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Report

A DETAILED REPORT ON THE SIMULTANEOUS EVALUATION OF THE FISSION CROSS-SECTIONS OF U-235, Pu-239 AND U-238 AND THE U-238 CAPTURE CROSS-SECTION IN THE ENERGY RANGE 100 eV TO 20 MeV

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CONTENTS

APPENDICES

CONTENTS (Cont'd)

CONTENTS (Cont'd)

1. Introduction

Among the most important cross-sections required for the calculation of fast reactor properties are the fission cross-sections of U-235, Pu-239 and U-238 and the capture cross-section of U-238. There are now many measurements of these quantities and their ratios over the energy range of interest (100 eV to 20 MeV), and in general these do not agree as well as would be expected from the quoted errors. Recently there have been a number of new measurements, the B-10(n,α) cross-section, which is a common standard below 100 keV, has also been shown to depart from a 1/v dependence[1] and structure has been observed in the U-235 fission cross-section[2] in the keV energy range. In the light of these factors it has become important to perform new evaluations of the cross-sections.

The present evaluation has three primary purposes. The first and most important is to provide the best values of cross-sections so that data files can be constructed for use in reactor calculations. The second purpose is to assess the uncertainties of the evaluated cross-sections - allowing comparison with accuracies specified in reactor data request lists - and the third is to recommend where further measurements are desirable. Evaluations are probably easiest to perform when there is only one measurement to consider. As there are usually several measurements of the cross-sections in a given energy range it has become necessary to try to identify the causes of any discrepancies so that the doubtful experiments can be detected and their results eliminated. This is a difficult problem because many of the experiments are badly documented. We have attempted to compare experiments by writing abstracts for each one giving the important parameters, corrections, etc. Because the results of the evaluation were required urgently this process had to be stopped. We hope, however, to complete it when time is available as it will make future evaluations much simpler. This type of evaluation work also makes it easier to fulfil the third purpose of evaluation. Where additional measurements are recommended it is vital that only reliable techniques should be used and if we know the faults and limitations of each type of measurement, then it is possible to recommend which method should be used or, failing that, which methods should not be adopted.

There have been a number of evaluations of the fission cross-sections of U-235, U-238 and Pu-239 and the capture cross-section of U-238 and these have suffered from at least one of the following defects:-

(a) It was assumed that the energy dependence of the cross-sections is smooth in and above the keV energy range. This is not true for the U-235 fission cross-section and there are doubts about the Pu-239 fission cross-section and the U-238 capture cross-section. As a result of this, measurements with monoenergetic neutron sources must now be given a lower weight above a few keV than that previously considered reasonable.

(b) The cross-sections have been considered independently. This does not take full advantage of the available data because the measurements of the cross-sections and their ratios form a highly inter-related set and the best evaluation must consider all available data simultaneously.

(c) Suspect experiments have not been identified and their results accordingly down-weighted or eliminated.

(d) The evaluated data at the extremities of the energy range of an evaluation are not necessarily consistent with the data immediately beyond.

and (e) The best values of any cross-section or ratio have been obtained from a curve drawn by hand through the data and so tend to be subjective. With this technique it is difficult to update satisfactorily an existing evaluation as new data become available and to take account adequately of the assigned weights of a large number of experiments.

The present evaluation has been designed to overcome these defects, but, because the results were required urgently, we have not been able to computerise the fitting of curves through the data; as discussed in an earlier report[3] we planned to use a modified version of the cubic spline fitting programme of Horsley et al[4]. The evaluation was completed in March 1971 using the data available on 1st January 1971. These evaluated data have been briefly discussed in a memorandum[5] and above 25 keV have been incorporated into the following files in the U.K. Nuclear Data Library: U-235 DFN 271D, U-238 DFN 272A and Pu-239 DFN 269D. Below 25 keV the data have been used in Genex type evaluations[6]. Since the evaluation was completed, however, some significant measurements have become available and in writing this report slight omissions and errors have been found in the input data but these cause only minor changes to the evaluated data. This document considers the data available in October 1971 and recommends evaluated numbers which are slightly different from those reported earlier. The original values are given in Appendix 3.

The remainder of the paper is divided up as follows. In Section 2 the techniques of evaluation are discussed. Section 3 considers the energy range below 100 keV where the evaluation is primarily based on measurements obtained using white spectrum neutron sources and the time-of-flight technique. Section 4 considers the data in the higher energy regions while in Section 5 the evaluated results are discussed. The conclusions and recommendations resulting from the work are summarised in Section 6.

2. Technique of Evaluation

The discovery of structure in the U-235 fission cross-section in the keV energy range[2] has had very important consequences in the design of the present evaluation. The bulk of the measurements made below 30 keV have been obtained by the time-of-flight technique and hence the data are continuous and the true average cross-sections can be obtained. Above 30 keV there are many measurements at 'spot points' and above 100 keV all the data are essentially of this type. When there is significant structure in the cross-section a simultaneous evaluation can only be performed if the measurements can be averaged over identical energy intervals which in practice requires continuous data. If there is no structure and the cross-sections have a smooth and slowly varying energy dependence when averaged over the energy resolution of the 'spot point' measurements then we can perform a simultaneous evaluation. For the cross-sections we are considering, virtually no measurements of the cross-section ratios have been made below 100 keV using the time-of-flight technique and hence the simultaneous evaluation technique can only be used above 100 keV where the structure in the cross-sections, particularly the U-235 fission cross-section, has essentially vanished. Below 100 keV the cross-sections have been evaluated independently giving, where possible, the highest weight to the continuous measurements.

In order to perform an evaluation it is necessary to collect together all the results that are available for the cross-sections being considered. This in principle is a simple problem now that the world's Nuclear Data Centres are responsible for keeping and storing the available numbers. However, in practice the data, particularly the older measurements, sometimes require renormalising or their energy dependence needs altering so that the up-to-date energy variation of the standard cross-section is used. In order that the reader of this report knows exactly which data have been used in this evaluation the values are given in Appendix 1 together with comments on how the data have been modified.

There are usually several measurements of a cross-section or ratio in a given energy region and there are often serious discrepancies. It is, therefore, necessary to critically examine the experiments so that the doubtful ones can be detected and their results down-weighted or eliminated. For this purpose we started the evaluation by trying to prepare an abstract of each experiment using a standardised format and examples of these were included in the progress report on this evaluation[3]. However, because the results of the evaluation were required on a short time scale it was necessary to stop the preparation of these abstracts. The critical examination of the experiments was of course not stopped and a list of rejected experiments is given in Appendix 2.

Above 100 keV, where there are measurements of cross-sections and their ratios, the cross-sections are over-determined by the available data. Therefore, there is a considerable advantage in considering all the data simultaneously. The procedure we have adopted is to take each cross-section and ratio and make a plot of the appropriate experimental data. A curve is then drawn by hand on each plot to give the best representation of the data. At a given neutron energy the value of the cross-section or ratio is read from each of the curves and these constants, referred to as starting values, are used in the following way. A computer programme obtains, at the given energy (E), the optimum values of the cross-sections (σ_i) which cause the quantity F(E) to be a minimum, where F(E) is obtained from

$$F(E) = G(E) + H(E) \qquad (1)$$

The value of G(E) is given by

$$G(E) = \Sigma W_i(X_i - \sigma_i)^2 \qquad (2)$$

where the sum is taken over all the available cross-section types and X_i and W_i are the starting value and weight of the ith cross-section respectively. The quantity H(E) is defined by

$$H(E) = \Sigma W_{kl}(R_{kl} - \sigma_k/\sigma_l)^2 \qquad (3)$$

where the sum is taken over all the available combinations of the ratios of cross-sections. For any combination, σ_k and σ_l are the best values of the cross-sections and R_{kl} and W_{kl} are the starting value and weight of the ratio. We wish now to consider the methods we have used to assess the values of the weights (W_i and W_{kl}). It should be stressed that these weights although based on the experimental data refer to the starting values and <u>not</u> to the individual experimental measurements. For a given cross-section and ratio, W would be related to the spread and accuracy of the measured data if all the errors were random.

In practice the errors are probably predominately systematic in origin and therefore the choice of the values of W has to be made by the evaluator. Only the relative values of W are important since if all values are modified by the same factor the optimum values of the cross-sections do not alter. Therefore, the evaluator has to choose the cross-sections or ratios which he considers most likely to be in error and give these the relatively smallest values of W because relatively large differences between the best values and the starting values are generally only possible when W is relatively small. It is convenient to work with values of Δ rather than values of W and these are related through the formulae

$$W_i = \frac{1}{\Delta_i^2 X_i^2} \quad \text{and} \quad W_{kl} = \frac{1}{\Delta_{kl}^2 R_{kl}^2} \qquad (4)$$

It is these values of Δ which will be quoted later in the paper. The minimisation procedure is repeated at as many energy points as are necessary to represent the known structure in the cross-sections.

The process of selecting the starting values from curves drawn through the data by hand is not ideal. It is difficult to take account adequately of the experimental errors particularly where there are many measurements. Experience, however, shows that no serious errors are likely to be caused by this technique if care is taken and the curves are approved by all the authors of this work.

It might be thought that application of the minimisation procedure at spot energies could lead to fluctuations in the evaluated cross-sections. In practice this does not happen and this is presumably due to the fact that the starting values have been obtained from smooth curves and the Δ values do not change rapidly from point to point.

3. Cross-sections below 100 keV

In this section we will consider the data on U-235(n,f), Pu-239(n,f) and U-238(n,γ). First of all we will consider the continuous data obtained by the time-of-flight technique for each isotope in turn and then we see what influence the spot point data have on the evaluation. In all cases the evaluation can be considered in two parts

(a) Normalisation

and (b) Shape.

The fission cross-sections of U-235 and Pu-239 should ideally be normalised to the values at 0.0253 eV of 580.2 ± 1.8 and 741.6 ± 3.1 barns obtained from a least squares fit to the thermal data[7]. An alternative analysis by de Volpi[8] increases these fission cross-section values by +0.95% and +0.12% respectively and so perhaps we should not consider the accuracy to be much better than ± 1%; even so the fission cross-section is known to its highest accuracy at thermal energies. It should be noted that the absolute measurements of fission cross-sections at all energies will depend upon the half lives of the foil constituents if α counting has been one of the methods of foil assay. Recent measurements of the U-234 and possibly Pu-239 half lives indicate errors of 1-2% in the recommended values and corrections for this effect would produce an increase in the U-235 cross-section and a decrease in the Pu-239 cross-section. We have made no attempt to correct the cross-sections for the changes in assay due to the revised half lives because the maximum corrections would be ~ 1%.

3.1 U-235 Fission Cross-section

In the case of U-235, no experiments giving data above 100 eV are normalised at thermal energies and therefore it is necessary to make cross-normalisations. Errors can be introduced into these due to energy scale and resolution differences but these can be minimised by normalising over large energy intervals. In the present evaluation we have normalised the experiments in the energy range 100 eV to 1 keV to an average cross-section of 13.44 barns (± 3.3%). This was obtained from the data given in Table 1 by initially calculating the best value of the integrated cross-section between 5 and 10 eV. The value of 282.4 b.eV was obtained by giving double weight to the data of Deruytter and Wagemans[9]. This was combined with the best value (43.55) of the ratio of integrated cross-sections from 100 eV to 1 keV and 5 to 10 eV obtained by giving the value of de Saussure et al[12] twice the weight assigned to Michaudon[13] to obtain the average cross-section from 100 eV to 1 keV. The resulting value of 13.67 barns (± 3%) was then combined with the data of Lemley et al[14] and Brown et al[15], which are absolute, to obtain the value of 13.44 barns (± 3.3%) for the average cross-section between 100 eV and 1 keV.

The shape of the U-235 fission cross-section in the energy range below 100 keV was evaluated by considering the energy ranges above and below 30 keV separately. The experiments considered are given in Table 2 and the neglected experiments are given in Appendix 2. The results of the experiments were corrected where necessary for the non-1/v behaviour of the B-10(n,α) cross-section using the formula recommended by Sowerby et al[1]. The experiments were normalised so that the average cross-section between 0.1 and 1 keV was unity. The average cross-section was then obtained for each experiment in 100 eV intervals below 1 keV, 1 keV intervals from 1 to 10 keV and 10 keV intervals from 10 to 30 keV and the best shape obtained by averaging together the various sets of data using the errors in Table 2. These errors are to a certain extent arbitrary but they are not unreasonable when the spread in the data is considered. The error in the values of Blons et al[16] was increased above 20 keV because the shape of their data above 25 keV appeared to be significantly different to the other measurements. This is most probably due to the effect of the time resolution of the BF_3 counter used for their neutron spectrum measurements. The best values of the cross-section were then obtained by normalising the best shape to the average cross-section of 13.44 barns (± 3.3%) from 0.1 to 1 keV. Because of the structure we wish to average the data in 1 keV intervals between 10 and 100 keV. Between 10 and 30 keV this was done by taking the weighted average of the data of Blons et al, Patrick et al and Lemley et al and then normalising the results to the broad averages from 10-20 and 20-30 keV obtained above.

In the energy range between 30 and 100 keV the data of Lemley et al are the only continuous measurement. Between 10 and 30 keV they are significantly lower (by up to 10%) than the other data and hence to get the best cross-section values we have renormalised the data of Lemley et al to the broad average data between 10 and 30 keV.

Table 1

Data used to normalise the U-235 fission cross-section measurements below 30 keV

Experiment	Normalisation at 2,200 m/sec (barns)	$\int_{5eV}^{10eV} \sigma_{nf}(E)dE$ (b-eV)	$\int_{100eV}^{1keV} \sigma_{nf}(E)dE$ (b-eV)	Ratio $\frac{\int_{100eV}^{1keV} \sigma_{nf}(E)dE}{\int_{5eV}^{10eV} \sigma_{nf}(E)dE}$	Average cross-section 0.1 - 1 keV (barns)
Deruytter et al(9)	580.2	282.1			
Bowman et al(10)	*577 580.2	292.1 293.7			
Shore and Sailor(11)	*582 580.2	272.4 271.6			
Weighted mean	580.2	282.4			
de Saussure et al(12)	-	284.1	12267	43.18	
Michaudon(13)	-	275.0	12177	44.28	
Weighted mean from low energy data		282.4 ± 4.5		43.55	13.67 ± 3%
Lemley et al(14)					11.87 ± 8%
Brown et al(15)					13.87 ± 8%
Final Value					+13.44 ± 3.3%

* Original normalisation

\+ error deduced from spread in observations

Table 2

Experiments used for evaluation of U-235 fission cross-section shape below 100 keV

Experiment	Energy Range (keV)	Flux Standard	Method	Error Assigned
Brown et al[15]	0.1-10	Li-6(n,α)	Underground nuclear explosion Fragment detection	8%
Blons et al[16]	0.1-30	B-10(n,α)	Linac Fragment detection	4% except 20-30 keV where 8%
de Saussure et al[12]	0.1-10	B-10(n,α)	Linac Fragment detection	4%
Van Shi-di et al[17]	0.1-10	B-10(n,α)	Pulsed reactor Neutron detection	8%
Michaudon[13]	0.1-20	B-10(n,α)	Linac Fragment detection	5%
Patrick et al[2]	0.1-30	Li-6(n,α)	Linac Neutron detection	5%
Lemley et al[14]	0.1-100	Li-6(n,α)	Underground nuclear explosion Fragment detection	8%

3.2 Pu-239 Fission Cross-section

The evaluation of the Pu-239 fission cross-section data below 30 keV has been performed in essentially the same manner as for U-235. In the case of Pu-239, however, data are available which extend from thermal energies to the energy range above 100 eV and therefore the best shape can be normalised without having to make a subsidiary cross-normalisation. The best value of the average cross-section from 0.1 - 1 keV was obtained from the data given in Table 3 as 10.23 barns (± 2.3%) The shape of the Pu-239 fission cross-section was evaluated from the data summarised in Table 4, the data being corrected where necessary for the non-1/v behaviour of the B-10(n,α) cross-section using the formula recommended by Sowerby et al. The data of Bollinger et al were only used below 0.4 keV because of their poor neutron energy resolution. The error of the James data was increased to 8% from 0.9 - 1 keV because his relatively poor energy resolution combined with structure means that his value is sensitive to small energy scale errors. The error for the Blons et al data was increased to 8% from 20-30 keV for the same reasons as for U-235. The best values of the cross-sections from 0.1 to 30 keV were then obtained by normalising the evaluated shape to an average cross-section of 10.23 barns (± 2.3%) between 0.1 and 1 keV.

Above 30 keV there are no continuous measurements of the Pu-239 cross-section. We have, therefore, had to obtain our evaluated curve from measurements of the Pu-239/U-235 ratio, which will be discussed in Section 4, combined with the U-235 data discussed above. The values obtained are in reasonably good agreement with the few spot point measurements which are available.

Table 3

Data used to normalise the Pu-239 fission cross-section

Experiment	Normalisation at 2,200 m/s (barns)	Average cross-section 0.1 - 1 keV (barns)
Gwin et al[18]	741.6	10.16 ± 3%
Bollinger et al[19]	741.6	10.16 ± 5%
Shunk et al[20]	-	10.00 ± 8%
Farrell et al[21]	-	11.37 ± 8%
Weighted mean		10.23 ± 2.3%

Table 4

Experiments used for evaluation of Pu-239 fission cross-section shape below 30 keV

Experiment	Energy Range (keV)	Flux Standard	Method	Error Assigned
Gwin et al[18]	0.1-20	B-10(n,α)	Linac Fragment detection	4%
James[22]	0.1-30	B-10(n,α)	Linac Fragment detection	5% 8% (0.9-1 keV)
Schomberg et al[23]	0.1-30	Li-6(n,α)	Linac Neutron detection	5%
Bollinger et al[19]	0.1-0.4	B-10(n,α)	Reactor and Chopper Fragment detection	5% (0.1-0.2 keV) 8% (0.2-0.4 keV)
Blons et al[24]	0.1-30	B-10(n,α)	Linac Fragment detection	4% 8% (20-30 keV)
Shunk et al[20]	0.1-10	Li-6(n,α)	Underground nuclear explosion Fragment detection	8%
Farrell et al[21]	0.1-30	Li-6(n,α)	Underground nuclear explosion Fragment detection	8%

3.3 U-238 Capture Cross-section

For the U-238 capture cross-section in this energy range the evaluation method is essentially the same as for the U-235 and Pu-239 fission cross-sections. Fortunately the available continuous time-of-flight data are all normalised at the 6.67 eV resonance by the saturated or black resonance method. (Data have also been obtained by Stavisskii et al[25] using the lead slowing down spectrometer between 5 eV and 30 keV but these have not been accepted because corrections were not fully made and the measurement was made relative to Au.) The question of consistent normalisation does not, therefore, exist and we essentially have only to find the best "shape". For

this cross-section there can be large corrections for multiple scattering and self-screening below 1 keV and we will therefore only evaluate the best average cross-sections above 1 keV. Below 1 keV any evaluation must be based on resonance parameters and these are outside the scope of the present work.

Table 5 gives details of the experiments used to obtain the best values of the cross-sections. The data were initially corrected so that all were obtained relative to the B-10(n,α) cross-section recommended by Sowerby et al and then the weighted average cross-sections were found using the errors given by the experimenters increased as shown in the table. (The averages were obtained in 1 and 10 keV intervals between 1 and 10 and 10 and 100 keV respectively.) The experimental data and average values are shown in Fig. 1* together with the available spot point measurements and the following points can be noted.

(1) Below 10 keV the shapes of the Moxon, Silver et al and Fricke et al data are similar though there are serious discrepancies around 6-7 keV (possibly due to the 5.9 keV aluminium resonance).

(2) Above 20 keV the shapes of the Moxon and Silver et al data are consistent (if we neglect the regions of the aluminium resonances at 35 and 89 keV) though the ratio of their absolute values is different from the value below 10 keV.

(3) The shape of the Fricke et al data above 20 keV differs from the other time-of-flight data which, however, agree with the shape of the Menlove and Poenitz data[30].

Therefore, we can conclude that the shape of the U-238 capture cross-section as well as the absolute values are uncertain in the 1-100 keV energy range.

Table 5

Experiments used to obtain evaluated U-238 $\sigma_{n\gamma}$ below 100 keV

Experiment	Method	Energy range data accepted (keV)	Comments
Moxon[26]	Linac, Moxon-Rae detector, relative to B-10(n,α γ), normalised at 6.6 eV, sample thickness 1.6×10^{-3} atoms/barn	1 - 100	Data revised[27]. Additional errors for uncertainty in self screening and multiple scattering: ± 2% (1-2 keV), ± 1.5% (2-3 keV), ± 1% (3-100 keV)
Fricke et al[28]	Linac, large liquid scintillator, relative to B-10(n,α) and H(n,n) below and above 80 keV, normalised at 6.6 eV, sample thicknesses 4.5×10^{-3} - 1.14×10^{-2} atoms per barn.	10 - 100	Data accepted above 10 keV only because relatively thick samples were used
Silver et al[29]	Linac, large liquid scintillator, relative to B-10(n,α), normalised at 6.6 eV, sample thicknesses 4×10^{-4} - 2.8×10^{-3} atoms per barn	1 - 100	Additional errors: ± 2% for errors in B-10(n,α) cross-section, ± 3% for coincidence between two halves of scintillator

*The references shown in the figures are given fully in Appendices 1 and 2.

3.4 Effect of Spot Point Data on Evaluated Data for the U-235 and Pu-239 Fission Cross-sections

So far in this energy range below 100 keV the evaluated numbers have been based upon continuous time-of-flight data so as to avoid errors due to the uncertainties in the neutron energy spectra of spot point measurements combined with the known structure in the cross-section curves. However, we cannot completely ignore the spot point data. Table 6 summarises the evaluated data on U-235 and Pu-239 fission cross-sections between 10 and 30 keV based solely upon continuous time-of-flight data. It can be seen that the ratio deduced from the independent normalisations for the two isotopes agrees extremely well with the measured ratios shown in Fig. 2. Now if we consider the spot point data paying particular attention to the measurements of Perkin et al[31], Knoll and Poenitz[32] and Szabo et al[33], and attempt to assess the effects of cross-section structure and energy uncertainty then we find that the evaluated numbers should be increased by 3.7% and 4.1% respectively for U-235 and Pu-239. Because the ratios of the cross-sections are in good agreement we consider that both should be raised by the same amount and we have chosen to increase the data by 4%, 3% and 2% in the energy ranges 20-30, 10-20 and less than 10 keV respectively. (The values between 0.1 and 1 keV could not be increased by 4% because the average values over this energy range are known to 3.3 and 2.3%.) As a result of this renormalisation the evaluated cross-sections above 30 keV were also adjusted since for U-235 the evaluation is based upon the Lemley et al data renormalised between 10 and 30 keV and the Pu-239 data are obtained from the U-235 evaluation and our evaluated Pu-239/U-235 fission cross-section ratio.

Table 6

U-235 and Pu-239 fission cross-section values between 10 and 30 keV based on continuous time-of-flight data

Energy (keV)	Average cross-sections based on time-of-flight data		Deduced ratio Pu-239/U-235	Measured ratio
	U-235 (barns)	Pu-239 (barns)		
10-15	2.629	1.754	0.667	0.667
15-20	2.322	1.630	0.702	0.702
20-25	2.094	1.565	0.747	0.737
25-30	2.038	1.535	0.753	0.742

The evaluated U-235 and Pu-239 fission cross-section data are given in Tables 7 and 8 respectively and in Figs. 3, 4, 5 and 6 they are compared to the experimental data. It can be seen that on the whole the evaluated numbers are well supported by the more recent measurements. The errors in the evaluated numbers given in Table 9 are difficult to assess and therefore can only be given approximately. Below 30 keV the evaluated cross-sections are not correlated and we consider that the errors for the U-235 and Pu-239 fission cross-sections are respectively 3.9 and 3.0% at approximately 100 eV increasing to ~ 4.5% in the region of 30 keV. The errors for each of the cross-sections are correlated over the 0.1 - 30 keV energy range such that if the

cross-section were renormalised in the low energy region then it would be necessary to alter the cross-section over the whole energy range. However, because of the spot point data the cross-sections would not be adjusted by the same percentage. Above 30 keV the errors in the two cross-sections are strongly correlated and the errors for U-235 and Pu-239 are approximately 6.5 and 7% respectively. The cross-section values are of course also correlated with the data below 30 keV and to a limited extent to the data above 100 keV.

