SUMMARY OF THE WORK OF THE NEANDC TASK FORCE ON U-238

Compiled by

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— assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;

— developing exchanges of scientific and technical information particularly through participation in common services;

— setting up international research and development programmes and joint undertakings.

In these and related tasks, NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.
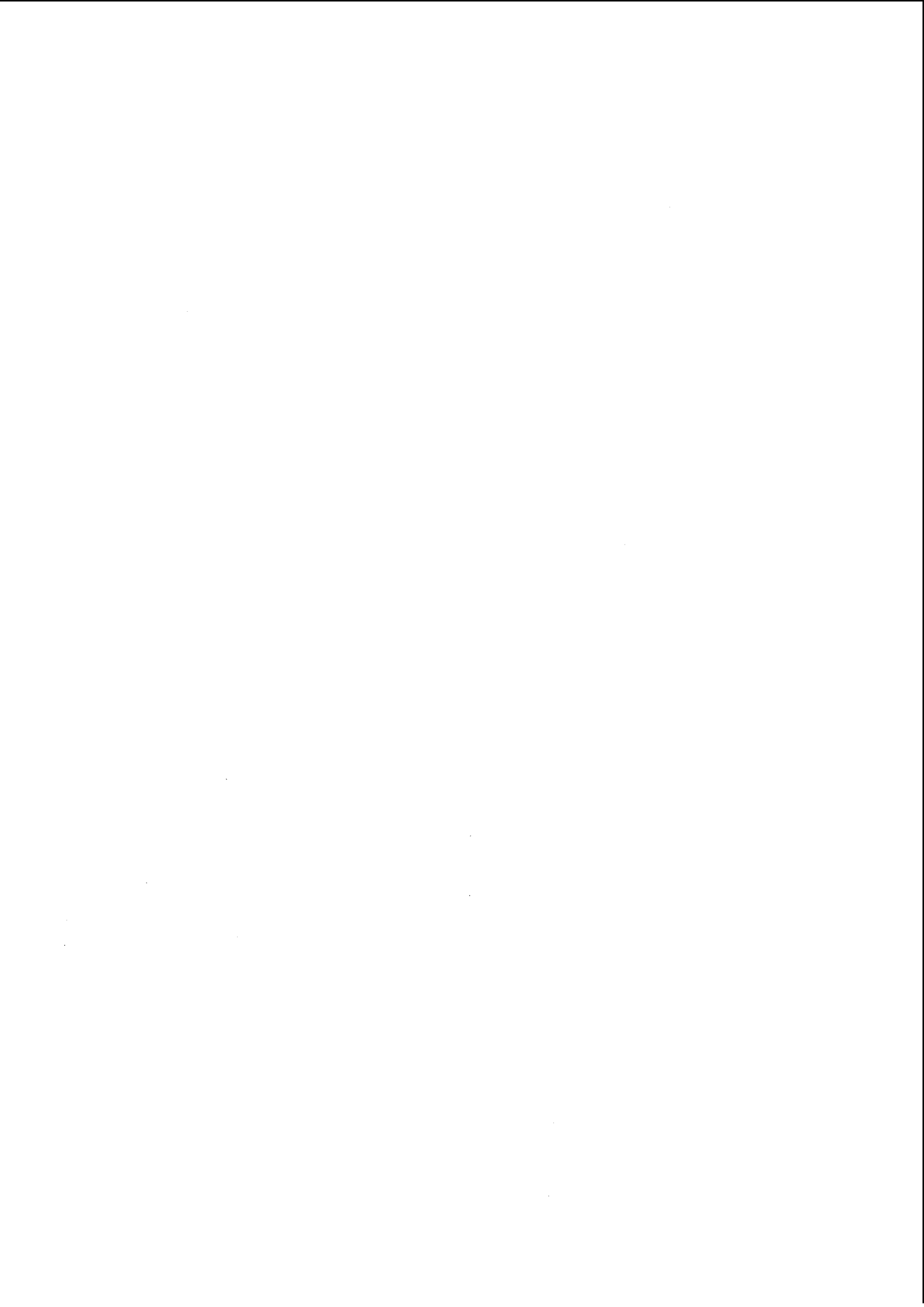
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Abstract

The work of the Nuclear Energy Agency Nuclear Data Committee (NEANDC) Task Force on U-238 is summarised. The Task Force was set up in 1982 to consider two discrepancies in U-238 data - the neutron widths of the resolved resonances above 1.4 keV and the capture cross-section in the resolved and unresolved resonance regions. The work is summarised historically and to put the activities of the Task Force into context the paper starts with a brief description of the methods and data used to determine U-238 resonance parameters. It follows with a description of the state of the data in 1982 and then describes the work of the Task Force in the period up to 1985, the period during which the Task Force found the reasons for the discrepancies. Consideration is then given to the period following 1985 during which resonance analysis on U-238 has been performed and a recommended set of parameters covering the energy range 0-10 keV produced. These are listed in an appendix to the paper and are now included in the U-238 evaluations contained in JEF-2 and ENDF/B-VI. Finally a review is given of the main conclusions of the Task Force followed by a list of work still requiring to be done.

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1.   Introduction

At the Antwerp Conference on Nuclear Data for Science and Technology in
September 1982 it was clear that there were longstanding inconsistencies in
measurements of nuclear data which were only likely to be solved by getting
experimenters and evaluators in the various laboratories to work together on the
problems. To this end the Nuclear Energy Agency Nuclear Data Committee (NEANDC)
formed two Task Forces at its meeting in Chalk River in September 1982 to
consider the discrepancies in the data of Fe-56 and U-238. This paper is
concerned with the work of the U-238 Task Force whose members are given in
Appendix 1.

The U-238 Task Force was set up to deal with two problems; the neutron
widths of the resolved resonances above 1.4 keV and the capture cross-section in
the resolved and unresolved resonance regions. Though the neutron width data
were consistent within a few per cent below 1.4 keV there were significant
differences between the most reliable measurements which increased with energy
to ~10 to 20% above 3 keV. The capture cross-section problem was well known;
the spread in the differential measurements below 30 keV was greater than
expected from the assigned errors and there were inconsistencies between
differential and integral data. The Task Force was therefore asked to answer
the following specific questions:

(1)   What is the cause of the discrepancy in the neutron widths?
(2)   Why are the capture cross-section measurements discrepant?

Having answered these it was then requested to produce a recommended set of
U-238 resonance parameters.

The purpose of this paper is to give a summary of the work of the Task Force and the main activities that arose from its considerations. (The paper mainly considers the resonance parameter problem as the capture cross-section discrepancies were partially resolved as a result of work on this [1].) As these activities are not yet completed the paper is unable to give the final resolved resonance parameters that will result from the analysis of the currently available measurements of U-238 transmission, capture and fission data. However, it is important to describe the results so far obtained as these satisfy the principal objectives set for the Task Force. The final parameters that will result from the analyses currently in progress can be published separately later as for Task Force considerations they will essentially be an addendum to this paper.

The Task Force did most of its work by correspondence. After two years, however, it was clear that both it and the Fe-56 Task Force had made sufficient progress, particularly on the analysis of transmission data, to warrant a joint meeting and this was held at the NEA Data Bank on the 9-10th October 1984. This paper draws heavily on the conclusions from that meeting as well as the reports presented to International Conferences in 1985 [2], 1988 [3,4] and 1990 [5]. The paper is written historically and it will be seen that following the Task Force meeting the work performed has been essentially the activities of 3 groups (Oak Ridge, the NEA Data Bank and Harwell) working to carry out its recommendations.

In order to get the context of the work into perspective the paper starts with a short section on the two main methods of determining resolved parameters from experimental data (area and shape analysis) followed by a section which describes the situation when the Task Force started. It then continues with a presentation of the Task Force's work and main conclusions.

2. Brief Description of Methods and Data Used to Determine U-238 Resonance Parameters

In order to understand the discussions in this paper it is necessary to briefly describe the methods that have been used to obtain U-238 resonance parameters. The discussion will be limited to transmission and capture cross-section measurements as scattering, self indication and fission cross-section measurements have only been used to a limited extent.

Full descriptions of the techniques that have been used in these measurements have been given elsewhere (e.g. Rae [6]) so only limited information will be given here.

All the measurements used in recent studies to obtain resonance parameters were made using white spectrum pulsed neutron sources. Hence neutron energies were always obtained by the time-of-flight technique. In the transmission measurements a neutron detector is placed in a collimated neutron beam from the pulsed source and the neutron counts are measured as a function of time-of-flight both when a sample of U-238 is placed in the neutron beam between the detector and the source and when it is removed. If the sample is larger than the neutron beam and is sufficiently far from both the source and detector that it subtends a fractional solid angle much smaller than the uncertainty aimed at in the experiment, then, assuming that any structure in the cross-section is wider than the resolution function, the transmission $(T(j))$ for the jth timing channel is related to the total cross-section $(\sigma_{nT}(j))$ by the equation

$$T(j) = \frac{C_I(j)\Theta_0}{C_0(j)\Theta_I} = \exp(-N \times \sigma_{nT}(j)) \qquad \dots (1)$$

where $C_I(j)$ and $C_0(j)$ are the background corrected counts in the detector for the jth timing channel when the uranium is in and out of the beam respectively, x is the thickness of the uranium sample in cm, N is the number of atoms of uranium per cm³ and Θ_0 and Θ_I are factors to normalise the counts to the same neutron output from the pulsed source.

In the capture cross-section measurement the capture events in a uranium sample illuminated by the collimated neutron beam are counted by a suitable gamma-ray detector placed close to the uranium but out of the beam. Again, assuming that any structure in the cross-section is wider than the resolution function, the observed background corrected count $C_\gamma(j)$ is related to capture cross-section $\sigma_{n\gamma}(j)$ by the equation

$$C_\gamma(j) = \epsilon\emptyset(j)[(1 - \exp(-N \times \sigma_{nT}(j)))\frac{\sigma_{n\gamma}(j)}{\sigma_{nT}(j)} + M] \qquad \dots (2)$$

where ϵ is the efficiency of the detector for capture events, $\emptyset(j)$ is the

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incident neutron flux on the sample, N and x are the number of atoms/cc and thickness of the sample as in equation (1) and M is the correction for neutrons that initially scatter in the sample and are captured on subsequent collisions.

In practice often both the resolution* and the effects of the thermal motion of the target nuclei (Doppler broadening) are wider than the structure in the nuclear cross-section and, in order to obtain the true nuclear cross-section from the observed data, it is necessary to include these effects in the formalism. Both effects broaden the observed resonances; the formalism to correct for the Doppler effect is essentially well known [7] though there are still some uncertainties and inconsistencies. The energy resolution of spectrometers is more of a problem as it depends upon the detailed design of the neutron producing target, flight path, and detector and in general it has not been directly measured. Normally the function is asymmetric and not the gaussian shape often assumed.

The resonance parameters are determined from the observed dips in the transmission measurements and peaks in the capture measurements by two basic techniques which are referred to as area and shape analysis methods. In area analysis advantage is taken of the fact that the area of a transmission dip or of a capture peak is unaffected by resolution or Doppler broadening effects so long as the sample is thin (N x σ_{nT} << 1) and the resonance is isolated. For thicker samples the areas are affected but an accurate knowledge of the broadening functions is not needed to calculate the effects. Area analysis methods have been described by Hughes [8] who showed that the resonance areas for transmission dips and capture peaks (A and A_γ) for very thin samples are given by equations (3) and (4) while the very thick sample transmission area (A_T) is given by equation (5)

$$A = (\pi/2) \times N\sigma_0\Gamma \qquad \qquad \dots (3)$$

$$A_\gamma = (\pi/2) \times N\sigma_0\Gamma_\gamma \qquad \qquad \dots (4)$$

$$A_T = (\pi \times N\sigma_0)^{1/2}\Gamma \qquad \qquad \dots (5)$$

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*The resolution function is the energy spectrum of neutrons arriving at the sample in a narrow time interval.

where σ_0 is the total cross-section at the resonance peak before resolution and Doppler broadening and is given by

$$\sigma_0 = 4\pi\lambda_0^2 g(\Gamma_n/\Gamma) \qquad \qquad \dots (6)$$

where $2\pi\lambda_0$ is the wavelength of a neutron at the resonance energy E_0 (eV),

  g is the resonance statistical weighting factor (= $(2J+1)/2(2I+1)$),

  Γ_n, Γ_γ and Γ are the neutron, capture and total widths of the resonance in eV,

  N is the number density in atoms/cm^3,

  X is the sample thickness in cm,

  J is the spin of the resonance

and I is the spin of the target nucleus

In general neither very thin nor very thick samples are used and codes are used to obtain the areas as functions on Γ_n and Γ_γ which in the limits are like equations 3, 4 and 5. The values of Γ_n and Γ_γ are then obtained by solving the equations by graphical methods. Typical cases [9] are shown in Fig. 1 where the transmission and capture data have been analysed using modified Atta-Harvey [10] and Tacasi [11] codes.

In shape analysis methods, detailed knowledge of the broadening functions is required because the aim is to compare the detailed calculated shapes of transmission and capture yield determinations with experimental data and obtain the resonance parameters by altering them to get a good fit using iterative methods.

3. Brief summary of the state of U-238 resolved resonance data in 1982

The purpose of this section is to give the flavour of the situation in 1982 when the Task Force was formed. It is not the purpose to review the available data in detail as such reviews were made in 1974, 1977 and 1982 by Moxon [12], de Saussure et al [13] and Moxon and Sowerby [14], the latter two dealing with experiments published between 1974 and 1977 and 1977 and 1982 respectively. By 1982 there were approximately 40 independent measurements of the parameters that had been performed since 1955. Most of the early ones cover only the low energy resonances and there were 6 sets of measurements extending to 4 keV and above (Garg et al [15], Carraro and Kolar [16], Rahn et al [17], Nakajima [18],
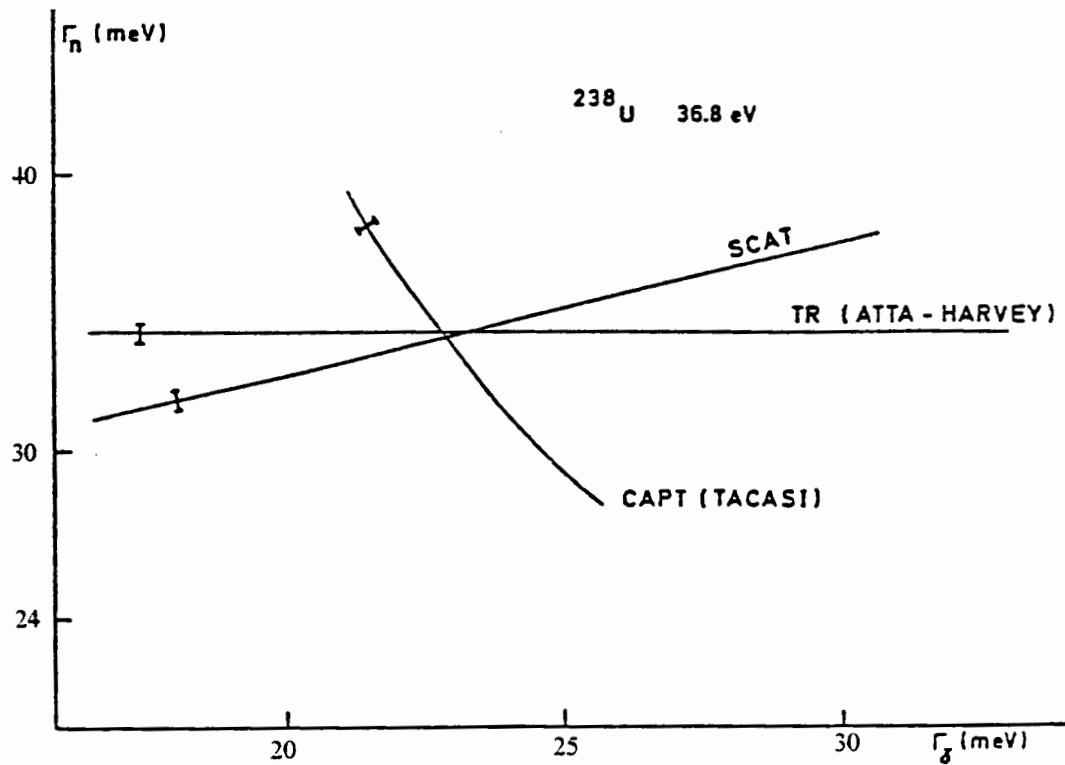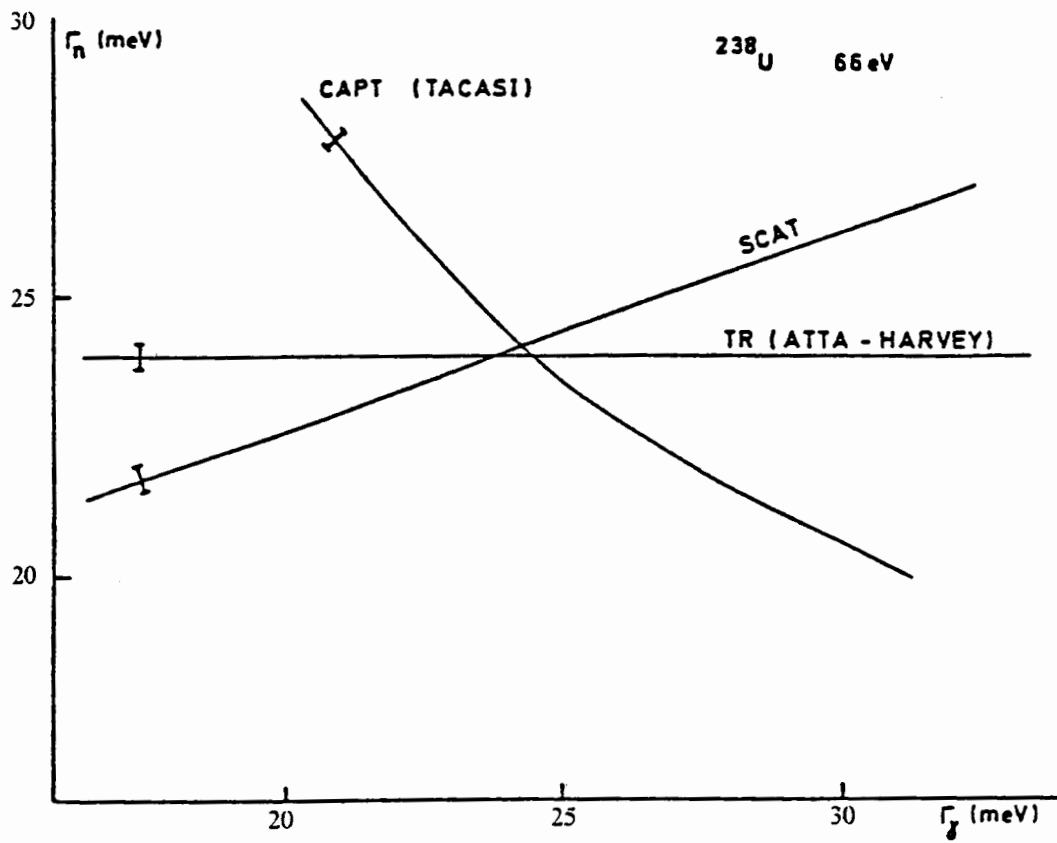
Figure 1   Example of area analysis of capture, scattering and transmission data
for two resonances at 66 eV and 36.8 eV

Olsen et al [19] and Poortmans et al [9]. The results of these experiments were often discrepant with some of the discrepancies being systematic in nature and not understood.

