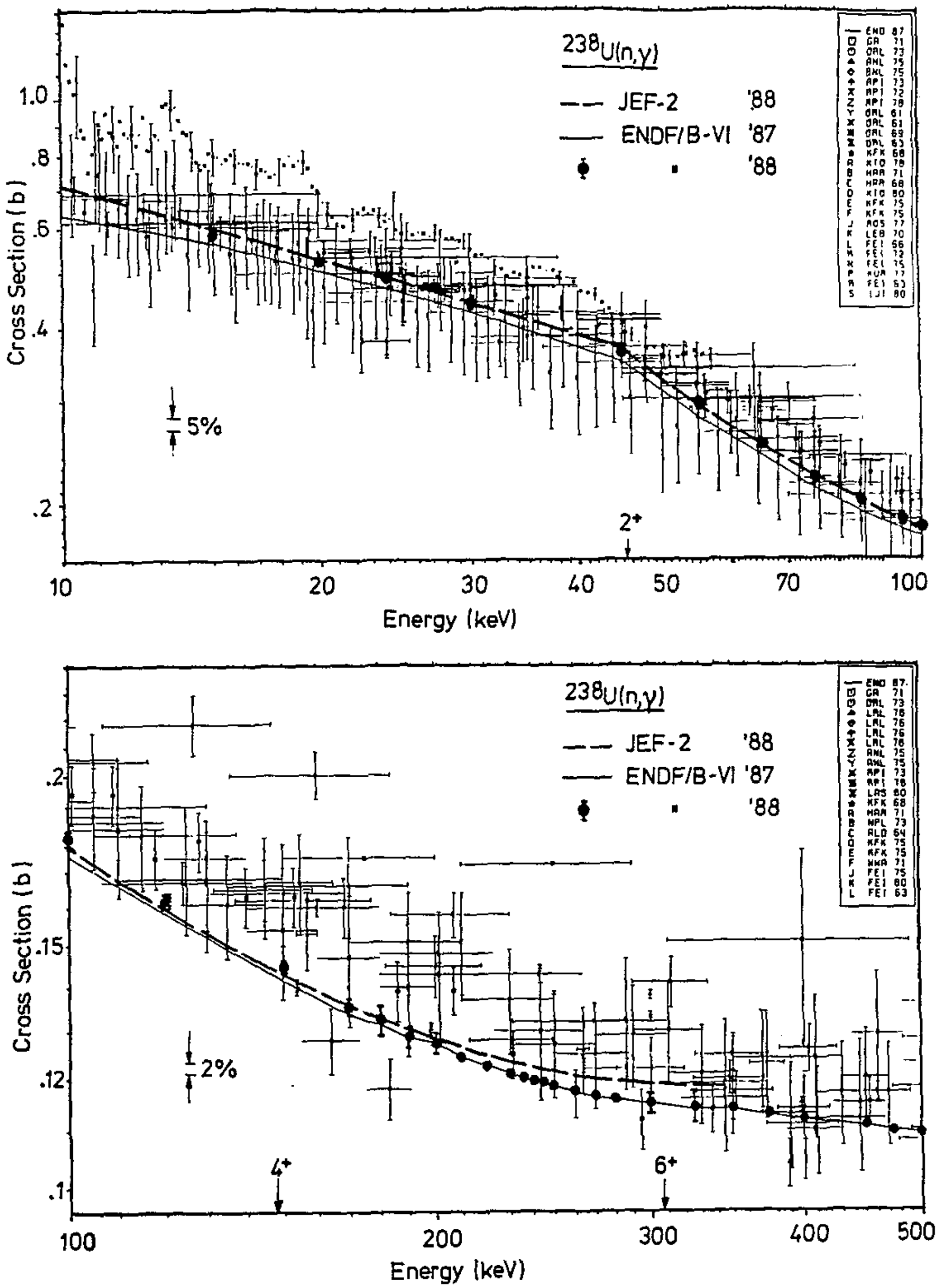

Fig. 6. Capture cross section evaluations and data. Inelastic thresholds are indicated by spin-parity characteristics of residual levels. Experimental data are indicative only. They are from NEA Data Bank EXFOR file, as given by authors, before final corrections for multiple scattering, unstated systematic errors etc., and before renormalization with current cross section standards.

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