Table 7

U-235(n,f) evaluated cross-section below 100 keV

E_n (keV)	σ_{nf} (barns)	E_n (keV)	σ_{nf} (barns)	E_n (keV)	σ_{nf} (barns)
0.1-0.2	21.31	30-31	2.117	68-69	1.795
0.2-0.3	20.79	31-32	2.155	69-70	1.817
0.3-0.4	13.46	32-33	2.026	70-71	1.798
0.4-0.5	13.75	33-34	2.023	71-72	1.773
0.5-0.6	15.14	34-35	1.968	72-73	1.720
0.6-0.7	11.63	35-36	1.963	73-74	1.686
0.7-0.8	11.15	36-37	1.969	74-75	1.743
0.8-0.9	8.399	37-38	1.959	75-76	1.778
0.9-1.0	7.762	38-39	1.948	76-77	1.774
1-2	7.455	39-40	1.979	77-78	1.605
2-3	5.486	40-41	2.110	78-79	1.580
3-4	4.866	41-42	1.932	79-80	1.684
4-5	4.391	42-43	1.949	80-81	1.730
5-6	3.943	43-44	1.896	81-82	1.725
6-7	3.477	44-45	1.859	82-83	1.712
7-8	3.373	45-46	1.820	83-84	1.707
8-9	3.071	46-47	1.868	84-85	1.728
9-10	3.165	47-48	1.854	85-86	1.657
10-11	2.868	48-49	1.899	86-87	1.590
11-12	2.785	49-50	1.897	87-88	1.603
12-13	2.565	50-51	1.876	88-89	1.692
13-14	2.748	51-52	1.895	89-90	1.666
14-15	2.573	52-53	1.911	90-91	1.644
15-16	2.393	53-54	1.890	91-92	1.614
16-17	2.376	54-55	1.837	92-93	1.612
17-18	2.333	55-56	1.848	93-94	1.621
18-19	2.507	56-57	1.851	94-95	1.566
19-20	2.349	57-58	1.881	95-96	1.704
20-21	2.111	58-59	1.799	96-97	1.643
21-22	2.166	59-60	1.926	97-98	1.601
22-23	2.336	60-61	1.876	98-99	1.628
23-24	2.080	61-62	1.858	99-100	1.689
24-25	2.195	62-63	1.843		
25-26	2.111	63-64	1.720		
26-27	2.091	64-65	1.766		
27-28	2.105	65-66	1.825		
28-29	2.204	66-67	1.801		
29-30	2.084	67-68	1.787		

Table 8

Pu-239(n,f) evaluated cross-section below 100 keV

E_n (keV)	σ_{nf} (barns)
0.1-0.2	18.95
0.2-0.3	18.02
0.3-0.4	8.823
0.4-0.5	9.478
0.5-0.6	15.36
0.6-0.7	4.494
0.7-0.8	5.628
0.8-0.9	4.955
0.9-1.0	8.170
1-2	4.267
2-3	3.193
3-4	2.923
4-5	2.299
5-6	2.132
6-7	1.955
7-8	2.071
8-9	2.227
9-10	1.863
10-15	1.807
15-20	1.679
20-25	1.628
25-30	1.596
30-35	1.63
35-40	1.57
40-45	1.61
45-50	1.56
50-55	1.63
55-60	1.63
60-65	1.63
65-70	1.62
70-75	1.63
75-80	1.59
80-85	1.63
85-90	1.55
90-95	1.56
95-100	1.60

Table 9

Estimated errors in evaluated average cross-sections in the energy range 0.1 - 100 keV

Energy Range (keV)	% Errors		
	U-235(n,f)	Pu-239(n,f)	U-238(n,γ)
0.1-0.2	3.9	3.0	-
0.3-0.4	3.9	3.1	-
0.7-0.8	3.9	3.1	-
1.0-2.0	3.9	3.6	6.0
3.0-4.0	3.9	4.0	6.0
7.0-8.0	4.2	4.0	6.0
10.0-20.0	4.4	4.0	6.0
30.0-40.0	5.5	6.0	8.0*
70.0-80.0	6.5	7.0	6.0
90.0-100.0	6.5	7.0	6.0

*This error is large because of the effect of the Al resonance

3.5 Effect of Spot Point Data on the Evaluated U-238 Capture Cross-section

The spot point measurements of the U-238 capture cross-section are best compared with the other data in the range 20-30 keV. Knowing the "energy" of the measurements it is possible to use the shape of the Moxon and Fricke et al data and adjust the spot point values so that they give an equivalent average cross-section from 20-30 keV. (The errors in the values have to be increased when this is done to allow for structure in the cross-sections and energy uncertainties.) The mean value of the adjusted data of Belanova[34] (as corrected by Miller and Poenitz[35]), Gibbons et al[36], Rose[37] and Menlove and Poenitz (neglecting the datum relative to Au) is 0.498 ± 0.019 barns and this is to be compared to the average of 0.507 ± 0.034 barns for the continuous time-of-flight data. Since these numbers are so close we will accept the average values calculated from the time-of-flight experiments for our evaluated curve and the numbers are given in Table 10 and plotted in Fig. 1. There are only limited spot point data available on the ratio of the U-238 capture cross-section to the U-235 fission cross-section in this energy range and we have decided to ignore these because of their relatively large errors, the known structure in the cross-sections and the energy uncertainties in the measurements. The errors in the evaluated cross-sections are again difficult to assess because above 10 keV the experimental values of the three time-of-flight experiments are discrepant in shape, particularly in the region of the Al resonance (typical errors from the spreads in data are ± 6%). Though the data of Moxon and Silver et al agree reasonably well below 10 keV their shapes over the 1-100 keV range are discrepant. The spot point data around 30 keV are consistent with the mean of the two measurements and if we renormalised their shapes in this energy range then they would be discrepant below 10 keV and again a suitable error would be ± 6%. Hence we consider that the error over the whole energy range is approximately ± 6%.

Table 10

U-238(n,γ) evaluated cross-section from 1-100 keV

Energy interval (keV)	Evaluated $\sigma_{n\gamma}$ (barns)
1 - 2	2.050
2 - 3	1.530
3 - 4	1.266
4 - 5	0.985
5 - 6	0.989
6 - 7	0.903
7 - 8	0.840
8 - 9	0.757
9 - 10	0.752
10 - 20	0.654
20 - 30	0.507
30 - 40	0.452
40 - 50	0.391
50 - 60	0.324
60 - 70	0.280
70 - 80	0.237
80 - 90	0.214
90 - 100	0.200

4. Cross-sections Between 100 keV and 20 MeV

In this energy interval the evaluations are based upon spot point measurements using the simultaneous evaluation technique discussed in Section 2. In the earlier report on the evaluation[3] we included data on the Au-197 capture cross-section in the energy range 100 keV to 1 MeV in the simultaneous fit. This was done because these measurements combined with data on the Au-197(n,γ)/U-235(n,f) ratio give information on the U-235 fission cross-section. The measurements of the Au-197 capture cross-section are at least as accurate as those for U-238(n,γ) and some were also performed using neutron flux measurement techniques not used for the other cross-sections we are considering. We have therefore continued to include the gold data in the evaluation.

In this section we will consider each cross-section or ratio in turn and obtain the starting values for the fitting procedure. (For convenience the energy ranges over which the data have been accepted are shown in Fig. 7.) First, however, we will consider the fission cross-section data in the vicinity of 14 MeV. Measurements of cross-section shape are frequently normalised in this region and hence it is advantageous to evaluate this energy at the start.

In the vicinity of 14 MeV measurements have been made of the absolute values of the U-235(n,f) and U-238(n,f) cross-sections and the Pu-239(n,f)/U-238(n,f), U-235(n,f)/U-238(n,f) and Pu-239(n,f)/U-235(n,f) cross-section ratios. The procedures used in determining the best values of these quantities at 14.0 MeV have been identical in all cases. First it was found for each of the quantities that a linear energy dependence adequately represents the data between 13 and 15 MeV. Then for each quantity, the mean gradient was calculated using the data from the measurements listed in column 2 of Table 11. These values were then used to obtain the equivalent cross-sections or ratios at 14.0 MeV for each of the experiments shown in column 3. Finally the weighted mean values, given in column 4, were calculated using weights which were mainly obtained from the errors assigned by the experimenters increased, where necessary, to allow for the errors in correcting to 14.0 MeV. In the case of U-235(n,f), however, Hansen et al were given low weight because of their large scattering corrections and poor documentation. (For U-238(n,f), however, their scattering correction is much smaller and they were given a weight based on their assigned errors.) Where experiments are listed in Columns 2 and 3 for a given quantity (e.g. Czyzewski for Pu-239(n,f)/U-238(n,f)) the value at 14.0 MeV was obtained from the least squares fit used to determine the slope of the data between 13 and 15 MeV.

It can be seen from Table 11 that the available data at 14 MeV are an overdetermined set since there are 5 pieces of information on 3 cross-sections. This is therefore a good example of the conditions suitable for applying the simultaneous evaluation technique. The data used as starting values are shown in Column 4, the corresponding Δ values are listed in Column 5 and the results of the simultaneous fit are given in Column 6. It should be noted that the differences between the evaluated and starting values are small when compared with errors of ~ ± 2% which we feel are typical of the accuracy currently achieved at this energy.

Table 11

Data used in the evaluation at 14 MeV

Cross-section or ratio	Experiments used to determine the gradient of the data between 13 and 15 MeV	Experiments used to obtain absolute values at 14 MeV	Mean value at 14 MeV used as starting value	Δ-value (%)	Evaluated data at 14 MeV
U-238(n,f)	Hansen et al[38] Adams et al[39] Pankratov et al[40] Pankratov[41]	Uttley and Phillips[42] Flerov et al[43] Billaud et al[44] Moat[45] Hansen et al[38]	1.127 b	2	1.126 b
U-235(n,f)	Pankratov[41] Pankratov et al[40] Hansen et al[38]	White[46] Hansen et al[38]	2.147 b	3	2.152 b
Pu-239(n,f)/U-238(n,f)	Czyzewski[47] Adams et al[39]	Hansen et al[38] Uttley and Phillips[42] Czyzewski[47] Moat[45]	2.288	2	2.269
U-235(n,f)/U-238(n,f)	Adams et al[39]	White and Warner[48] Uttley and Phillips[42] Berezin et al[49] Moat[45] Nyer[50]	1.897	2	1.911
Pu-239(n,f)/U-235(n,f)	No data available. Slope obtained from U-238(n,f)/Pu-239(n,f) and U-235(n,f)/ U-238(n,f) values	White and Warner[48]	1.165	3	1.187
Pu-239(n,f)	No data available.	No data available	-	-	2.555 b

4.1 U-235 Fission Cross-section

The accepted data on the U-235 fission cross-section are shown in Fig. 4 between 10 keV and 6 MeV and in Fig. 8 between 1 MeV and 20 MeV and given in Appendix 1. The data we have rejected are listed in Appendix 2 but some comments are appropriate. In the case of Allen and Ferguson[51] only the absolute values at 550 keV and 1.8 MeV were accepted. The data of Henkel[52] have been omitted because of uncertainties in the various corrections which have been made since the results were first published. The results of Kalinin and Pankratov[53] have been neglected because of uncertainties in the available values due to later changes[41] in the efficiency of their long counter (see section on Pu-239/U-235 fission ratio). Since the main purpose of the experiment of Smirenkin et al[54] was to investigate correlations between structure in the angular anisotropy of fission fragments and the fission cross-section rather than to make accurate measurements of the cross-section, their results have also been neglected. Also plotted in Fig. 4 are the data of Barry[55] and Bame and Cubitt[56] which are conventionally thought of as giving data on the Li-6(n,α) cross-section using U-235(n,f) as the standard. There is no doubt[57] that the Li-6 cross-section is known to a much higher accuracy than the U-235 fission cross-section, particularly below ~ 100 keV and therefore we have chosen to use these data as determinations of the U-235 fission cross-section based upon the Li-6(n,α) cross-section of Uttley and Diment[58].

In selecting our starting values for the simultaneous fit we gave greatest weight to the data of Szabo et al[33,59] and White[46] in the energy range below 1 MeV. In the 400-500 keV region these starting values are well supported by the recent data of Poenitz[60] and Kappeler[61] and at 100 keV they are consistent with the evaluated values discussed in the previous section. Above 1 MeV the data are very limited, particularly in the important energy range below 6 MeV where the data of Hansen et al have been corrected by up to 17% for scattering effects. It is therefore obvious that more measurements are urgently required. The existing data were measured some years ago without the benefit of time-of-flight or some other energy selection and background rejection method and hence improved measurements are possible. Above 9 MeV the data of Hansen et al[38] are significantly low, particularly at 14 MeV, and have essentially been ignored* in selecting the starting values.

4.2 Pu-239 Fission Cross-section

At the time this evaluation was started the only acceptable measurements of the Pu-239 fission cross-section between 100 keV and 14 MeV were the data of Allen and Ferguson[51] at 550 keV and 1.5 MeV. Recently Szabo et al have published two sets of measurements[33,59] and these have significantly improved our knowledge. The accepted values are shown on Fig. 6 and listed in Appendix 1. The starting values were selected giving greatest weight to the later measurements of Szabo et al[33] below 200 keV since

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* This raises the general question as to whether or not one should completely ignore a measurement if it is thought to be partially in error. We have found that many measurements fall into this category and if we ignored all these there would be very little acceptable data. One of the important advantages of the simultaneous evaluation method is that it is a great help in showing the presence of erroneous data.

these were made under experimental conditions where the corrections for neutron scattering were much lower than for the earlier set[59]. Starting values were obtainable only below 1.6 MeV and there is an obvious need for absolute measurements in the higher energy range where the evaluated data have to be based on ratio measurements.

4.3 Pu-239/U-235 Fission Cross-section Ratio

We have accepted all the known data on the Pu-239/U-235 fission cross-section ratio and the values are listed in Appendix 1 and shown in Figs. 2 and 9. There are a number of comments we would like to make on these measurements.

(i) The Gilboy and Knoll[62] data have been renormalised following consultation with the authors by increasing the mean of the results of their Method B and 0.94 times their Method A by 14.9%. This renormalisation factor was chosen to give agreement with our low energy normalisation between 10 and 30 keV and it can be seen that it brings the results into good agreement with most of the other data over the whole energy range.

(ii) We have used the data of Kalinin and Pankratov[53] as a ratio measurement because of uncertainties in their flux measurement.

(iii) The ratio data of Szabo et al[33] have been given zero weight because the data have already been accepted as measurements of the absolute fission cross-sections of U-235 and Pu-239.

In selecting our starting values between 30 and 100 keV we gave the greatest weight to the data of Pfletschinger and Kappeler[63]. Between 100 keV and 1 MeV these data, together with those of Poenitz[64] and White et al[65], were favoured though around 1 MeV the values were selected so that the evaluated fission cross-sections had a relatively smooth energy dependence. Above 1 MeV the data of Allen and Ferguson[51], Nesterov and Smirenkin[66] and Savin et al[67] appear to be low at their high energy limit while the data of Smith et al[68] appear high below about 3 MeV. In this region we have therefore given high weight in selecting our starting values to the data of Poenitz[64], White and Warner[48], the absolute measurements of Nesterov and Smirenkin (represented as ⊕) and above 3 MeV to the data of Smith et al and Kalinin and Pankratov[53].

4.4 U-238 Capture Cross-section

There are few measurements of the absolute U-238 capture cross-section above 100 keV and the data we have accepted are shown in Fig. 10 and given in Appendix 1. The data of Menlove and Poenitz[30], which were originally normalised to 0.479 barns at 30 keV have been renormalised to 0.466 barns so as to be consistent with our evaluation below 100 keV. In selecting our starting values we have given low weight to the data of Tolstikov et al[69] and to the data of Fricke et al[28] above ~ 400 keV.

4.5 The Ratio of the U-238 Capture to the U-235 Fission Cross-section

The accepted values of the U-238(n,γ) to U-235(n,f) ratio are shown in Fig. 11 and listed in Appendix 1. The values are shown below 100 keV but these are not used in the simultaneous evaluation. We have chosen to use the data of Barry et al[70] as ratio measurements for two reasons.

(a) The flux measurements were made using the fission chambers of White[46], which he had essentially calibrated absolutely during his fission cross-section measurements. This means that the U-238(n,γ) and U-235(n,f) measurements were based on a single set of flux determinations and since we can only include these once in our evaluation it is preferable that we consider the Barry et al measurement as a ratio to U-235(n,f) and

(b) their results would be discrepant with other measurements of the capture cross-section but appear to agree with other measurements of the ratio. Therefore, we reduce discrepancies by considering their data as a ratio and we also get some indication that there may be errors in the measurements of neutron flux in the absolute measurements of cross-sections.

The starting values were selected by giving little weight to the data of Linenberger and Miskel[71]. At 100 keV the curve had to be consistent with the lower energy evaluation and therefore it has to be significantly lower than the data of Barry et al between 100 and 200 keV.

4.6 Au-197 Capture Cross-section and its Ratio to the U-235 Fission Cross-section

A complete evaluation has not been performed on the Au-197 cross-section and the data we have used are our selection of good measurements. The data are plotted in Figs. 12 and 13 and listed in Appendix 1.

In selecting our starting values of the cross-section we have given high weight below 500 keV to the data of Poenitz et al[72] and Harris et al[73]. At higher energies there are only a few data points and these have essentially been given roughly equal weight. As far as the ratio of cross-sections is concerned we have given the highest weight to the data of Barry[74]. It is important to note that the measurement of Harris et al used the associated activity method to measure the flux and that the measurement of Robertson et al[75] used a calibrated Na-Be neutron source. These techniques have not been used in the other cross-section measurements we are evaluating and hence we consider it important to include the Au-197 capture cross-section in this work.

4.7 U-238 Fission Cross-section

The accepted values of the U-238 fission cross-section are shown in Fig. 14 and listed in Appendix 1. There are many more measurements in the vicinity of 14 MeV than are shown and these have been discussed above. The data of Adams et al, Pankratov et al and Pankratov have been renormalised to our evaluated value of 1.126 barns at 14 MeV. We consider that this cross-section should be given high weight in the evaluation for two reasons:-

(a) one expects larger errors in the fission cross-section measurements for the thermally fissile nuclei than the fertile nuclei due to the effects of scattered and room return neutrons and

(b) the available measurements are in good agreement.

4.8 U-238/U-235 Fission Cross-section Ratio

The accepted data on the U-238/U-235 fission ratio are given in Appendix 1 and

shown above 1.8 MeV in Fig. 15. The detailed data of Lamphere[76] have been renormalised between 2 and 3 MeV by a factor of 0.9388 to bring them into closer agreement with the values of Stein et al[77], White and Warner and Kalinin and Pankratov. Below 1.8 MeV the renormalised Lamphere data have been used to define the U-238(n,f) threshold region. This renormalisation was performed because the Lamphere data are old and not supported by the more recent data. In selecting the starting values at about 2 MeV the data of Stein et al were given approximately equal weight with the data of White and Warner.

4.9 The U-238/Pu-239 Fission Cross-section Ratio

The accepted data on the U-238/Pu-239 fission cross-section ratio are shown in Fig. 16 and listed in Appendix 1. Below 13 MeV only one set of data is available and therefore this ratio should not be given particularly high weight in the evaluation. Above 15 MeV the data appear to be discrepant and we have given the data of Adams et al highest weight in selecting our starting values.

4.10 Selection of Values of Δ Used in the Simultaneous Fit

In Section 2 of the paper the method of simultaneously fitting the data was described. The final evaluated cross-sections depend upon (a) the starting values of the cross-sections and ratios and (b) the weights W (or, as given in equation (4), the values of Δ). We have discussed the starting values above and in this section we will discuss the selection of the values of Δ.

In an earlier report on this evaluation[3] it was found that the values of the U-235 fission cross-section were not consistent with the data on the U-238(n,γ) and Au-197(n,γ) cross-sections in the energy range 100 to 700 keV. It was suggested at that time that the U-235 fission cross-section data could be in error. Since then, however, there have been U-235 fission cross-section measurements by Szabo et al[33,59], Kappeler[61] and Poenitz[60] and these tend to confirm the older data. Therefore, it would appear that the errors are more likely to be in the measurements of U-238(n,γ), Au-197(n,γ), U-238(n,γ)/U-235(n,f) or Au-197(n,γ)/U-235(n,f) than in U-235(n,f) and this conclusion is fundamental in our selection of values of Δ. We also consider that ratio measurements of cross-sections are less likely to be in error than absolute measurements for the following reasons:-

(a) No absolute determination of neutron flux is required in a ratio measurement

(b) The errors due to scattered and room return neutrons are minimised in ratio measurements when the two cross-sections have a similar energy dependence

(c) Two identical detectors can be used for measuring fission cross-section ratios and this must minimise the corrections.

The greater consistency of ratio measurements confirms these views.

We have, therefore, made the Δ values for ratio measurements smaller than those for cross-section determinations. It follows, therefore, that if there are inconsistencies in the data the simultaneous adjustment procedure will in general not alter the values of the ratios as much as the absolute values of the cross-sections.

The values of Δ are shown in Table 12 and some detailed comments can now be made.

Table 12

The values of Δ used in the simultaneous fitting procedure (expressed as a percentage)

Inclusive Energy Range (MeV)	U-235 (n,f)	Pu-239 (n,f)	U-238 (n,f)	U-238 (n,γ)	Au-197 (n,γ)	Pu-239 (n,f) to U-235 (n,f) ratio	U-238 (n,γ) to U-235 (n,f) ratio	Au-197 (n,γ) to U-235 (n,f) ratio	U-238 (n,f) to U-235 (n,f) ratio	U-238 (n,f) to Pu-239 (n,f) ratio
0.1 - 0.17	3	5		6	6	3	5	5		
0.20- 0.20	3	5		6	6	2	4	5		
0.25- 0.60	3	7		6	6	2	4	5		
0.7 - 0.8	3	7		6	6	3	4	5		
0.9 - 0.9	3	7			6	3	(4)	5		
0.95- 1.0	3	7			6	3	(5)	5		
1.2 - 1.2	4	7				4	(8)		(7)	
1.4 - 1.4	4	7				4	(8)		(5)	
1.6 - 1.6	4	7	6			4	(8)		3	
1.8 - 1.8	4		6			(4)	(8)		3	
2.0 - 2.2	4		5			4	(10)		3	7
2.4 - 2.4	5		5			4	(10)		3	7
2.6 - 2.6	6		5			4	(10)		3	7
2.8 - 3.0	7		5			4	(10)		3	7
3.5 - 3.5	7		5			5	(10)		3	7
4.0 - 4.5	7		5			5	(14)		3	7
5.0 - 5.0	7		5			6	(14)		3	7
5.5 - 5.5	6		5			6	(14)		3	7
6.0 - 6.5	7		5			6	(33)		7	7
7.0 - 7.0	7		4			6	(33)		7	7
8.0 - 8.0	7		4			6	(33)		20	7
9.0 - 9.0*	7		5							(7)
10.0 -10.0	6		5							(10)
11.0 -12.0*	5		4							(10)
13.0 -13.0*	5		4							(5)
14.0 -14.0	3		2			3			2	2
15.0 -15.0	5		4						6	(5)
16.0 -16.0	5		4						6	(6)
17.0 -17.0	5		4						8	(6)
18.0 -19.0	5		4						8	(7)
20.0 -20.0*	5		4							(8)

Values in brackets are not required in simultaneous fit as one cross-section in the ratio is not overdetermined

*At these energies the data are not overdetermined and no simultaneous fit is possible

(i) For U-235(n,f) the values are smallest below 1 MeV where there are a number of good measurements. As one goes to higher energies, Δ increases as the number and accuracy of the measurements both decrease. Above 10 MeV the data of Pankratov et al and Pankratov agree well and it is reasonable to reduce Δ. At these energies the data of Hansen et al are low by ~ 10% and have been given zero weight.

(ii) The values for Pu-239(n,f) increase at 0.25 MeV because the measurements of Szabo et al[33] do not extend above 200 keV. The Δ values are higher than for U-235(n,f) because there are fewer experiments.

(iii) The values for U-238(n,f) should be largest at low energies and decrease with increasing energies as there tend to be more measurements above 11 MeV, all of which are consistent. Above 2.6 MeV the Δ values are smaller than for U-235 because the scattering corrections in the experiments are much smaller.

(iv) The values for U-238(n,γ) and Au-197(n,γ) are kept constant as a function of energy. There are more data for the Au cross-section but we have assumed similar errors because we have not made a complete evaluation of all the Au data.

(v) The values for the Pu-239(n,f)/U-235(n,f) ratio are lowest at low energies and increase at higher energies because of increasing discrepancies. The values between 0.1 and 0.17 MeV are higher than those at slightly higher energies because of the possible effects of structure in the fission cross-sections. These should be of less importance as the energy increases.

(vi) The values for U-238(n,γ)/U-235(n,f) ratio increase with increasing neutron energy because the experimental errors do this. The value from 0.1 to 0.17 MeV is high because of the discrepancy between the measurements in this region and the values based on an extrapolation of the low energy evaluation below 100 keV.

(vii) The variation of Δ for the U-238(n,f)/U-235(n,f) ratio essentially follows the errors in the experimental data. The value is kept at 3% between 1.6 and 5.5 MeV because of the accurate experiments of Stein et al and White and Warner. The experiment of Stein et al is one of the few measurements performed using a mono-energetic neutron source and the time-of-flight technique and consequently, since the background due to scattered and room return neutrons will be small, this ratio must be given high weight in the simultaneous fit.

(viii) The values for the U-238(n,f)/Pu-239(n,f) ratio are relatively large because there are only the data of Hansen et al below ~ 13 MeV and it is not clear if these are entirely independent of the other data measured by this group which are included elsewhere in the evaluation. The error increases between 10 and 12 MeV because of the lack of data points and increased experimental errors. Above 14 MeV a lower error is necessary because of the data of Adams et al but this has to be increased at the highest energies because of increasing discrepancies.

Using the starting values shown as dashed lines on Figs. 2, 4, 6 and 8 to 16 and the values of Δ discussed above, the simultaneous fit produces our evaluated cross-sections which are shown as solid lines on the figures and are listed in Table 13. The errors in these numbers are discussed in the next section.

Table 13

Evaluated cross-sections above 100 keV

Energy (MeV)	Au-197(n,γ) (barns)	U-235(n,f) (barns)	Pu-239(n,f) (barns)	U-238(n,f) (barns)	U-238(n,γ) (barns)
0.100	0.341	1.566	1.517		0.198
0.130	0.315	1.493	1.465		0.177
0.170	0.284	1.401	1.431		0.158
0.200	0.269	1.345	1.419		0.149
0.250	0.249	1.288	1.421		0.137
0.300	0.224	1.252	1.444		0.130
0.350	0.199	1.219	1.467		0.124
0.400	0.180	1.183	1.468		0.121
0.500	0.146	1.135	1.505		0.122
0.600	0.1207	1.109	1.531	0.0010	0.133
0.700	0.1062	1.135	1.608	0.0008	0.144
0.800	0.0970	1.162	1.667	0.0026	0.148
0.900	0.0946	1.201	1.686	0.0082	0.148
0.950	0.0947	1.218	1.692	0.0122	0.146
1.000	0.0947	1.234	1.710	0.0121	0.144
1.20		1.268	1.800	0.0393	0.132
1.40		1.273	1.870	0.129	0.102
1.60		1.320	2.005	0.372	0.0818
1.80		1.356	2.061	0.487	0.0705
2.00		1.319	2.016	0.522	0.0581
2.20		1.286	1.968	0.525	0.0489
2.40		1.246	1.910	0.515	0.0411
2.60		1.214	1.870	0.507	0.0352
2.80		1.193	1.848	0.503	0.0298
3.00		1.174	1.830	0.502	0.0258
3.5		1.127	1.799	0.506	0.0195
4.0		1.093	1.754	0.512	0.0151
4.5		1.066	1.714	0.513	0.0119
5.0		1.047	1.679	0.514	0.0097
5.5		1.037	1.684	0.540	0.0083
6.0		1.115	1.806	0.613	0.0072
6.5		1.273	1.917	0.753	0.0067
7.0		1.465	2.015	0.874	0.0064
8.0		1.674	2.213	0.956	0.0059
9.0		1.748	2.261	0.963	0.0054
10.0		1.753	2.267	0.952	0.0049
11.0		1.735	2.293	0.954	0.0045
12.0		1.735	2.333	0.966	0.0041
13.0		2.010	2.441	1.008	0.0038
14.0		2.152	2.555	1.126	0.0034
15.0		2.217	2.589	1.238	0.0031
16.0		2.277	2.566	1.303	0.0029
17.0		2.255	2.524	1.343	0.0026
18.0		2.105	2.385	1.319	0.0024
19.0		2.094	2.326	1.335	0.0022
20.0		2.110	2.427	1.439	0.0020

5. Discussion

5.1 Energy Range Below 100 keV

It can be seen from Figs. 3 and 5 that the U-235 and Pu-239 fission cross-section data have a considerable spread about our evaluated curves. The data plotted are not consistently normalised but are the published results corrected where necessary for the non-1/v dependence of the B-10(n,α) cross-section. By renormalisation only some of the discrepancies are removed and therefore it is concluded that there are uncertainties in the shapes of the cross-sections as well as their absolute values. We concluded in Section 3.4 that the average cross-sections of U-235 and Pu-239 from 0.1 to 1 keV are known to ± 3.3% and ± 2.3% respectively. Recent work by Deruytter and Wagemans[9,78] has shown that accuracies of ~ ± 1% are attainable in the 1 to 20 eV range but considerable work has still to be done before such accuracies extend into the keV energy range. There are three main areas where errors can arise as the neutron energy increases:

(a) the properties of the fission process (e.g. $\bar{\nu}$, angular distributions of fragments and neutrons, total γ-ray energy) and hence the efficiency of fission detectors may alter as higher partial waves (p, d, etc.) become more predominant. (N.B. p-wave contributions to the average Pu-239 fission cross-section are approximately 7, 25, 38 and 63% at 1.5, 5.5, 9.5 and 25 keV respectively).