The problem for evaluators was therefore to obtain a set of recommended data from an unsatisfactory data base. Moxon and Sowerby reviewed the main evaluations performed since 1974. By 1982 it was clear that it was necessary to use a multilevel formalism [19] and to include the contribution of levels outside the resolved resonance region. However, most of the measurements had been analysed using the single level Breit Wigner formalism [13,14]. The evaluations therefore attempted to estimate the best parameters by renormalising parameters and adjusting the errors for individual experiments or by giving higher weight to the experiments that had been done recently. However, these studies did not show why the problems existed, particularly above 1.4 keV.

In 1982 Coates et al [20] in a paper aimed at showing what needed to be done to improve nuclear data measurements reviewed a number of topics including the U-238 resolved resonance parameters. The rest of this section is based on their review which provides a good description of the problems as they were then perceived.

In order to demonstrate the inconsistencies observed in 1982, some typical resonances and the data then available will be considered. First let us look at some examples in the energy range below 1 keV where overlapping s- and p-wave levels should not be a problem. It had been noted [14] that most experiments in U-238 tend to give discrepant Γ_n data at their high energy limit when they are running out of energy resolution. Good resolution is always desirable in resonance analysis because it minimises the problem of overlapping resonances and it enables good background measurements to be made. Measurements for two typical resonances at 20.9 eV and 958.6 eV are shown in Figs. 2 and 3. The poor resolution data should be discarded from these (i.e. the data of Harvey et al, Lynn and Pattenden, Fluharty et al, Levin and Hughes, and Bollinger et al for the 20.9 eV resonance, and Rosen et al, Firk et al and Malecki et al for the 958.6 eV resonance). If other data where there are grounds for rejection are also disregarded (Asghar et al (error in normalisation) and Garg et al (superseded by Rahn et al)), a consistent data set is left for the 958.6 eV resonance, but an inconsistent one for the 20.9 eV case. However, this

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inconsistency is largely produced by the datum of Block et al where Γ_n is more than three standard deviations from the mean.

Attention is now turned to the region above 1 keV where there are fewer measurements although all of these have adequate resolution. It is noticeable that for some cases the Γ_n values are in good agreement while for neighbouring resonances there are discrepancies. A typical example is the pair of strong s-wave resonances at 2581.3 eV and 2597.8 eV whose data are shown in Fig. 4. The resonances are reasonably close but well resolved so it is unlikely that experimental errors will produce discrepancies for one and not the other. However, there is a significant chance that p-wave resonances could overlap with one or both resonances. If there is overlap then it can be shown [14] that if area analysis is performed on capture data the apparent Γ_γ will always tend to be greater than the value for a single resonance. Rohr et al [21] have data on Γ_γ for about 90 resonances above 1 keV and approximately half of these appear to have anomalously high values of Γ_γ. One of these is the 2581 eV resonance where Γ_γ is 25.8±0.5 meV, while for the neighbouring 2598 eV resonance Γ_γ has the normal value of 22.5±1 meV. It is therefore suggested that one reason for inconsistencies in this energy range is overlapping resonances and these can be identified because they have anomalously high Γ_γ values.

It is more usual in resonance analysis to use area rather than shape methods because (1) it is less expensive and (2) knowledge of the resolution and Doppler broadening functions are not so important. Derrien and Ribon [22], however, have discussed the advantages of shape analysis and conclude that:

(a) shape analysis provides all the information resulting from area analysis - even if the resolution and Doppler broadening functions are in error

(b) shape analysis can identify errors in normalisation and background. Some codes allow these quantities to be adjusted during the fitting procedure.

In recent years before 1982 there had been significant improvements to shape analysis techniques. By that time such analysis could be performed simultaneously on different data types (e.g. capture and transmission) and for several sample thicknesses [23]. However, these codes have to be used with care because there are many parameters fixed in obtaining the final fit. Usually the

Γn (meV) Γγ (meV)

EXPERIMENT		Γn (meV) 8 9 10	Γγ (meV) 20 24 28 32	ANALYSIS	FORMALISM	MEASUREMENTS ANALYSED
HARVEY et al	(1955)	⊢●⊣	x (ASSUMED)	AREA	SLBW	TRANSMISSION
LYNN & PATTENDEN	(1955)	⊢●⊣	⊢—×—⊣	AREA	SLBW	TRANSMISSION (n,γ) (n,n)
FLUHARTY et al	(1956)	⊢—●—⊣	⊢—×—⊣	AREA /SHAPE	SLBW (?)	TRANSMISSION
LEVIN & HUGHES	(1956)	⊢—●—⊣	⊢——×——⊣	AREA	SLBW	TRANSMISSION
BOLLINGER et al	(1957)	⊢●⊣	⊢×⊣	AREA /SHAPE	SLBW	TRANSMISSION
ASGHAR et al	(1966)	⊢●⊣	⊢——×——⊣	AREA	SLBW	(n,γ) (n,n)
RAHN et al	(1972)	⊢—●—⊣	⊢—×—⊣	AREA /SHAPE	SLBW	TRANSMISSION SELF INDICATION (n,γ)
OLSEN et al	(1977)	⊢●⊣	⊢×⊣	SHAPE	MLBW	TRANSMISSION
NAKAJIMA	(1980)	⊢—●—⊣	x (ASSUMED)	AREA	SLBW*	TRANSMISSION
LIOU & CHRIEN	(1977)	⊢—●—⊣	⊢×⊣	AREA /SHAPE	SLBW /MLBW	TRANSMISSION SELF INDICATION (n,γ)
POORTMANS et al	(1977)	⊢●⊣	⊢×⊣	AREA	SLBW	TRANSMISSION (n,γ) (n,n)
HASTE et al	(1978)	⊢●⊣	⊢×⊣	SHAPE	MLBW	TRANSMISSION
BLOCK et al	(1979)	⊢●⊣	××	AREA	MLBW	SELF INDICATION (n,γ)

* The multilevel effects are considered to be within the quoted error

Figure 2 Measurements of the resonance parameters of the 20.9 eV resonance in U-238 available in 1982.

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Γn (meV)   Γγ (meV)

EXPERIMENT		Γn (meV) 100·0 200·0	Γγ (meV) 16 20 24	ANALYSIS	FORMALISM	MEASUREMENT ANALYSED
ROSEN et al	(1960)			AREA	SLBW	SELF INDICATION
FIRK et al	(1963)			AREA	SLBW	TRANSMISSION
GARG et al	(1964)			AREA	SLBW	TRANSMISSION
ROHR et al	(1970)			AREA	SLBW	TRANSMISSION [@] (n,γ)
CARRARO & KOLAR	(1970)			AREA	SLBW	TRANSMISSION [@]
MALECKI et al	(1972)			AREA	SLBW	TRANSMISSION (n,γ)
RAHN et al	(1972)			AREA /SHAPE	SLBW	TRANSMISSION SELF INDICATION (n,γ)
NAKAJIMA	(1980)			AREA	SLBW	TRANSMISSION
POORTMANS et al	(1981)			AREA	SLBW	TRANSMISSION (n,γ) (n,n)
OLSEN et al	(1979)			SHAPE	MLBW	TRANSMISSION

[@] Same transmission data analysed.

Figure 3 Measurements of the resonance parameters of the 958.6 eV resonance in U-238 available in 1982.

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variation of these parameters would produce little or no effect on the values of the other adjustable ones. For the rare instances where this is not true, fits corresponding to local minima are obtained with underestimated error values. Some examples of parameters which are unexpectedly different from the general consensus may be explained by this effect (e.g. Block et al at 20.9 eV [24] and Haste et al for the 189 eV resonance [25]). More recently Bayes' Theorem has been utilised to improve the analysis [26] and this appears to remove some of the problems encountered with conventional least squares techniques which take no account of previous information and often do not take into full account the correlated errors in the data.

Fig. 4 also shows the changes in Γ_n when Derrien [27] performed shape analysis on the data of Carraro and Kolar and Rahn et al which had previously been analysed by area analysis. It can be seen that shape analysis leads to consistent data for both resonances. This was true for all resonances analysed by Derrien. The large change in Γ_n between shape and area analysis of the data of Rahn et al is due to a background adjustment which is required to obtain a good fit to the data. Shape analysis is believed to be more likely than area analysis to obtain the correct answer when there are overlapping resonances. Coates et al therefore recommended that shape analysis be applied simultaneously to high resolution (≤ 0.1 ns/m) capture and transmission data to confirm this.

In 1982 there was good evidence that the analysis of U-238 data using single and multilevel formalisms can produce different resonance parameters [28]. It follows therefore that for accuracy, multilevel formalisms must be used unless it can be shown that the use of the single level formalism leads to negligible errors.

Finally on a cautionary note it must be remembered that sophisticated codes of the sort under discussion are only useful if they have been validated in some acceptable way.

The following points emerged from this 1982 discussion on U-238:

(1) Resonance parameters obtained from poor resolution experiments are unreliable.

2581·3 eV RESONANCE ($\Gamma_\gamma = 25\cdot8 \pm 0\cdot5$ meV) Γn (meV)

EXPERIMENT

CARRARO & KOLAR (1971)

RAHN et al   (1972)

NAKAJIMA   (1979)

OLSEN et al   (1979)

POORTMANS et al (1981)

MEAN VALUES

300   400   500

SHAPE ANALYSIS DERRIEN

AREA   SHAPE

2597·8 eV RESONANCE ($\Gamma_\gamma = 22\cdot5 \pm 1\cdot1$) Γn (meV)

CARRARO & KOLAR (1971)

RAHN et al   (1972)

NAKAJIMA   (1979)

OLSEN et al   (1979)

POORTMANS et al (1981)

MEAN VALUES

700   800

SHAPE ANALYSIS DERRIEN

AREA SHAPE

× SHAPE ANALYSIS
● AREA ANALYSIS
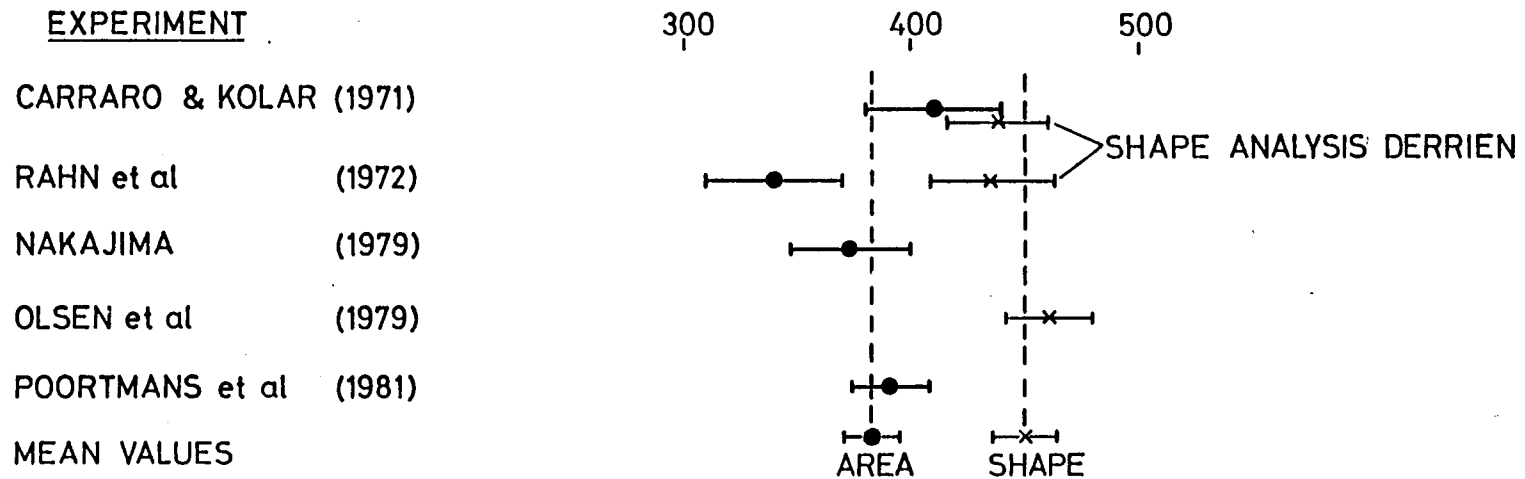
Figure 4 The Γ_γ values for the 2581.3 eV and 2597.8 eV resonances in U-238 available in 1982.

(2) There are occasions where measurements produce parameters which are significantly different from the general consensus for no apparent reason.

(3) In the energy range above 1 keV overlapping resonances are a cause of some of the discrepancies.
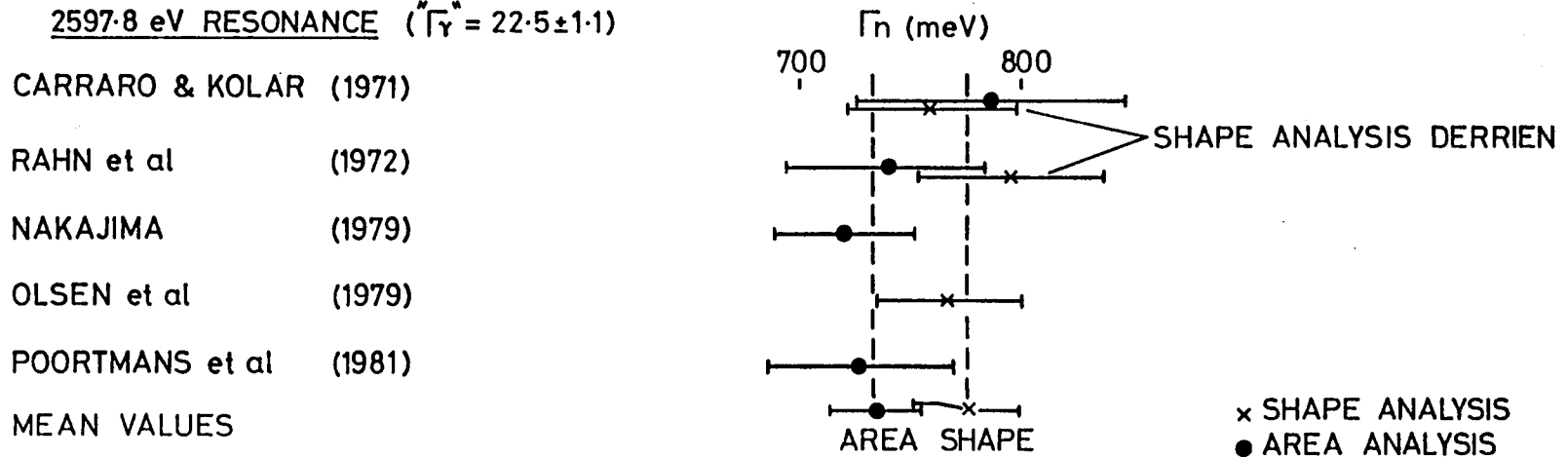
(4) The most reliable resonance analyses are performed if

       (a) a multilevel formalism is adopted
       (b) shape analysis is used
and (c) a full error analysis is performed, preferably using Bayes' Theorem

(5) Shape analysis can identify significant experimental errors and problems.

4. First thoughts and work of the Task Force on the causes of the discrepancies in the period up to 1985

(a) Neutron Width Discrepancies

The first action of the Task Force following its setting up in 1982 was to gather together the thoughts and ideas of its members. From this a programme of work was drawn up which placed more emphasis on the neutron width discrepancy than on the capture cross-section problem. The reason for this was that it was believed the latter was only likely to be solved by performing new accurate measurements that stressed small corrections and new approaches and techniques which would take time.

The systematic differences in neutron widths could be due to a variety of causes including:

(i) Errors in the measurement of neutron transmissions; in particular due to background corrections, count loss effects and normalisation factors (the factors Θ_0 and Θ_I in equation (1))

(ii) Errors produced by the method of resonance analysis

(iii) Errors due to inadequate knowledge of resolution functions

(iv) Problems due to overlapping resonances

The Task Force realised that only one of the six measurements giving resonance data extending from 1.4 to 4 keV had used this shape analysis method. As such methods can determine the origins of systematic errors in neutron widths it was decided that there was some merit in getting several laboratories to perform some shape analyses on several of the better and more recent transmission measurements. As each would use their own codes this would also help to validate the codes and show up possible errors.

The data of Geel [9], JAERI [18] and Oak Ridge [19] were therefore distributed to the Task Force in 1983 for analysis over 3 limited energy regions 1.45 to 1.81, 2.48 to 2.8 and 3.82 to 4 keV (regions 3, 2 and 1 respectively). Results of shape analyses were reported to the Task Force by Derrien, Moxon, Olsen and Syme. The analyses of Olsen [29] and Moxon [30] which use the codes SIOB [31] and REFIT [23] were, however, the most comprehensive and so will be discussed in this paper; the results of Derrien and Syme came to similar conclusions. SIOB and REFIT are completely independent codes and as far as is known have no common subroutines. There are a number of differences between the codes and some of these are listed in Table 1. In the Task Force context the most significant of these is the resolution function where completely different approaches are adopted. There are a number of other detailed differences between the analyses of Olsen and Moxon. The most important is that Olsen obtained resonance parameters from all 3 sets of data while Moxon only obtained parameters from the ORNL data and then showed that these fitted the Geel and JAERI data when used with resolution functions derived from the appropriate data.

The main conclusion of both analyses is that the prime reason for the discrepancy in the neutron widths is that the experimental resolution functions are wider and more complex than the experimenters have assumed. There is no evidence that measurement errors (e.g. background or normalisation errors) are significant although for the SIOB analyses for regions 1 and 2 of the JAERI and Geel data the background parameters could not be determined independently of the resolution function. However, it must also be noted that in all analyses of the Geel data the resolution function formulation poorly represents the ^{3}He high pressure gas scintillators used to obtain the data. As an example of the resolution functions consider those obtained by Olsen for region 1 which are

TABLE 1 Comparison of SIOB and REFIT

	SIOB	REFIT
Resonance formalism	MLBW	One channel reduced R-matrix
Resolution function	Normalised moderator functions $(x^2\exp(-x))$ or $\exp(-x^2)$ plus normalised exponential tail due to multiple scattering	Convolution of components taking into account: (1) shape of initial fast neutron pulse (2) rise and decay of fast neutrons hitting moderator to allow for attenuation of neutrons through source and possible decay due to multiplying target (3) timing channel width (4) time spread produced by moderator $(x^2\exp(-x))$ (5) angle of flight path to moderator (6) detector response for slab including multiple scattering exponential tail (7) a gaussian time jitter
Doppler broadening	Free gas model Gaussian convolution using chi and psi functions	Free gas model numerical integration
Data analysed	Transmission	Transmission and capture (includes multiple scattering correction)

given in Table 2. It can be seen that the values of d and L (defined in the
Table) are much greater than expected. Moxon has, of course, different
parameters to describe the moderator function. The width of his function is
defined by a parameter λ_m and if the d from SIOB only includes the time
spread produced by the moderator then d ~ 3.4 λ_m. Moxon finds that
λ_m = 8.8 and 7.8 mm for regions 1 and 3. However, if he fits the U-238
capture data of de Saussure et al [32] in region 3 he obtains a value for λ_m
of 5.8 mm, which is the same as values deduced from many capture measurements at
Harwell. It is thus clear that, in the resolution function models used by both
Olsen and Moxon, the moderator function is taking up the effect of other
broadening mechanisms. Syme et al [33] have investigated these and shown that
for linacs these are likely to be associated with neutron scattering in the
vicinity of the detector.

TABLE 2 Resolution function parameters obtained by Olsen for region 1

| | ORNL | | Geel | JAERI |
	(from shape analysis)	(by Monte Carlo calculation)	(from shape analysis)	(from shape analysis)
d (mm)	33.4	24	38.4	123
L (mm)	41.3	20	(48)	(142)
F	0.313	0.35	0.16	0.22

The values in brackets were fixed in the analysis and were determined from analyses in the lower energy regions.

d is the full width at half maximum of the moderator function ($x^2 \exp(-x)$ or $\exp(-x^2)$) excluding the burst time width.

L is the equivalent-distance half life of the exponential tail in mm.

F is the fraction in the exponential tail.

The resonance parameters obtained from the analyses are shown in Figures 5, 6 and 7 for the energy regions 3, 2 and 1. It can be seen that when the same ORNL data are analysed by the two completely independent codes the differences in neutron widths are small (less than 1 to 2% on average) though there is a slight indication that they are larger for region 1. Figure 8 shows the average neutron widths as obtained by Olsen [29] compared with the original published values and the ENDF/B-V and JENDL-2 evaluations and it can be seen that the new data are significantly higher. On average there is no evidence that the values deduced from one experiment are significantly different to those from another except perhaps for the JAERI data in region 1 where the energy resolution is not particularly good. This led to the conclusion that it was obviously necessary to completely reanalyse the data above 1.4 keV and until this was done the recommended sets of resonance parameters in ENDF/B-V, JENDL-2 and JEF-1 would be unsatisfactory.

At the meeting of the Task Forces at the NEA Data Bank in October 1984 a discussion was held on the work which was necessary to improve the resonance parameter data. It was agreed that in the short term it was necessary to reanalyse the available transmission data using a shape analysis code with a suitable resolution function. In practice it was perhaps only necessary to analyse the ORNL data [19] as this was superior in quality. The analysis would go to as high an energy as possible (10 keV). In the longer term the following
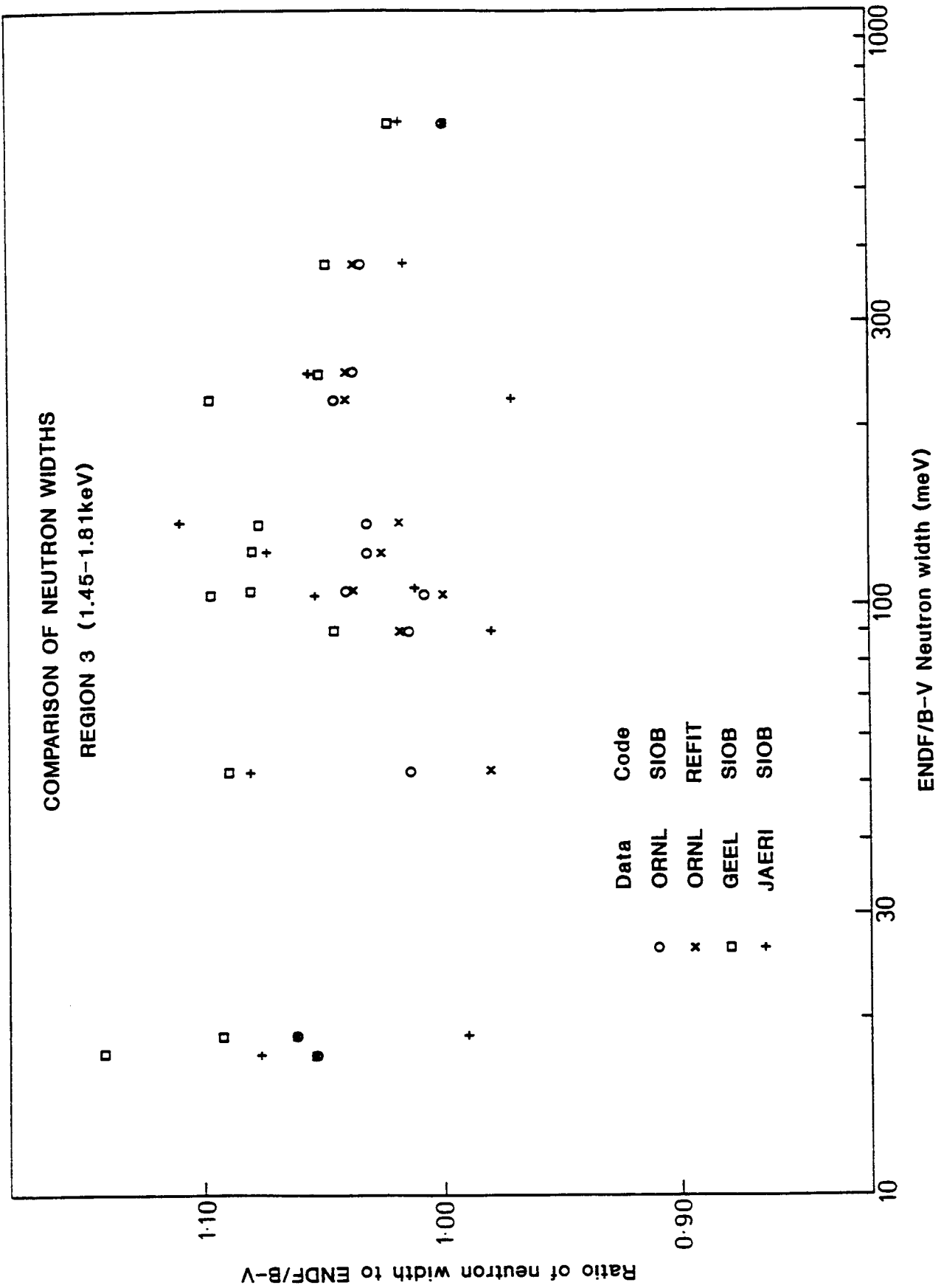
Figure 5

COMPARISON OF NEUTRON WIDTHS
REGION 2 (2.48 to 2.8keV)

Data	Code
ORNL	SIOB
ORNL	REFIT
GEEL	SIOB
JAERI	SIOB

○ × □ +

Ratio of neutron width to ENDF/B-V

ENDF/B-V Neutron width (meV)

Figure 6

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COMPARISON OF NEUTRON WIDTHS
REGION 1 (3.82–4keV)

Ratio of neutron width to ENDF/B-V

Data		Code
o	ORNL	SIOB
×	ORNL	REFIT
□	GEEL	SIOB
+	JAERI	SIOB

ENDF/B-V Neutron width (meV)

Figure 7

24

Figure 8

25
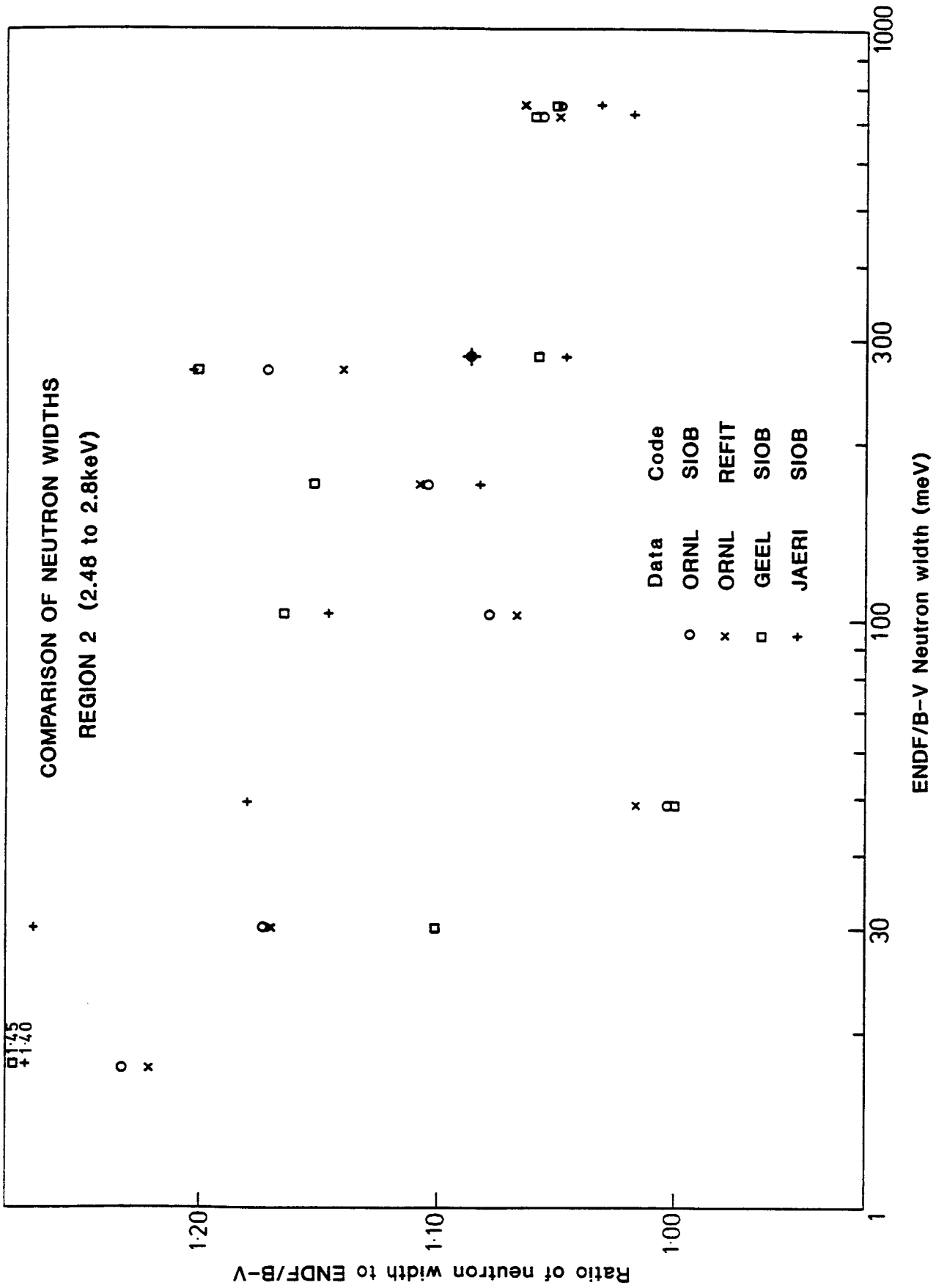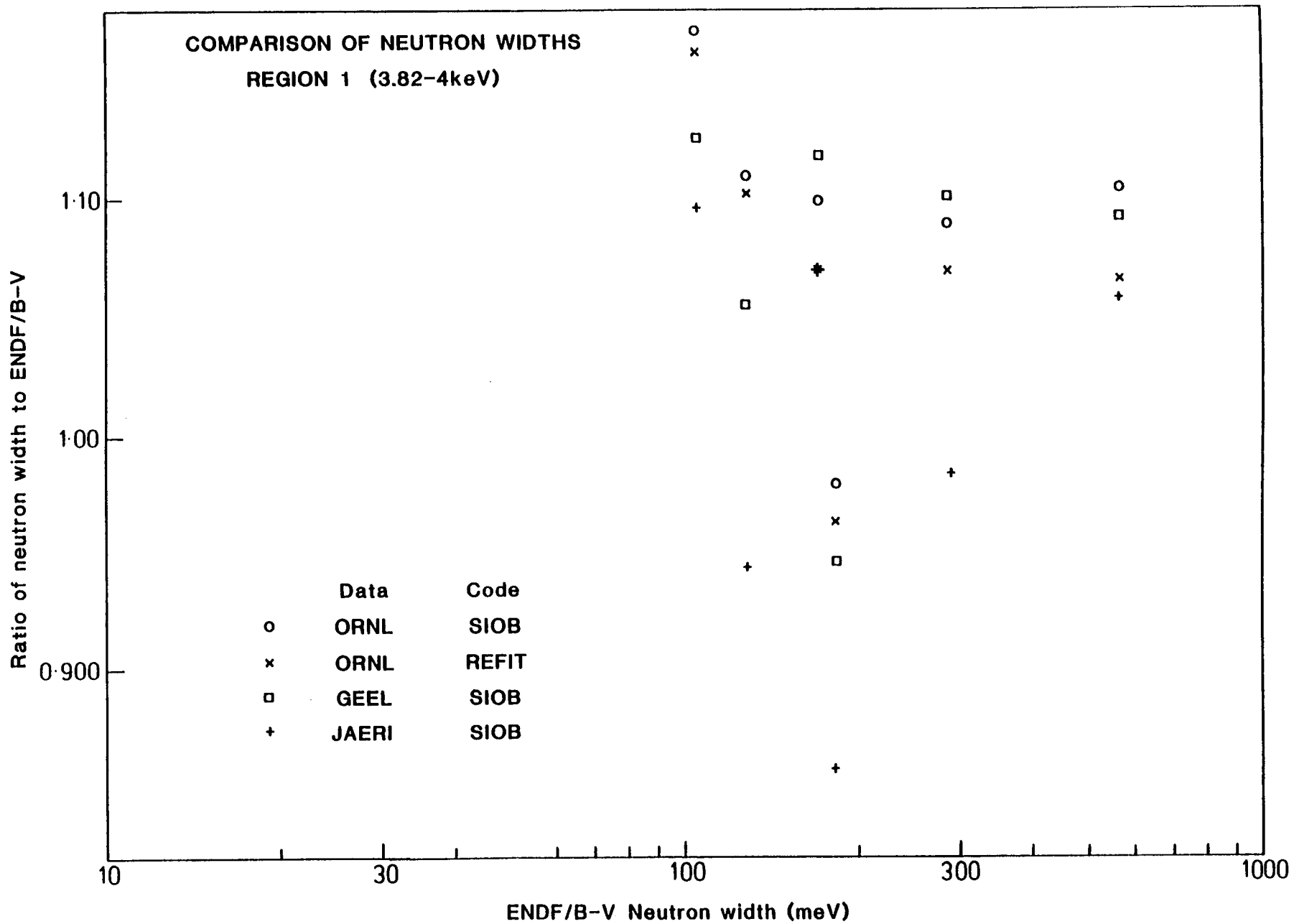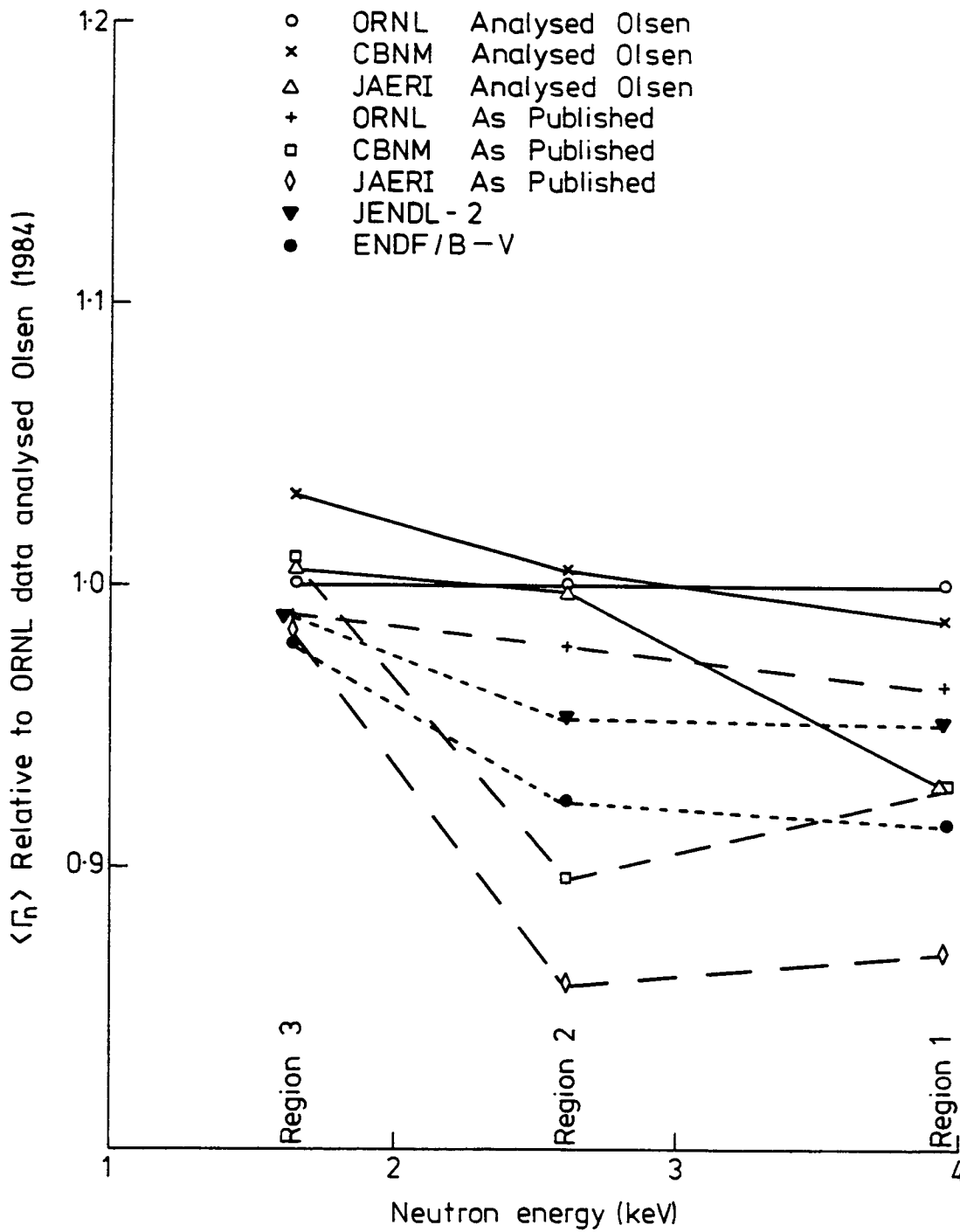
work also appeared to be necessary:

(1) A high resolution capture cross-section measurement (~150 m flight path) is urgently needed.

(2) There is a need for measurements to give more ℓ-wave assignments for resolved resonances.

(3) Higher resolution transmission measurements are desirable. To get a significant improvement over the present data, measurements are required using cooled samples on a 200 to 300 m flight path using a ~10 ns burst width and a neutron detector which has an improved and well known resolution function.

(4) A measurement of Γ_γ for p-wave resonances is required.

At the close of the Task Force meeting a discussion was held on how to improve future transmission experiments and their analysis. In order that future experiments do not repeat past mistakes a list of desirable practices is given below.

(i)   Always use several sample thicknesses including one thick one. The thickest sample should always give zero transmission for the principal resonances.

(ii)   Choose a detector whose resolution function can be understood and modelled. If it is a Li-glass scintillator keep photomultipliers and light guides out of the neutron beam. A boron-slab viewed by gamma-ray detectors may be better as there are no resonant impurities (e.g. Ce) in the neutron detector and the effects of multiple scattering are reduced.

(iii)   Measure resolution function of the detector and of the neutron source.

(iv)   Monitor the shape of the neutron producing accelerator pulse.

(v)   Measure the components of the neutron background and understand them. For example is the background dependent on the neutron flux at a slightly higher energy?

(vi)   Minimise dead time corrections; measure pulse to pulse variation of neutron production.

(vii)   Check there are no gain shifts due to count rate variations.

(viii) Monitor detector performance during experiment.

(ix)   If the neutron source is moderated use a single moderator. Otherwise make sure the moderators are decoupled.

(x)   Always analyse data taken with background samples (notch filters) and check their consistency with data taken with them removed.

(xi)   Where possible base resolution function on convolution of physical parameters whose energy dependence is understood.

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(b) Capture Cross-section Discrepancy

Though the U-238 capture cross-section was known in 1983 to ~±5% between
~30 and 500 keV [34] the uncertainty was as large as ±10% between 1 and 30 keV.
The differential data, therefore, did not meet the accuracy of ±3% or less
required by the users of the data [35]. Most of the capture cross-section
measurements in the lower energy range were old so the Task Force felt that
reanalysis of all these would be impossible and that new measurements would
therefore be required. However, it was also clear that improved capture
cross-section measurements alone would not necessarily remove the discrepancy.
They had to be combined with an ability to make more reliable calculations of
self-screening factors in the unresolved energy range. Accurate measurements of
the U-238 capture cross-section are difficult to make particularly below 30 keV
where prompt gamma-ray detection methods must be used (difficulties are
particularly due to the low neutron binding energy of U-239). Since very thin
samples cannot be used, multiple scattering and self-screening corrections have
to be made to the differential measurements. The Task Force therefore felt that
the resolution of the capture cross-section discrepancy was likely to require
work in the following areas:

(1) Extension of the resolved energy range to higher energies. A consistent
     analysis of high resolution transmission and capture data in the energy
     range 1 to ~10 keV appears to be the most promising approach.