(b) the cross-sections used for flux measurement e.g. Li-6(n,α) and B-10(n,α) are known with decreasing accuracy. It has been estimated[57, 1] that the cross-sections are known to ± 1, ± 1 and ± 2% (Li-6) and ± 1, ± 2 and ± 3% (B-10) at 1, 10 and 100 keV respectively and the uncertainties in the efficiency of detectors using these reactions must be greater.

(c) in time-of-flight experiments using white spectrum sources the neutron energy resolution gets worse, the count rate per unit time increases and one is working closer to the intense burst of unmoderated source neutrons and γ-rays produced by the accelerator. All these can have their detrimental effect though of course the background does not increase as rapidly as the counts per unit time. It is particularly important to measure both the neutron flux and the fission events with identical neutron resolution, otherwise as has been seen earlier, errors can occur when there is structure in the neutron spectrum.

The fission cross-section measurements in the energy range below 30 keV are on the whole not well documented, their errors are not normally fully discussed and one cannot be certain that the changes in the fission process with increasing energy do not affect the results. For these reasons we consider the errors to be as high as 4.5% below 30 keV even though some selected data[22] agree better than this. Between 30 and 100 keV the situation is even worse. There are no continuous measurements for Pu-239 and for U-235 the only existing published measurement is not particularly accurate. Therefore we recommend that further careful, well documented measurements of these fission cross-sections should be performed. In particular they should be normalised at low

energies (eV range or even lower), cover as broad an energy range as possible and attempt to avoid some of the errors discussed above.

It can be seen from Figs. 4 and 17 that for U-235 our evaluated fission cross-section agrees reasonably with the Hart evaluation below 5 keV. At higher energies it is significantly lower and this is a consequence of Hart[79], who essentially follows Davey[80], giving high weight to the data of Perkin et al[31] at 22.8 keV and White[46] at 40 keV. However, by 65 keV the evaluations are agreeing within 3%. For Pu-239 it is seen from Figs. 5 and 18 that below 30 keV the present evaluation and that of Hart are not as discrepant as for U-235. This is a consequence of Hart using the James and Patrick[81] evaluation which can be considered as an early version of a simultaneous evaluation. Above 10 keV the evaluation of Davey starts approximately 10% higher than ours; Ribon and Le Coq[82] on the other hand agree below 30 keV when average cross-sections are compared. Above 30 keV there is a tendency for all other evaluations to be lower and this is a consequence of either using lower values of the Pu-239/U-235 fission ratio or following the data of Szabo et al. The differences between the evaluations above 30 keV are, however, never as large as the estimated errors of ± 7%.

The evaluation of the U-238 capture cross-section below 100 keV is not satisfactory. As can be seen from Fig. 1 there are 3 continuous measurements covering the energy range 1 to 100 keV but though these are all normalised by the saturated resonance technique at 6.6 eV there are differences in shape and normalisation in the keV energy range. There are spot point data around 30 keV and as discussed in Section 3.5 these lead to an average cross-section from 20 to 30 keV of 0.498 ± 0.019 barns which is 1.8 ± 7.8% lower than our evaluated figure of 0.507 barns. In the energy range below ~ 5 keV our evaluation can be compared with the values deduced from resolved resonance parameters by James[83] and Pitterle and Durston[84]. The evaluated capture cross-sections are compared in Table 14 and it can be seen that our values are larger. The Pitterle and Durston values are based on the Rahn et al[85] values of Γ_n and a value of Γ_γ of 23.5 meV while James based his evaluation of Γ_γ and Γ_n solely on the Rahn et al data. The differences between these resonance parameter based evaluations are mainly due to the methods of allowing for missed resonances and it is disturbing to find that their results are significantly lower than ours. However, we consider the accuracy of the average cross-section deduced from resonance parameters to be no better than ± 10% and therefore the discrepancies may not be significant and our evaluated cross-sections need no adjustment. It is obvious from this that a measurement should be performed which can be used to obtain good values of resonance parameters and average cross-sections.

Table 14

Comparison of the evaluated values of the U-238 capture cross-section with the values obtained by resolved resonance parameters

Energy Interval (keV)	Present Evaluation (barns)	James (barns)	Pitterle & Durston (barns)
1 - 2	2.050	1.784	1.87
2 - 3	1.530	1.275	1.40
3 - 4	1.266	1.142	1.24

There are a number of other recent evaluations of the U-238 capture cross-section below 100 keV and some of these are compared with the present one in Fig. 19. The evaluation of Pitterle[86] for ENDF/BII agrees reasonably well with ours above 4 keV (the same is also true for ENDF/BIII). Below 4 keV the evaluation is based on resonance parameters and as discussed above, such evaluations tend to be low compared to ours. The best value at 30 keV is 0.456 barns and this agrees well with our value of 0.466 barns. The value for the Davey[87] evaluation at 30 keV, however, is 0.482 barns which is 3.4% higher than ours and at lower energies Davey recommends values up to 5% higher though between 2 and 4 keV the difference is not so large. The evaluation of Abagyan et al[88], however, agrees well with Davey and gives 0.49 barns at 30 keV. The FD4 data, whose origin has been described by Rowlands and Macdougall (ref. (89)), is significantly lower than the present work below 30 keV. Campbell and Rowlands[90] have shown that these FD4 data do not require significant adjustment in order to bring measured and calculated integral reactor properties into agreement; a conclusion supported by the Cadarache jeu Version 2 given by Barré and Bouchard[91] above 10 keV which also follows low cross-section values. It therefore appears as if there is a significant discrepancy between the U-238 capture data which satisfactorily predicts reactor properties and the differential measurements. The evaluations based on resolved resonance parameters, however, appear to fit the integral evidence.

It should be noted that the uranium in fast reactors is usually in fairly thick pieces and there are large differences (a factor of 2 possible under certain conditions) between the effective shielded cross-section and the infinite dilution cross-section which we have evaluated. In differential measurements the samples are much thinner and maximum corrections of ~ 10% are typical. Silver et al[29] have made measurements with samples of thickness 0.0004 and 0.0028 atoms per barn and the results agree within 2% in the region where the corrections are large for the thicker sample (e.g. at 1 to 2 keV the corrections for self screening and multiple scattering are 1.4% and 8.8% respectively and the corrected measurements differ by 1%). Obviously the present situation is far from satisfactory and we make the following recommendations.

(1) Investigations are required to find the causes of the discrepancies between the existing careful differential measurements

(2) Additional experiments are desirable particularly when the causes of discrepancy have been investigated

(3) Work is required to show that the self-screening calculations in reactor physics codes are correct.

5.2 Energy Range Above 100 keV

In the energy range above 100 keV the cross-sections were considered simultaneously and hence the evaluated values selected for the various cross-sections are not independent. As has been stated previously the highest weights (lowest values of Δ) were given to the cross-section ratio measurements and the highest weights for the cross-section data were assigned to the U-238 and U-235 fission cross-sections above and below 2.2 MeV respectively.

In general the simultaneous evaluation does not lead to large significant

differences between the starting values and the evaluated numbers. Below 1 MeV, however, the simultaneous fit gives evaluated values which are lower than the starting values for U-235(n,f), Pu-239(n,f), U-238(n,γ)/U-235(n,f) and Au-197(n,γ)/U-235(n,f) and higher than the starting values for U-238(n,γ) and Au-197(n,γ). This is a consequence of the inconsistencies between the fission and capture cross-sections discussed in the previous section. Our selection of starting and Δ values has forced the major changes to be made in the U-238(n,γ) and Au-197(n,γ) cross-sections. When the measurements of U-235(n,f) and Pu-239(n,f) are omitted from the fit and these cross-sections are deduced from the capture cross-section data and ratio measurements, the values are 5-6% lower. This fact is important when the errors in the cross-sections are being considered.

In the energy range below 1 MeV the evaluated U-235 fission cross-section does not support the low data of Poenitz[92] above 200 keV. A lower U-235 fission cross-section would require a lower Pu-239 fission cross-section and it can be seen in Fig. 6 that our evaluated Pu-239(n,f) curve is already low compared to the existing data. This is balanced against the fact that the evaluated values of both the Au-197 and U-238 capture cross-sections tend to be higher than the directly measured values.

Above 1 MeV the simultaneous fit gives evaluated data which are only slightly different from the starting values except above 15 MeV where the U-235(n,f) data are modified. The values of the U-235, Pu-239 and U-238 fission cross-sections are very consistent with the measurements of their ratios and on the surface this would tend to suggest that the cross-sections are well known. However, there are a number of reasons why this may not be true:-

(a) There are few acceptable absolute measurements of fission cross-sections between 1 and 14 MeV and in addition authors have tended to make measurements on more than one cross-section. In consequence there may be systematic errors in the absolute measurements which cancel out when their ratios are compared to direct ratio determinations.

(b) The absolute fission cross-section measurements below 1 MeV are on the whole consistent with ratio determinations. There are, however, serious discrepancies when the capture data are included in the evaluation.

(c) The integral of the U-238 fission cross-section in a fission spectrum is not consistent with direct measurements of this quantity (see Table 15). The ratio of the averages for U-238(n,f) and U-235(n,f) in a fission spectrum also appears wrong but the ratio for Pu-239 and U-235 appears correct. The latter ratio is not sensitive to changes in the fission spectrum and hence this suggests that the discrepancies are likely to originate from errors in the fission cross-section of U-238 and/or the shape of the fission spectrum.

(d) There is some recent evidence that our evaluated values of the U-238 fission cross-section and/or its ratio to the U-235 fission cross-section might be in error. Kuks et al[98] obtain a value of 0.55 ± 0.02 barns for the U-238 cross-section at 2.5 MeV and Poenitz and Armani[99] report measurements of the U-238 to U-235 fission cross-section ratio in agreement with data of Lamphere[76]. The latter data were renormalised by a factor of 0.9388 in the present evaluation.

Table 15

Average cross-sections in a fission spectrum

Comments	U-238(n,f) (mb)	U-235(n,f) (mb)	Pu-239(n,f) (mb)	U-235(n,f) / U-238(n,f)	Pu-239(n,f) / U-235(n,f)
Calculated					
Present evaluation					
(a) Watt Cranberg	282	1236	1776	4.38	1.437
$T = 0.965$ MeV, $E_f = 0.5331$ MeV					
(b) Maxwellian	272	1238	1770	4.55	1.430
$T = 1.290$ MeV					
Measurements					
Leachman and Schmitt[93]	312				
Richmond[94]	300				1.423
Nikolaev et al[95]	310				
Fabry et al[96]				3.58	
Grundl[97]				3.85	

Spectra used

Watt Cranberg $N(E) = \text{const.}\ \exp(-E/T).\ \text{Sinh}\sqrt{\frac{4E\,E_f}{T^2}}$

Maxwellian $N(E) = \text{const.}\ \sqrt{E}\ \exp(-E/T)$

The points listed above suggest that our evaluation of the U-238 fission cross-section may well be in error and because of ratio determinations there may also be errors in our evaluations for U-235 and Pu-239 above 1 MeV. At the present time all the recent U-238 data have not been documented and we prefer therefore to give them low weight. However, we have taken them into account in assessing the errors of the evaluation which are given in Table 16. The errors in the energy range 0.1 to 1 MeV are kept as large as ~ 6% or greater because of the discrepancies between the fission and capture cross-section data discussed above. The errors at 14 MeV are small because of the high accuracy and excellent agreement of the data. However, as we have suggested for other energy ranges this could be fortuitous. Some of the errors are most probably not symmetric; it is more probable that all the cross-sections are lower rather than higher between 0.1 and 1 MeV, and above the U-238 threshold it is more probable that the U-238 fission cross-section is higher rather than lower. Because of the difficulty in fully expressing all the correlations in the evaluation we have not attempted to quote asymmetrical errors.

Table 16

Errors in evaluated cross-sections in energy range 0.1 - 20 MeV

Neutron Energy (MeV)	Percentage Errors			
	U-235(n,f)	Pu-239(n,f)	U-238(n,f)	U-238(n,γ)
0.1	5.8	6.0		6.6
0.3	5.8	6.5		6.6
0.7	5.8	6.5	20.0	7.0
1.0	5.8	7.0	10.0	7.0
3.0	6.0	7.2	6.0	11.0
7.0	6.0	8.5	5.5	33.0
10.0	7.0	10.0	5.5	-
14.0	2.0	2.0	2.0	-
20.0	7.0	8.5	5.5	-

It can be seen from Fig. 17 that the present evaluation of the U-235 fission cross-section agrees reasonably well with those of Hart and Davey considering that we estimate the errors to be ~ 6%. Between 100 and 700 keV our evaluation is up to 4% lower as a consequence of being able to consider later measurements and of including capture cross-section data in the simultaneous adjustment. Above 1 MeV the Hart evaluation is different because it accepts the data of Henkel[52], which we have neglected, and uses the Smith et al[68] data, which have been superseded by those of Hansen et al. The evaluation of Davey above 1 MeV agrees well with ours except below 2 MeV where the discrepancy arises because he has given very high weight to the data of White while we considered that the data of Diven[100] and the datum of Allen and Ferguson at 1.8 MeV were also reliable.

Fig. 18 shows the comparisons of the Pu-239 fission cross-section evaluations and on the whole they agree reasonably well except perhaps above 10 MeV and between 100 and 700 keV. The differences above 10 MeV are principally due to differences in the methods of evaluation. Both Hart and Greene et al[101] evaluated the Pu-239/U-235 fission cross-section ratio and multiplied this by an evaluated U-235 fission cross-section to obtain their Pu-239 data. The values of U-235 fission cross-section they adopted are the main cause of their differences with the present work. Between 100 keV and 700 keV the present evaluation is lower than the others mainly because our U-235 fission cross-section evaluation is lower. In the case of Ribon and Le Coq the difference arises because they followed the measurements of Szabo et al.

The U-238 fission cross-section evaluations are compared in Fig. 20 and it can be seen that the major differences are in the plateaux regions. Our evaluation is based mainly upon the absolute measurements of the U-238 fission cross-section while the others are deduced from evaluations of the U-235 fission cross-section and U-238/U-235 fission cross-section ratios. The evaluation of Hart was probably kept high in the energy region 2 to 4 MeV in order to bring the integral of the cross-section in a fission spectrum more into line with the measurements of this quantity. Therefore, it is not surprising that it is different. Although the agreement between the various evaluations is good, this does not mean that the uncertainties are less than the estimated errors of 5.5 - 6%.

The evaluations of U-238(n,γ) shown in Fig. 19 are not in particularly good agreement below 600 keV. At higher energies the agreement is better because there are only limited data. The present evaluation is lower than the others because the others tend to be based on evaluations of the U-238(n,γ)/U-235(n,f) ratio and the U-235 fission cross-section and our values of both these quantities are probably lower over some parts of the energy range. The recent ENDF/BIII evaluation is however lower than the present one over most of the range as it follows the data of Fricke et al[28].

Fig. 21 shows a comparison of Au-197(n,γ) evaluations and it can be seen that there is good agreement with the present work except near 1 MeV where the situation is not clear. The datum of Robertson et al[75] (see Fig. 12) indicates that the energy dependence of the cross-section may not change rapidly in this energy range and the emphasis given to these authors in the present work probably explains the differences.

An important conclusion deduced from this discussion is that the differences between recent evaluations are mainly due to differences in the philosophies adopted as there is little difference between the data the various evaluators consider reliable. Therefore it appears that the discrepancies in the experimental data are not likely to be resolved by further evaluation work and consequently we must look to additional measurements to do this. Before discussing those which we consider are necessary it is worth noting how well the present evaluations calculate integral reactor properties. Rowlands[102] has discussed how the new FGL5U fast reactor data set, which uses the present evaluated data, fits integral measurements and gives the adjustments that must be made to improve the fit. One should not consider that these adjustments give the true cross-sections but they do give an indication where further work is desirable. The following comments on the proposed adjustments are of interest.

(a) The U-238 capture cross-section is reduced by 12% (0.5 - 25 keV), 8% (25 - 50 keV) and 6% (50 - 500 keV).

(b) Between 1 keV and 1 MeV only minor adjustments are proposed for the Pu-239 fission cross-section while adjustments of -5% decreasing to -3% are necessary between 1 and 200 keV for U-235.

(c) Adjustments are necessary in the fission cross-sections above 1 MeV particularly in the case of U-238. It is difficult to be certain as to the magnitude of these as they are not independent of adjustments to the fission neutron spectrum and the inelastic cross-section of U-238. However, as a result of this there must be doubts about the U-238/U-235 fission ratio measurements and in the absolute values of the U-238 and U-235 fission cross-sections.

5.3 Recommendations for Further Measurements

Before recommending in detail the measurements we consider necessary to solve existing discrepancies there are some general comments we would like to make. The history of scientific measurements shows us that the most recent data are not necessarily correct. Therefore one new measurement is not by itself sufficient to remove a discrepancy unless this identifies the errors in the previous experiments. An integrated world-wide programme is obviously desirable for the important quantities and the measurements should be made using as many different techniques as possible. When there is agreement then perhaps the discrepancies have been solved, though one must not forget that it is not unknown for experimenters to obtain results close to the value obtained in the better earlier measurements.

The U-235 fission cross-section is an important standard over the energy range above 100 keV. Improved measurements are required over the whole energy range up to 20 MeV and we would recommend that they should be made using the time-of-flight technique or some equally good neutron energy selection method. In the energy range below 1 MeV in particular there are advantages in using white spectrum neutron sources so that the effects of cross-section structure are eliminated. These measurements should help to resolve the discrepancies between fission and capture data in the lower energy region and improve our knowledge of fission cross-sections above 1 MeV where there are surprisingly few absolute measurements except in the energy range around 14 MeV. It would be very nice if a single experiment could span the energy range thermal to 14 MeV as the most accurate measurements have been made at these energies.

The discrepancies in the U-238 capture cross-section measurements should be reduced mainly by the measurements recommended below 100 keV. However, it is obviously desirable to have further measurements above 100 keV. At the present time virtually all the reliable data in this energy range, except those of Fricke et al which are not particularly accurate, have been made by or relative to an activation measurement. Therefore we recommend that any new measurements of the absolute value of the U-238 capture or its ratio to the U-235 fission cross-section should preferably not use this technique. If other techniques are used then there is the additional advantage that the time-of-flight method can be used. In absolute measurements of cross-sections,

particularly capture cross-sections, it is recommended that the use of intermediate standards (e.g. Au-197) should be avoided as these only add to the uncertainties.

As plutonium will be the fuel most used in fast reactors, the fission cross-section of Pu-239 is obviously of prime importance. As we have seen there are very few absolute cross-section measurements and we recommend that an experimental programme on Pu-239 fission similar to that recommended for U-235 fission should be performed. Above 1 MeV the ratio of the Pu-239 and U-235 cross-sections is not particularly well known and measurements are recommended between 1 and 14 MeV.

The measured U-238 fission cross-section appears to be discrepant with integral data though the differential measurements of fission cross-sections all appear to be consistent in the energy range above 2 MeV. An important integral quantity is the average U-238 fission cross-section in a fission spectrum and since the absolute measurements of this are old a further measurement is recommended. Measurements of the absolute U-238 fission cross-section and ratio measurements relative to the U-235 fission cross-section are also desirable. There is a strong case for making the U-238 cross-section the primary fission standard above 2 MeV because the effects of scattered and room return neutrons are small. The comments made about the recommended techniques for the U-235 measurements also apply to U-238.

This list of recommended experiments is very comprehensive and is not placed in any order of priority. However, the principal discrepancies between differential and integral data are associated with the fission and capture cross-sections of U-238. In consequence it would appear that measurements directly commenting on these discrepancies have the highest importance.

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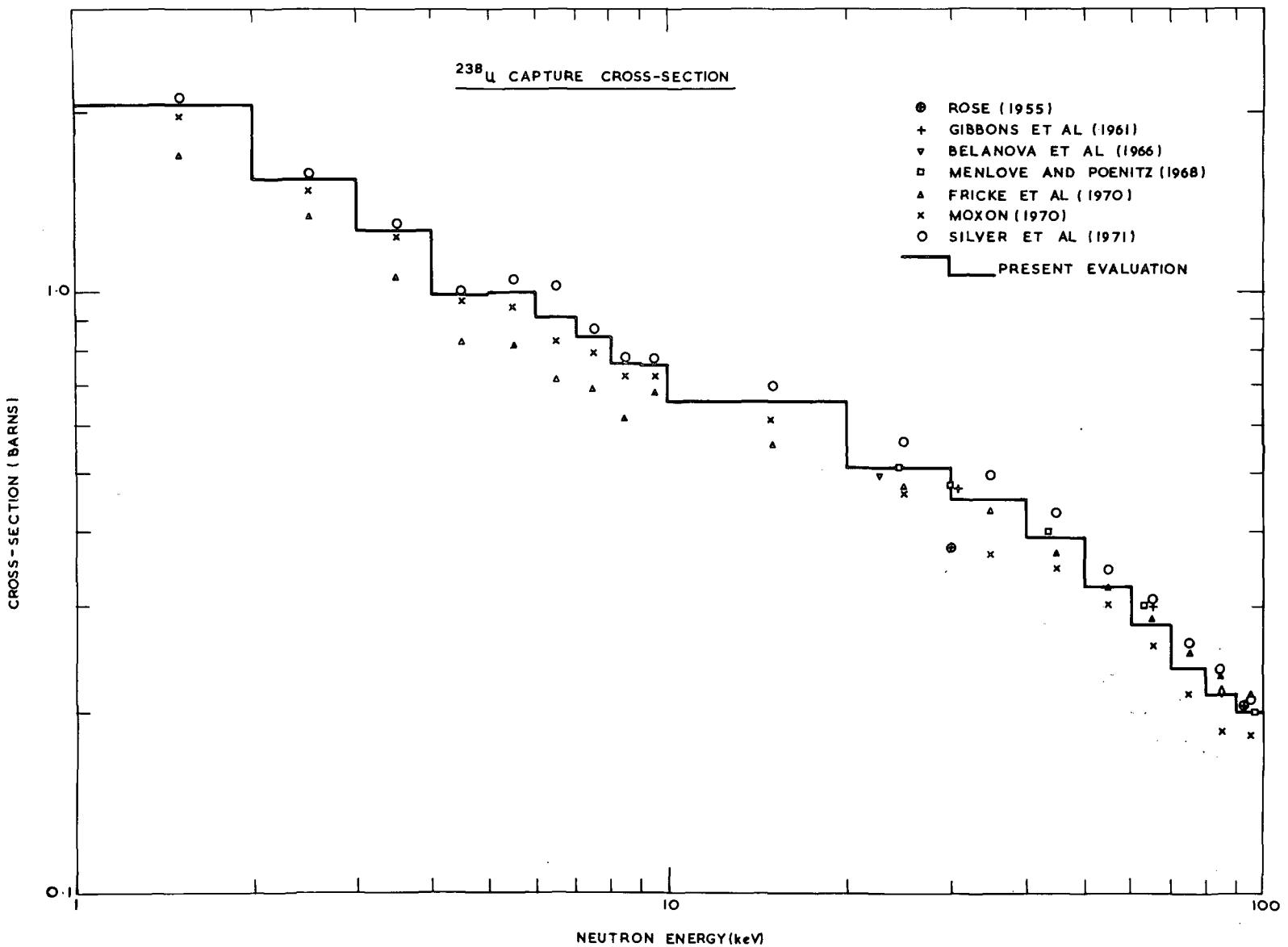
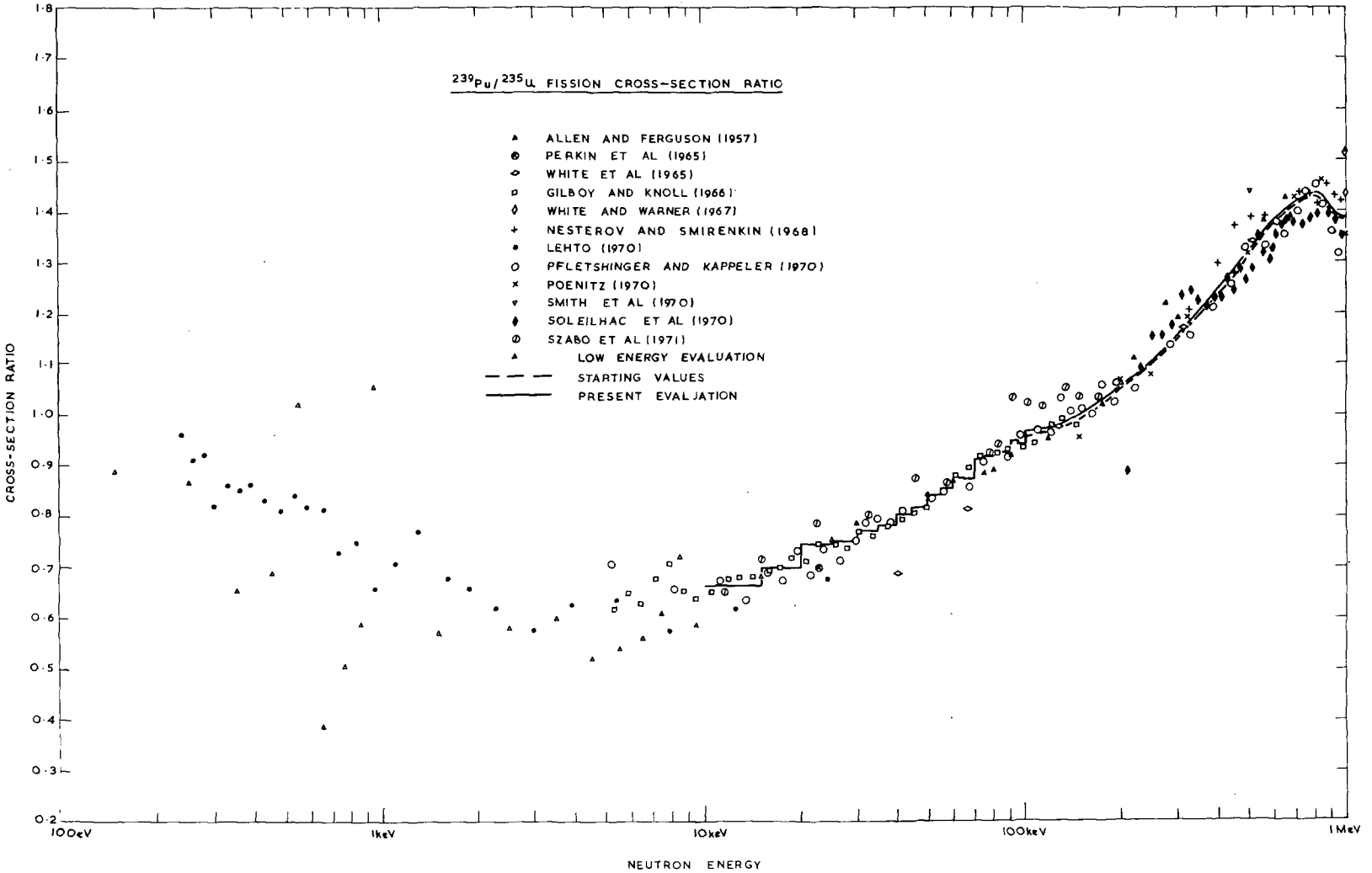
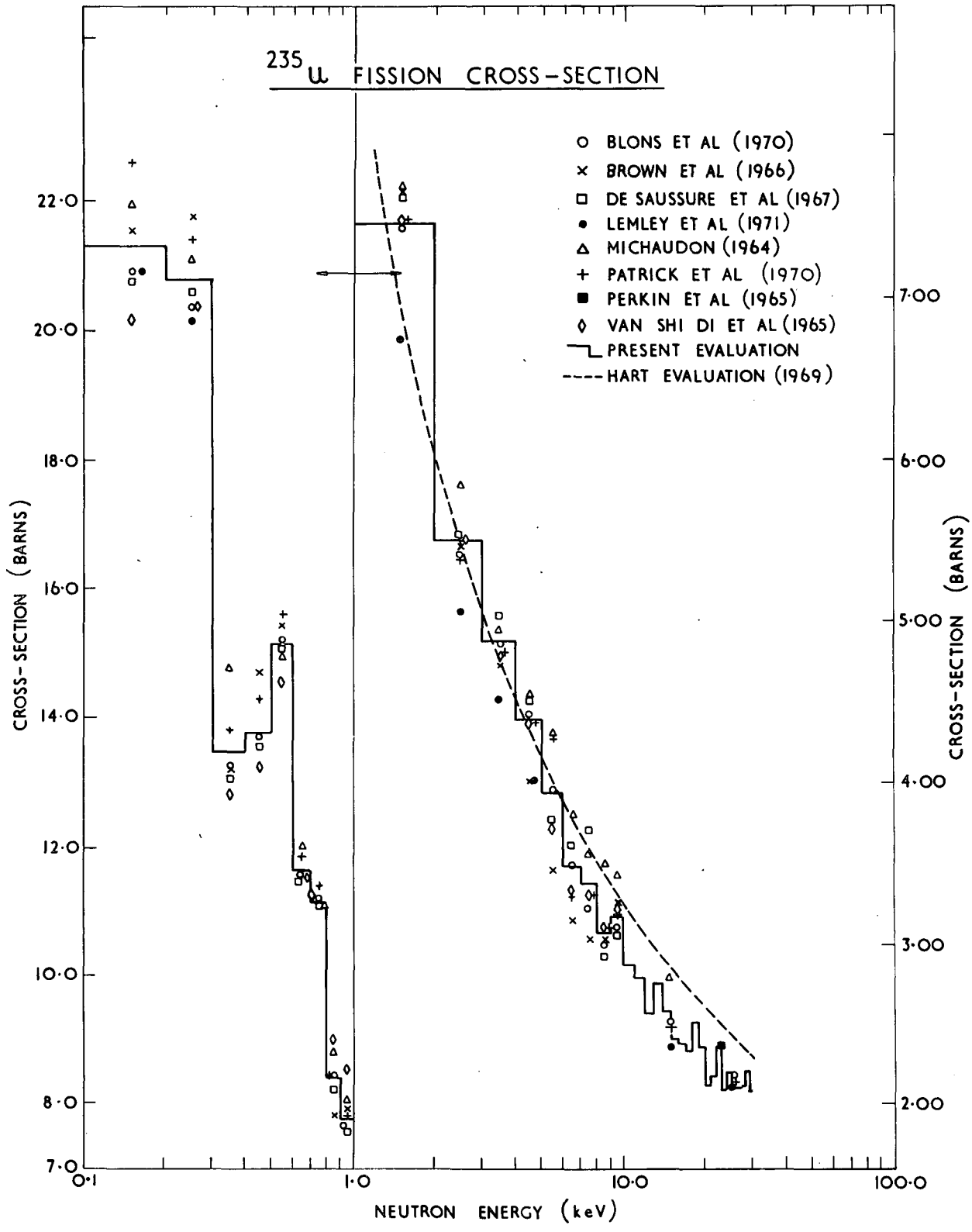


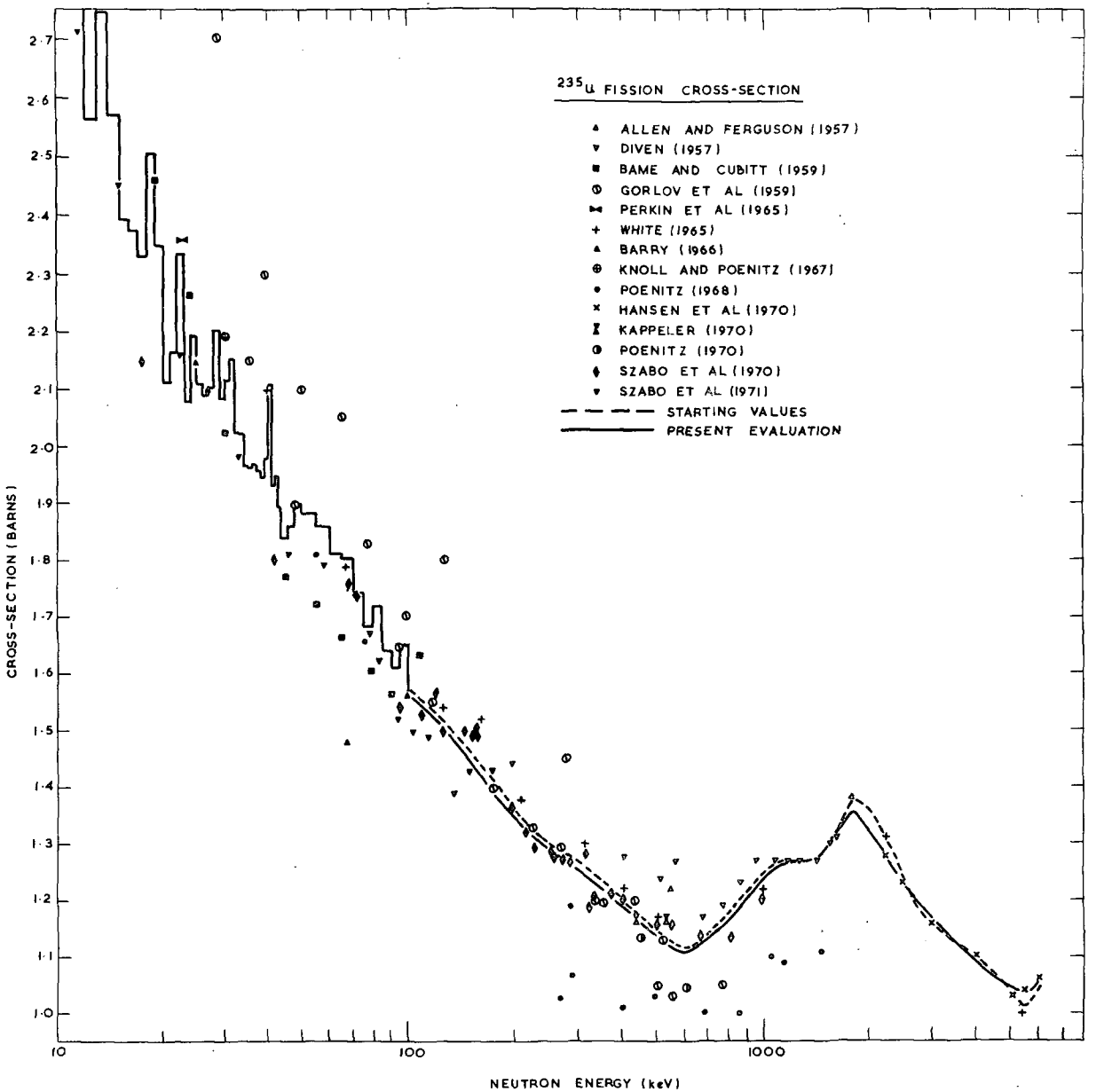
AERE - R 7273 Fig. 1
The capture cross-section of U-238 between 1 and 100 keV.



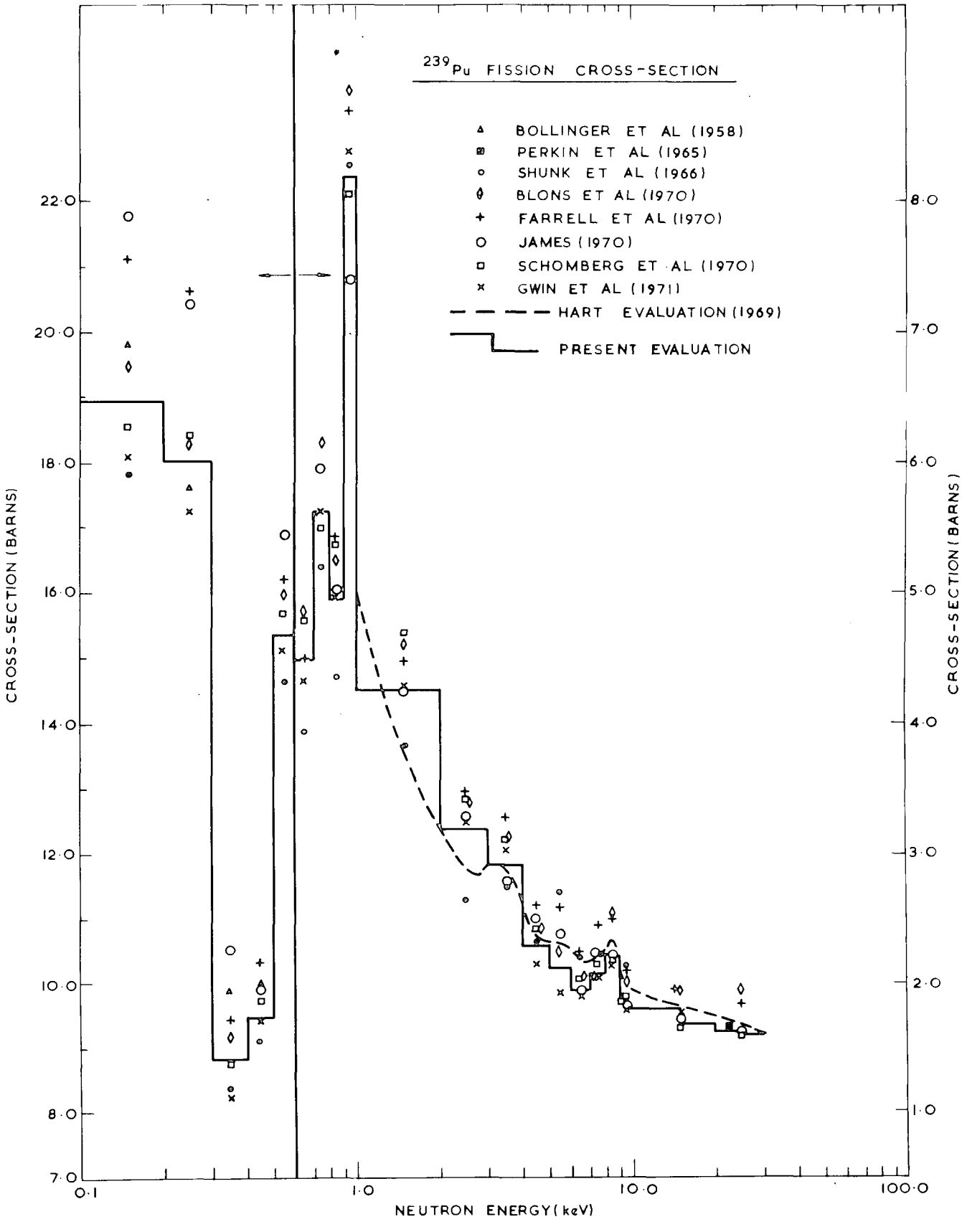
AERE - R 7273 Fig. 2
The ratio of the fission cross-sections of Pu-239 and U-235 between 100 eV and 1 MeV.



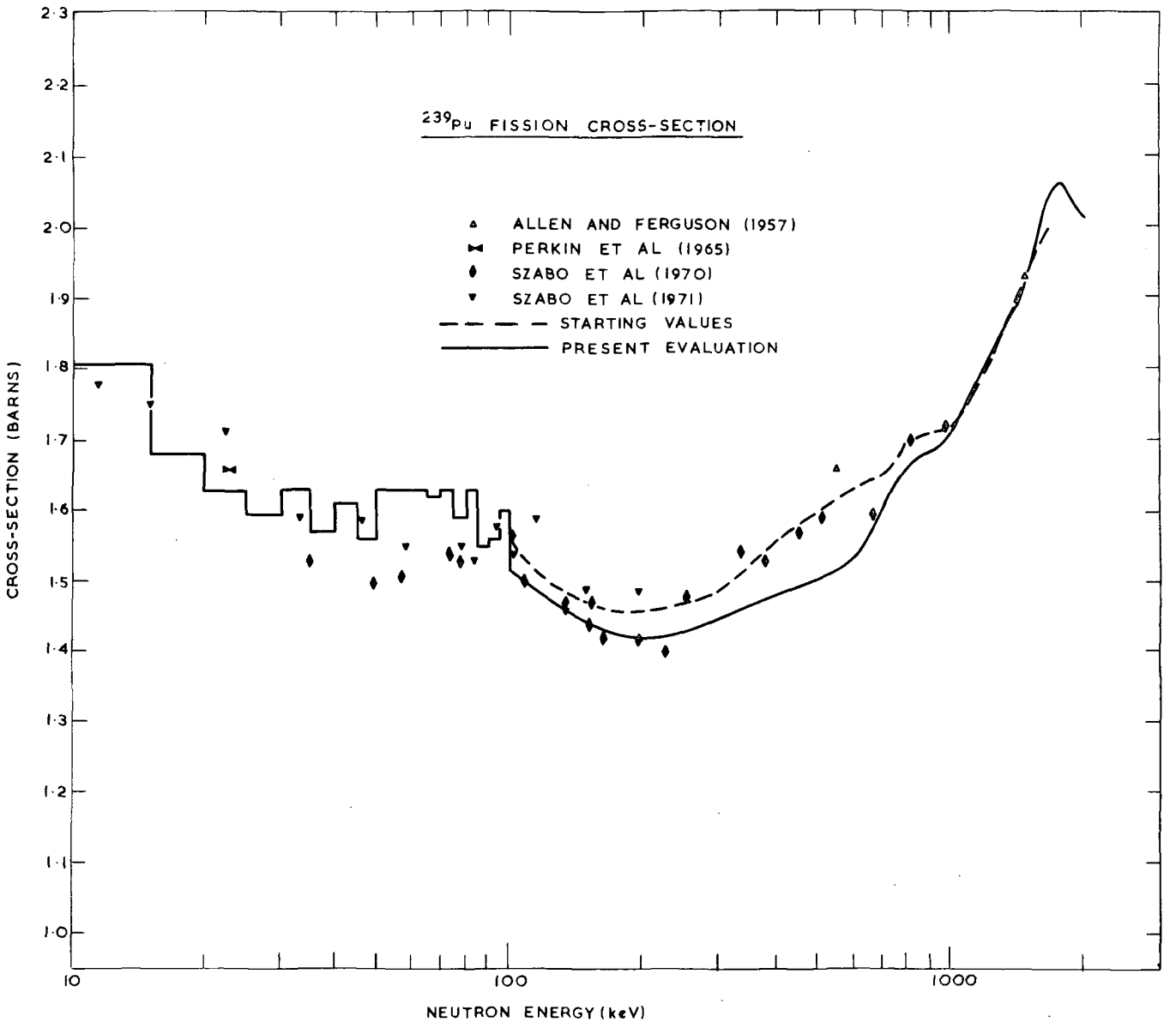
AERE - R 7273 Fig. 3
The fission cross-section of U-235 between 0.1 and 30 keV.



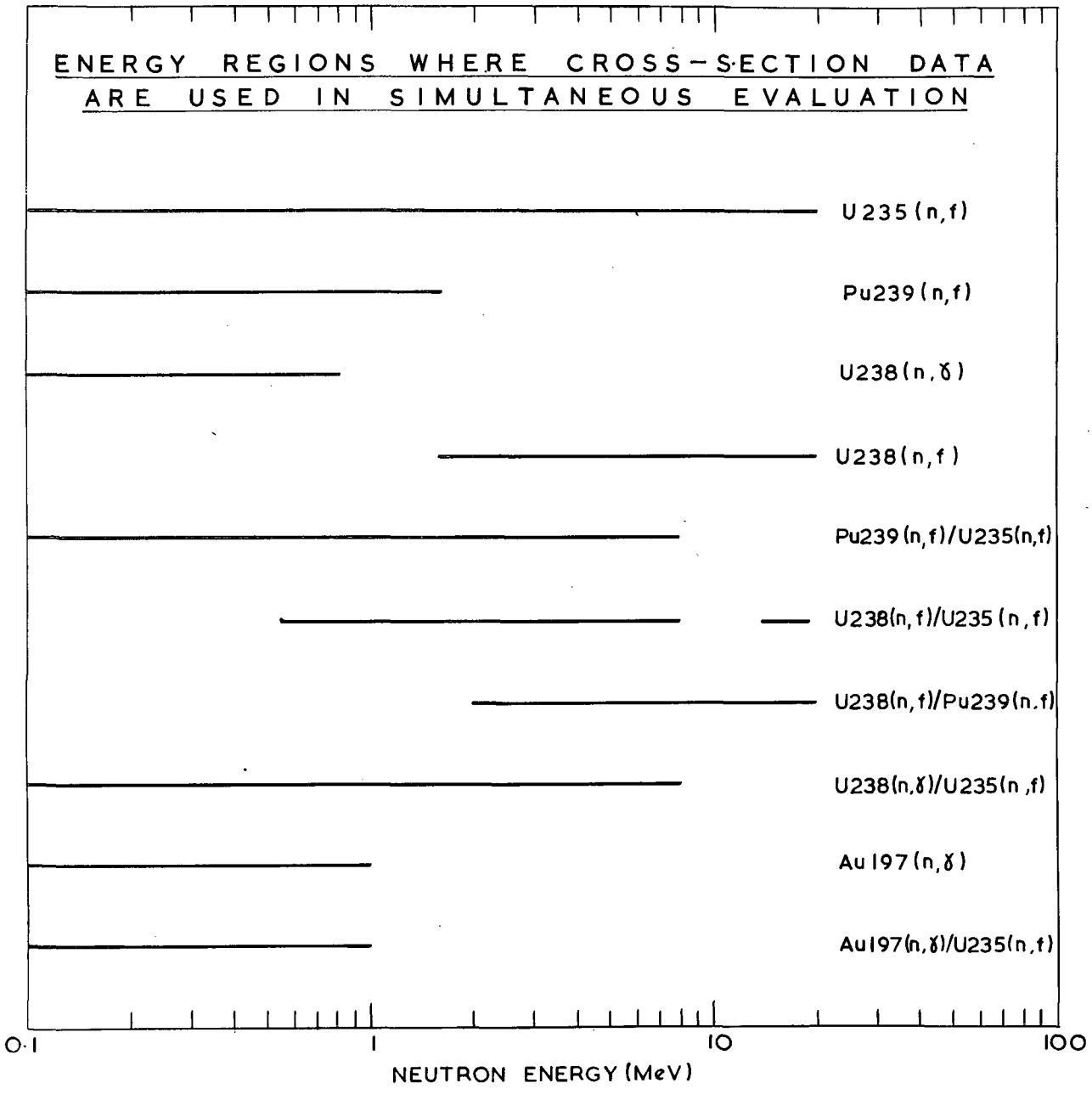
AERE - R 7273 Fig. 4
The fission cross-section of U-235 between 10 keV and 6 MeV.



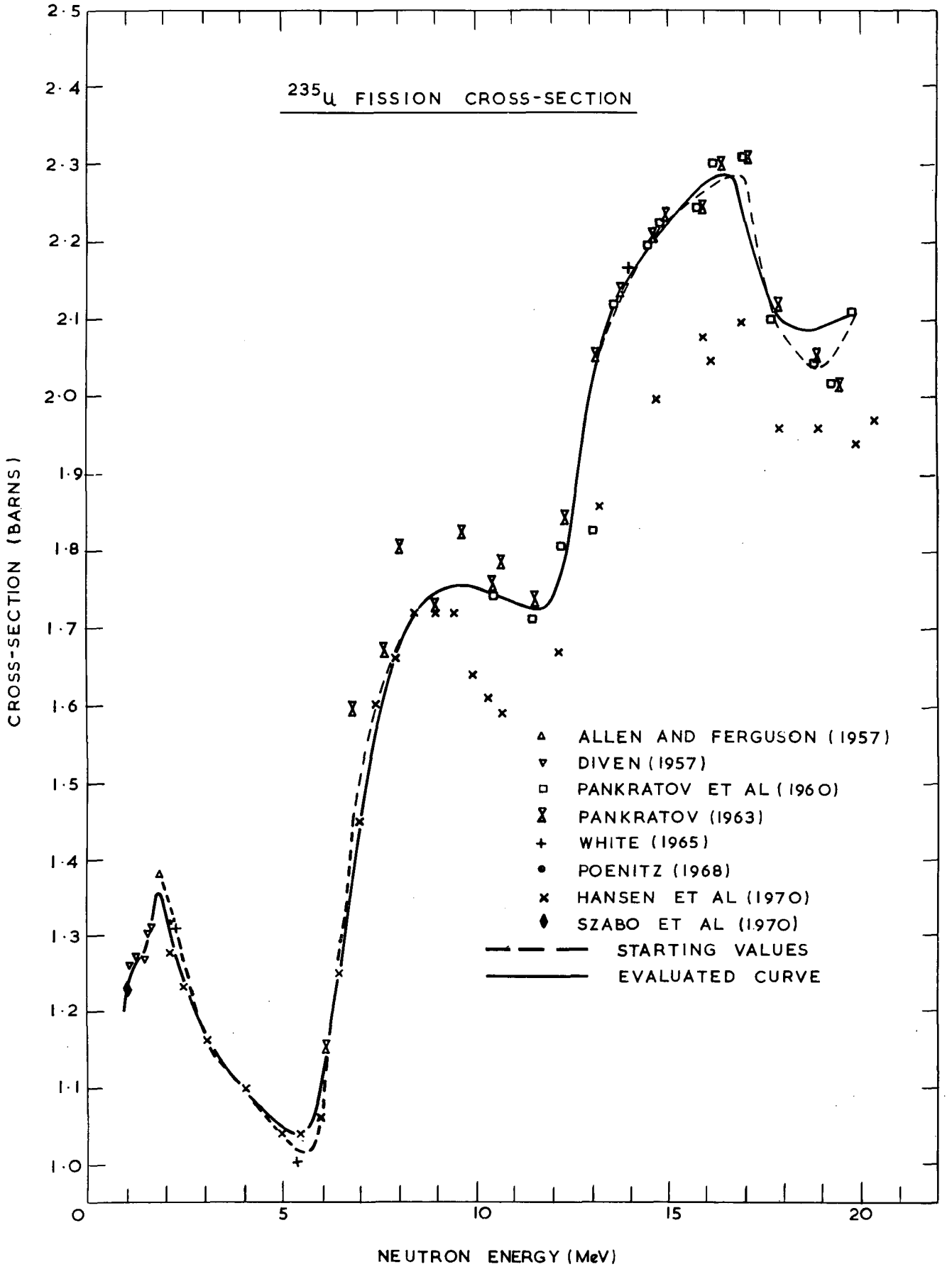
AERE - R 7273 Fig. 5
The fission cross-section of Pu-239 between 0.1 and 30 keV.