(2) Improvement of representation in unresolved energy range so that
     self-screening and multiple scattering effects can be calculated more
     accurately.

(3) Check of resolved and unresolved data using benchmark data.

(4) Improved measurements of capture cross-section using a variety of
     techniques. A comparison of techniques is also desirable as is a
     measurement with a cooled sample.

However, before the new data were available some progress had been made in
finding the cause of the problems. In order to include all the small resonances
in his analysis of the transmission data in region 3 (1.45 to 1.81 keV) and
because there was some evidence [21] that the 1782 eV resonance was a doublet,
Moxon analysed the capture cross-section data of de Saussure et al [32] in this
region. He found that the data were inconsistent with the parameters obtained
from the transmission data and an assumed value of Γ_γ of 23.5 meV* unless the

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*Subsequently it has been shown that the average value of Γ_γ is 23.0 meV.

capture data were renormalised by a factor of ~0.9. The same renormalisation
factor is obtained for resonances with a large range of neutron widths
($\Gamma_n \ll \Gamma_\gamma$ to $\Gamma_n \gg \Gamma_\gamma$). Since the factor is independent of Γ_n for small
Γ_n, a renormalisation factor independent of Γ_n can only be obtained if Γ_γ
has a similar value of 23.5 meV for all resonances. Studies at lower energies
showed that the renormalisation factor was energy dependent and that at the 6.6
eV resonance no renormalisation was required. It was found that above the first
resonance the cross-sections of de Saussure et al had to be multiplied by a
correction factor (F) given by

$$F = 0.845*Exp(0.38421/SQRT(E))$$

where E is the energy in eV.

When this correction factor is applied the average values of the capture
cross-section are reduced and the values renormalised to the ENDF/B-VI standards
are given in Table 3. Also given are corrected values for Moxon [36] also
renormalised to ENDF/B-VI standards.

Moxon has also looked at his own data and finds that they are correctly
normalised within the quoted errors. The reduction of the de Saussure et al
data brings the more reliable capture cross-section measurements into better
agreement particularly above the resolved resonance region. It also tends to
bring the differential and integral data more into agreement and hence tends to
remove the discrepancy.

It has never been clearly established why the de Saussure et al experiment
was incorrectly normalised above the 6.6 eV resonance. The form of the
correction suggests an error in the neutron flux determination perhaps due to
incorrect treatment of absorption in the overlap filter. However, this is
largely conjecture as the raw experimental data are no longer available. The
Task Force therefore thought that improved measurements that stress small
corrections and new approaches and techniques were still desirable.

Finally it should be noted that the inclusion of the capture data helped to
confirm that the 1782 eV resonance is a doublet of s-wave resonances
approximately 0.5 eV apart. The doublet improves the fit to the transmission

data and obviates the need to have a resonance of abnormally high Γ_γ (~43 meV). The advantage gained by using capture data in the resonance analysis in this case adds support to the conclusion reached previously that transmission and capture data should both be used in any further analyses.

(c) Conclusions Reached by 1985

By the time of the Santa Fé Conference in 1985 [2] the Task Force had reached the following main conclusions:

(1) The discrepancy in the neutron widths of the resolved resonances had been shown to be due to the experimental resolution functions being wider and more complex than the experimenters have assumed.*

(2) The presently published values of the neutron widths were in error and so re-analysis was necessary, using shape analysis methods. The analysis should consider both transmission and capture measurements and cover the energy range up to 10 keV.

(3) It follows that all existing evaluations of resolved resonance parameters were in error. Ideally re-evaluations must wait for the re-analysis to be completed.

(4) The experimental resolution function of the best set of high resolution transmission data (Olsen et al [19]) is uncertain above 4 keV.

(5) In the longer term the following experimental work appears necessary

  (a) there is a need for measurements to give more ℓ-wave assignments for resolved resonances

  (b) higher resolution transmission measurements are desirable (e.g. cooled samples, 200/300 m flight path, 10 ns burst width, detector with improved and well known resolution function)

(6) There was evidence that the important capture cross-section data of de Saussure et al [32] were incorrectly normalised (at energies above the 6.6 eV resonance) which tends to reduce the discrepancies in the capture cross-section measurements.

(7) Further capture cross-section measurements, which emphasise new approaches and techniques and minimise corrections were still desirable.

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*In hindsight the inadequacy of these assumed resolution functions is not surprising as it had been noted that the systematic differences between sets of parameters increase with neutron energy and for any measurement tend to be largest when it is beginning to run out of energy resolution.

TABLE 3 Corrected Average Capture Cross-sections Renormalised to ENDF/B-VI
Standards

Average Energy (keV)	de Saussure+ renormalised (barns)	Moxon renormalised (barns)	Poenitz evaluation (barns)
0.15	16.3509		16.84
0.25	8.4759		8.627
0.35	2.9395		2.901
0.45	2.6912		2.671
0.55	4.6416	4.9869	4.252
0.65	3.4589	3.7606	3.460
0.75	1.8058	2.1142	1.733
0.85	2.8263	3.3871	2.892
0.95	3.8964	3.6541	3.824
1.5	1.8156	1.9822	1.842
2.5	1.3340	1.4891	1.397
3.5	1.1198	1.2397	1.153
4.5	0.8718	0.9697	0.882
5.5	0.8716	0.9464	0.861
6.5	0.8546	0.8303	0.775
7.5	0.7366	0.7995	0.736
8.5	0.6597	0.7294	0.643
9.5	0.6530	0.7278	0.653
15	0.5879	0.6166	0.581
25	0.4725	0.4675	0.478
35	0.4234	0.3760	0.415
45	0.3599	0.3495	0.361
55	0.2911	0.3003	0.295
65	0.2521	0.2556	0.251
75	0.2183	0.2140	0.220
85	0.1980	0.1832	0.200
95	0.1754	0.1801	0.186

It was therefore clear by the Summer of 1985 that the cause of the neutron
width discrepancy had been established. Progress had also been made on the
capture cross-section problem. However, the final resolution of this problem
came about from activities external to the Task Force though to a limited extent
these may have been influenced by the Task Force's thoughts and findings.

5.   The Resonance Analysis Work on U-238 Post 1985

Following the Santa Fé Conference on Nuclear Data for Science and
Technology, the activities of the Task Force have involved fewer of its members
and work has essentially been concentrated on tasks related to the production of
improved resonance parameters. The following activities have taken place:

(a)   A new shape analysis by Olsen [37] at Oak Ridge of the transmission
      data of Olsen et al [19] using the code SIOB.

(b)   A new high resolution measurement of the capture cross-section of
      U-238 by Macklin et al [38] at Oak Ridge.

(c)   A new high resolution transmission measurement using cooled samples by
      Harvey et al [39] at Oak Ridge.

(d)   A new shape analysis using the code REFIT of transmission and capture
      data by Moxon et al [4,5] at Harwell and the NEA Data Bank.

As the new measurements of Harvey et al have not so far been included in any of
the resonance analysis work because of resource limitations, they will only be
described briefly. The other items partly took place in parallel and this has
produced some problems which will be discussed later.

     The resonance analysis of Olsen was a major step forward as it produced the
neutron widths of 676 resonances between 0.9 and 10 keV from a consistent least-
squares simultaneous shape analysis of the 150 m, 4 sample transmission data of
Olsen et al using the code SIOB. The resolution function whose parameters were
found as part of the analysis had the same form as described in Section 4(a).
The values of d, L and F, which are defined in Table 2, are given in Table 4
averaged over 3 keV energy intervals. As was found before, this resolution
function is wider and more asymmetric than one would have initially assumed.
There was, however, no clear trend of the parameters with average neutron
energy. It should be noted that it was also found that the parameters from some
of the fits differed significantly from these average values. Such differences
could partially be due to the presence of small resonances not included in the
fitting procedure.

TABLE 4   Resolution Function Parameters from the Analysis of Olsen [37]

Energy Range	d (mm)	F	L (mm)
1 - 4	32.0	0.33	39.6
4 - 7	31.4	0.38	41.1
7 - 10	32.7	0.33	42.0

Fig. 9 shows a section of the simultaneous fit in the energy range around
5.5 keV and it can be seen that the fits are reasonably good. All resonances
were fitted as $J = \frac{1}{2}$ levels; in general the smaller resonances were assumed to
be $\frac{1}{2}^-$ levels and the larger resonances $\frac{1}{2}^+$ levels. However, above 6 to 8 keV it
becomes important that "on average" the levels are correctly divided into s- and
p-wave populations since the difference in the s- and p-wave resonance shapes
has an appreciable effect on the extracted resolution function, which in turn
influences the $g\Gamma_n$ values of all the resonances. This sensitivity does not
occur at lower energies because the $g\Gamma_n$ values of the p-wave resonances are
too small to have an effect. The division into s- and p-wave populations was
therefore done following the prescription of Bollinger and Thomas [40] assuming
that the strength functions were 1.0×10^{-4} and 1.9×10^{-4} respectively. The
resonance parameters obtained are given in Appendix 2. Below 4 keV the widths
are substantially larger than those obtained in the original analysis of the
data [19].

The high resolution measurement of the U-238 capture cross-section [38] was
also a major step forward. The Oak Ridge scintillator tank (ORELAST) was used
as the capture detector on a 151.9 m flight path of the Oak Ridge Linear
Accelerator (ORELA). Measurements were made for two sample thicknesses. The
pulse width of the accelerator was typically 14 nsec and timing channels of 4 ns
or greater were used. The neutron spectrum was measured using a Li-glass
scintillator positioned just upstream of the ORELAST tank. The resulting
capture yield data cover the energy range 254 eV to 2.5 MeV. The experiment was
normalised to 8 small resonances in the energy range below 1070 eV where
essentially the normalisation constant is proportional to the neutron width.
The normalisation was accurate to ±6% and ±8% for the 0.01236 and 0.00309 atoms
per barn samples respectively. The backgrounds were estimated by performing
runs at two pulse repetition frequencies and extracting the energy dependent
background from the data on the assumption that it is always due to neutrons
generated more than one accelerator pulse previously. The time-independent
backgrounds were measured by blocking off the neutron beam with a polyethylene
plug (for the U-238 data) and from the count rate at the bottom of the 5.903 keV
aluminium resonance dip (for the Li glass detector). The overall uncertainties
in the measured U-238 capture yields due to background were about ±5% up to 10
keV and ±4% from 10 to 100 keV. These measurements produced data which had
better resolution than the transmission measurements of Olsen et al [19] with a
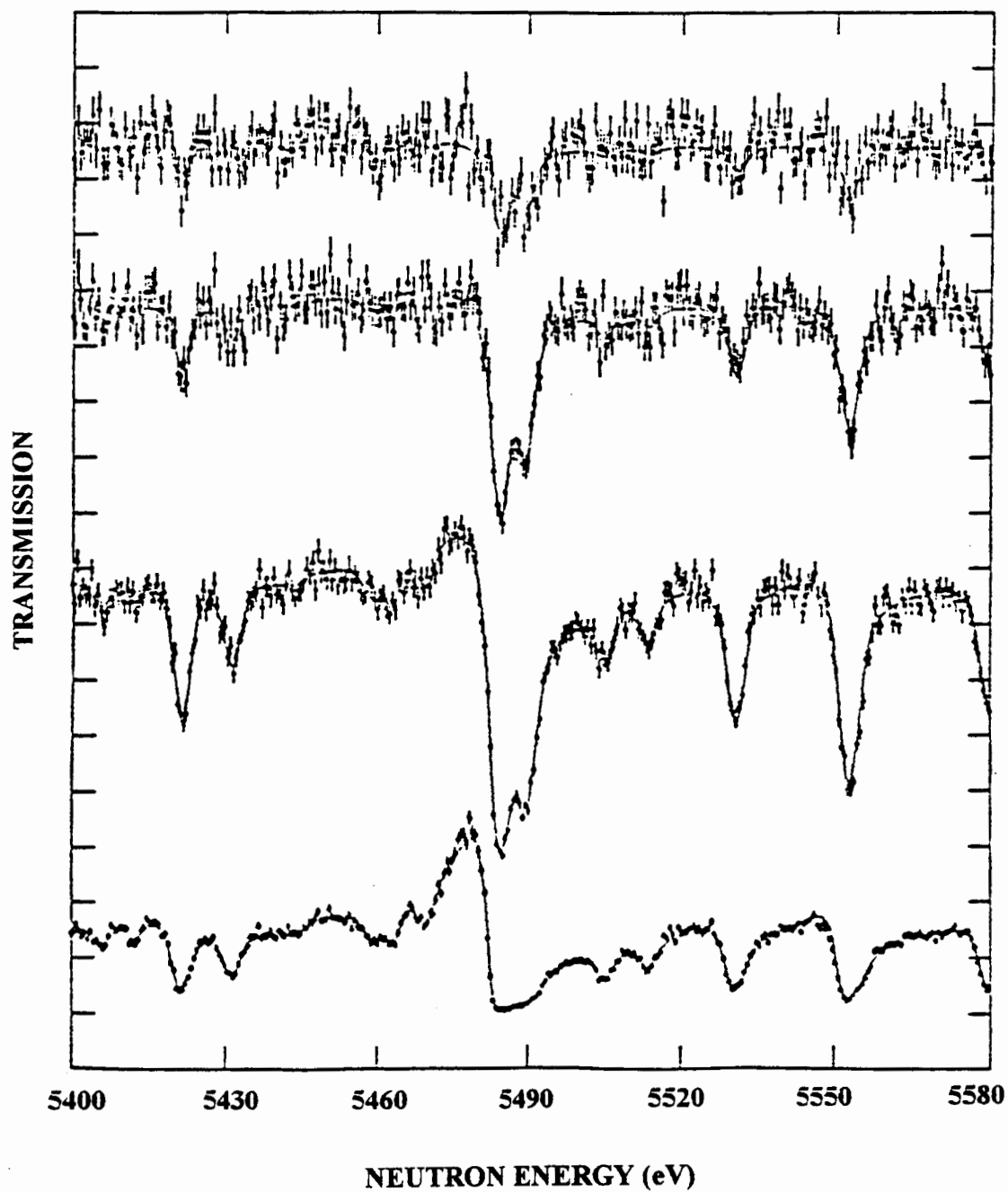similar flight path length.

Figure 9 Simultaneous least-squares fit with multi-level Breit-Wigner formalism
by Olsen to transmission data for 0.076 (upper curve), 0.254, 1.080
and 3.62 cm thick (lower curve) samples of U-238.

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The new U-238 transmission measurements at Oak Ridge were also an important addition to the data available for resonance analysis - unfortunately at the present time resources have not been made available to analyse them. Measurements were made from 1 to 100 keV for 3 sample thicknesses at a flight path of 201.558 m on ORELA using a new neutron detector with a 1 cm thick NE110 based proton recoil scintillator coupled to two photomultipliers mounted outside the neutron beam. The accelerator burst widths were 6 ns for the thickest sample (0.1748 atoms/barn) and 15 ns for the 0.0396 and 0.01235 atoms per barn samples. The neutron energy resolution was less than the Doppler broadening below 15 keV. These data when combined with the capture data of Macklin et al [38] should enable U-238 resonance parameters to be extracted up to 15 keV if required.

The new resonance analysis by Moxon et al [4] which uses the shape analysis code REFIT was underway before the new resonance analysis of Olsen [37] and the new capture measurements of Macklin et al [38] were available. REFIT is the only code available that will perform shape analysis of capture yield measurements where it is necessary to take into account the effects of multiple scattering in the capture samples as well as the necessary resolution and Doppler broadening calculations. This makes the analysis very expensive in computer time and to minimise costs it is only possible to analyse a limited number of measurements. Table 5 shows the data that have been used.

TABLE 5 Data used in the U-238 resolved resonance analysis

Energy range	Capture data	Transmission data
0-900 eV	*de Saussure et al [32] Moxon [36] **	Olsen et al [28]
900-4000 eV	*de Saussure et al [32] Macklin et al [38]	Olsen et al [19]
4000-10,000 eV	Macklin et al [38]	Olsen et al [19]

* Data renormalised

**First few resonances only

Above 4 keV the selection of experiments is easy as only the data of Macklin et al and Olsen et al have the necessary resolution. Below 4 keV the selection was made bearing in mind the following points: quality of data, ability to model the resolution function of the experiment and availability of results. The selection of transmission data was made easier because the work of the U-238 Task Force [2] had previously shown that the parameters obtained from the improved shape analyses of the data of Poortmans et al [9], Nakajima [18] and Olsen et al [19] were on average the same and the data of Olsen et al were of far higher quality.

It has been seen that the modelling of the experimental neutron energy resolution function is of crucial importance. It is also clear that the uncertainties in the function are more serious for transmission measurements than for capture measurements because the amount of material in the neutron beam associated with the detector has not been minimised in most transmission detectors. The uncertainties arise because the shape of the function cannot be directly measured as a function of neutron energy though information can be obtained from subsidiary measurements (see below). In principle detailed Monte Carlo calculations of its shape, which take account of the effect of the details of the neutron producing target, flight path and detector and their environments, can be made but in practice this has essentially not been done. It is therefore necessary to have a model of the function which needs to be as physically meaningful as possible if its variation with incident neutron energy is to be established. The parameters in this model can be deduced by studying the shapes of suitable narrow, well resolved resonances. Unfortunately few of these exist and the parameters in the model are usually estimated as part of the shape analysis procedure for each experiment considered. Obviously these parameters may not be correct unless all the small resonances are included in the analysis. Why therefore should one believe that the formulation of the function used in REFIT is good in the analyses discussed below? The answer is that the function gives a good physical representation whose parameters are well established because

(1)   both capture yield and transmission data are analysed
(2)   as many resonance parameters as possible have been identified and included in the analysis

The REFIT analyses to produce U-238 resonance parameters are all being performed in a number of stages listed below. In all of these the resonances are divided into s- and p-wave populations using known assignments [41,42,43] where possible and making use of the work of Smith [44] which is based on reproducing the known spacing distributions and the Porter-Thomas distribution of neutron widths.

(1) An evaluated list of neutron widths obtained from previous analyses is produced. Where possible this uses the results of recent shape analyses of data.

(2) These parameters are used, assuming that the capture width (Γ_γ) is 23.0 meV if not otherwise known to compute the shape of the capture yield using the version of REFIT which does a simplified multiple scattering cross-section. The shapes of the measured and computed capture yields are then compared and the resonances not seen in transmission but visible in capture are identified; neutron widths are estimated and added to the evaluated list. Care is taken in all this to ensure, by fitting the transmission data in some cases, that the estimated parameters are consistent with the transmission data.

(3) Stage 2 is repeated until all possible small levels have been identified in the capture yield data and this is reasonably fitted by the evaluated parameters.

(4) A simultaneous fit of the transmission and capture data is performed using the version of REFIT which does a more exact multiple scattering correction and values of the Γ_n and Γ_γ are obtained as appropriate.

At the present time Stage 3 has been reached for the whole energy range up to 10 keV. For the energy range below 4 keV the data are well known and Stage 4 may not be necessary. Above 4 keV the adequacy of the data gets worse as one goes to higher energies but there may be some small levels that need to be added to the present list. For further discussions it is convenient first to discuss the energy range below 4 keV starting at low energies.