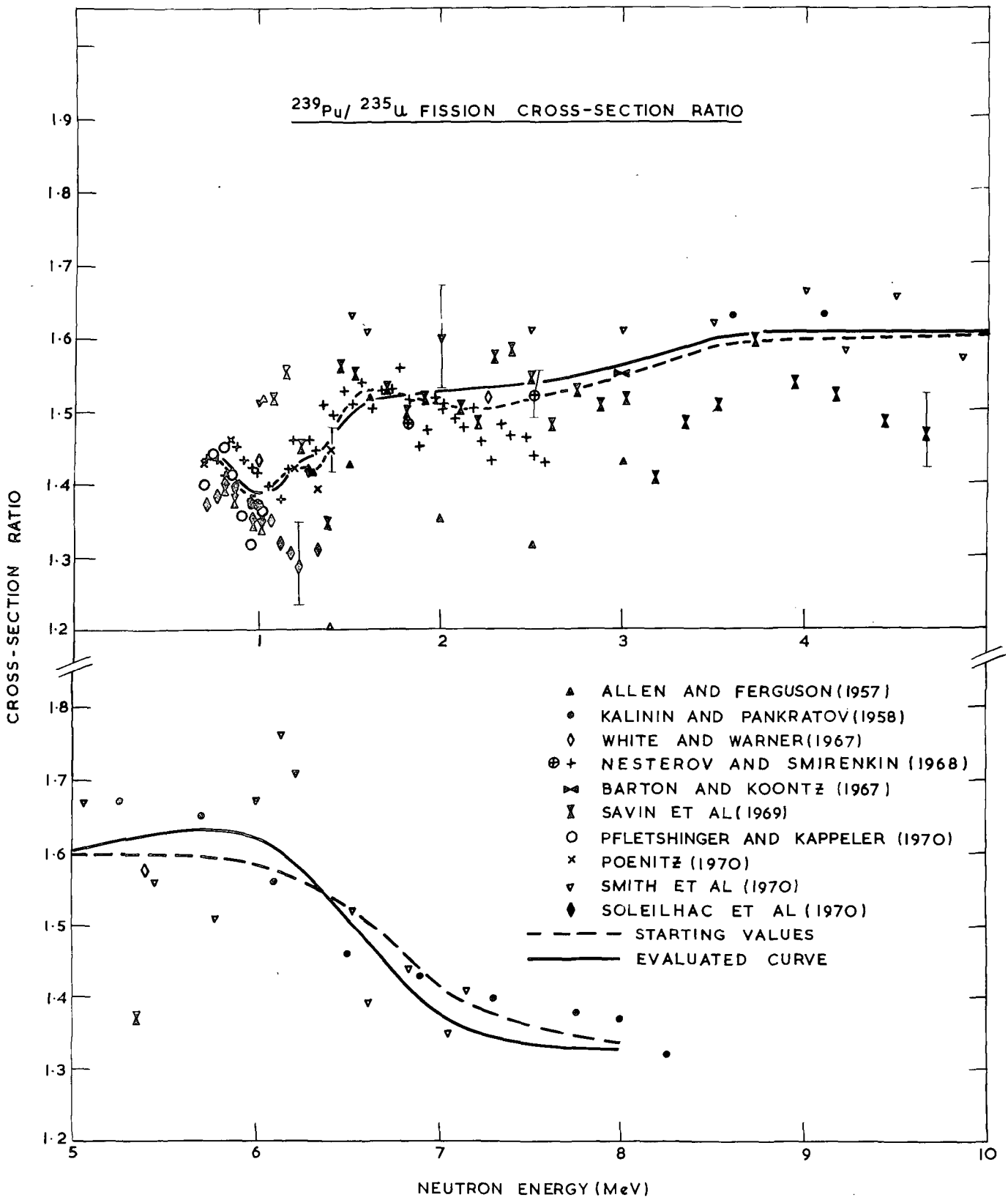
AERE - R 7273 Fig. 6
The fission cross-section of Pu-239 between 10 keV and 2 MeV.



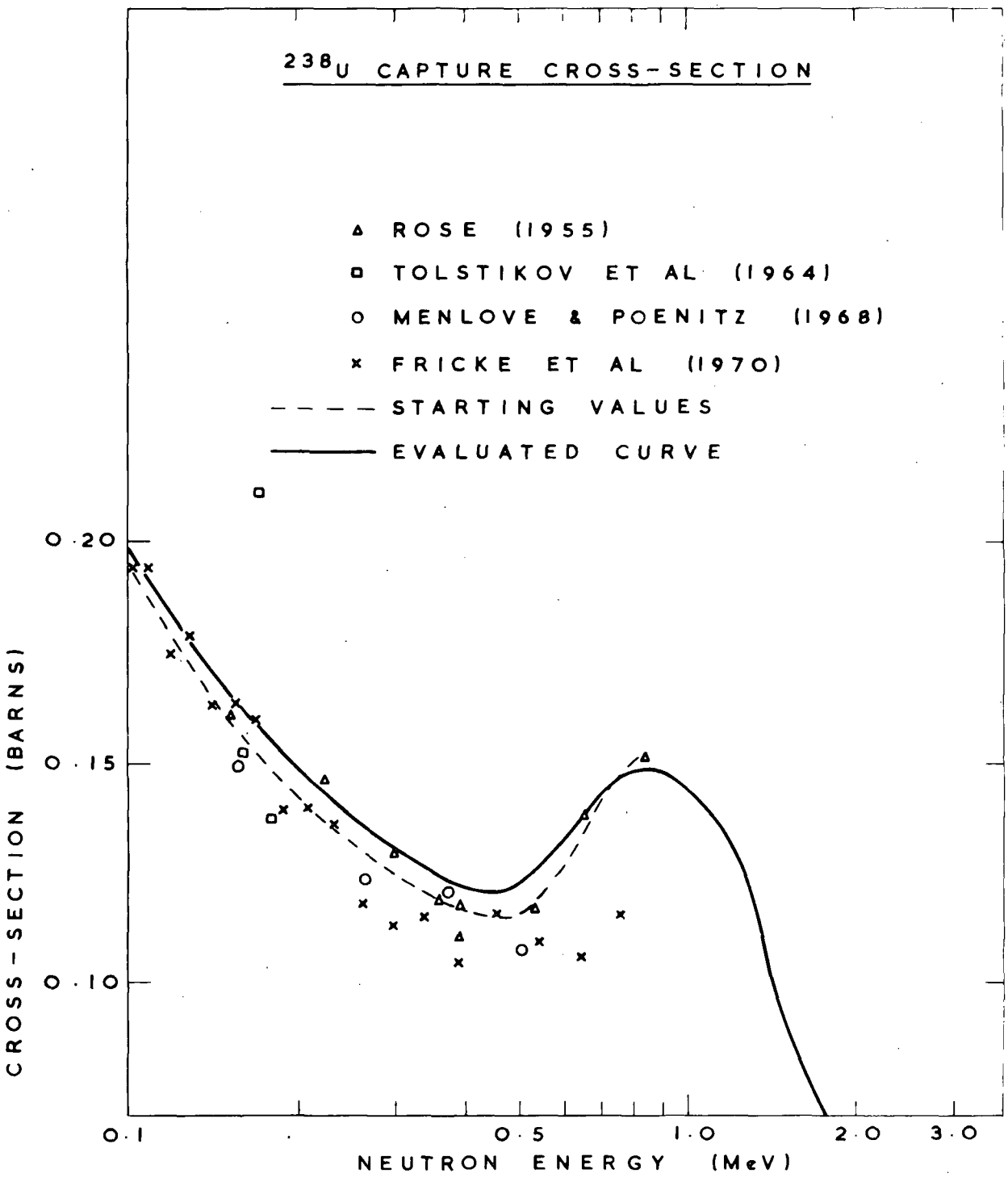
AERE - R 7273 Fig. 7
Energy regions where cross-section data have been accepted for use in the simultaneous evaluation.



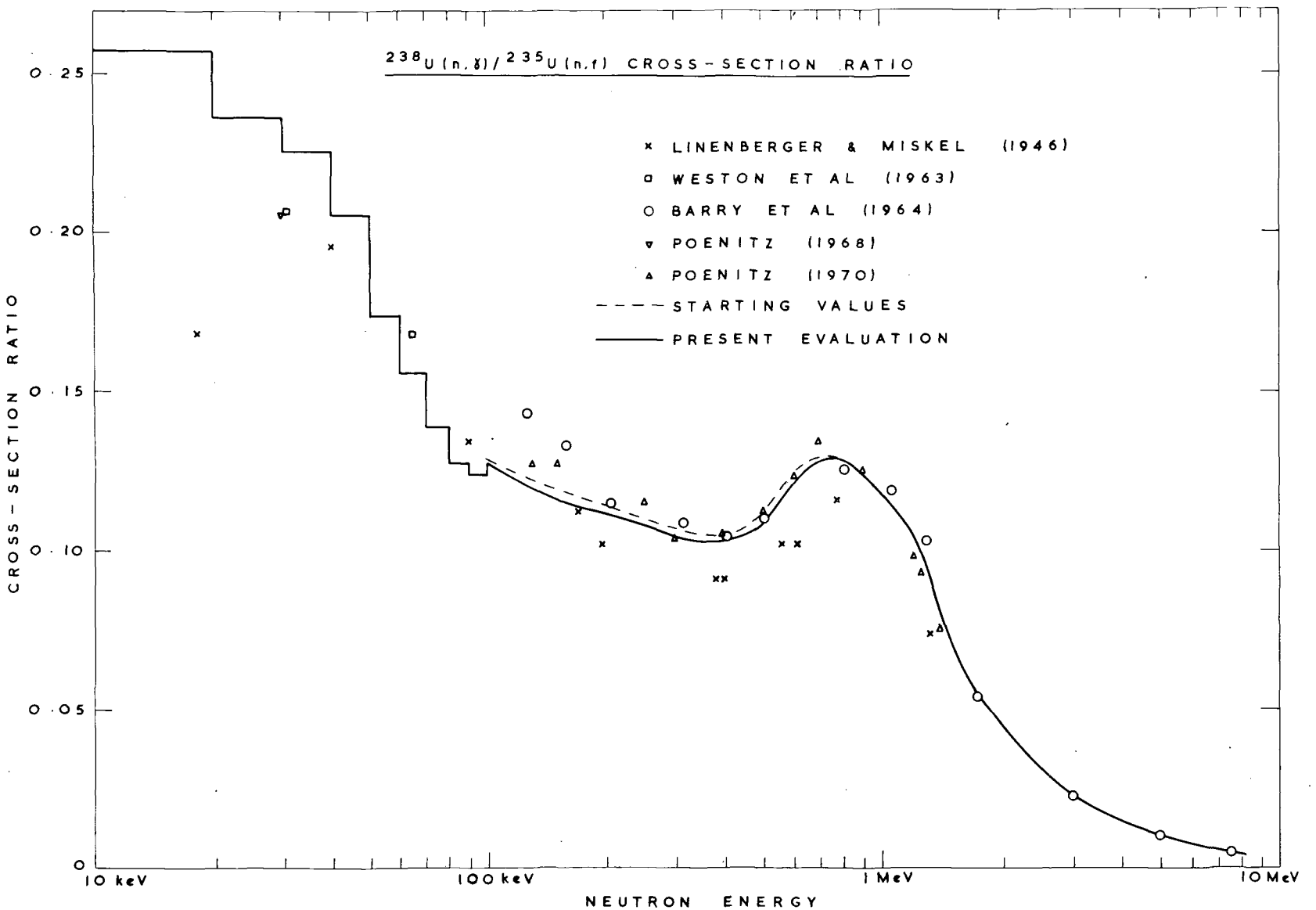
AERE - R 7273 Fig. 8
The fission cross-section of U-235 between 1 and 20 MeV.



AERE - R 7273 Fig. 9
The ratio of the fission cross-sections of Pu-239 and U-235 between 0.7 and 8 MeV.

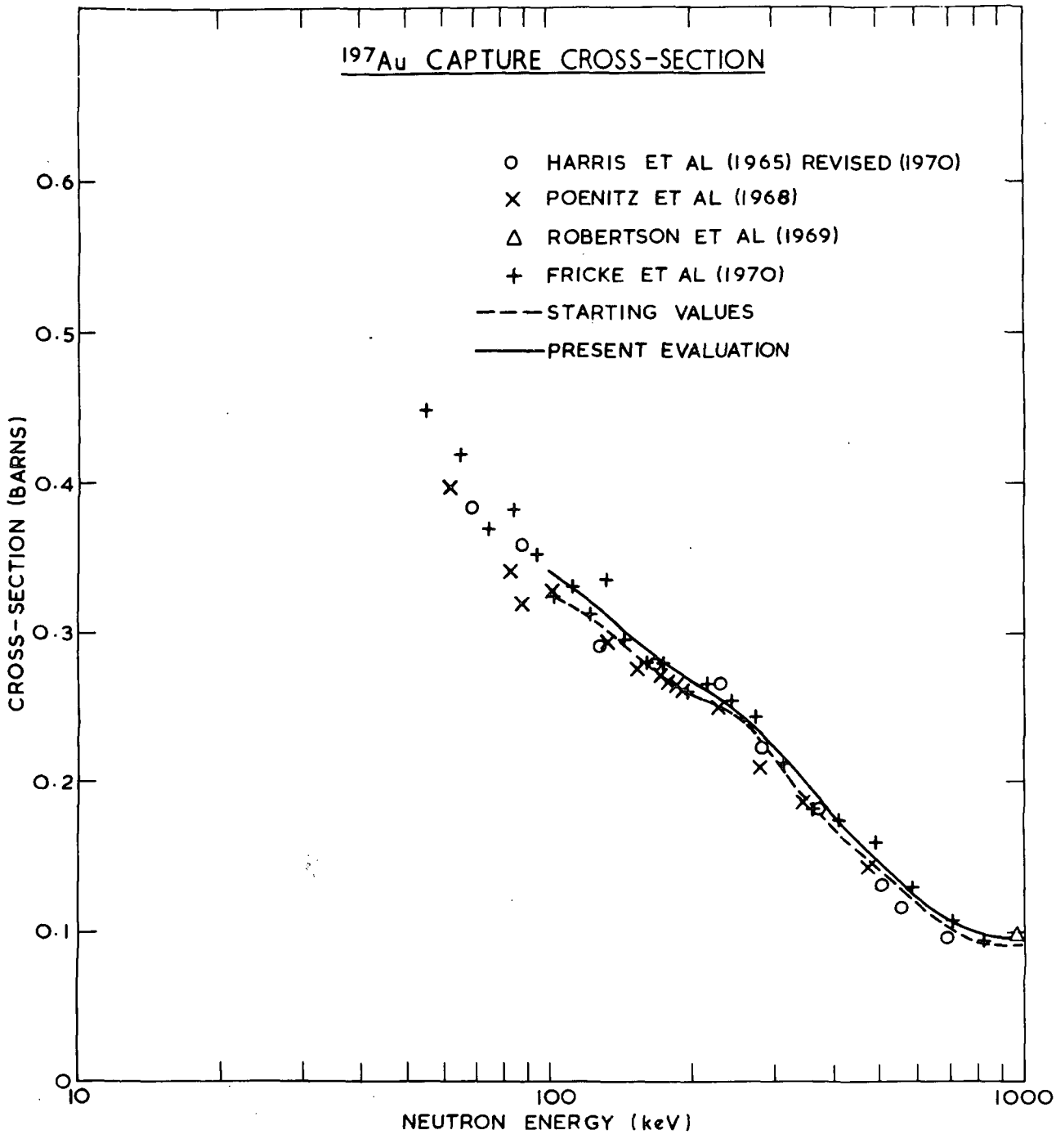


AERE - R 7273 Fig. 10
The capture cross-section of U-238 between 0.1 and 1.8 MeV.

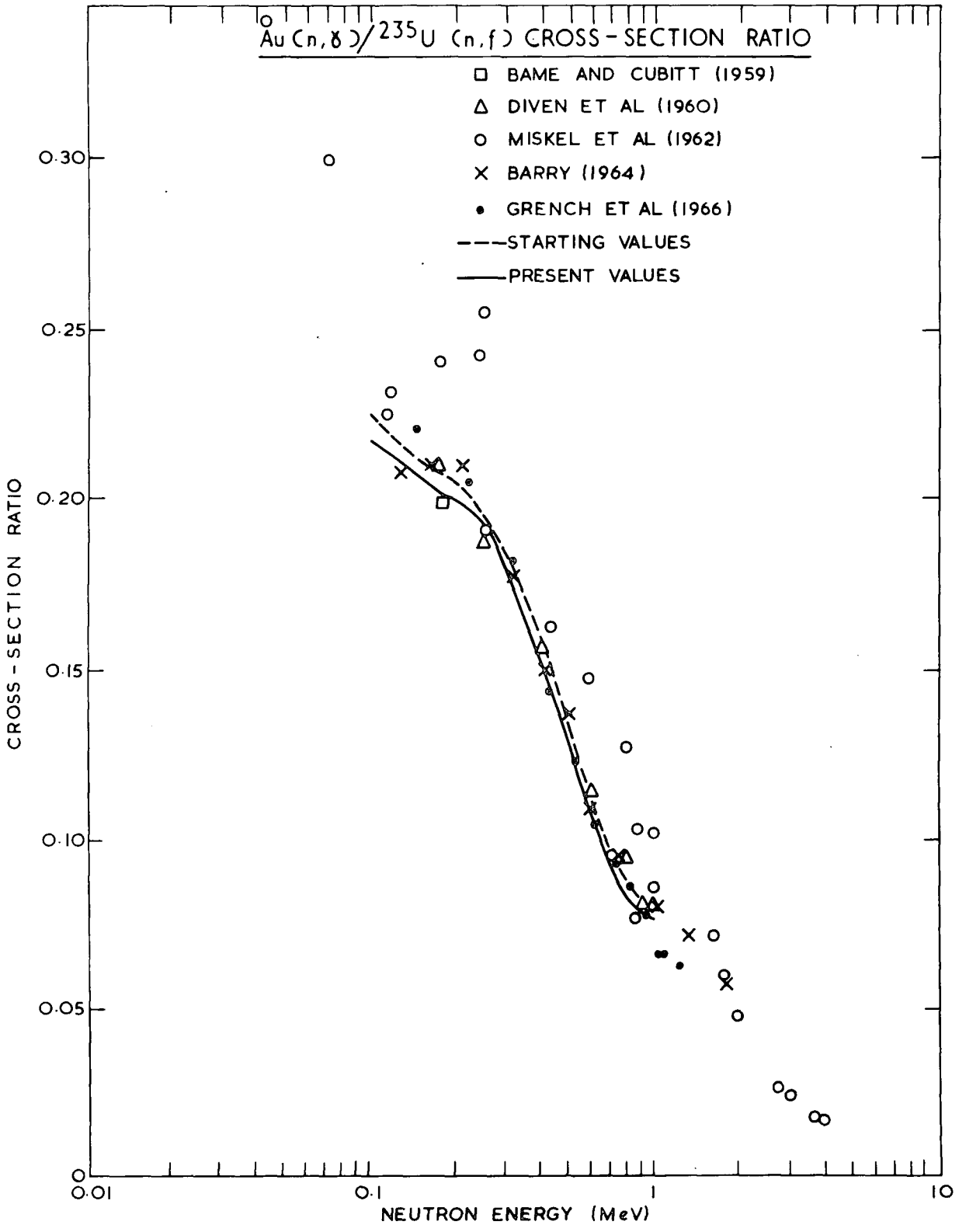


AERE - R 7273 Fig. 11

The ratio of the U-238 capture cross-section and the U-235 fission cross-section between 10 keV and 8 MeV.

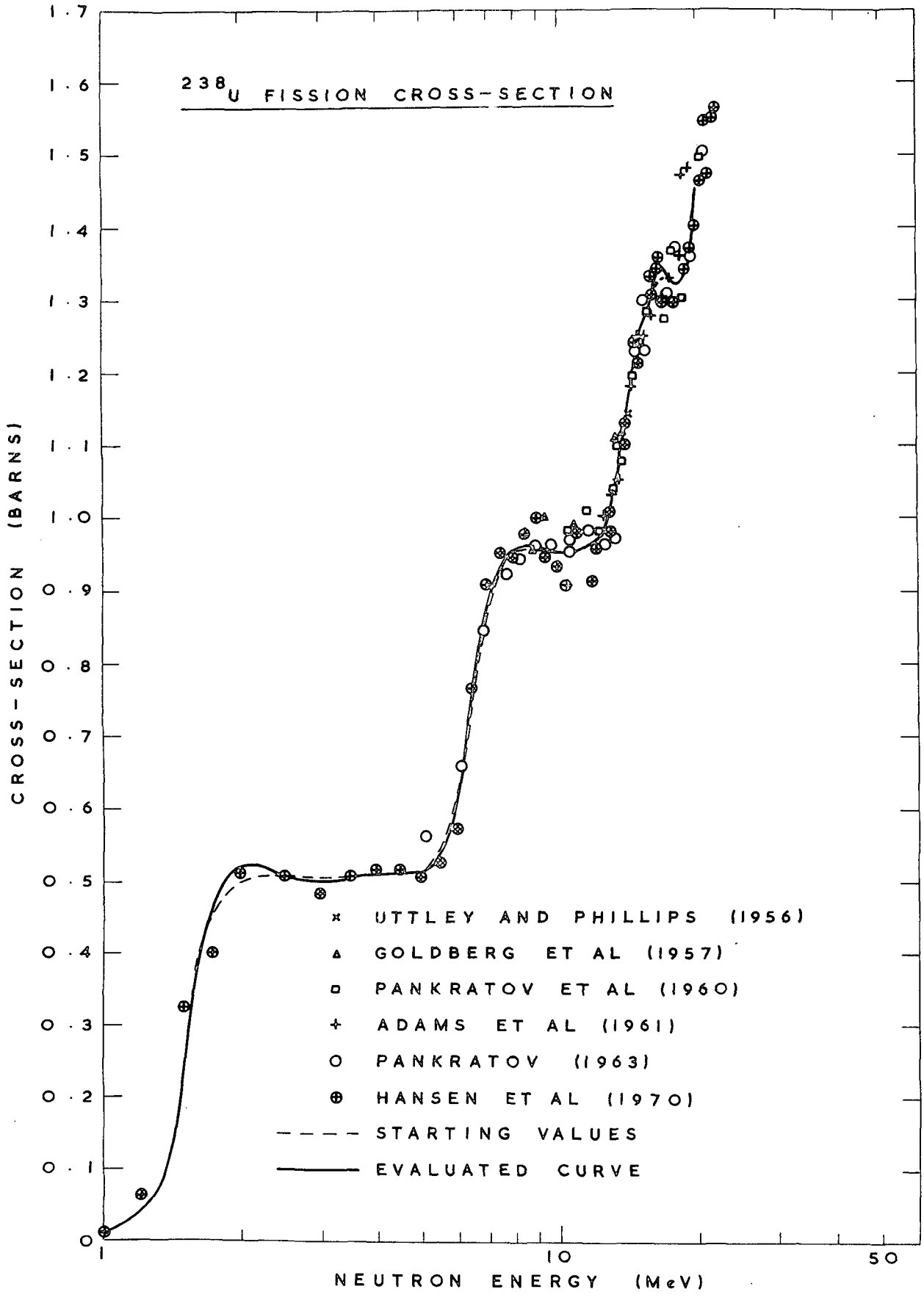


AERE - R 7273 Fig. 12
The capture cross-section of gold between 100 and 1000 keV.