In the low energy range the evaluated parameters have been obtained from a variety of data and analyses. For example for the large s-wave resonances the transmission data have been analysed below ~300 eV to obtain values of Γ_γ, Γ_n and T_{eff} (the effective temperature in the gas model of Doppler broadening) and the results are given in Table 6. These values have been used

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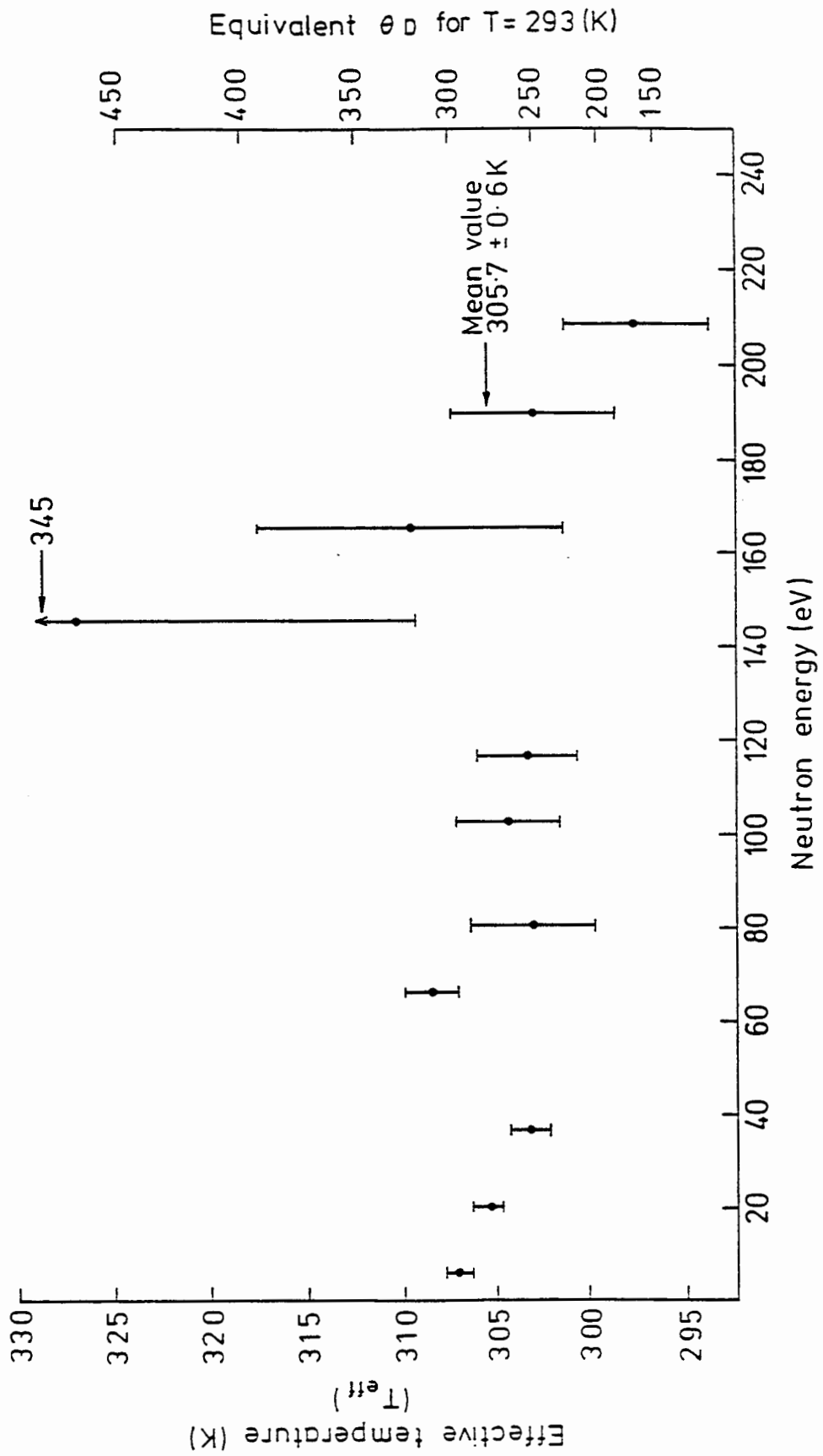
EFFECTIVE TEMPERATURE OBTAINED FOR U METAL SAMPLES · BY RESONANCE
SHAPE ANALYSIS

Figure 10

for Γ_γ (208 eV resonance and below) and Γ_n (311 eV and below). The average value of Γ_γ from the Table is 23.0±0.05* meV which is slightly lower than previous determinations, probably due to the values of Γ_n being higher. The values of T_{eff} have been discussed elsewhere [45]; as can be seen from Figure 10 they indicate that solid state effects may be present for the first two resonances and that T_{eff} is inconsistent with the value derived from the Debye temperature (Θ_D) of ~200K. Between 311 eV and ~1 keV the neutron widths for s-waves were obtained by adjusting the values of Olsen et al [28] upwards by 2½ to 4% (to compensate for the use of an incorrect resolution function in the original analysis) or from new transmission analyses. (For p-waves below 1 keV the Γ_n values were taken from existing analyses.) The values of Γ_γ were obtained by renormalising the data of Poortmans et al [9] to allow for changes in Γ_n values between the one assumed in their analysis and the values now recommended or, except for the 721.69 eV resonance where the value of 4.7 meV of Auchampaugh et al [46] was adopted, by assuming a value of 23.0 meV.

TABLE 6   Fitted parameters for low energy resonances in U-238**

Resonance energy (eV)	Capture width (Γ_γ) (meV)	Neutron width (Γ_n) (meV)	Effective temperature (T_{eff})	
			(meV)	(K)
6.6741	22.997±0.042	1.4926±0.0023	26.461±0.065	307.05± 0.7
20.8735	22.911±0.040	10.258 ±0.0093	26.320±0.082	305.43± 0.81
36.6849	22.890±0.048	34.129 ±0.023	26.117±0.110	303.11± 1.16
66.0382	23.364±0.121	24.605 ±0.041	26.587±0.134	308.44± 1.51
80.7521	23.416±0.577	1.865 ±0.022	26.108±0.275	302.99± 3.37
102.5677	23.416±0.195	77.704 ±0.195	26.211±0.233	304.27± 2.79
116.9077	22.995±0.261	25.486 ±0.093	26.134±0.240	303.22± 2.67
145.6713	19.086±8.58	0.8470±0.042	28.181±1.53	327.01±17.75
165.3107	25.763±2.94	3.367 ±0.0075	26.664±0.71	309.37± 8.12
189.6853	22.378±0.403	173.2 ±0.32	26.094±0.39	302.87± 4.41
208.5244	23.937±0.31	51.11 ±0.20	25.641±0.31	297.54± 3.71
237.3984	25.795±0.84	27.159 ±0.16	26.410±0.38	306.47± 4.41
273.6695	25.173±1.18	25.78 ±0.18	25.767±0.41	299.01± 4.76
291.0123	20.995±2.08	16.873 ±0.17	26.618±0.54	308.88± 6.27
311.3067	21.610±3.48	1.089 ±0.133	26.631±3.81	309.04±44.2

**The errors are the values given by the code and do not take full account of systematic errors.

*Systematic errors not included.

COMPARISON OF MEASURED U^{238} CAPTURE YIELD DATA OF MOXON (1969)
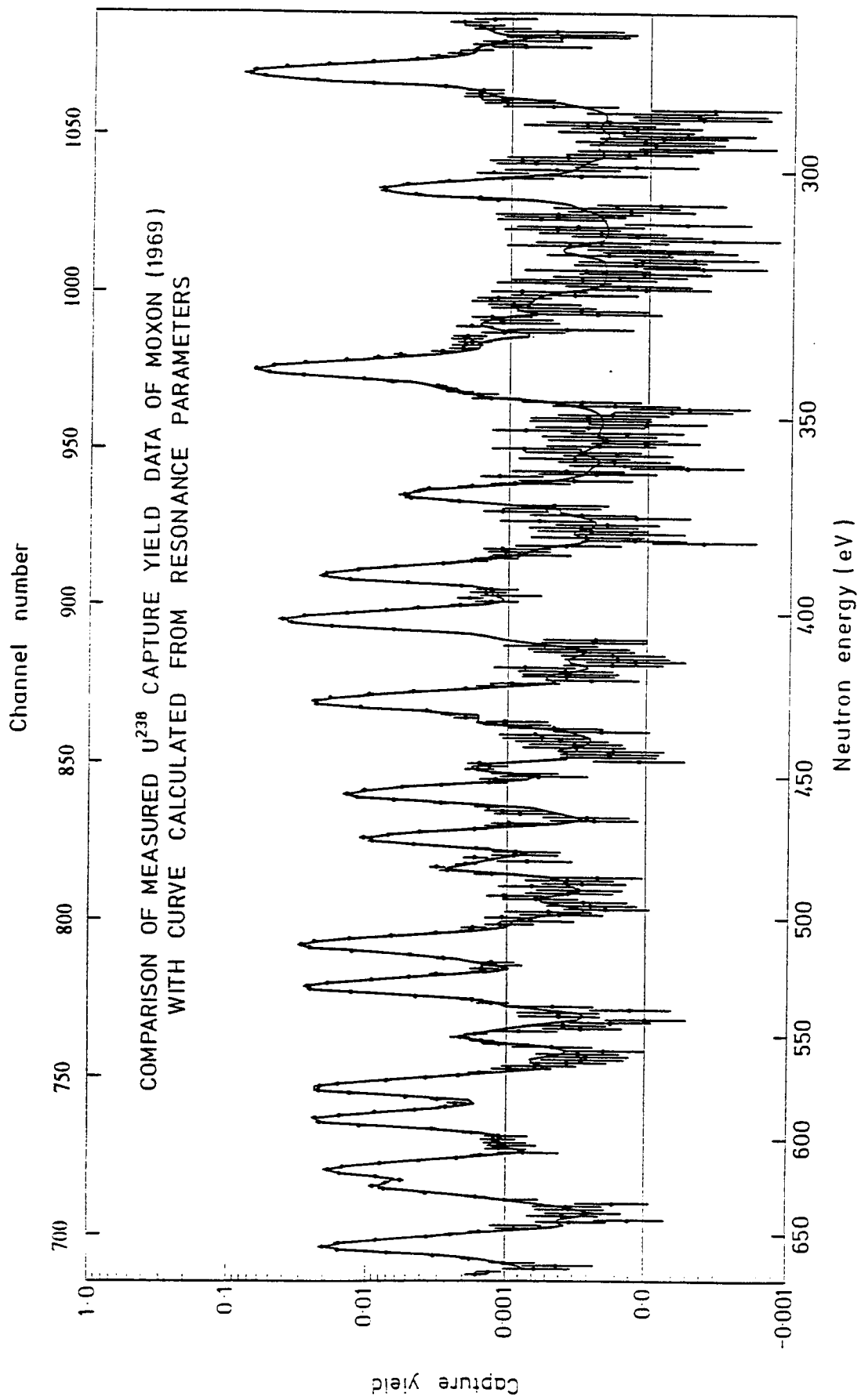WITH CURVE CALCULATED FROM RESONANCE PARAMETERS

Figure 11

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The set of parameters obtained fits both the transmission and capture yield data well. As an example Fig. 11 shows a comparison of the measured yield data of Moxon [36] with a curve calculated with REFIT from the parameters described above and it can be seen that the agreement is excellent.

Between 1 and 4 keV the list of neutron widths is derived from REFIT analyses of Moxon combined with data from Olsen et al [19] (the new analysis of Olsen mentioned above was not available when this energy range was in progress) and the results that had been obtained in regions 1, 2 and 3 studied by the Task Force. Except for the 1211.11 eV resonance where sub-threshold fission occurs and the value of 14.13 meV was adopted, Γ_γ has been assumed to be 23.0 meV. Where overlapping resonances are needed to fit the data they are always analysed on the assumption that Γ_γ has this value. The resonance at ~1787.7 eV has been mentioned before where either Γ_γ has to be 46 meV or there are two s-wave resonances with Γ_n = 492.5 and 163.2 meV very close together. (At this energy the average $g\Gamma_n$ for p-wave resonances is ~1 meV.)

As the analysis approached 4 keV it was clear that a full representation of the resonance cross-section without background contributions due to unresolved resonances was not going to be possible much above 4 keV as the capture yield data of de Saussure et al [32] was running out of energy resolution. However, Macklin et al [38] kindly provided their high resolution data in preliminary form. About the same time the new resonance analysis of transmission data by Olsen et al became available and so it was possible to continue the analysis as described from 1 to 4 keV to higher energies obtaining the initial set of neutron widths from the unpublished work of Moxon and the new analysis of Olsen. Thus by 1988 a set of parameters was obtained to 10 keV which gave a fairly good representation of the preliminary capture yield data at 4 keV but was less adequate at 10 keV.

As examples of the analyses and the problems encountered, Figs. 12 and 13 show a comparison of measured transmission and capture data of Olsen et al and Macklin et al with values calculated from resonance parameters in the 4970 to 5070 eV and 9180 to 9320 eV energy ranges. In the lower energy range two peaks are visible in the capture cross-section at ~5038 eV but only one is readily apparent in the transmission data. In the calculation shown it is assumed that the upper of the peaks at ~5040 eV has a Γ_n of 133 meV. To get a reasonable
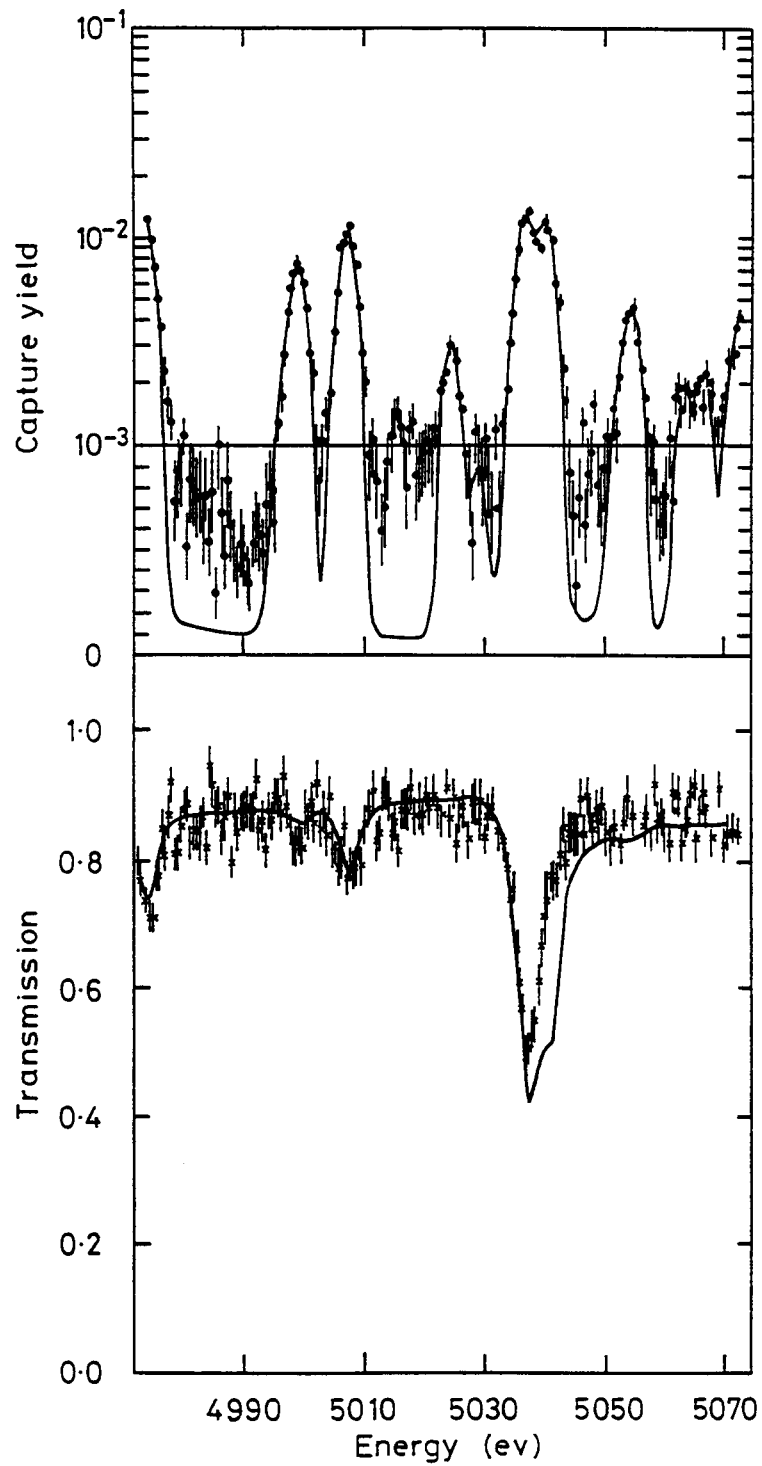
Figure 12   Comparison of the preliminary capture yield data of Macklin et al and
            the transmission data of Olsen et al with the curve calculated from
            the 1988 set of resonance parameters.

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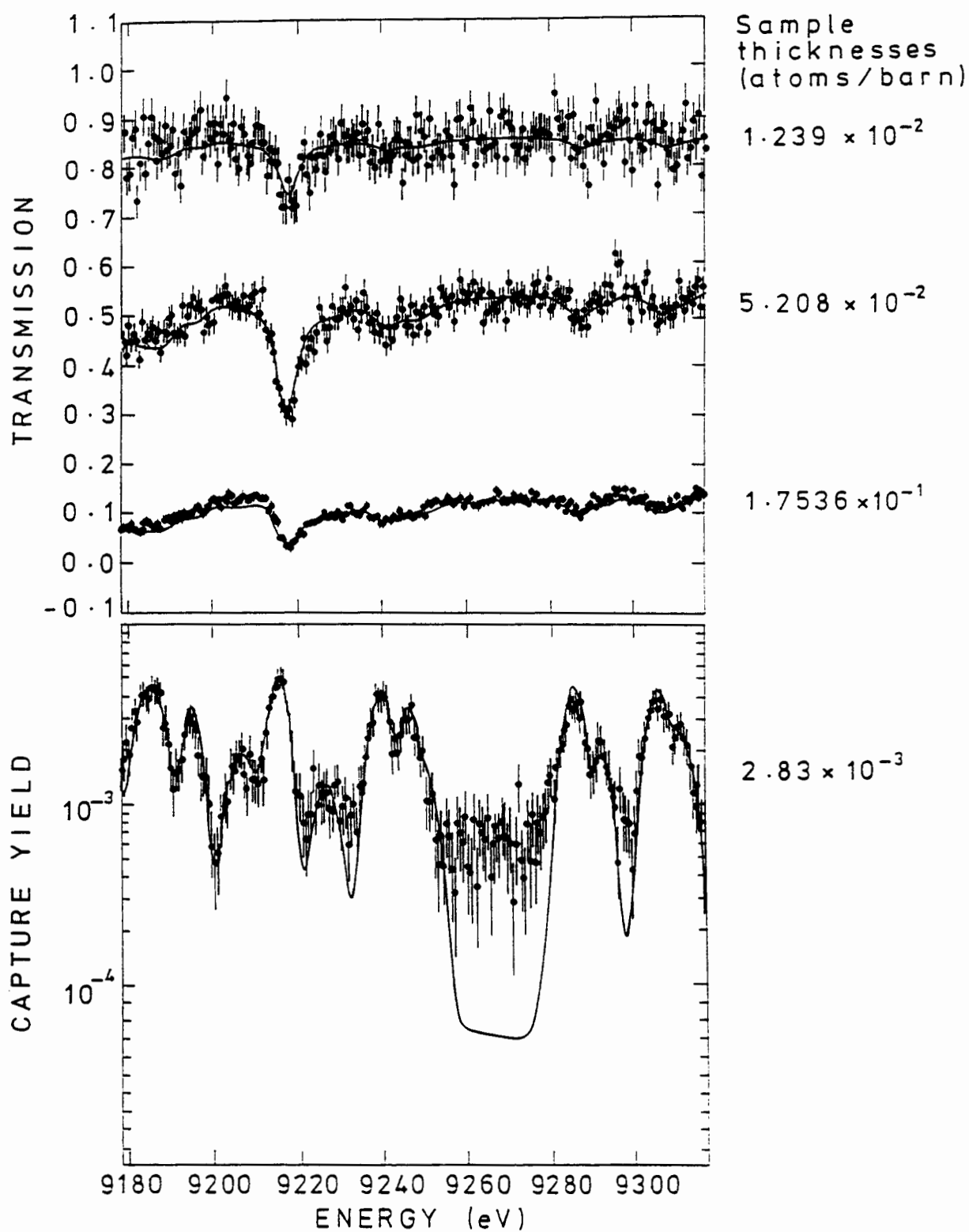
Figure 13 Comparison of transmission measurements of Olsen et al and
preliminary capture yield measurements of Macklin et al with values
calculated from resonance parameters.

fit this resonance has to be replaced by two resonances with neutron widths ~17 meV which will hardly be visible in the transmission data. In the upper energy range the transmission data can be fitted with 6 resonances between 9180 and 9320 eV while the analysis shown requires 21 resonances to fit the capture data. As ~36% of the capture cross-section between 9 and 10 keV is accounted for by resonances not seen in transmission measurements and many of the missing resonances overlap with the larger resonances visible in these data, the need to analyse both capture and transmission data by shape analysis methods is clearly demonstrated.