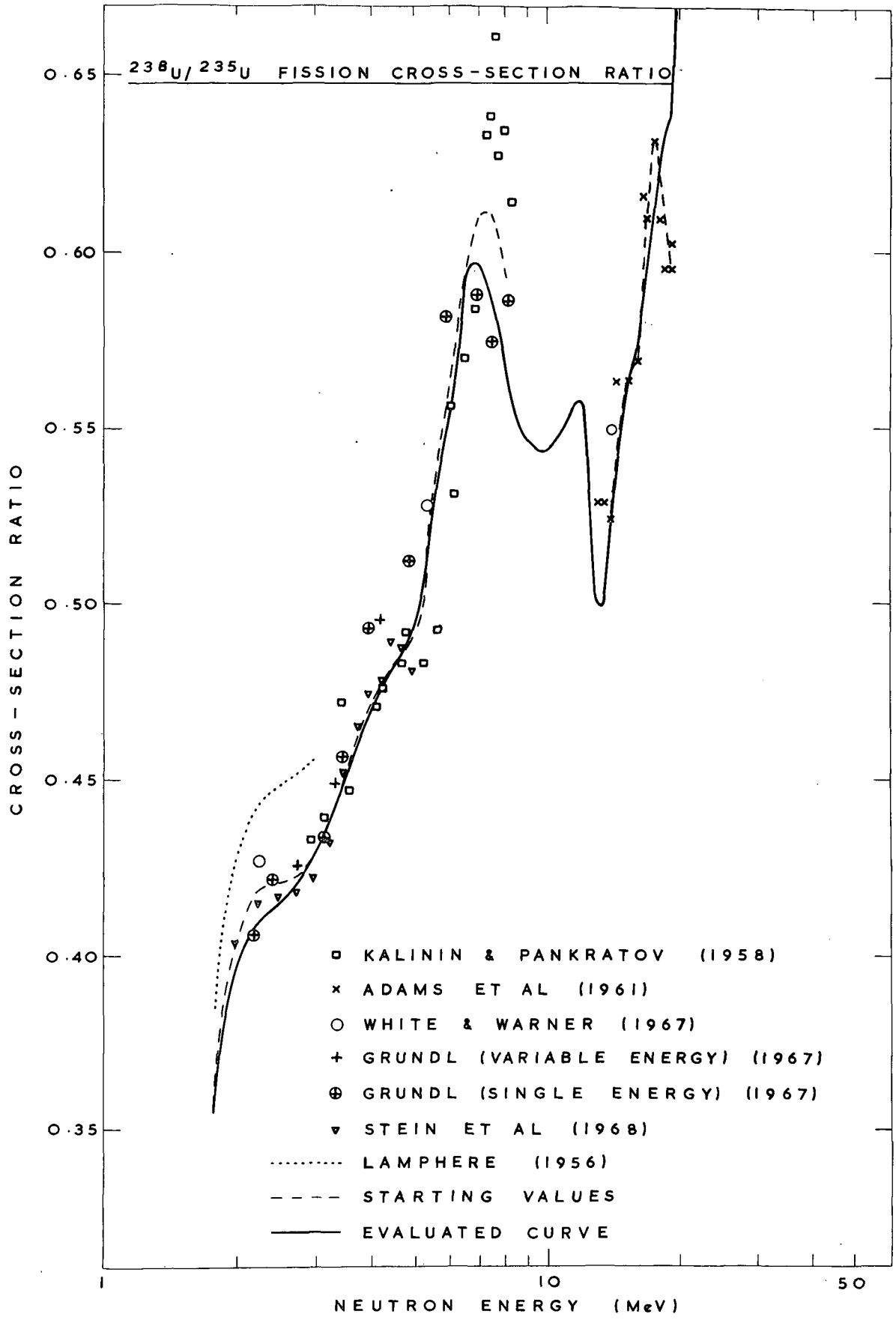


AERE - R 7273 Fig. 13

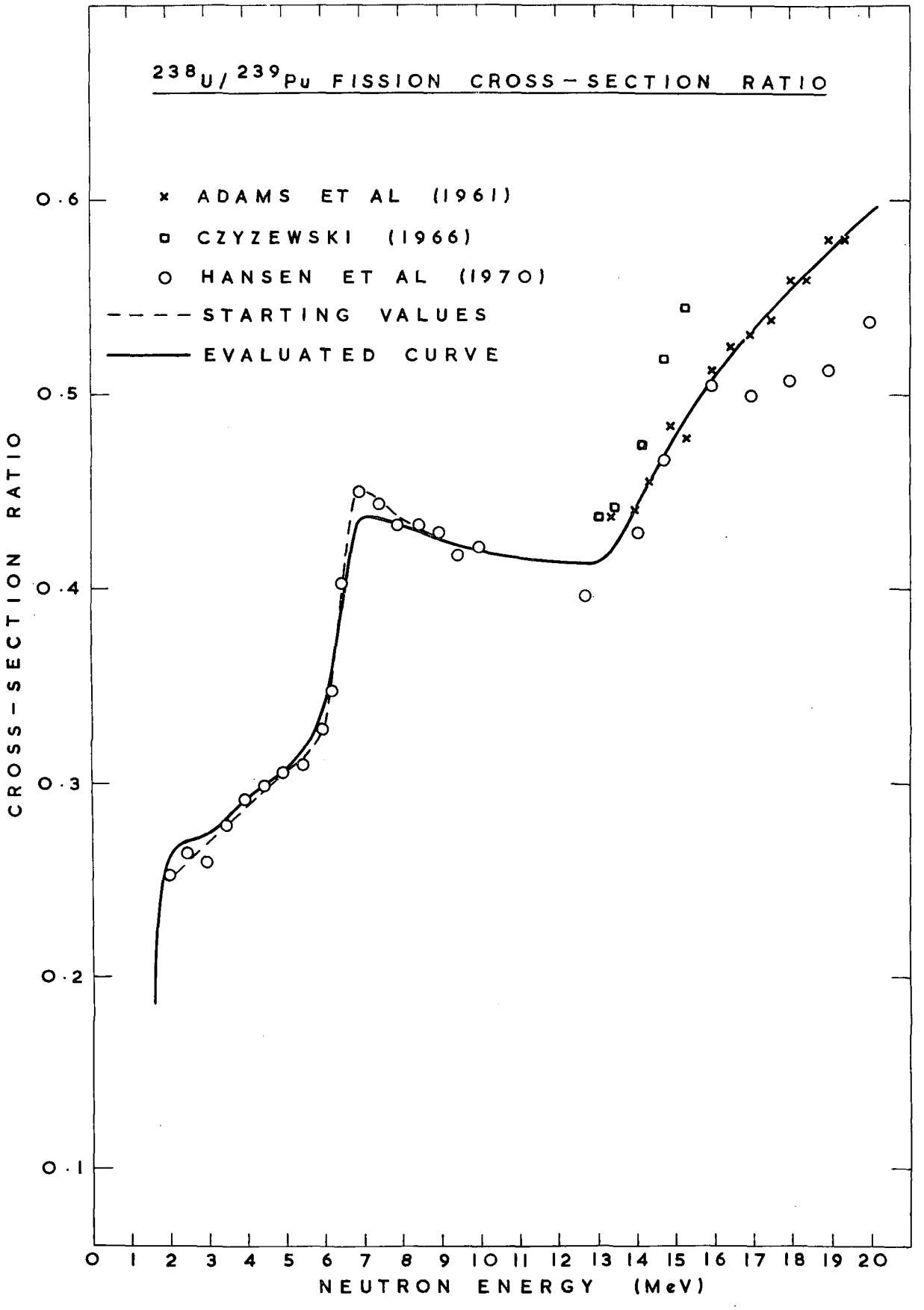
The ratio of the Au capture cross-section and the U-235 fission cross-section between 0.1 and 4 MeV.



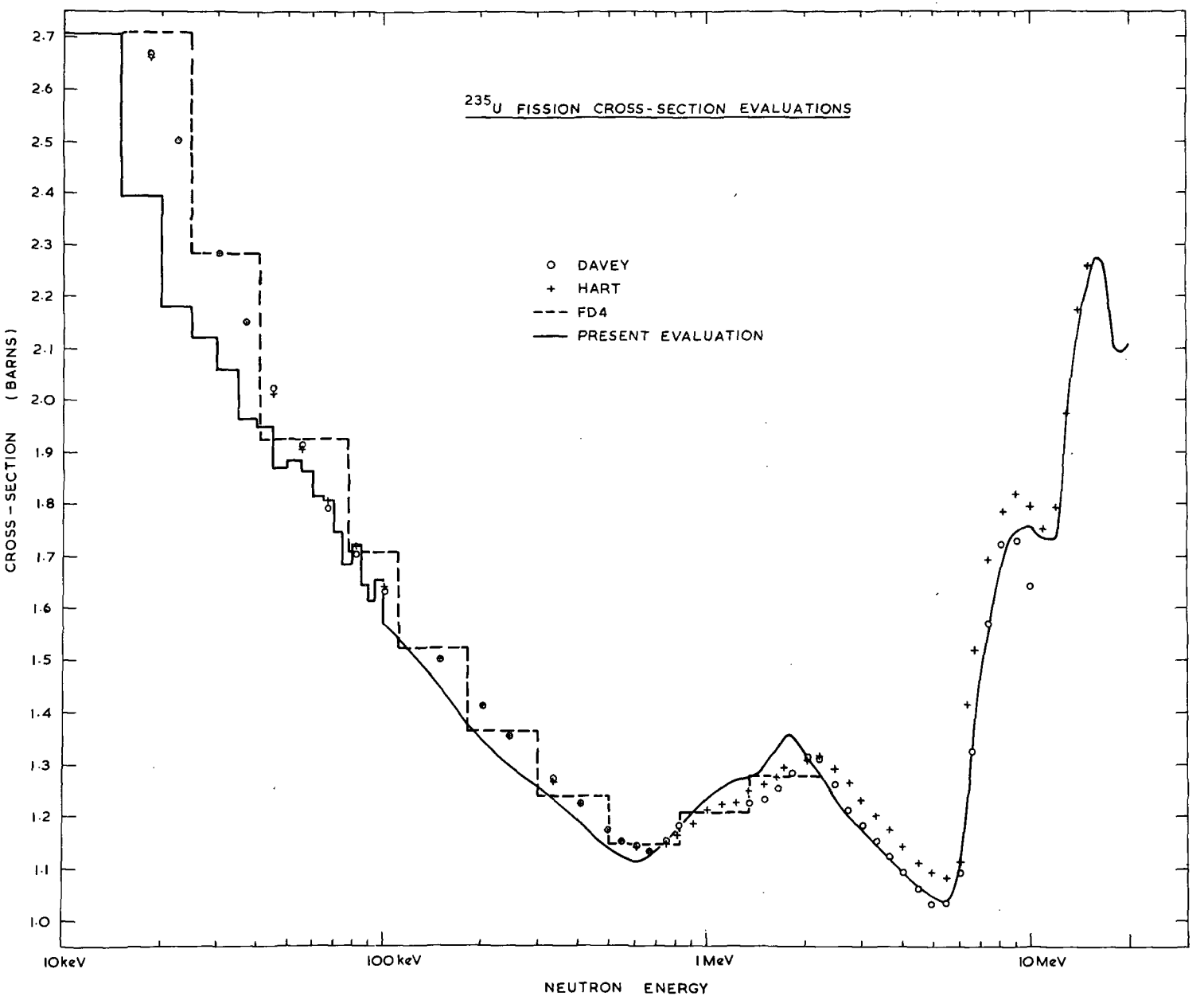
AERE - R 7273 Fig. 14
The fission cross-section of U-238 between 1 and 20 MeV.



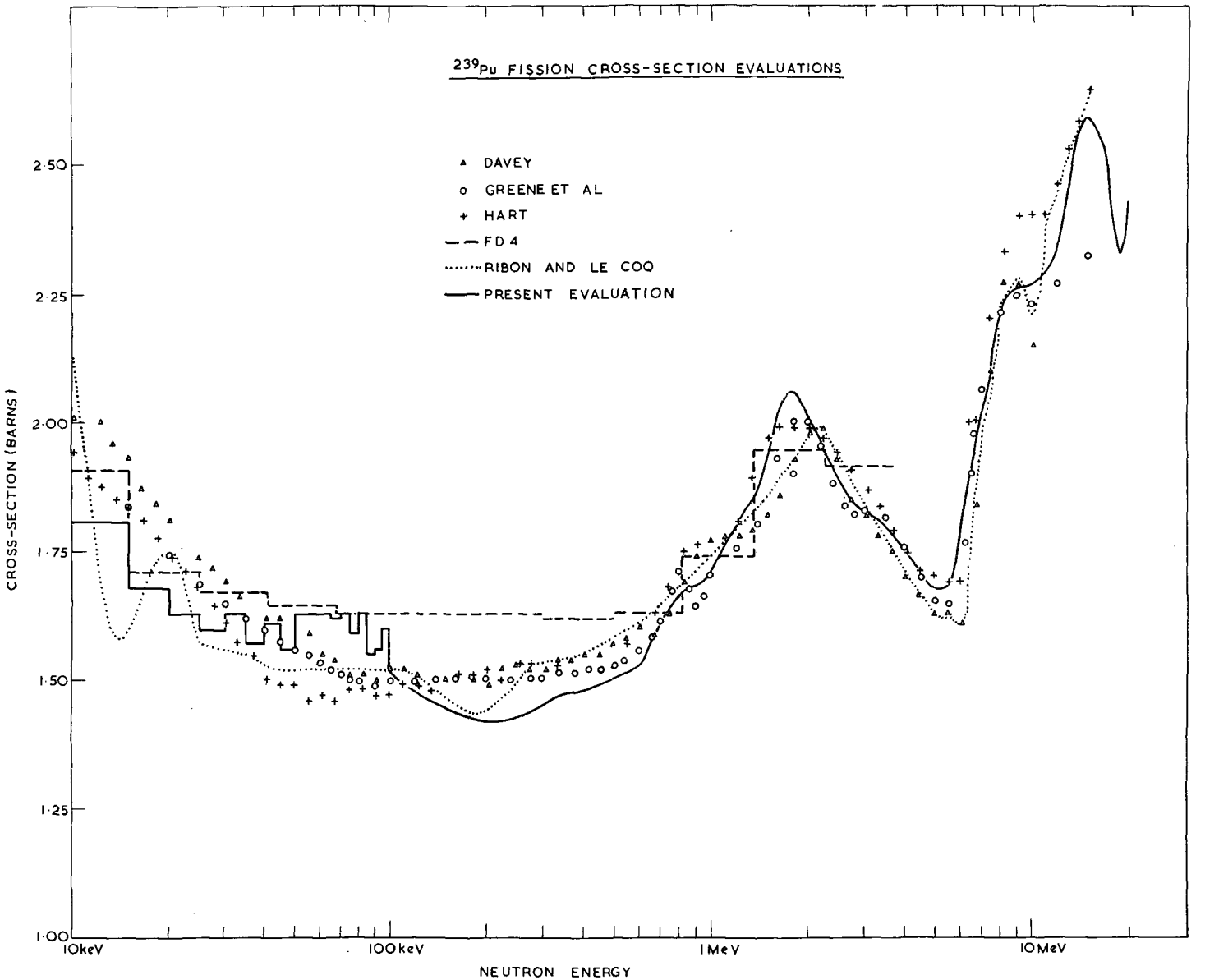
AERE - R 7273 Fig. 15
The ratio of the fission cross-sections of U-238 and U-235 between 2 and 20 MeV.



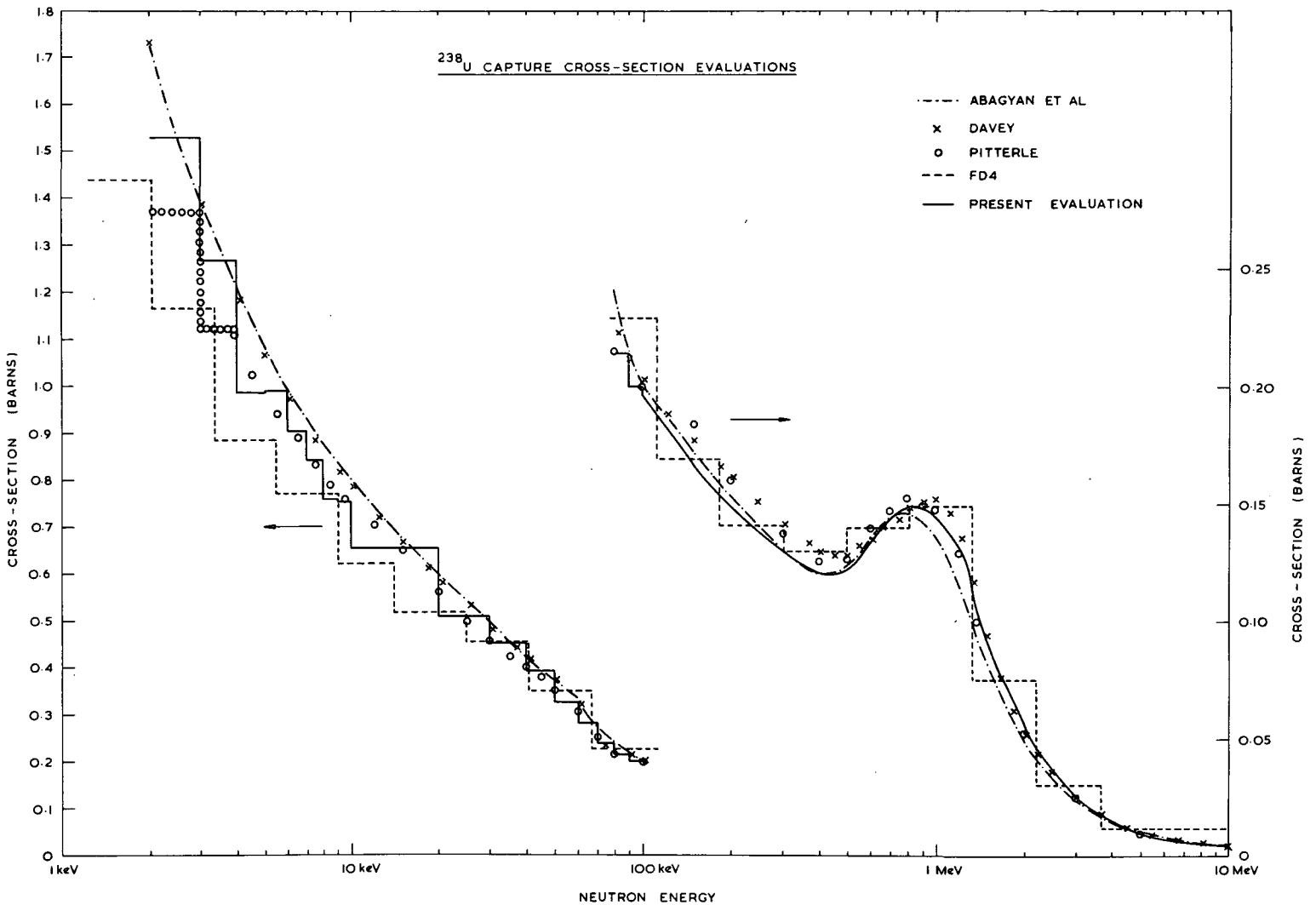
AERE - R 7273 Fig. 16
The ratio of the fission cross-sections of U-238 and Pu-239 between 2 and 20 MeV.



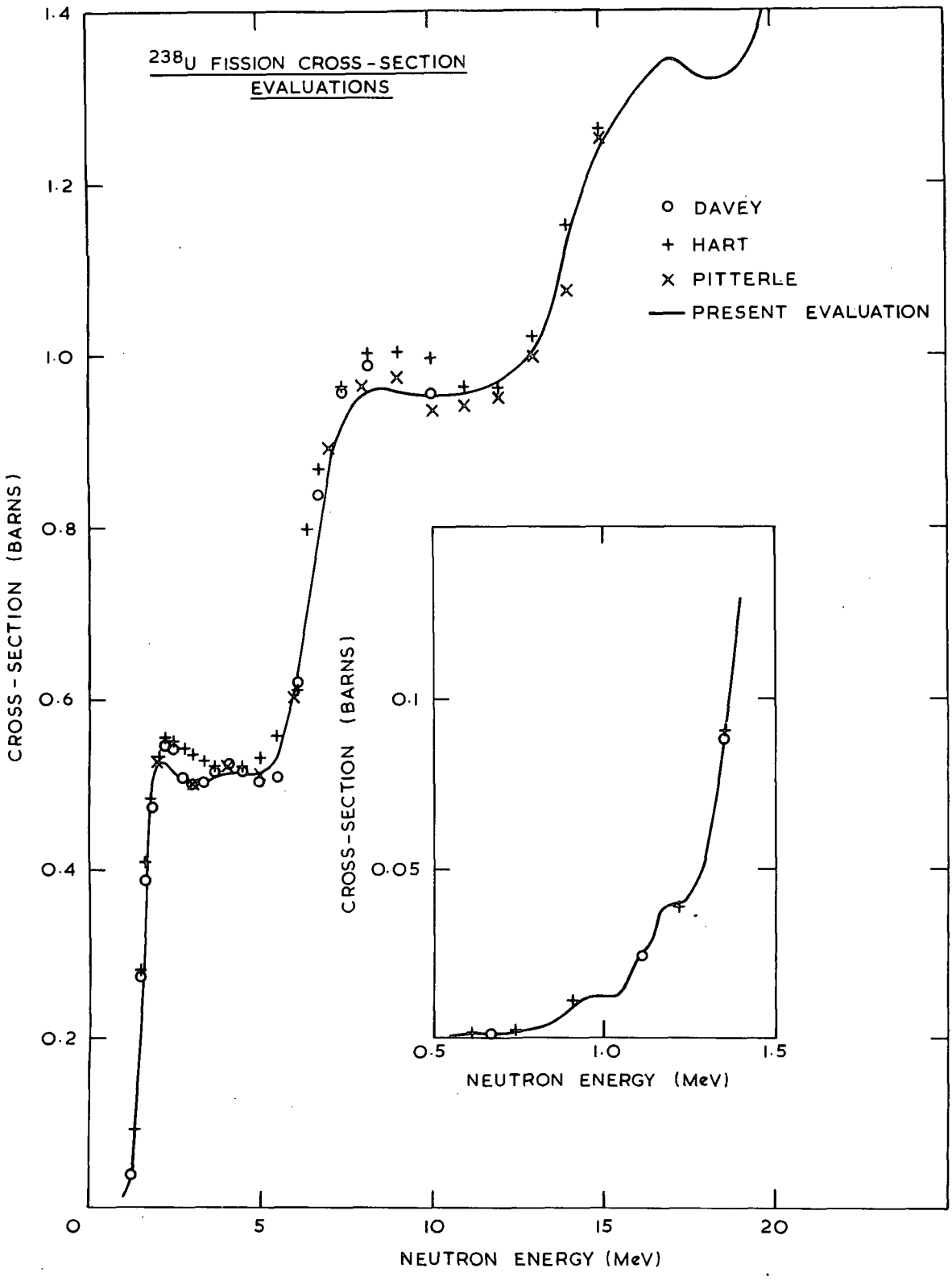
AERE - R 7273 Fig. 17
A comparison of some evaluations of the fission cross-section of U-235 between 10 keV and 20 MeV.



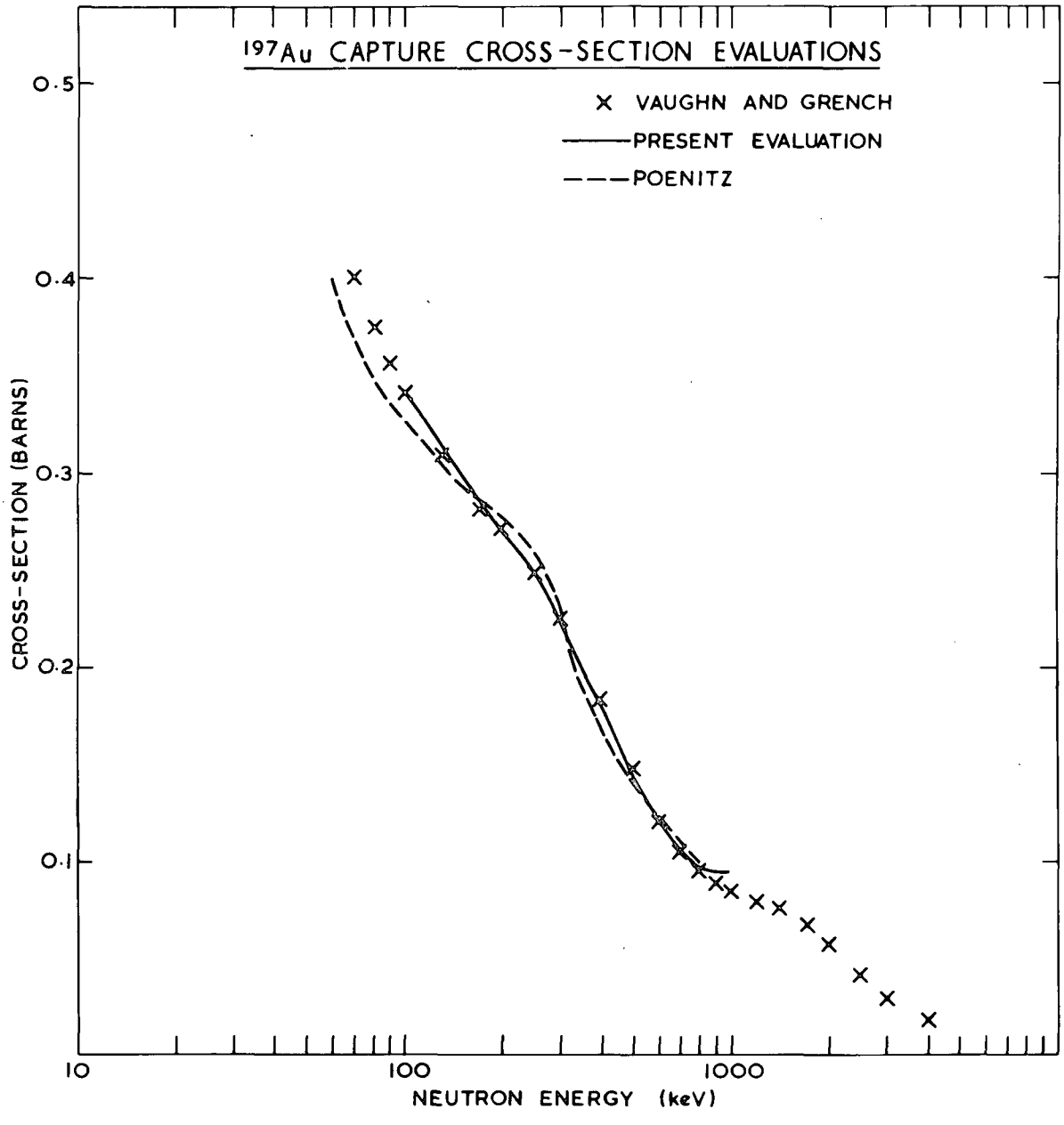
AERE - R 7273 Fig. 18
A comparison of some evaluations of the fission cross-section of Pu-239 between 10 keV and 20 MeV.



AERE - R 7273 Fig. 19
A comparison of some evaluations of the capture cross-section of U-238 between 2 keV and 10 MeV.



AERE - R 7273 Fig. 20
A comparison of some evaluations of the fission cross-section of U-238 between 0.5 and 20 MeV.



AERE - R 7273 Fig. 21

A comparison of some evaluations of the capture cross-section of gold between 0.1 and 1 MeV.

Appendix 1

All the experimental data for neutron energies above 100 eV that have been accepted in the evaluation are listed in this Appendix, together with full references. For the sake of completeness some ratio data, that have been given zero weight in the evaluation, are also included and in these cases an appropriate comment is made.

The data have been corrected for the non 1/v energy dependence of the B-10(n,α) cross-section using the formula of Sowerby et al[1] and it is noted where a correction has been made to the published data. Table 1(1) gives the factors used in correcting the data; these were calculated for the energy range E_1 to E_2 (keV) from the formula

$$\text{Factor} = \frac{\int_{E_1}^{E_2} \sigma(E)\, dE}{\int_{E_1}^{E_2} \frac{19.30}{\sqrt{E}}\, dE}$$

where $\sigma(E) = \frac{13.837}{\sqrt{E}} - 0.312 - 1.014 \times 10^{-2} \sqrt{E} + \frac{2.809 \times 10^5}{\sqrt{E}\,[(170.3-E)^2 + 2.243 \times 10^4]}$

and E is in keV.

Table 1(2) gives the references for the evaluations shown in Figs. 17 to 21.

Table 1(1)

Factors used to correct average cross-section measurements based on a 1/v B-10(n,α) cross-section to the energy dependence recommended by Sowerby et al[1]

Energy Interval (keV)	Factor	Energy Interval (keV)	Factor
0.01 - 0.02	0.99800	10.00 - 15.00	0.96090
0.02 - 0.03	0.99742	15.00 - 20.00	0.95815
0.03 - 0.04	0.99696	20.00 - 25.00	0.95723
0.04 - 0.05	0.99656	25.00 - 30.00	0.95764
0.05 - 0.06	0.99621	10.00 - 11.00	0.96248
0.06 - 0.07	0.99590	11.00 - 12.00	0.96155
0.07 - 0.08	0.99560	12.00 - 13.00	0.96073
0.08 - 0.09	0.99533	13.00 - 14.00	0.96002
0.09 - 0.10	0.99507	14.00 - 15.00	0.95941
0.10 - 0.20	0.99395	15.00 - 16.00	0.95888
0.20 - 0.30	0.99222	16.00 - 17.00	0.95843
0.30 - 0.40	0.99086	17.00 - 18.00	0.95806
0.40 - 0.50	0.98971	18.00 - 19.00	0.95776
0.50 - 0.60	0.98869	19.00 - 20.00	0.95752
0.60 - 0.70	0.98778	20.00 - 21.00	0.95735
0.70 - 0.80	0.98695	21.00 - 22.00	0.95723
0.80 - 0.90	0.98618	22.00 - 23.00	0.95717
0.90 - 1.00	0.98546	23.00 - 24.00	0.95716
1.00 - 2.00	0.98241	24.00 - 25.00	0.95720
2.00 - 3.00	0.97789	25.00 - 26.00	0.95729
3.00 - 4.00	0.97455	26.00 - 27.00	0.95743
4.00 - 5.00	0.97188	27.00 - 28.00	0.95761
5.00 - 6.00	0.96967	28.00 - 29.00	0.95783
6.00 - 7.00	0.96779	29.00 - 30.00	0.95809
7.00 - 8.00	0.96618		
8.00 - 9.00	0.96478		
9.00 - 10.00	0.96355		
10.00 - 20.00	0.95964		
20.00 - 30.00	0.95742		
30.00 - 40.00	0.96028		
40.00 - 50.00	0.96660		
50.00 - 60.00	0.97558		
60.00 - 70.00	0.98668		
70.00 - 80.00	0.99938		
80.00 - 90.00	1.01314		
90.00 - 100.00	1.02734		

Table 1(2)

References of evaluations shown in Figs. 17 to 21

Cross-section	Reference
U-235(n,f) Pu-239(n,f) U-238(n,f)	W.G. Davey, Nucl. Sci. and Eng. 32 (1968) 35.
U-235(n,f) Pu-239(n,f) U-238(n,f)	W. Hart, AHSB(S)R-169 (1969).
Group cross-sections of U-235(n,f) U-238(n,γ) Pu-239(n,f)	J.L. Rowlands and J.D. Macdougall, BNES Conf. on the Physics of Fast Reactor Operation and Design, p. 180 (1969)
Pu-239(n,f)	P. Ribon and G. Le Coq, CEA-N-1484 (1971)
Pu-239(n,f)	N.M. Greene, J.L. Lucius and C.W. Craven Jnr., ORNL-TM-2797 (1970).
U-238(n,γ)	L.P. Abagyan, A.I. Abramov, M.N. Nikolaev, Yu. Ya Stavisskii and V.A. Tolstikov, Nuclear Data for Reactors, Vol. 2, 667, IAEA Vienna (1970).
U-238(n,γ) U-238(n,f)	T.A. Pitterle, WARD-4181-1 (1971).
U-238(n,γ)	W.G. Davey, Nucl. Sci. and Eng. 39 (1970) 337.
Au-197(n,γ)	W.P. Poenitz, Symp. on Neutron Standards and Flux Normalisation, p. 320, Argonne (1970).
Au-197(n,γ)	F.J. Vaughn and H.A. Grench, Proc. Knoxville Conf. on Neutron Cross-sections and Technology, Vol. 1, p. 430 (1971).

In the following list of data, the various cross-sections or ratios are considered in turn starting on the pages indicated below:

C.A.UTTLEY AND J.A.PHILLIPS
AERE NP/R 1996. (1956)

FISSION CROSS SECTION U238

ENERGY(MEV)	SIG NF	ERROR
14.1000	1.1400	0.0300
15.0000	1.4100	0.0700

M.D.GOLDBERG, W.S.HALL AND J.M.LEBLANC
WASH 745 (1957)
VALUES TAKEN FROM R.J.HOWERTON UCRL 5226 (1958). NORMALISED AT 14 MEV
FISSION CROSS SECTION U238

ENERGY(MEV)	SIG NF	ERROR
8.8000	0.9600	0.0500
9.4000	1.0000	0.0500
10.7000	0.9900	0.0500
13.2000	1.1100	0.0550
13.8600	1.1200	0.0550

P.BILLAUD, C.CLAIR, M.GAUDIN, R.GENIN, R.JOLY, J.L.LEROY, A.MICHAUDON,
J.OUVRY, C.SIGNARBIEUX AND G.VENDRYES.
GENEVA CONF. 1958 VOL. 16 P106
FISSION CROSS SECTION U238

ENERGY(MEV)	SIG NF	ERROR
13.6000	1.0900	0.1000

N.N.FLEROV, A.A.BEREZIN AND I.E.CHELNOKOV
ATOMNAYA ENERGIYA 5 657 (1958) ALSO J. NUCL. ENER. A/B 11 173 (1960)

FISSION CROSS SECTION U238

ENERGY(MEV)	SIG NF	ERROR
14.6000	1.1300	0.0500

A.MOAT
UNPUBLISHED REPORT (1958)

FISSION CROSS SECTION U238

ENERGY(MEV)	SIG NF	ERROR
14.0000	1.1300	0.0180

B.ADAMS,R.BATCHELOR AND T.S.GREEN
J. NUCL. ENER. A/B 14(1961)85
FISSION CROSS SECTION U238
MULTIPLIED BY 1.126 TO NORMALISE TO 1.126 BARNS AT 14.0 MEV

ENERGY(MEV)	SIG F 238U
12.7000	1.0020
13.0000	1.0250
13.5000	1.0470
14.0000	1.1260
14.5000	1.1710
15.0000	1.2500
15.4000	1.2500
16.0000	1.2720
16.4000	1.3400
17.0000	1.2950
17.5000	1.3290
18.4000	1.3510
18.9000	1.4640
19.4000	1.4750

V.M.PANKRATOV,N.A.VASLOV AND B.V.RYBAKOV
J. NUCL. ENER. A/B 16(1962)494
FISSION CROSS SECTION U238
MULTIPLIED BY 0.9674 TO NORMALISE TO 1.126 BARNS AT 14.0 MEV

ENERGY(MEV)	SIG NF
10.6000	0.9770
11.6000	1.0060
12.3000	0.9770
13.1000	1.0350
13.6000	1.0930
13.8000	1.0740
14.5000	1.1900
15.0000	1.2380
15.8000	1.2770
16.4000	1.2960
17.1000	1.2670
17.7000	1.3640
18.4000	1.2960
18.9000	1.3450
20.4000	1.4900

V.M.PANKRATOV
SOV. J. AT. ENER. 14(1963)167
FISSION CROSS SECTION U238
MULTIPLIED BY FACTOR 0.9707 TO NORMALISE TO 1.126 BARNS AT 14.0 MEV

ENERGY(MEV)	SIG NF
5.1000	0.5630
6.1000	0.6600
6.9000	0.8450
7.7000	0.9220
8.2000	0.9420
9.0000	0.9610

9.7000	0.9610	
10.7000	0.9510	
10.9000	0.9710	
11.7000	0.9800	
12.6000	0.9610	
13.4000	1.0480	
14.0000	1.1260	
14.8000	1.2230	
15.4000	1.2910	
16.2000	1.3400	
16.7000	1.3590	
17.3000	1.3010	
18.0000	1.3590	
18.7000	1.3590	
19.2000	1.3590	
20.7000	1.4940	
21.7000	1.5920	
21.9000	1.6310	
23.5000	1.9030	
24.2000	1.8350	
24.8000	1.9120	
25.8000	1.8640	
26.4000	1.9030	
20.5000	1.4620	3.9000
20.7500	1.4670	4.2000
21.0000	1.5420	3.9000
21.2500	1.4710	3.9000
21.5000	1.5490	4.4000
22.0000	1.5640	5.9000
22.5000	1.7560	8.6000

G.HANSEN,S.MCGUIRE AND R.K.SMITH
PRIVATE COMMUNICATION FROM DR. L.STEWART (1970)

FISSION CROSS SECTION U238

ENERGY(MEV)	SIG NF	PERCENTAGE ERROR
1.0000	0.0120	42.0000
1.2050	0.0620	19.0000
1.5000	0.3240	5.2000
1.7360	0.4000	6.0000
2.0000	0.5120	4.6000
2.5000	0.5090	5.3000
3.0000	0.4840	5.0000
3.5000	0.5100	4.4000
4.0000	0.5170	4.4000
4.5000	0.5170	4.3000
5.0000	0.5060	4.3000
5.5000	0.5270	4.1000
6.0000	0.5750	4.0000
6.5000	0.7670	4.0000
7.0000	0.9060	3.9000
7.5000	0.9510	3.9000
8.0000	0.9450	3.8000
8.5000	0.9790	3.8000
9.0000	0.9990	3.9000

9.5000	0.9460	4.2000
10.0000	0.9350	4.9000
10.5000	0.9070	5.7000
11.0000	0.9790	7.2000
11.9000	0.9130	5.9000
12.2000	0.9590	4.1000
13.0000	1.0060	4.3000
13.2000	0.9780	5.4000
14.1000	1.0980	3.9000
14.8000	1.2400	4.2000
15.0000	1.2120	3.9000
16.0000	1.3310	3.9000
16.1000	1.3060	4.0000
17.0000	1.2980	3.9000
18.0000	1.2970	4.0000
19.0000	1.3400	3.9000
19.5000	1.3700	4.4000
20.0000	1.4010	3.9000

W.D.ALLEN AND A.T.G.FERGUSON
PROC. PHYS. SOC. 70A(1957)573

FISSION CROSS SECTION U235

ENERGY(KEV)	SIG NF	PERCENTAGE ERROR
550.0000	1.2200	3.5000
1800.0000	1.3800	3.5000

B.C.DIVEN
PHYS. REV. 105(1957)1350

FISSION CROSS SECTION U235

ENERGY(MEV)	SIG NF	ERROR
1.6200	1.3100	0.0500
1.5450	1.3000	0.0500
1.4240	1.2700	0.0400
1.2720	1.2700	0.0400
1.1710	1.2700	0.0400
1.0950	1.2700	0.0400
1.0250	1.2600	0.0500
0.9440	1.2700	0.0500
0.8650	1.2300	0.0600
0.7700	1.1900	0.0600
0.6730	1.1700	0.0600
0.5620	1.2700	0.0700
0.5130	1.2400	0.0700
0.4030	1.2800	0.0800

S.J.BAME AND R.L.CUBITT
PHYS. REV. 114(1959)1580
LI6(N,ALPHA)/U235(N,F) (REVISED. CCDN NW-3) CONVERTED FISSION CROSS SECTION USING LI6(N,ALPHA) CROSS SECTION OF UTTLEY AND DIMENT

ENERGY(KEV)	SIG NF
14.0000	2.7510
19.0000	2.4590
24.0000	2.2630
30.0000	2.0260
45.0000	1.7710
55.0000	1.7210
65.0000	1.6620
78.0000	1.6050
90.0000	1.5660
106.0000	1.6320

G.V.GORLOV,B.M.GOKHBERG,V.M.MOROZOV,G.A.OTROSHENKO AND V.A.SHIGIN
J. NUCL. ENER. A/B 12(1960)79

FISSION CROSS SECTION U235

ENERGY(KEV)	SIG NF	ERROR
35.5000	2.1500	0.1500
29.0000	2.7000	0.1900

39.5000	2.3000	0.1610
48.5000	1.9000	0.1330
50.0000	2.1000	0.1470
65.0000	2.0500	0.1440
76.5000	1.8300	0.1280
94.0000	1.6500	0.1160
100.0000	1.7000	0.1190
116.0000	1.5500	0.1090
127.5000	1.8000	0.1260
173.0000	1.4000	0.0980
225.0000	1.3300	0.0930
268.0000	1.3000	0.0910
280.0000	1.4500	0.1020
336.0000	1.2000	0.0840
355.0000	1.2000	0.0840
435.0000	1.2000	0.0840
500.0000	1.0500	0.0740
515.0000	1.1300	0.0790
560.0000	1.0300	0.0720
770.0000	1.0500	0.0740

V.M.PANKRATOV,N.A.VASLOV AND B.V.RYBAKOV
J. NUCL. ENER. A/B 16(1962)494

FISSION CROSS SECTION U235 NORM. TO 2.152 BARNS AT 14.0 MEV

ENERGY(MEV)	SIG NF
10.5000	1.7410
11.5000	1.7120
12.3000	1.8080
13.1000	1.8270
13.7000	2.1230
14.6000	2.2000
14.9000	2.2280
15.9000	2.2480
16.3000	2.3050
17.1000	2.3140
17.8000	2.1040
18.9000	2.0470
19.4000	2.0180
19.9000	2.1140

V.M.PANKRATOV
SOV. J. AT. ENER. 14(1963)167

FISSION CROSS SECTION U235 NORM. TO 2.152 BARNS AT 14.0 MEV.

ENERGY(MEV)	SIG NF
6.1000	1.1620
6.8500	1.5950
7.6500	1.6720
8.1000	1.8060
9.0000	1.7290
9.6500	1.8250
10.4500	1.7580
10.7000	1.7870

11.6000	1.7390
12.4000	1.8450
13.2000	2.0560
13.9000	2.1420
14.7500	2.2100
15.1000	2.2380
16.0500	2.2480
16.5000	2.3060
17.2000	2.3150
18.0000	2.1230
19.0000	2.0560
19.6000	2.0170

A.MICHAUDON
REPORT CEA-R 2552 (1964)
NORMALISED TO 282.4 B.EV FROM 5 TO 10 EV. CORRECTED FOR NON 1/V B-10(N,ALPHA)
AVERAGE FISSION CROSS SECTION U235

ENERGY(KEV) AV	SIG NF
0.1500	21.9600
0.2500	21.1100
0.3500	14.7800
0.4500	13.5300
0.5500	14.9600
0.6500	12.0000
0.7500	11.1400
0.8500	8.7790
0.9500	8.0460
1.5000	7.6830
2.5000	5.8410
3.5000	4.9380
4.5000	4.5360
5.5000	4.2970
6.5000	3.8040
7.5000	3.5570
8.5000	3.5060
9.5000	3.4150
15.0000	2.7870

J.L.PERKIN,P.H.WHITE,P.FIELDHOUSE,E.J.AXTON,P.CROSS AND J.C.ROBERTSON
J.NUCL.ENER. 19(1965)423

FISSION CROSS SECTION U235

ENERGY(KEV)	RATIO	ERROR
22.8000	2.3600	0.0600

VAN SHI-DI,VAN YUN-CHAN,E.DERMENDZHIEV AND YU.V.RYABOV
PROC. IAEA CONF. PHYSICS AND CHEMISTRY OF FISSION(SALZBURG,1965)VOL.1,P.287
NORMALISED TO 580.2 BARNS AT 0.025 EV. CORRECTED FOR NON 1/V B-10(N,ALPHA)
AVERAGE FISSION CROSS SECTION U235

ENERGY(KEV) AV	SIG NF
0.1500	20.1800
0.2500	20.3300

0.3500	12.7900
0.4500	13.2000
0.5500	14.5200
0.6500	11.5000
0.7500	11.1700
0.8500	8.9540
0.9500	8.5260
1.5000	7.4610
2.5000	5.4790
3.5000	4.7670
4.5000	4.3590
5.5000	3.7040
6.5000	3.3360
7.5000	3.3040
8.5000	3.1030
9.5000	3.2090
15.0000	3.1290

P.H.WHITE
J. NUCL. ENER. 19(1965)325

FISSION CROSS SECTION U235

ENERGY(MEV)	SIG NF	PERCENTAGE ERROR
0.0400	2.1000	3.0000
0.0670	1.7860	3.0000
0.1270	1.5400	2.5000
0.1600	1.5200	2.5000
0.2070	1.3800	2.5000
0.3120	1.3000	2.5000
0.4040	1.2200	2.5000
0.5050	1.1700	2.5000
1.0000	1.2200	2.5000
2.2500	1.3100	3.0000
5.4000	1.0300	5.0000
14.1000	2.1700	2.0000

J.F.BARRY
PROC. CONF. NEUT. CROSS SECTIONS AND TECH. (WASHINGTON,1966)P763
LI6(N,ALPHA)/U235(N,F) CONVERTED TO FISSION CROSS SECTION
USING LI6(N,ALPHA) CROSS SECTION OF UTTLEY AND DIMENT

ENERGY(KEV)	SIG NF	ERROR
25.0000	2.1240	0.1280
67.0000	1.4790	0.1050
100.0000	1.5550	0.0580

W.K.BROWN,D.W.BERGEN AND J.D.CRAMER
PROC. CONF. NEUT. CROSS SECTIONS AND TECH. (WASHINGTON,1966)VOL.2,P.971

AVERAGE FISSION CROSS SECTION U235

ENERGY(KEV) AV	SIG NF
0.1500	21.5600
0.2500	21.7500

0.3500	13.2100
0.4500	14.6900
0.5500	15.4300
0.6500	11.4800
0.7500	10.9900
0.8500	7.8210
0.9500	7.9320
1.5000	7.6530
2.5000	5.4640
3.5000	4.7210
4.5000	4.0130
5.5000	3.4590
6.5000	3.1490
7.5000	3.0340
8.5000	3.0300
9.5000	3.2430

G.DE SAUSSURE,R.GWIN,L.W.WESTON,R.W.INGLE,R.R.FULLWOOD AND R.W.HOCKENBURY
ORNL TM 1804 (1967)
CORRECTED FOR NON 1/V B-10(N,ALPHA)
AVERAGE FISSION CROSS SECTION U235

ENERGY(KEV) AV	SIG NF
0.1500	20.7700
0.2500	20.6100
0.3500	13.0500
0.4500	13.5700
0.5500	15.1100
0.6500	11.4600
0.7500	11.1000
0.8500	8.2200
0.9500	7.5700
1.5000	7.4200
2.5000	5.5300
3.5000	5.0300
4.5000	4.5100
5.5000	3.7800
6.5000	3.6100
7.5000	3.7100
8.5000	2.9200
9.5000	3.0600

G.F.KNOLL AND W.P.POENITZ
J. NUCL. ENER. 21(1967)643

FISSION CROSS SECTION U235

ENERGY(KEV)	SIG NF	ERROR
30.0000	2.1900	0.0600

W.P.POENITZ
PROC. CONF. NEUTRON CROSS SECTIONS AND TECHNOLOGY(WASHINGTON,1968),VOL.1,P.503

FISSION CROSS SECTION U235

ENERGY(KEV)	SIG NF	ERROR
30.0000	2.1900	0.0600

55.0000	1.8100	0.0900
76.0000	1.6500	0.1000
267.0000	1.0300	0.0800
280.0000	1.2600	0.1500
285.0000	1.1900	0.0900
290.0000	1.0700	0.0600
400.0000	1.0100	0.0500
496.0000	1.0300	0.0500
695.0000	1.0000	0.0500
850.0000	0.9900	0.0500
1040.0000	1.1000	0.0500
1150.0000	1.0900	0.0500
1470.0000	1.1100	0.0600

J.BLONS,G.DEBRIL,J.FERMANDJIAN AND A.MICHAUDON
PROC. IAEA CONF. NUCL. DATA FOR REACTORS(HELSINKI,1970)VOL.1,P.469
CORRECTED FOR NON 1/V B-10(N,ALPHA)
AVERAGE FISSION CROSS SECTION U235

ENERGY(KEV) AV	SIG NF
0.1500	20.9000
0.2500	20.3400
0.3500	13.2600
0.4500	13.7300
0.5500	15.1700
0.6500	11.5800
0.7500	11.1700
0.8500	8.4370
0.9500	7.6250
1.5000	7.4440
2.5000	5.4070
3.5000	4.8620
4.5000	4.4240
5.5000	3.9620
6.5000	3.4870
7.5000	3.2140
8.5000	3.0050
9.5000	3.1020
15.0000	2.5040
25.0000	2.1740

J.BLONS,G.DEBRIL,J.FERMANDJIAN AND A.MICHAUDON
PROC. IAEA CONF. NUCL. DATA FOR REACTORS(HELSINKI,1970)VOL.1,P.469
CORRECTED FOR NON 1/V B-10(N,ALPHA)
AVERAGE FISSION CROSS SECTION U235

ENERGY(KEV) AV	SIG NF
10.5000	2.7680
11.5000	2.7130
12.5000	2.5280
13.5000	2.6970
14.5000	2.6080
15.5000	2.3850
16.5000	2.3470
17.5000	2.3060
18.5000	2.4610
19.5000	2.2510

20.5000	2.0430
21.5000	2.1350
22.5000	2.2470
23.5000	2.0180
24.5000	2.1670
25.5000	2.0720
26.5000	2.1370
27.5000	2.2550
28.5000	2.3280
29.5000	2.3320

G. HANSEN, S.MCGUIRE AND R.K.SMITH
PRIVATE COMMUNICATION FROM DR. L.STEWART(1970)

FISSION CROSS SECTION U235

ENERGY(MEV)	SIG NF	PERCENTAGE ERROR
2.2200	1.2800	7.0000
2.5000	1.2300	6.7000
3.0000	1.1600	6.6000
4.0000	1.1000	6.1000
5.0000	1.0400	5.9000
5.4600	1.0400	5.8000
6.0000	1.0600	5.8000
6.4100	1.2500	5.3000
6.9700	1.4500	5.2000
7.4700	1.6000	5.2000
7.9700	1.6600	5.1000
8.4700	1.7200	5.3000
8.9800	1.7200	5.5000
9.4700	1.7200	5.9000
9.9800	1.6400	6.8000
10.3700	1.6100	6.9000
10.7300	1.5900	7.9000
12.2000	1.6700	5.6000
13.3000	1.8600	5.7000
14.8000	2.0000	5.3000
16.0000	2.0800	5.3000
16.2000	2.0500	5.6000
17.0000	2.1000	5.2000
18.0000	1.9600	5.3000
19.0000	1.9600	5.3000
20.0000	1.9400	5.2000
20.5000	1.9700	5.3000

F.KAPPELER
SYMP. NEUTRON STANDARDS AND FLUX NORMALISATION, ARGONNE (1970) P272

FISSION CROSS SECTION U235

ENERGY(KEV)	SIG NF	PERCENTAGE ERROR
440.0000	1.1700	3.5000
530.0000	1.1700	3.5000

B.H.PATRICK,M.G.SOWERBY AND M.G.SCHOMBERG.

J.NUCL. EN. 24(1970)269
AVERAGE FISSION CROSS SECTION U235

ENERGY(KEV) AV	SIG NF
0.0550	68.6310
0.0650	15.5070
0.0750	34.9310
0.0850	30.3900
0.0950	23.5570
0.1500	22.5780
0.2500	21.3960
0.3500	13.8000
0.4500	14.2950
0.5500	15.6070
0.6500	11.8650
0.7500	11.4120
0.8500	8.4260
0.9500	7.7870
1.5000	7.4840
2.5000	5.3860
3.5000	4.8060
4.5000	4.3660
5.5000	4.2710
6.5000	3.2940
7.5000	3.2980
8.5000	3.1040
9.5000	3.1900
15.0000	2.4800
25.0000	2.1300

W.P.POENITZ
SYMP. NEUTRON STANDARDS AND FLUX NORMALISATION, ARGONNE (1970) P281

FISSION CROSS SECTION U235

ENERGY(KEV)	SIG NF	ERROR
552.0000	1.0850	0.0430
644.0000	1.0560	0.0420

I.SZABO,J.P.MARQUETTE,E.FORT AND J.L.LEROY
SYMP. ON NEUTRON STANDARDS AND FLUX NORMALISATION,ARGONNE,P257 (1970)

FISSION CROSS SECTION U235.