Table 7 gives the number of resonances in the 1988 set of data. It can be seen that many additional resonances have been included in the parameter set above those in previous evaluations such as ENDF/B-V.

TABLE 7   Number of resonances included in analysis of 1988

Energy range (keV)	Transmission analysis Olsen et al [28] Olsen [37]		Present analysis transmission and capture	ENDF/B-V
0 - 1	107		156	146
1 - 2		91	148	120
2 - 3		83	133	91
3 - 4		79	132	85
4 - 5		73	190	
5 - 6		81	162	
6 - 7		73	166	
7 - 8		70	152	
8 - 9		55	151	
9 - 10		60	168	

It had been decided that for JEF-2 the evaluation of Poenitz [47] undertaken as part of the ENDF/B-VI standards evaluation would be used for the U-238 capture cross-section. It was therefore disappointing to find that though there was broadly good agreement between this and the average cross-section calculated from the 1988 parameter set below 4 keV, between 4 and 10 keV the difference between them progressively increases. Careful investigation showed that part of the problem was due to the use of the preliminary data of Macklin et al in the analysis. The use of the final data tended to reduce but did not eliminate the problem. Further analysis showed that some renormalisation and background correction of the data was required. This is not surprising as

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neither the background nor the normalisation were accurately known. As an example of how well the data can be fitted when corrections are applied, Figure 14 shows the data of Macklin et al in the vicinity of the 1393.8 and 1405.4 eV resonances when corrections for normalisation (factor = 1.0878 and background yield = 6.7 x 10^{-4}) have been applied. From this comparison the excellent agreement shows (a) the gas model of Doppler broadening with an effective temperature (305.7 K) is correct in this energy range, (b) the code REFIT performs correctly the necessary multiple scattering Doppler and resolution broadening and (c) the renormalisation and background correction are necessary.

The next stage of the work was to establish the corrections that had to be applied to the data of Macklin et al over the whole energy range to 10 keV. An important feature of the study has been to investigate if the corrections have any energy dependence as

(1)   backgrounds usually have an energy dependent component

and   (2)   energy dependent normalisation errors can arise from errors in neutron flux determinations.

It is well known that the shape analysis method enables background and normalisation corrections to be found - it is normal practice to do so in the analysis of transmission data. At first, therefore, a number of attempts were made using the code REFIT to check the normalisation and background of the Macklin et al data. These were unsatisfactory in the high energy region where the method was particularly needed as the deduced corrections were highly correlated. The reasons for this are not completely clear, however it is believed to be due in part to the effect of overlapping resonances which are not visible in transmission data. In view of this it was decided to work resonance by resonance.

The principle of the method adopted is that using a shape analysis code the peak height in a capture measurement (and its capture area) can be derived from the resonance parameters obtained from transmission measurements. Under certain circumstances the derived quantity is accurate and hence can be used to normalise the experiment. Normally capture experiments are normalised at very low energies using resonances where the neutron width (Γ_n) is much less than the capture width (Γ_γ) and, on resonance, the samples are thick. Under these
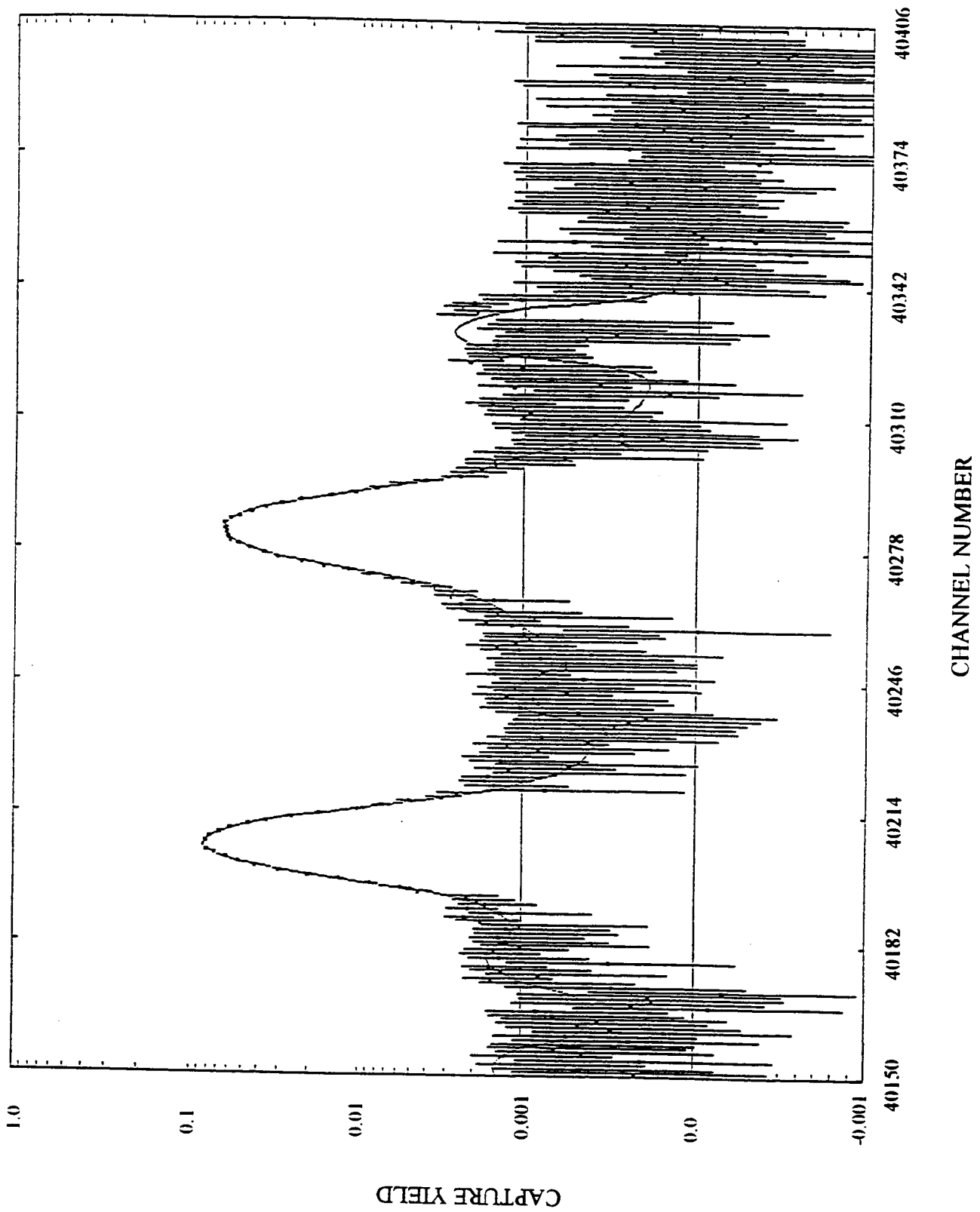
Figure 14   Comparison of the calculated yield curve with renormalised and
            background corrected final data of Macklin et al in the vicinity of
            the large s-wave resonances at 1405.4 (Γ_n = 75.5 meV) and 1393.8
            (Γ_n = 215 meV) eV resonances.

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conditions a fraction $\Gamma_\gamma/(\Gamma_\gamma + \Gamma_n)$ (i.e. ~100%) of the incident neutrons are absorbed in the sample and hence the experiment can be normalised. As one goes to higher energies multiple scattering is more important but the normalisation can be checked by calculating capture areas (and peak heights if the Doppler and resolution broadening data are adequate). It is important that the resonances are isolated and the best (independent of assumptions) data are obtained when

(a) $\Gamma_n \ll \Gamma_\gamma$ and Γ_n accurately determined from transmission data

or (b) $\Gamma_n \gg \Gamma_\gamma$

In these two cases the capture area $((g\Gamma_n\Gamma_\gamma)/(\Gamma_n+\Gamma_\gamma))$ is proportional to Γ_n and Γ_γ respectively.

The method using $\Gamma_n \ll \Gamma_\gamma$ was adopted by Macklin et al but there are very few resonances which obey the criteria. The resulting normalisation has an accuracy of ±7.8% for the 0.00309 atoms/barn sample which is being analysed in the present study. The method using resonances with $\Gamma_n \gg \Gamma_\gamma$ essentially assumes a value of Γ_γ. This is not unreasonable as examination of parameters below 1 keV where the data of Macklin et al are not used shows that the values of Γ_γ have an R.M.S. deviation of ±0.68 meV. Therefore it has been assumed that Γ_γ is 23 meV and is independent of neutron energy and a comparison made of the measured and calculated capture areas for resonances in the Macklin et al data which are isolated and do not overlap with others. The resulting data are shown in Fig. 15 where it can be seen that above about 600 eV the ratio is approximately constant and has a spread in values consistent with the expected spread in Γ_γ values. It can also be seen that the ratios appear to be independent of Γ_n but that below 600 eV there is evidence of an energy dependent normalisation. From these data it is concluded that the Macklin et al experiment needs to be renormalised by a factor 1/0.91. Examination of the data showed that the factor appeared to fit satisfactorily up to 10 keV.

During the examination of the data to produce the ratio of resonance areas discussed above, the level of between resonance capture was examined systematically. It was found that above about 3 keV the level was constant at 0.0007, which is equivalent to a cross-section of 0.227 barns.

By the time that these background and renormalisation factors had been deduced there was not time to modify the Macklin et al data and perform a new

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Figure 15   The ratio of the measured to calculated capture areas for a selection
of resolved resonances in the data of Macklin et al. The solid
squares, open squares and solid diamonds are for resonances with Γ_n
values <40, 40-80 and >80 meV respectively.

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resonance analysis before a set of parameters was needed for the preliminary
JEF-2 (and ENDF/B-VI) evaluations. A procedure to correct the parameters
obtained with the preliminary Macklin et al data above 4 keV was therefore
developed.

The first step in this was to calculate, using REFIT and the experimental
conditions of the Macklin et al experiment, the peak height (P) for a range of
isolated resonances with a range of neutron widths (Γ_n) and resonance
energies (E_R) between 4 and 10 keV. Using these an algorithm was developed
giving P as a function of g, Γ_n, Γ_γ and E_R as in equation (7)

$$P = F(g, \Gamma_n, \Gamma_\gamma, E_R) \tag{7}$$

Using this, P was first calculated for each resonance for which there were
parameters and then it was corrected for background and normalisation to give a
revised peak height (P_r) given by

$$P_r = (P - 0.0007)/0.91 \tag{8}$$

From P_r a revised value of Γ_n was obtained using equation (7). Corrections
were not made for all resonances as (a) there was a limiting value of Γ_n above
which no corrections were made and (b) values of Γ_n were never increased.
Where the correction procedure lead to a negative value of P_r then it has been
assumed that Γ_n equals 1×10^{-10} eV but the resonance is retained.

The resulting parameters have been used in the preliminary JEF-2 file and
in ENDF/B-VI. As can be seen from Table 8 the capture cross-section calculated
from the revised data (some modifications were also made below 4 keV) agrees
well with the evaluation of Poenitz except in the energy range 6 to 7 keV. This
energy range contains a number of strong s-wave resonances which probably cause
the corrections for self screening and multiple scattering used in the
measurements considered by Poenitz to be in error. Table 9 shows the number of
resonances included in the 1990 set of data.

In order to produce the evaluated set of parameters, resonances outside the
range 0 to 10 keV have to be included. These were chosen so that

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TABLE 8 Comparison of average capture cross-sections for U-238

Energy Interval (keV)	Average capture cross-section (barns)		
	Poenitz [47]	Calculated from resonance parameters	
		Initial 1988 set	Final 1990 set following renormalisation and background correction
0.1-0.2	16.84 ±0.38	16.69	16.69
0.2-0.3	8.627±0.183	8.815	8.815
0.3-0.4	2.901±0.061	2.942	2.942
0.4-0.5	2.671±0.057	2.684	2.684
0.5-0.6	4.252±0.148	4.935	4.935
0.6-0.7	3.460±0.067	3.548	3.548
0.7-0.8	1.733±0.033	1.838	1.838
0.8-0.9	2.892±0.056	2.958	2.958
0.9-1.0	3.824±0.074	4.078	4.078
1.0-2.0	1.842±0.035	1.873	1.873
2.0-3.0	1.397±0.029	1.354	1.354
3.0-4.0	1.153±0.026	1.148	1.148
4.0-5.0	0.882±0.021	0.958	0.878
5.0-6.0	0.861±0.019	0.968	0.897
6.0-7.0	0.775±0.017	0.964	0.876
7.0-8.0	0.736±0.016	0.801	0.690
8.0-9.0	0.643±0.015	0.752	0.628
9.0-10.0	0.653±0.013	0.819	0.654

(1) the known 2200 m/s and resonance integral values are reproduced

(2) the scattering radius is correctly reproduced through the resonance region using the technique recommended by Fröhner [48]

The fission widths adopted in the evaluation are based on the data of Difilippo et al [49]. The values were revised to take into account the new values of Γ_γ and Γ_n and the analysis of Auchampaugh et al [46]. Above 1211 eV the fission clusters are not resolved but they are taken into account by arbitrarily dividing the cluster fission area between nearby s-wave resonances.

TABLE 9   Number of resonances included in analysis of 1990

Energy range (keV)	Transmission analysis		Present analysis transmission and capture				ENDF/B-V
	Olsen et al [28]	Olsen [37]	s	$p_{1/2}$	$p_{3/2}$	Total	
0 - 1	107		48	38	79	165	146
1 - 2		91	48	36	81	165	120
2 - 3		83	45	34	64	143	91
3 - 4		79	49	30	60	139	85
4 - 5		73	46	55	89	190	
5 - 6		81	48	40	75	163	
6 - 7		73	48	47	71	166	
7 - 8		70	46	41	65	152	
8 - 9		55	47	42	62	151	
9 - 10		60	48	40	80	168	

Appendix 3 gives the resulting set of parameters in ENDF/B-VI format which are currently contained in the JEF-2 file for U-238. As an example of the data, Table 10 shows the values of energy, neutron, capture and fission widths for some selected s-wave resonances which predominantly have capture widths not equal to 23 meV or have non-zero fission widths.

The 1990 set of parameters is not the final set and as stated in the introduction work is still going on - though reduced funding in the UK for the work is stretching the timescale. The present parameter set is currently being benchmark tested and this work may lead to further modifications of the data. However, the parameters are much superior to anything available previously and should enable reactor parameters to be calculated with confidence and accuracy.

6.   Review of Main Conclusions Reached by the Task Force

The work of the U-238 Task Force established by the NEANDC in 1982 has taken many years and is still not complete. However, a number of major conclusions can be drawn.

(1)   The Task Force has established that the discrepancies in the neutron widths of U-238 above 1.4 keV were due to the resolution functions of experiments being broader and more complex than the experimenters assumed.

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TABLE 10 Resonance parameters for selected s-wave resonances (see text)

Resonance energy (eV)	Neutron width (eV)	Capture width (eV)	Fission width (eV)
-4405.25	1.0855E+02	2.3000E-02	0.0000E+00
- 33.30	1.0730E-02	2.3000E-02	1.1025E-06
6.6740	1.4930E-03	2.3000E-02	9.9900E-09
20.871	1.0260E-02	2.2910E-02	5.4200E-08
36.682	3.4130E-02	2.2890E-02	9.7700E-09
66.032	2.4600E-02	2.3360E-02	5.2650E-08
80.749	1.8650E-03	2.3000E-02	6.0490E-08
102.56	7.1700E-02	2.3420E-02	1.2860E-08
116.902	2.5490E-02	2.2990E-02	0.0000E+00
189.67	1.7320E-01	2.2380E-02	3.5730E-08
208.51	5.1110E-02	2.3940E-02	8.3470E-08
237.38	2.7160E-02	2.4540E-02	3.5420E-08
273.66	2.5780E-02	2.2100E-02	0.0000E+00
291.00	1.6870E-02	2.2120E-02	0.0000E+00
347.79	8.2000E-02	2.2510E-02	2.3200E-07
376.93	1.1290E-03	2.3000E-02	1.4000E-07
410.24	2.0090E-02	2.3900E-02	0.0000E+00
434.07	9.7870E-03	2.2880E-02	0.0000E+00
463.17	5.6130E-03	2.2800E-02	1.3460E-06
478.43	4.1260E-03	2.3000E-02	2.2900E-07
518.36	5.0470E-02	2.3120E-02	2.2900E-07
535.30	4.5050E-02	2.3490E-02	3.6600E-07
580.10	4.8070E-02	2.4650E-02	0.0000E+00
595.03	8.9770E-02	2.3010E-02	1.0020E-06
619.96	3.0280E-02	2.3020E-02	1.4400E-07
661.30	1.2960E-01	2.4150E-02	0.0000E+00
693.21	4.1750E-02	2.3190E-02	0.0000E+00
708.38	2.1180E-02	2.2820E-02	3.3300E-05
721.693	1.7940E-03	4.7000E-03	4.1100E-04
730.23	5.1000E-04	2.3000E-02	1.4900E-04
821.53	7.0340E-02	2.2280E-02	2.3500E-07
851.166	6.5640E-02	2.3760E-02	2.5970E-06
856.26	8.9810E-02	2.3310E-02	1.4050E-06
937.28	1.5570E-01	2.3380E-02	0.0000E+00
958.788	2.1100E-01	2.3400E-02	0.0000E+00
1140.47	2.3820E-01	2.3000E-02	2.3380E-06
1167.81	9.3800E-02	2.3000E-02	1.5300E-05
1211.36	1.0570E-02	1.4130E-02	2.3600E-04
5696.70	3.4900E-02	2.3000E-02	2.8610E-05
5733.20	3.8600E-02	2.3000E-02	2.7710E-05
7092.05	2.8716E-03	2.3000E-02	5.9330E-04
7126.11	3.7806E-02	2.3000E-02	1.0420E-04
7418.9	2.9630E-01	2.3000E-02	3.4100E-04
7780.77	6.0990E-01	2.3000E-02	1.5830E-04
7807.35	3.2420E-01	2.3000E-02	1.6400E-04
9345.38	2.1647E-03	2.3000E-02	6.3360E-04
9360.671	8.7513E-02	2.3000E-02	6.7290E-05
14484.85	1.9683E+02	2.3000E-02	0.0000E+00

(2) The values of U-238 neutron widths published before 1981 are therefore often in error particularly above 1.4 keV and reanalysis of data was required using shape analysis methods to provide reliable parameters. It was shown that it is necessary to use both transmission and capture measurements in this analysis and to extend the resolved resonance region to 10 keV so as to avoid problems in calculating self-screening factors in the unresolved resonance region.

(3) The problem of the discrepancies between capture cross-section measurements and the inconsistencies between integral and differential data was shown to be partially due to the incorrect normalisation of the experiment of de Saussure et al.

(4) The Task Force stimulated new measurements and resonance analyses. The high resolution measurements of U-238 capture by Macklin et al [38] and of U-238 transmission by Harvey et al [39] are particularly notable. The new analyses by Olsen [37] and Moxon et al [4,5] which provide the bulk of the material for the present paper would not have occurred without the Task Force.

(5) As a result of the efforts mentioned above a much improved and reliable set of U-238 parameters is now available for reactor calculations.

(6) The Task Force - along with the Fe-56 Task Force has shown how the measurement of high resolution transmission data can be improved. They also showed that shape analysis methods must be used to obtain reliable resonance parameters. As far as resonance formalisms are concerned multilevel representations must be used (R-matrix being particularly recommended with the use of MLBW being discouraged).

(7) Though the Task Force has only considered U-238 it is clear that many of the problems it has encountered will be present in most other nuclides.

(8) It is therefore clear that unless the resonance parameters of these have been produced in the last few years using the methods recommended above they are likely to be in error.

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Though much has been achieved by the Task Force there remain things that it considers to be important that have not been done.

(a) There is a need for measurements to give more ℓ-wave assignments for the resolved resonances in U-238.

(b) A measurement is required of Γ_γ for p-wave resonances.

(c) Though it is believed that the discrepancy in the U-238 capture cross-section has been solved a new accurate measurement is still desirable between ~1 and 500 keV.

(d) It is desirable to include the high resolution transmission measurements of Harvey et al [39] in the analysis and extend the resolved range as high as possible e.g. up to ~15 keV.

(e) Doppler broadening is still normally carried out using the gas model though there is evidence that this is unsatisfactory for the first two resonances and there is other evidence (see for example Moxon and Sowerby [45]) that this model is unsatisfactory.

(f) When all the resonance analysis work is complete it is desirable to investigate the resonance parameters and see how well they fit the expected parameter and spacing distributions.

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Appendix 1

Members of the U-238 Task Force

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Y. Nakajima	JAERI, Tokai-Mura
D. K. Olsen	ORNL
F. Poortmans	CBNM, Geel
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M. G. Sowerby	Harwell (Chairman)
D. B. Syme	Harwell

Other people who were not formally members of the Task Force but over the years have been heavily involved in its work include:

C. Nordborg	NEA Data Bank
Roger L. Macklin	ORNL
R. W. Smith	Winfrith

Appendix 2
^{238}U Resonance Parameters of Olsen
(Nuclear Science and Engineering, 104 102, 1986)

E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)	E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)
891.22	0.03	0.74	0.03	1331.44	0.04	1.42	0.06
905.03	0.01	57.6	0.4	1360.80	0.10	0.45	0.05
910.01	0.02	1.25	0.04	1386.47	0.10	0.35	0.05
925.10	0.01	14.94	0.18	1393.82	0.02	217.2	1.0
937.03	0.01	153.6	0.7	1405.43	0.02	75.5	0.6
940.95	0.06	0.62	0.05	1416.92	0.02	2.92	0.09
958.53	0.01	211.1	0.8	1419.76	0.02	9.69	0.18
964.32	0.08	0.48	0.06	1427.99	0.02	29.9	0.4
977.39	0.03	0.80	0.04	1444.04	0.02	15.88	0.25
991.63	0.01	382.8	1.0	1447.62	0.05	1.11	0.07
1005.37	0.33	0.12	0.05	1473.83	0.01	126.4	0.8
1011.43	0.02	1.82	0.07	1510.36	0.06	0.88	0.06
1022.94	0.01	8.87	0.15	1522.71	0.01	252.7	1.3
1029.13	0.02	2.34	0.07	1527.55	0.13	1.01	0.15
1033.74	0.05	0.67	0.04	1534.65	0.09	0.93	0.09
1047.33	0.05	0.50	0.04	1547.09	0.03	2.99	0.10
1054.45	0.01	96.7	0.6	1550.43	0.02	4.16	0.12
1062.71	0.04	0.94	0.06	1565.33	0.02	5.51	0.12
1067.66	0.04	0.99	0.05	1568.14	0.07	0.91	0.07
1074.02	0.04	0.92	0.05	1591.39	0.04	1.23	0.06
1081.72	0.02	1.53	0.05	1597.91	0.01	386.2	1.5
1095.16	0.02	2.30	0.06	1622.67	0.01	103.1	0.8
1098.61	0.01	22.2	0.3	1638.06	0.01	52.9	0.6
1102.87	0.02	2.13	0.06	1662.42	0.01	230.4	1.1
1109.08	0.01	38.5	0.4	1688.75	0.01	109.7	0.9
1118.97	0.05	0.55	0.04	1706.70	0.06	1.21	0.08
1131.38	0.01	3.65	0.07	1709.81	0.01	91.5	0.9
1140.36	0.01	239.4	0.9	1722.84	0.01	18.3	0.3
1152.72	0.08	0.46	0.05	1745.53	0.05	1.57	0.08
1155.05	0.05	0.73	0.05	1755.86	0.01	139.4	1.0
1159.40	0.04	0.76	0.05	1776.04	0.07	0.74	0.06
1167.64	0.01	92.0	0.6	1781.52	0.08	6.9	0.6
1176.10	0.04	3.4	0.3	1782.70	0.01	658.1	2.4
1177.23	0.01	65.1	0.6	1797.39	0.06	2.95	0.19
1194.82	0.01	97.5	0.6	1808.36	0.02	19.3	0.4
1201.42	0.12	0.38	0.06	1823.67	0.12	0.83	0.10
1211.11	0.01	10.82	0.17	1834.78	0.18	0.52	0.10
1219.85	0.08	0.47	0.05	1846.13	0.02	12.3	0.3
1230.12	0.08	0.41	0.04	1868.12	0.12	1.16	0.12
1233.19	0.06	0.52	0.04	1869.76	0.07	1.73	0.13
1245.07	0.01	259.4	0.9	1881.12	0.06	1.71	0.10
1251.30	0.12	0.65	0.09	1893.92	0.06	1.49	0.09
1267.04	0.01	30.7	0.4	1902.88	0.01	48.3	0.6
1272.97	0.01	27.9	0.4	1913.31	0.02	4.71	0.12
1276.46	0.07	0.80	0.07	1917.21	0.02	46.1	0.6
1285.23	0.18	0.25	0.06	1925.46	0.09	0.94	0.09
1298.62	0.02	3.50	0.09	1942.82	0.14	0.52	0.07
1311.04	0.47	0.09	0.05	1953.82	0.02	4.16	0.09
1317.00	0.02	4.71	0.10	1969.04	0.02	825.3	1.9
1324.13	0.24	0.19	0.05	1974.97	0.02	448.2	1.2
				1990.25	0.17	1.23	0.21

E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)	E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)
2001.01	0.29	0.49	0.14	2632.65	0.10	3.86	0.30
2023.75	0.01	229.1	1.5	2636.49	0.16	2.08	0.27
2030.54	0.02	51.8	0.9	2658.52	0.07	4.25	0.24
2048.94	0.09	1.77	0.16	2672.12	0.02	304.9	1.9
2052.62	0.21	0.73	0.14	2682.38	0.21	1.78	0.30
2071.30	0.06	2.52	0.15	2696.38	0.02	34.8	0.7
2080.65	0.08	1.70	0.13	2701.48	0.15	2.14	0.25
2086.06	0.04	4.28	0.14	2717.22	0.01	188.5	1.6
2088.53	0.02	26.7	0.5	2750.72	0.02	49.8	0.9
2096.21	0.02	30.0	0.5	2762.65	0.03	20.9	0.5
2103.90	0.08	1.76	0.13	2766.64	0.08	4.77	0.30
2114.03	0.19	0.66	0.11	2774.72	0.17	1.73	0.23
2124.13	0.04	3.19	0.13	2787.39	0.03	19.3	0.5
2145.46	0.01	72.0	0.8	2799.51	0.06	5.31	0.27
2152.69	0.01	310.3	1.7	2806.38	0.03	11.5	0.4
2172.63	0.06	2.07	0.12	2811.63	0.07	4.44	0.25
2186.52	0.01	593.4	2.1	2816.17	0.20	1.35	0.20
2201.19	0.01	105.2	1.2	2829.28	0.03	23.6	0.5
2215.38	0.06	3.30	0.21	2865.39	0.02	237.0	1.8
2241.32	0.12	1.21	0.14	2877.83	0.09	1.78	0.14
2259.65	0.01	103.1	1.1	2882.76	0.02	675.2	3.1
2264.17	0.04	6.00	0.15	2897.21	0.04	21.3	0.7
2266.57	0.02	239.2	1.9	2918.58	0.07	5.66	0.32
2271.02	0.09	3.52	0.32	2922.96	0.09	5.26	0.33
2281.91	0.01	203.6	1.5	2925.68	0.08	5.8	0.4
2294.20	0.14	1.68	0.19	2933.63	0.02	46.6	0.9
2296.71	0.07	3.62	0.21	2945.40	0.14	2.59	0.27
2315.91	0.02	21.3	0.5	2956.98	0.03	27.8	0.7
2328.04	0.23	0.78	0.15	2967.55	0.09	3.92	0.28
2338.58	0.03	9.09	0.24	2988.65	0.06	7.0	0.3
2352.75	0.01	51.4	0.8	3003.63	0.03	139.8	1.7
2355.70	0.02	93.5	1.3	3014.94	0.31	1.11	0.25
2368.78	0.05	4.45	0.20	3024.77	0.07	3.98	0.23
2384.15	0.26	0.64	0.14	3028.61	0.03	154.7	2.1
2391.95	0.02	33.1	0.6	3043.78	0.13	3.2	0.3
2397.74	0.05	4.35	0.19	3059.67	0.03	39.3	0.9
2401.77	0.05	4.12	0.17	3072.24	0.25	1.41	0.25
2411.18	0.03	6.13	0.19	3081.03	0.16	2.13	0.25
2418.79	0.16	0.89	0.13	3088.79	0.10	3.78	0.25
2426.90	0.01	171.3	1.4	3102.90	0.15	1.93	0.24
2446.70	0.01	234.4	1.5	3109.85	0.03	224.8	2.3
2455.74	0.02	19.5	0.5	3112.99	0.09	12.9	1.0
2489.09	0.01	110.5	1.2	3130.43	0.11	3.59	0.28
2501.80	0.06	3.47	0.18	3133.92	0.05	11.4	0.4
2521.38	0.02	21.4	0.4	3149.06	0.03	131.9	1.7
2526.84	0.17	0.93	0.13	3169.82	0.04	11.6	0.4
2548.11	0.01	753.3	2.3	3178.86	0.02	96.9	1.5
2559.49	0.01	305.8	1.8	3188.95	0.02	124.6	1.8
2581.08	0.01	474.6	2.0	3205.82	0.02	114.0	1.7
2597.53	0.01	779.5	3.5	3219.75	0.06	7.0	0.4
2605.83	0.18	4.3	0.6	3226.39	0.03	28.9	0.7
2611.24	0.13	4.2	0.5				
2619.95	0.02	49.6	1.0				

E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)	E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)
3240.13	0.31	1.12	0.25	3902.17	0.03	313.6	3.1
3248.89	0.03	32.7	0.8	3914.98	0.03	121.6	2.2
3264.31	0.22	1.54	0.23	3927.59	0.08	11.1	0.6
3267.52	0.05	8.9	0.4	3932.93	0.08	10.5	0.6
3273.24	0.03	16.6	0.4	3940.00	0.03	176.2	2.7
3279.57	0.02	308.9	2.9	3954.87	0.03	141.7	2.3
3297.53	0.05	10.2	0.4	4008.82	0.22	3.8	0.5
3307.94	0.06	4.92	0.25	4014.70	0.23	3.6	0.5
3312.20	0.02	178.6	2.2	4024.94	0.33	2.4	0.5
3321.67	0.02	161.7	2.0	4037.56	0.08	12.8	0.5
3333.68	0.02	128.9	1.9	4041.56	0.05	75.3	2.0
3341.18	0.11	4.6	0.4	4064.31	0.06	34.2	1.1
3346.73	0.22	1.89	0.31	4081.04	0.16	5.0	0.5
3355.86	0.05	150.1	3.6	4090.30	0.05	137.0	2.8
3367.27	0.36	1.14	0.33	4125.23	0.05	45.8	1.3
3378.29	0.06	7.5	0.4	4132.15	0.11	9.2	0.6
3383.59	0.16	2.4	0.3	4148.70	0.23	3.6	0.5
3389.67	0.03	30.4	0.7	4165.55	0.06	34.5	0.9
3399.16	0.05	7.4	0.3	4169.02	0.05	174.9	3.3
3408.72	0.02	263.9	2.3	4179.18	0.06	43.9	1.4
3417.68	0.16	2.8	0.3	4211.07	0.05	60.5	1.6
3436.47	0.02	455.1	2.6	4225.63	0.11	9.3	0.6
3458.12	0.02	752.2	3.7	4258.97	0.05	34.2	1.0
3485.75	0.02	109.9	1.7	4278.36	0.16	4.5	0.5
3495.74	0.07	9.1	0.5	4300.10	0.04	170.2	2.4
3513.35	0.29	1.7	0.3	4307.48	0.04	123.0	2.5
3522.10	0.16	3.1	0.3	4315.65	0.09	11.6	0.7
3528.44	0.08	5.8	0.4	4325.76	0.04	101.4	2.2
3561.54	0.02	278.0	2.1	4334.54	0.10	10.4	0.6
3574.03	0.02	454.0	2.7	4352.96	3.30	0.7	0.4
3594.94	0.02	66.3	1.3	4363.93	0.20	3.3	0.4
3623.22	0.02	27.6	0.6	4370.56	0.04	108.2	2.4
3629.78	0.02	553.2	4.2	4375.57	0.05	47.3	1.5
3637.00	0.15	7.7	0.8	4395.87	0.11	8.5	0.6
3654.32	0.28	2.0	0.4	4402.34	0.29	2.7	0.5
3662.18	0.29	1.8	0.4	4409.18	0.19	4.3	0.5
3673.51	0.10	5.4	0.4	4436.18	0.40	122.7	2.4
3683.28	0.10	4.8	0.4	4467.21	0.15	5.2	0.5
3693.27	0.03	420.6	3.3	4473.10	0.17	4.5	0.5
3716.85	0.03	111.7	1.9	4489.71	0.07	13.8	0.6
3724.83	0.14	4.3	0.4	4503.42	0.08	8.0	0.5
3734.28	0.03	225.9	2.8	4512.47	0.04	639.4	4.4
3741.75	0.29	2.4	0.5	4544.23	0.04	120.8	2.2
3765.18	0.03	108.4	1.8	4562.80	0.27	3.0	0.5
3782.05	0.03	490.4	3.4	4568.54	0.04	56.8	1.5
3825.21	0.12	4.9	0.4	4594.85	0.05	36.1	1.1
3831.59	0.06	13.0	0.5	4614.96	0.12	8.1	0.5
3857.75	0.03	621.8	4.0	4618.78	0.06	23.4	0.9
3869.58	0.12	7.4	0.5	4632.99	0.05	35.2	1.1
3873.07	0.03	187.7	3.2	4642.41	0.17	5.5	0.5
3879.99	0.27	3.5	0.6	4663.59	0.04	154.3	2.4
3894.60	0.09	7.2	0.5				

E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)	E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)
4695.89	0.04	37.2	1.1	5286.03	0.16	8.6	0.7
4702.82	0.12	7.5	0.4	5295.31	0.23	5.7	0.7
4706.47	0.04	360.5	4.4	5310.69	0.09	29.7	1.1
4728.13	0.06	31.0	1.1	5319.82	1.30	1.0	0.6
4736.91	0.16	7.2	0.7	5324.55	0.16	9.6	0.8
4744.85	0.14	8.1	0.7	5345.84	0.06	71.7	1.7
4749.92	0.23	5.0	0.6	5354.10	0.07	123.1	3.0
4754.38	0.16	7.4	0.7	5366.72	0.10	22.9	1.0
4766.13	0.05	37.8	1.2	5405.03	0.13	10.7	0.8
4785.43	0.07	19.4	0.8	5411.53	0.16	8.4	0.7
4792.89	0.13	7.5	0.6	5420.65	0.04	80.5	2.0
4800.40	0.04	203.0	3.4	5430.96	0.05	41.3	1.4
4809.47	0.11	13.2	0.8	5458.27	0.13	11.3	0.7
4819.34	0.10	12.9	0.7	5462.51	0.09	18.8	0.9
4836.97	0.05	40.1	1.2	5469.23	0.09	15.9	0.8
4850.70	0.14	6.7	0.6	5484.13	0.03	378.4	8.1
4860.04	0.04	282.4	3.7	5489.08	0.05	206.1	5.5
4881.40	0.24	4.5	0.6	5504.66	0.07	29.0	1.2
4886.84	0.15	8.1	0.7	5513.32	0.09	20.1	1.0
4899.39	0.04	117.9	2.2	5530.46	0.04	93.5	2.4
4908.61	0.04	150.7	2.9	5552.41	0.04	185.6	3.2
4914.97	0.14	8.2	0.8	5579.30	0.04	79.5	2.1
4921.72	0.05	219.2	3.7	5620.14	0.23	5.8	0.7
4943.72	0.31	3.8	0.6	5637.98	0.03	490.6	3.9
4956.08	0.04	173.9	2.9	5650.68	0.04	594.0	4.9
4974.41	0.05	79.7	1.9	5673.73	0.04	97.5	2.3
4991.13	1.28	0.9	0.6	5683.37	0.04	152.2	3.2
4998.85	0.11	11.7	0.7	5696.75	0.07	35.8	1.5
5007.30	0.05	58.4	1.6	5712.78	0.13	22.7	1.7
5023.54	0.29	4.2	0.7	5722.63	0.17	15.8	1.4
5035.50	0.81	8.6	1.1	5733.00	0.10	37.4	2.1
5036.96	0.07	340.5	6.8	5744.83	0.24	10.3	1.3
5053.93	0.37	3.8	0.8	5757.56	0.08	135.0	4.8
5072.96	0.24	10.0	1.3	5764.17	0.19	16.6	1.7
5075.78	0.13	25.5	1.8	5770.91	0.46	5.2	1.2
5085.09	0.31	7.8	1.3	5776.73	0.53	4.2	1.1
5087.91	0.09	71.3	3.0	5790.07	0.09	56.4	2.7
5118.95	0.06	172.1	3.5	5796.41	2.33	1.0	1.0
5138.37	0.13	12.3	0.8	5807.74	0.11	24.2	1.8
5160.41	0.31	4.9	0.7	5814.42	0.13	127.5	8.3
5164.42	0.13	14.9	0.9	5828.06	0.07	113.1	3.9
5171.51	0.65	1.9	0.6	5839.19	0.08	159.7	5.1
5178.64	0.17	8.4	0.8	5849.63	0.15	22.9	1.8
5190.73	0.22	7.0	0.7	5861.63	0.07	199.6	5.7
5195.06	0.17	9.9	0.8	5873.21	0.10	51.3	2.8
5210.03	0.12	15.5	0.9	5887.20	1.40	1.9	1.2
5213.95	0.15	10.5	0.8	5893.76	0.21	17.4	1.9
5221.09	0.08	36.5	1.4	5904.99	1.26	2.6	1.5
5243.49	0.08	35.5	1.3	5918.76	0.08	410.7	9.0
5260.20	0.08	176.8	4.2	5930.41	0.36	8.1	1.6
5264.38	0.20	12.4	1.4	5936.91	0.12	35.4	2.3
5279.75	0.11	14.6	0.8				

E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)	E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)
5944.40	0.46	5.9	1.3	6613.45	0.47	5.2	1.0
5952.74	0.65	3.8	1.2	6635.20	0.06	86.4	2.5
5970.50	0.13	20.6	1.5	6656.74	0.32	10.0	1.1
5976.20	0.08	68.4	3.1	6660.76	0.13	31.3	1.6
5987.41	0.18	14.7	1.4	6668.36	0.14	20.5	1.3
5996.93	0.08	85.7	3.6	6688.60	0.24	9.8	1.0
6015.13	0.12	16.3	1.0	6702.62	0.38	5.2	0.9
6037.13	0.03	549.6	4.6	6713.12	0.05	470.5	6.0
6050.11	0.04	155.2	3.0	6742.52	0.05	918.0	7.1
6060.60	0.04	329.2	4.4	6763.83	0.07	96.1	3.1
6082.95	0.81	3.3	1.0	6782.69	0.09	47.2	2.0
6086.92	0.21	11.2	1.1	6796.86	0.09	49.9	2.3
6092.19	0.05	71.6	2.2	6816.45	0.13	23.6	1.5
6143.58	0.11	21.3	1.1	6826.97	0.07	82.6	2.7
6148.80	0.44	3.8	0.7	6836.79	0.67	4.0	1.1
6169.88	0.04	1442.2	8.4	6848.88	0.26	10.4	1.2
6187.10	0.09	42.0	2.3	6861.66	0.29	8.7	1.1
6195.02	0.05	124.6	3.2	6867.34	0.61	4.9	0.9
6200.43	0.05	230.3	5.5	6871.24	0.08	74.7	2.4
6206.56	0.34	12.4	2.0	6878.20	0.05	506.6	9.0
6215.51	0.34	8.0	1.2	6887.79	0.61	5.0	1.6
6232.54	0.04	174.7	3.4	6892.96	0.06	179.3	5.0
6247.66	0.04	259.5	4.4	6902.87	0.19	20.6	1.8
6258.31	0.38	7.3	1.3	6911.67	0.43	7.7	1.3
6266.35	0.24	11.1	1.2	6916.89	0.11	41.0	2.2
6282.93	2.10	1.4	1.2	6928.53	0.06	171.1	4.1
6286.72	0.51	6.3	1.3	6956.42	0.06	112.7	3.0
6292.46	0.11	27.5	1.4	6968.07	0.06	296.9	5.1
6299.22	0.18	14.5	1.2	6995.32	0.28	11.4	1.4
6317.24	0.66	3.3	0.8	7015.22	0.11	33.3	1.8
6321.40	0.07	60.0	2.1	7025.84	0.07	104.8	3.3
6330.34	0.09	29.3	1.5	7036.64	0.20	17.6	1.5
6342.84	0.04	219.6	4.0	7049.15	0.26	11.2	1.3
6356.46	0.50	4.7	1.0	7063.93	0.06	204.2	4.2
6365.72	0.12	22.0	1.3	7073.36	0.07	115.7	3.6
6381.76	0.12	21.0	1.2	7089.60	0.40	8.1	1.3
6392.37	0.34	6.4	0.9	7096.14	0.31	10.5	1.3
6403.88	0.21	11.0	1.0	7126.80	0.08	74.8	2.5
6414.97	0.13	18.8	1.1	7147.25	0.14	25.1	1.5
6430.24	0.10	26.0	1.2	7160.05	0.83	3.3	1.1
6445.32	0.05	111.6	3.0	7169.93	0.18	21.9	1.6
6450.68	0.07	37.8	1.9	7174.76	0.24	14.4	1.4
6460.57	0.04	822.9	6.9	7184.42	0.17	33.6	2.0
6506.87	0.04	306.2	4.4	7187.82	0.09	283.4	6.9
6522.24	0.22	12.0	1.2	7199.61	0.17	35.9	1.9
6528.83	0.44	5.0	1.0	7203.22	0.09	283.8	7.5
6539.41	0.04	397.1	4.7	7213.32	0.33	10.7	1.4
6550.66	0.04	344.8	5.1	7218.23	0.08	148.6	4.6
6569.95	0.29	10.7	1.4	7239.46	0.16	20.4	1.5
6595.79	0.20	14.5	1.3	7250.20	0.08	120.1	3.8
				7263.92	0.45	6.7	1.2
				7272.47	0.46	6.2	1.2

E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)	E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)
7286.46	0.07	608.5	8.2	8139.08	0.06	292.6	6.0
7301.82	0.18	26.1	2.1	8152.85	0.19	33.0	2.3
7323.44	0.40	8.3	1.4	8163.11	0.38	12.7	1.7
7341.13	0.18	22.0	1.6	8191.20	0.36	10.7	1.5
7367.13	0.17	19.2	1.4	8204.62	0.05	479.1	6.1
7373.35	0.10	46.7	2.1	8215.77	0.05	466.7	7.6
7400.96	0.19	18.2	1.5	8224.69	0.06	492.9	8.4
7418.90	0.07	289.0	5.1	8262.55	0.06	608.4	7.6
7431.18	0.10	57.1	2.3	8273.93	0.60	11.7	2.6
7439.56	0.18	55.2	4.2	8289.99	0.06	343.8	6.3
7442.81	0.20	52.4	4.2	8327.29	0.06	374.0	6.3
7454.08	0.31	12.0	1.5	8356.61	0.08	172.6	5.1
7503.76	0.27	11.7	1.3	8373.48	0.40	15.2	2.1
7522.64	0.04	267.4	4.9	8383.79	0.17	42.0	2.7
7536.22	0.26	17.2	1.4	8399.81	0.08	146.8	4.4
7540.13	0.07	203.8	5.4	8409.98	0.09	122.3	4.9
7552.03	0.13	28.0	1.8	8418.25	0.30	24.6	2.7
7561.01	0.05	189.9	5.0	8463.53	0.36	14.0	1.8
7592.25	0.04	344.1	5.9	8493.40	0.50	27.7	7.2
7603.28	0.20	21.6	2.0	8495.98	0.14	207.4	8.5
7616.75	0.05	158.0	4.3	8511.37	0.27	19.4	2.1
7624.56	0.10	57.9	2.7	8525.67	0.43	9.8	1.3
7639.33	0.26	15.0	1.6	8530.90	0.08	402.6	8.2
7660.96	0.11	39.0	2.0	8555.57	0.10	84.3	3.5
7668.17	0.39	8.6	1.3	8566.50	0.64	8.3	1.8
7677.47	0.13	39.4	1.8	8581.03	0.40	12.8	1.8
7681.96	0.08	107.4	4.0	8594.06	0.13	50.5	2.7
7699.06	0.04	397.5	6.8	8608.13	0.43	20.5	2.6
7725.21	0.68	4.8	1.3	8611.80	0.15	113.3	5.6
7733.76	0.07	74.5	2.9	8638.21	0.07	336.0	6.7
7758.05	0.18	20.9	1.6	8656.78	0.11	78.4	3.8
7773.84	0.09	35.2	1.5	8710.24	0.07	1046.8	10.3
7780.77	0.04	609.9	8.9	8733.09	0.17	48.3	3.3
7807.35	0.07	324.2	19.4	8746.32	0.56	10.0	2.0
7810.77	0.22	119.3	14.7	8763.32	0.25	19.4	2.0
7842.37	0.09	87.1	4.3	8770.81	0.08	201.9	6.1
7847.00	0.14	69.4	4.2	8784.64	0.35	17.8	2.2
7881.95	0.28	16.8	1.7	8794.29	0.27	22.3	2.2
7904.17	0.17	31.8	1.8	8822.48	0.14	53.5	2.9
7909.24	0.10	91.6	3.4	8844.47	0.07	353.4	6.6
7927.32	0.39	11.1	1.5	8855.13	0.10	133.8	5.0
7934.95	0.14	43.3	2.3	8866.26	0.96	6.0	2.0
7944.70	0.20	25.0	1.8	8879.45	0.27	18.5	2.1
7960.29	0.41	11.2	1.5	8888.78	0.08	310.0	8.1
7966.65	0.51	9.0	1.5	8898.43	0.33	22.1	2.8
7978.88	0.07	129.1	4.4	8913.01	0.49	11.7	2.0
7986.93	0.13	45.1	2.6	8924.34	0.36	16.1	2.1
8003.49	0.19	24.3	1.7	8945.67	0.07	198.9	5.2
8035.25	0.05	297.6	4.7	8959.55	0.29	45.4	4.9
8047.44	0.05	758.0	8.4	8962.99	0.12	354.0	9.5
8087.65	0.65	5.7	1.4				
8104.09	0.05	748.0	8.0				

E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)
9005.40	0.70	8.1	2.2
9013.23	0.23	58.2	6.8
9017.31	0.31	79.8	7.7
9022.78	0.20	70.7	7.3
9036.29	0.19	38.7	3.0
9056.13	0.07	374.2	8.5
9072.33	0.19	51.0	3.4
9079.80	0.19	49.0	3.3
9092.16	0.16	55.7	3.4
9104.85	0.37	17.7	2.2
9141.39	0.08	158.2	5.0
9151.73	0.12	66.0	3.3
9165.02	0.08	717.6	12.8
9175.96	0.60	16.3	3.5
9186.43	0.28	31.9	3.3
9216.10	0.09	204.4	6.4
9239.76	0.38	22.6	2.7
9246.39	0.44	18.7	2.6
9286.27	0.31	23.7	2.4
9306.99	0.30	22.9	2.4
9327.17	0.33	20.8	2.4
9360.87	0.09	143.0	5.1
9375.50	1.22	5.0	1.9
9381.74	0.11	141.7	5.7
9405.21	0.27	20.7	2.4
9415.42	0.12	82.1	3.1
9420.40	0.09	349.0	10.8
9442.51	0.22	32.2	2.7
9455.90	0.88	5.2	2.1
9465.23	0.18	100.8	10.1
9468.81	0.10	856.3	16.6
9487.89	0.35	24.5	3.1
9505.93	0.51	13.6	2.4
9528.77	0.07	210.6	6.0
9553.16	0.90	13.3	4.9
9557.22	0.28	56.5	6.7
9575.09	0.10	85.0	3.4
9586.83	0.10	83.1	3.5
9593.88	0.07	189.7	6.4
9616.51	0.23	26.3	2.4
9628.18	0.07	368.0	17.7
9632.65	0.24	118.9	13.2
9648.90	0.08	161.6	5.9
9662.61	0.46	16.3	2.6
9679.93	0.12	78.2	3.7
9701.25	0.18	49.1	3.1
9708.61	0.22	35.8	2.8
9724.86	0.06	409.4	7.8
9740.92	0.09	159.0	5.7
9765.51	0.20	42.8	3.1
9774.38	0.17	54.0	3.5
9801.71	0.18	47.3	3.1

E(eV)	ΔE(eV)	$g\Gamma_n$(meV)	$\Delta g\Gamma_n$(meV)
9832.77	0.17	45.9	3.1
9850.68	0.15	44.6	2.9
9860.62	0.19	30.3	1.6
9866.43	0.07	789.0	13.3
9903.63	0.18	51.3	3.5
9932.99	0.11	96.4	4.2
9956.00	0.07	191.4	5.8
9983.95	0.10	111.6	4.5
10000.40	0.20	39.9	2.9

APPENDIX 3

^{238}U Resonance Parameters of Moxon et al (1990 set) in ENDF/B-VI Format

[Resonances with a neutron width of 1.0E-10 eV are ones included in the 1988 set which produced calculated resonance peaks which are lower than the background level assumed for the Macklin et al high resolution capture measurements in the production of these data - see text]

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 9.22380+ 4 2.36006+ 2            0          0          1            09237 2151  458
 9.22380+ 4 1.00000+ 0            0          0          2            09237 2151  459
 1.00000- 5 1.00000+ 4            1          3          0            09237 2151  460
 0.00000+ 0 9.42848- 1            0          0          2            29237 2151  461
 2.36006+ 2 0.00000+ 0            0          0       3138          5239237 2151  462
-4.40525+ 3 5.00000- 1 1.08550+ 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  463
-4.13300+ 2 5.00000- 1 7.07210- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  464
-3.93300+ 2 5.00000- 1 6.89890- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  465
-3.73300+ 2 5.00000- 1 6.72120- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  466
-3.53300+ 2 5.00000- 1 6.53870- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  467
-3.33300+ 2 5.00000- 1 6.35090- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  468
-3.13300+ 2 5.00000- 1 6.15740- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  469
-2.93300+ 2 5.00000- 1 5.95760- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  470
-2.73300+ 2 5.00000- 1 3.30640- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  471
-2.53300+ 2 5.00000- 1 3.18310- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  472
-2.33300+ 2 5.00000- 1 3.05480- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  473
-2.13300+ 2 5.00000- 1 2.92100- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  474
-1.93300+ 2 5.00000- 1 2.78060- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  475
-1.73300+ 2 5.00000- 1 2.63290- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  476
-1.53300+ 2 5.00000- 1 2.47630- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  477
-1.33300+ 2 5.00000- 1 2.30910- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  478
-1.13300+ 2 5.00000- 1 2.12880- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  479
-9.33000+ 1 5.00000- 1 1.93180- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  480
-7.33000+ 1 5.00000- 1 1.71230- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  481
-5.33000+ 1 5.00000- 1 1.46010- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  482
-3.33000+ 1 5.00000- 1 1.07300- 2 2.30000- 2 2.01000- 6 0.00000+ 09237 2151  483
 6.67400+ 0 5.00000- 1 1.49300- 3 2.30000- 2 0.00000+ 0 9.99000- 99237 2151  484
 2.08710+ 1 5.00000- 1 1.02600- 2 2.29100- 2 5.42000- 8 0.00000+ 09237 2151  485
 3.66820+ 1 5.00000- 1 3.41300- 2 2.28900- 2 0.00000+ 0 9.77000- 99237 2151  486
 6.60320+ 1 5.00000- 1 2.46000- 2 2.33600- 2 5.26500- 8 0.00000+ 09237 2151  487
 8.07490+ 1 5.00000- 1 1.86500- 3 2.30000- 2 0.00000+ 0 6.04900- 89237 2151  488
 1.02560+ 2 5.00000- 1 7.17000- 2 2.34200- 2 1.28600- 8 0.00000+ 09237 2151  489
 1.16902+ 2 5.00000- 1 2.54900- 2 2.29900- 2 0.00000+ 0 0.00000+ 09237 2151  490
 1.45660+ 2 5.00000- 1 8.47000- 4 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  491
 1.65290+ 2 5.00000- 1 3.36700- 3 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  492
 1.89670+ 2 5.00000- 1 1.73200- 1 2.23800- 2 0.00000+ 0 3.57300- 89237 2151  493
 2.08510+ 2 5.00000- 1 5.11100- 2 2.34900- 2 8.34700- 8 0.00000+ 09237 2151  494
 2.37380+ 2 5.00000- 1 2.71600- 2 2.45400- 2 0.00000+ 0 3.54200- 89237 2151  495
 2.57216+ 2 5.00000- 1 3.40000- 5 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  496
 2.73660+ 2 5.00000- 1 2.57800- 2 2.21000- 2 0.00000+ 0 0.00000+ 09237 2151  497
 2.91000+ 2 5.00000- 1 1.68700- 2 2.21000- 2 0.00000+ 0 0.00000+ 09237 2151  498
 3.11320+ 2 5.00000- 1 1.08900- 3 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  499
 3.47790+ 2 5.00000- 1 8.20000- 2 2.25100- 2 2.32000- 7 0.00000+ 09237 2151  500
 3.53450+ 2 5.00000- 1 2.40000- 5 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  501
 3.76930+ 2 5.00000- 1 1.12900- 3 2.30000- 2 0.00000+ 0 1.40000- 79237 2151  502
 3.97620+ 2 5.00000- 1 6.20700- 3 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  503
 4.10240+ 2 5.00000- 1 2.00900- 2 2.39000- 2 0.00000+ 0 0.00000+ 09237 2151  504
 4.34070+ 2 5.00000- 1 9.78700- 3 2.28800- 2 0.00000+ 0 0.00000+ 09237 2151  505
 4.63170+ 2 5.00000- 1 5.61300- 3 2.28800- 2 1.34600- 6 0.00000+ 09237 2151  506
 4.78430+ 2 5.00000- 1 4.12600- 3 2.30000- 2 0.00000+ 0 2.29000- 79237 2151  507
 4.88910+ 2 5.00000- 1 8.84000- 4 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  508
 5.18360+ 2 5.00000- 1 5.04700- 2 2.31200- 2 2.29000- 7 0.00000+ 09237 2151  509
 5.35300+ 2 5.00000- 1 4.50500- 2 2.34500- 2 0.00000+ 0 3.66000- 79237 2151  510
 5.50830+ 2 5.00000- 1 8.20000- 5 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  511
 5.80100+ 2 5.00000- 1 4.08700- 2 2.46500- 2 0.00000+ 0 0.00000+ 09237 2151  512
 5.95030+ 2 5.00000- 1 8.97700- 2 2.30100- 2 1.00200- 6 0.00000+ 09237 2151  513
 6.19960+ 2 5.00000- 1 3.02800- 2 2.30200- 2 0.00000+ 0 1.44000- 79237 2151  514
 6.28540+ 2 5.00000- 1 6.31800- 3 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  515
 6.61300+ 2 5.00000- 1 1.29600- 1 2.41500- 2 0.00000+ 0 0.00000+ 09237 2151  516
 6.93210+ 2 5.00000- 1 4.17500- 2 2.31900- 2 0.00000+ 0 0.00000+ 09237 2151  517
 7.08380+ 2 5.00000- 1 2.11800- 2 2.28200- 2 3.33000- 5 0.00000+ 09237 2151  518
 7.21693+ 2 5.00000- 1 1.79400- 3 4.70000- 3 0.00000+ 0 4.11000- 49237 2151  519
 7.30230+ 2 5.00000- 1 5.10000- 4 2.30000- 2 1.49000- 4 0.00000+ 09237 2151  520
 7.65100+ 2 5.00000- 1 8.15900- 3 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  521
 7.90860+ 2 5.00000- 1 6.66100- 3 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  522
 8.21530+ 2 5.00000- 1 7.03400- 2 2.22800- 2 0.00000+ 0 2.35000- 79237 2151  523
 8.51166+ 2 5.00000- 1 6.56400- 2 2.37600- 2 2.59700- 6 0.00000+ 09237 2151  524
 8.56260+ 2 5.00000- 1 8.98100- 2 2.33100- 2 0.00000+ 0 1.40500- 69237 2151  525
 8.66530+ 2 5.00000- 1 5.59300- 3 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  526
 9.05110+ 2 5.00000- 1 5.62500- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  527
 9.25230+ 2 5.00000- 1 1.51000- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151  528
 9.37280+ 2 5.00000- 1 1.55700- 1 2.33800- 2 0.00000+ 0 0.00000+ 09237 2151  529
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9.58788+ 2 5.00000- 1 2.11000- 1 2.34000- 2 0.00000+ 0 0.00000+ 09237 2151   530
9.91810+ 2 5.00000- 1 3.83700- 1 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151   531
1.00524+ 3 5.00000- 1 1.60000- 4 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151   532
1.02308+ 3 5.00000- 1 8.42000- 3 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151   533
1.05465+ 3 5.00000- 1 9.67000- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151   534
1.05708+ 3 5.00000- 1 1.40000- 4 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151   535
1.09871+ 3 5.00000- 1 1.90000- 2 2.30000- 2 0.00000+ 0 0.00000+ 09237 2151   536
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