ENERGY(KEV)	SIG NF	ERROR
17.5000	2.1500	0.0900
27.0000	2.1000	0.0800
42.0000	1.8000	0.0600
68.0000	1.7650	0.0450
72.5000	1.7400	0.0550
95.0000	1.5400	0.0550
110.0000	1.5300	0.0500
120.0000	1.5700	0.0550

125.0000	1.5000	0.0500
145.0000	1.5000	0.0550
150.0000	1.4500	0.0450
152.0000	1.4400	0.0400
154.0000	1.4400	0.0350
156.0000	1.4500	0.0450
195.0000	1.3650	0.0550
215.0000	1.3250	0.0450
227.0000	1.2950	0.0350
251.0000	1.2850	0.0350
257.0000	1.2750	0.0550
272.0000	1.2750	0.0450
286.0000	1.2700	0.0350
313.0000	1.2850	0.0450
320.0000	1.1900	0.0450
331.0000	1.2100	0.0450
369.0000	1.2150	0.0450
407.0000	1.2050	0.0350
506.0000	1.1600	0.0300
540.0000	1.1600	0.0450
665.0000	1.1400	0.0350
810.0000	1.1350	0.0350
1010.0000	1.2050	0.0350

J.R.LEMLEY,G.A.KEYWORTH AND B.C.DIVEN
NUCL. SCI. ENG. 43(1971)281

AVERAGE FISSION CROSS SECTION U235

ENERGY(KEV) AV	SIG NF
0.1500	20.9000
0.2500	20.1500
0.6500	11.0870
1.5000	6.7410
2.5000	5.0570
3.5000	4.5110
4.5000	4.0100
7.5000	3.1050
15.0000	2.3380
25.0000	2.1010

J.R.LEMLEY,G.A.KEYWORTH AND B.C.DIVEN
NUCL. SCI. ENG. 43(1971)281
ORIGINAL DATA INCREASED BY +5.7% TO GIVE EVALUATED DATA 30-100 KEV
FISSION CROSS SECTION OF U235 AVERAGED IN 1KEV INTERVALS

ENERGY(MEV) AV	SIG NF
0.3050	2.1170
0.3150	2.1550
0.3250	2.0260
0.3350	2.0230
0.3450	1.9680
0.3550	1.9630
0.3650	1.9690
0.3750	1.9590
0.3850	1.9480
0.3950	1.9790

0.4050	2.1100
0.4150	1.9320
0.4250	1.9490
0.4350	1.8960
0.4450	1.8590
0.4550	1.8200
0.4650	1.8680
0.4750	1.8540
0.4850	1.8990
0.4950	1.8970
0.5050	1.8760
0.5150	1.8950
0.5250	1.9110
0.5350	1.8900
0.5450	1.8370
0.5550	1.8480
0.5650	1.8510
0.5750	1.8810
0.5850	1.7990
0.5950	1.9260
0.6050	1.8760
0.6150	1.8580
0.6250	1.8430
0.6350	1.7200
0.6450	1.7660
0.6550	1.8250
0.6650	1.8010
0.6750	1.7870
0.6850	1.7950
0.6950	1.8170
0.7050	1.7980
0.7150	1.7730
0.7250	1.7200
0.7350	1.6860
0.7450	1.7430
0.7550	1.7780
0.7650	1.7740
0.7750	1.6050
0.7850	1.5800
0.7950	1.6840
0.8050	1.7300
0.8150	1.7250
0.8250	1.7120
0.8350	1.7070
0.8450	1.7280
0.8550	1.6570
0.8650	1.5900
0.8750	1.6030
0.8850	1.6920
0.8950	1.6660
0.9050	1.6440
0.9150	1.6140
0.9250	1.6120
0.9350	1.6210
0.9450	1.5660
0.9550	1.7040
0.9650	1.6430
0.9750	1.6010
0.9850	1.6280
0.9950	1.6890

I.SZABO,G.FILIPPI,J.L.HUET,J.L.LEROY AND J.P.MARQUETTE
PROC. CONF. NEUT. CROSS SECTIONS AND TECHNOLOGY(KNOXVILLE,1971)VOL.2,P573

FISSION CROSS SECTION U235

ENERGY(KEV)	SIG NF	ERROR
11.5000	2.7100	0.0900
15.0000	2.4500	0.0700
22.5000	2.1600	0.0600
33.0000	1.9300	0.0600
46.0000	1.8100	0.0500
58.0000	1.7900	0.0500
78.0000	1.6700	0.0500
83.5000	1.6200	0.0500
93.0000	1.5200	0.0400
103.5000	1.5000	0.0400
116.0000	1.4900	0.0400
135.0000	1.3900	0.0400
150.0000	1.4300	0.0400
172.0000	1.4300	0.0400
199.0000	1.3900	0.0400

W.NYER
LAMS-938 (1950)

RATIO OF FISSION CROSS SECTIONS U235/U238

ENERGY(MEV)	RATIO	ERROR
14.0000	1.9100	0.0500

R.W.LAMPHERE
PHYS. REV. 104(1956)1654
ORIGINAL DATA MULTIPLIED BY 0.9388
RATIO FISSION CROSS SECTIONS U238/U235

ENERGY(MEV)	RATIO
0.5730	0.0004
0.6090	0.0009
0.6430	0.0008
0.6800	0.0007
0.7010	0.0007
0.7200	0.0013
0.7400	0.0013
0.7560	0.0014
0.7770	0.0018
0.7940	0.0021
0.8140	0.0028
0.8310	0.0032
0.8520	0.0044
0.8690	0.0049
0.8920	0.0057
0.9090	0.0079
0.9290	0.0082
0.9490	0.0103
0.9690	0.0100
0.9920	0.0098
1.0080	0.0099
1.0280	0.0103
1.0460	0.0108
1.0670	0.0116
1.0860	0.0165
1.1070	0.0205
1.1260	0.0207
1.1460	0.0259
1.1650	0.0310
1.1860	0.0309
1.2060	0.0309
1.2290	0.0301
1.2460	0.0337
1.2660	0.0338
1.2890	0.0404
1.3060	0.0460
1.3200	0.0591
1.3450	0.0647
1.3680	0.0845
1.3850	0.1028
1.4080	0.1248

1.4330	0.1518
1.4500	0.1782
1.4760	0.2180
1.4850	0.1880
1.4980	0.2340
1.5150	0.2570
1.5350	0.2550
1.5650	0.2590
1.5800	0.2690
1.6050	0.2850
1.6200	0.3010
1.6500	0.3090
1.6680	0.3220
1.6930	0.3180
1.7100	0.3240
1.7380	0.3360
1.7530	0.3470
1.7760	0.3530
1.8000	0.3640
1.8200	0.3700
1.8450	0.3850
1.8760	0.3770
1.9230	0.3990
1.9650	0.3970
2.0170	0.4000
2.0530	0.4070
2.0800	0.4160
2.1180	0.4220
2.1530	0.4170
2.2000	0.4190
2.2050	0.4220
2.3000	0.4210
2.3450	0.4260
2.3950	0.4150
2.4400	0.4100
2.4800	0.4250
2.5000	0.4220
2.5500	0.4250
2.6000	0.4160
2.6500	0.4160
2.7050	0.4250
2.7460	0.4250
2.8000	0.4210
2.8550	0.4290
2.9020	0.4100
2.9540	0.4220
2.9950	0.4270

C.A.UTTLEY AND J.A.PHILLIPS
AERE NP/R 1996 (1956)

RATIO OF FISSION CROSS SECTIONS U235/U238

ENERGY(MEV)	RATIO	ERROR
14.1000	1.9300	0.0300

A.A.BEREZIN,G.A.STOLIAROV,YU.V.NIKOLSKII AND I.E.CHELNOKOV.
ATOMNAYA ENERGIYA 5 659 (1958) ALSO J.NUCL.ENER. A/B 11 (1960) 175

RATIO OF FISSION CROSS SECTIONS U235/U238

ENERGY(MEV)	RATIO	ERROR
14.6000	2.0300	0.0900

S.P.KALININ AND V.M.PANKRATOV
GENEVA CONF. 1958, VOL.16,P136

RATIO FISSION CROSS SECTIONS U238/U235

ENERGY(MEV)	RATIO
2.9500	0.4360
3.1500	0.4390
3.4500	0.4720
3.6000	0.4470
4.1500	0.4710
4.2500	0.4760
4.7000	0.4830
4.8000	0.4920
5.3000	0.4830
5.7000	0.4920
6.1000	0.5560
6.2000	0.5310
6.5000	0.5700
6.9000	0.5840
7.3000	0.6330
7.4000	0.6380
7.6500	0.6610
7.8000	0.6270
8.0000	0.6340
8.3000	0.6140

A.MOAT
UNPUBLISHED REPORT (1958)

RATIO OF FISSION CROSS SECTIONS U235/U238

ENERGY(MEV)	RATIO	ERROR
14.0000	1.8800	0.0700

B.ADAMS,R.BATCHELOR AND T.S.GREEN
J. NUCL. ENER. 14(1961)85
NORMALISED TO 0.5232 AT 14.0 MEV.
RATIO OF FISSION CROSS SECTIONS U238/U235

ENERGY(MEV)	RATIO	ERROR
13.2000	0.5285	0.0110
13.5000	0.5285	0.0050
14.0000	0.5232	0.0050
14.4000	0.5626	0.0180
15.3000	0.5626	0.0060

16.0000	0.5687	0.0060
16.5000	0.6155	0.0150
16.9000	0.6084	0.0220
17.4000	0.6304	0.0230
18.0000	0.6084	0.0140
18.4000	0.5946	0.0210
19.0000	0.5946	0.0210
19.4000	0.6014	0.0210

J.A.GRUNDL
NUCL. SCI. ENG. 30(1967)39
FIRST 5 POINTS VARIABLE PROJ.ENERGY - REMAINDER SINGLE PROJ.ENERGY
RATIO FISSION CROSS SECTIONS U238/U235

ENERGY(MEV)	RATIO
1.6800	0.3400
2.1900	0.4140
2.7500	0.4260
3.3500	0.4490
4.2100	0.4950
1.1900	0.0367
2.1800	0.4060
2.4400	0.4220
3.1600	0.4340
3.4100	0.4570
3.9500	0.4930
4.9100	0.5120
5.9500	0.5820
6.9700	0.5870
7.5000	0.5740
8.0700	0.5860

P.H.WHITE AND D.P.WARNER
J. NUCL. ENER. 21(1967)671

RATIO FISSION CROSS SECTIONS U238/U235

ENERGY(MEV)	RATIO	PERCENTAGE ERROR
2.2500	0.4270	2.0000
5.4000	0.5280	2.0000
14.1000	0.5490	2.0000

W.E.STEIN,R.K.SMITH AND H.L.SMITH
PROC. CONF. NEUTRON CROSS SECTIONS AND TECHNOLOGY(WASHINGTON,1968)VOL.1.,P627
TOTAL ABSOLUTE ERROR OF MEASUREMENTS 2.2%
RATIO FISSION CROSS SECTIONS U238/U235

ENERGY(MEV)	RATIO	RELATIVE ERROR
1.5000	0.2200	0.0030
2.0000	0.4030	0.0040
2.2500	0.4150	0.0040
2.5000	0.4170	0.0040
2.7500	0.4180	0.0040
3.0000	0.4220	0.0040

3.2500	0.4320	0.0050
3.5000	0.4520	0.0050
3.7500	0.4650	0.0050
4.0000	0.4740	0.0040
4.2500	0.4780	0.0050
4.5000	0.4890	0.0060
4.7500	0.4870	0.0050
5.0000	0.4810	0.0050

B.ROSE
AERE NP/R 1743 (1955) SEE ALSO J.NUCL.ENER. 8(1959)197

CAPTURE CROSS SECTION U238 IN MILLIBARNS

ENERGY(KEV) AV	SIG NG	ERROR
29.0000	376.0000	77.0000
93.0000	204.0000	37.0000
152.0000	161.0000	8.0000
224.0000	146.0000	8.0000
300.0000	129.0000	7.0000
360.0000	118.0000	8.0000
390.0000	110.0000	6.0000
392.0000	117.0000	8.0000
530.0000	116.0000	8.0000
682.0000	138.0000	9.0000
840.0000	151.0000	10.0000

J.L.PERKIN,L.P.O'CONNOR AND R.F.COLEMAN
PROC. PHYS. SOC.,72(1958)505

CAPTURE CROSS SECTION U238

ENERGY(MEV)	SIG NG	ERROR
14.5000	0.0033	0.0005

J.H.GIBBONS,R.L.MACKLIN,P.D.MILLER AND J.H.NEILER
PHYS.REV. 122(1961)182

CAPTURE CROSS SECTION U238

ENERGY(KEV)	SIG NG	ERROR
30.0000	0.4730	0.0470
65.0000	0.3020	0.0300

V.A.TOLSTIKOV,L.E.SHERMAN AND YU.YA.STAVISSKII
J. NUCL. ENER. A/B 18(1964)599
CORRECTED FOR NON 1/V B-10(N,ALPHA),NORMALISED TO BELANOVA ET AL AT 22.8 KEV
CAPTURE CROSS SECTION U238

ENERGY(KEV)	SIG NG
15.0000	0.5590
21.0000	0.4960
23.0000	0.4950
29.0000	0.4780
39.0000	0.4440
48.0000	0.3650
53.0000	0.2620
70.0000	0.2430
160.0000	0.1520
170.0000	0.2110
180.0000	0.1370

T.S.BELANOVA,A.A.VANKOV,F.F.MIKHAILUS AND YU YA STAVISSKII
J.NUCL.ENER. 20(1966)411
CORRECTED BY MILLER AND POENITZ NUCL.SCI.ENG. 35(1969)295
CAPTURE CROSS SECTION U238

ENERGY(KEV)	SIG NG	ERROR
22.8000	0.4950	0.0400

H.O.MENLOVE AND W.P.POENITZ
NUCL.SCI.ENG. 33(1968)24

CAPTURE CROSS SECTION U238 RENORMALISED TO 0.466 BARNS AT 30 KEV

ENERGY(KEV)	SIG NG	ERROR
24.4000	0.5020	0.0270
30.0000	0.4660	0.0140
43.8000	0.3930	0.0190
63.3000	0.2940	0.0140
97.3000	0.1960	0.0110
157.0000	0.1490	0.0090
264.0000	0.1230	0.0090
373.0000	0.1200	0.0110
503.0000	0.1070	0.0100

M.C.MOXON
UKAEA REPORT AERE-R6074(1969)

AVERAGE CAPTURE CROSS SECTION U238. VALUES REVISED 1970

ENERGY(KEV) AV	SIGMA NG
1.5000	1.9740
2.5000	1.4800
3.5000	1.2320
4.5000	0.9635
5.5000	0.9395
6.5000	0.8243
7.5000	0.7933
8.5000	0.7232
9.5000	0.7225
15.0000	0.6119
25.0000	0.4623
35.0000	0.3687
45.0000	0.3486
55.0000	0.3005
65.0000	0.2564
75.0000	0.2154
85.0000	0.1853
95.0000	0.1833

M.P.FRICKE,W.M.LOPEZ,S.J.FREISENHAN,A.D.CARLSON AND D.G.COSTELLO
IAEA CONF. ON NUCLEAR DATA FOR REACTORS(HELSINKI,1970),VOL.2,P.265
CORRECTED FOR NON 1/V B-10(N,ALPHA) BELOW 80 KEV
AVERAGE CAPTURE CROSS SECTION U238. AVERAGED IN 1 OR 10 KEV INTERVALS

ENERGY(KEV) AV	MEAN
95.0000	0.2120
85.0000	0.2270
75.0000	0.2500
65.0000	0.2890
55.0000	0.3290
45.0000	0.3800
35.0000	0.4470
25.0000	0.4960
15.0000	0.5760
9.5000	0.7000
8.5000	0.6360
7.5000	0.7130
6.5000	0.7350
5.5000	0.8370
4.5000	0.8420
3.5000	1.0870
2.5000	1.3570
1.5000	1.7240

M.P.FRICKE,W.M.LOPEZ,S.J.FRIESENHAN,A.D.CARLSON AND D.G.COSTELLO
PROC. IAEA CONF. NUCLEAR DATA FOR REACTORS(HELSINKI,1970)VOL.2,P.265
RELATIVE ERROR QUOTED. TOTAL SYSTEMATIC UNCERTAINTY IS 12.0%
CAPTURE CROSS SECTION U238

ENERGY(KEV)	SIG NG	PERCENTAGE ERROR
100.8000	0.1940	5.0000
108.9000	0.1940	5.0000
118.0000	0.1740	5.0000
128.2000	0.1790	5.0000
139.9000	0.1630	5.0000
153.2000	0.1630	5.0000
168.5000	0.1600	5.0000
186.2000	0.1390	5.0000
206.9000	0.1390	4.0000
231.2000	0.1250	4.0000
260.0999	0.1170	4.0000
294.7000	0.1120	5.0000
336.7998	0.1140	4.0000
388.5000	0.1040	4.0000
453.2000	0.1150	4.0000
535.3999	0.1090	5.0000
642.2998	0.1060	6.0000
752.0000	0.1150	10.0000

E.G.SILVER,G.DE SAUSSURE,R.B.PEREZ AND R.W.INGLE
PROC. CONF. NEUTRON CROSS SECTIONS AND TECHNOLOGY(KNOXVILLE,1971)VOL.2,P.728
CORRECTED FOR NON 1/V B-10(N,ALPHA)
AVERAGE CAPTURE CROSS SECTION U238

ENERGY(KEV) AV	SIG NG
0.5500	5.3800
0.6500	4.0000
0.7500	2.0800
0.8500	3.3000
0.9500	4.6000
1.5000	2.1100
2.5000	1.5800
3.5000	1.3000
4.5000	1.0000
5.5000	1.0400
6.5000	1.0200
7.5000	0.8650
8.5000	0.7750
9.5000	0.7700
15.0000	0.6950
25.0000	0.5620
35.0000	0.4950
45.0000	0.4300
55.0000	0.3450
65.0000	0.3050
75.0000	0.2600
85.0000	0.2350
95.0000	0.2100

G.A.LINENBERGER AND J.A.MISKEL
LOS ALAMOS REPORT LA-467 (1946)

RATIO CAPTURE CROSS SECTION U238/FISSION CROSS SECTION U235

ENERGY(KEV)	RATIO	ERROR
5.0000	0.1650	0.0230
18.0000	0.1680	0.0250
40.0000	0.1950	0.0300
90.0000	0.1330	0.0200
170.0000	0.1110	0.0180
195.0000	0.1010	0.0180
380.0000	0.0900	0.0180
400.0000	0.0900	0.0180
560.0000	0.1010	0.0180
615.0000	0.1010	0.0180
770.0000	0.1150	0.0180
1310.0000	0.0730	0.0150
5900.0000	0.0150	0.0080

L.W.WESTON,G.DE SAUSSURE AND R.GWIN
EANDC 33U PAGE 64 (1963)

RATIO CAPTURE CROSS SECTION U238/FISSION CROSS SECTION U235

ENERGY(KEV)	RATIO	ERROR
30.0000	0.2060	0.0170
64.0000	0.1670	0.0140

J.F.BARRY,J.BUNCE AND P.H.WHITE
J. NUCL. ENER. A/B 18(1964)481

RATIO CAPTURE CROSS SECTION U238/FISSION CROSS SECTION U235

ENERGY(KEV)	RATIO	ERROR
0.1270	0.1420	0.0070
0.1600	0.1320	0.0060
0.2070	0.1140	0.0040
0.3120	0.1080	0.0050
0.4040	0.1030	0.0040
0.5050	0.1090	0.0040
0.8100	0.1240	0.0070
1.0600	0.1180	0.0060
1.3000	0.1020	0.0050
1.7500	0.0530	0.0030
3.0000	0.0220	0.0020
5.0000	0.0095	0.0013
7.6000	0.0036	0.0011

W.P.POENITZ
TRANS.AM.NUCL.SOC. 12(1968)279

RATIO CAPTURE CROSS SECTION U238/FISSION CROSS SECTION U235

ENERGY(KEV)	RATIO	ERROR
30.0000	0.2050	0.0080

W.P.POENITZ
NUCL. SCI. ENG. 40(1970)383

RATIO CAPTURE CROSS SECTION U238/FISSION CROSS SECTION U235

ENERGY(KEV)	RATIO	ERROR
130.0000	0.1260	0.0060
150.0000	0.1260	0.0060
250.0000	0.1140	0.0040
300.0000	0.1030	0.0030
400.0000	0.1040	0.0030
500.0000	0.1110	0.0030
600.0000	0.1220	0.0040
700.0000	0.1330	0.0040
900.0000	0.1240	0.0040
1200.0000	0.0970	0.0040
1250.0000	0.0920	0.0040
1400.0000	0.0740	0.0030

W.D.ALLEN AND A.T.G.FERGUSON
PROC. PHYS. SOC. 70A(1957)573
FISSION CROSS SECTION PU239. ERRORS QUOTED IN TABLE ARE STATISTICAL ONLY.
TAKE TOTAL ERROR TO BE 3.5%

ENERGY(KEV)	SIG NF	ASSUMED ERROR
550.0000	1.6600	0.0580
1500.0000	1.9300	0.0680

L.M.BOLLINGER,R.E.COTE AND G.E.THOMAS
PROC. GENEVA CONF. PEACEFUL USES AT. ENER. (1958)VOL.15,P.127
RENORMALISED TO 741.68 AT 0.0253 EV. CORRECTED FOR NON 1/V B-10(N,ALPHA)
AVERAGE FISSION CROSS SECTION PU239

ENERGY(KEV) AV	SIG NF
0.1500	19.8000
0.2500	17.6200
0.3500	9.8930

J.L.PERKIN,P.H.WHITE,P.FIELDHOUSE,E.J.AXTON,P.CROSS AND J.C.ROBERTSON
J.NUCL.ENER. 19(1965)423

FISSION CROSS SECTION PU239

ENERGY(KEV)	SIG NF	ERROR
22.8000	1.6600	0.0700

E.R.SHUNK,W.E.BROWN AND R.LABAUVE
WASHINGTON CONF. NEUTRON CROSS SECTIONS AND TECH. CONF. 660303 P.979 (1966)

AVERAGE FISSION CROSS SECTION PU239

ENERGY(KEV) AV	SIG NF
0.1500	17.8200
0.2500	18.2500
0.3500	8.3250
0.4500	9.1050
0.5500	14.6600
0.6500	3.9410
0.7500	5.1950
0.8500	4.3600
0.9500	8.2780
1.5000	3.8320
2.5000	2.6410
3.5000	2.7440
4.5000	2.3130
5.5000	2.7100
6.5000	2.2030
7.5000	2.2320
8.5000	2.4620
9.5000	2.1370

J.BLONS,H.DERRIEN AND A.MICHAUDON
PROC. IAEA CONF. NUCLEAR DATA FOR REACTORS(HELSINKI,1970)VOL.1,P.513
RENORMALISED THROUGH BOLLINGER ET AL TO 741.6B AT 0.0253 EV
AVERAGE FISSION CROSS SECTION PU239 CORRECTED FOR NON 1/V B-10(N,ALPHA)

ENERGY(KEV) AV	SIG NF
0.1500	19.4830
0.2500	18.3120
0.3500	9.1810
0.4500	10.0100
0.5500	15.9920
0.6500	4.8490
0.7500	6.1470
0.8500	5.2570
0.9500	8.8460
1.5000	4.5990
2.5000	3.4080
3.5000	3.1410
4.5000	2.4180
5.5000	2.2620
6.5000	2.0440
7.5000	2.0490
8.5000	2.5390
9.5000	2.0090
15.0000	1.9430
25.0000	1.9500

J.A.FARRELL,G.F.AUCHAMPAUGH,M.S.MOORE AND P.A.SEEGER
PROC. IAEA CONF. NUCLEAR DATA FOR REACTORS(HELSINKI,1970)VOL.1,P.543

AVERAGE FISSION CROSS SECTION PU239

ENERGY(KEV) AV	SIG NF
0.1500	21.1000
0.2500	20.6000
0.3500	9.4300
0.4500	10.3000
0.5500	16.2000
0.6500	4.5000
0.7500	6.1100
0.8500	5.4300
0.9500	8.6700
1.5000	4.4700
2.5000	3.4700
3.5000	3.2800
4.5000	2.5900
5.5000	2.5900
6.5000	2.2300
7.5000	2.4400
8.5000	2.4800
9.5000	2.1100
15.0000	1.9400
25.0000	1.8500

G.D.JAMES
PROC. IAEA CONF. NUCLEAR DATA FOR REACTORS(HELSINKI,1970)VOL.1,P.267
CORRECTED FOR NON 1/V B-10(N,ALPHA)
AVERAGE FISSION CROSS SECTION PU239

ENERGY(KEV) AV	SIG NF
0.1500	21.7600
0.2500	20.4000
0.3500	10.5200
0.4500	9.9150
0.5500	16.8900
0.6500	-
0.7500	5.9470
0.8500	5.0300
0.9500	7.4010
1.5000	4.2350
2.5000	3.2740
3.5000	2.7870
4.5000	2.5020
5.5000	2.3740
6.5000	1.9410
7.5000	2.2370
8.5000	2.2160
9.5000	1.8310
15.0000	1.7200

M.G.SCHOMBERG,M.G.SOWERBY,D.A.BOYCE,K.J.MURRAY, AND D.L.SUTTON
PROC. IAEA CONF. NUCLEAR DATA FOR REACTORS(HELSINKI,1970)VOL.1,P.315

AVERAGE FISSION CROSS SECTION PU239

ENERGY(KEV) AV	SIG NF
0.1500	18.5500
0.2500	18.4300
0.3500	8.7600
0.4500	9.7500
0.5500	15.6800
0.6500	4.8000
0.7500	5.4900
0.8500	5.3800
0.9500	8.0400
1.5000	4.7100
2.5000	3.4300
3.5000	3.1100
4.5000	2.4300
5.5000	-
6.5000	2.0300
7.5000	2.1600
8.5000	2.2000
9.5000	1.9000
15.0000	1.6600
25.0000	1.5900

I.SZABO,G.FILIPPI,J.L.HUET,J.L.LEROY AND J.P.MARQUETTE
SYMP. NEUTRON STANDARDS AND FLUX NORMALISATION (ARGONNE,1970),P.257
THESE DATA SUPERCEDE VALUES IN NUCLEAR DATA FOR REACTORS VOL.1,P229 (1970)
FISSION CROSS SECTION PU239.

ENERGY(KEV)	SIG NF	ERROR
35.0000	1.5300	0.0700
49.0000	1.4950	0.0600
57.0000	1.5050	0.0500
73.0000	1.5400	0.0550
77.5000	1.5300	0.0550
102.0000	1.5650	0.0550
109.0000	1.5000	0.0500
135.0000	1.4700	0.0500
152.0000	1.4400	0.0400
154.0000	1.4750	0.0400
165.0000	1.4200	0.0400
197.0000	1.4200	0.0400
226.0000	1.4000	0.0550
251.0000	1.4800	0.0400
331.0000	1.5450	0.0350
377.0000	1.5300	0.0350
453.0000	1.5700	0.0400
506.0000	1.5900	0.0400
665.0000	1.5950	0.0400
810.0000	1.7000	0.0400
972.0000	1.7200	0.0400

R.GWIN,L.W.WESTON,G. DE SAUSSURE,R.W.INGLE,J.H.TODD,F.E.GILLESPIE,
R.W.HOCKENBURY AND R.C.BLOCK
NUCL. SCI. AND ENG. 45(1971)25
AVERAGE FISSION CROSS SECTION PU239. CORRECTED FOR NON 1/V B-10(N,ALPHA)

ENERGY(KEV) AV	SIG NF
0.1500	18.0900
0.2500	17.2700
0.3500	8.2300
0.4500	9.4000
0.5500	15.1300
0.6500	4.3500
0.7500	5.6300
0.8500	4.9700
0.9500	8.3800
1.5000	4.2800
2.5000	3.2600
3.5000	3.0400
4.5000	2.1500
5.5000	1.9300
6.5000	1.9300
7.5000	2.0600
8.5000	2.1400
9.5000	1.8100
15.0000	1.7400

I.SZABO,G.FILIPPI,J.L.HUET,J.L.LEROY AND J.P.MARQUETTE
PROC. CONF. NEUT. CROSS SECTIONS AND TECHNOLOGY(KNOXVILLE,1971)VOL.2,P.573

FISSION CROSS SECTION 239PU

ENERGY(KEV)	SIG NF	ERROR
11.5000	1.7780	0.0580
15.0000	1.7500	0.0520
22.5000	1.7100	0.0600
33.0000	1.5900	0.0400
46.0000	1.5900	0.0400
58.0000	1.5500	0.0400
78.0000	1.5500	0.0500
83.5000	1.5300	0.0400
93.0000	1.5800	0.0400
103.5000	1.5400	0.0400
116.0000	1.5900	0.0400
135.0000	1.4600	0.0500
150.0000	1.4900	0.0400
172.0000	1.4800	0.0400
199.0000	1.4900	0.0400

C.A.UTTLEY AND J.A.PHILLIPS
AERE NP/R 1996 (1956)

RATIO OF FISSION CROSS SECTIONS PU239/U238

ENERGY	RATIO	ERROR
14.1000	2.2600	0.0600
15.0000	2.1700	0.0700

A.MOAT
UNPUBLISHED REPORT (1958)

RATIO OF FISSION CROSS SECTIONS PU239/J238

ENERGY	RATIO	ERROR
14.0000	2.3100	0.0600

B.ADAMS,R.BATCHELOR AND T.S.GREEN
J. NUCL. ENER. 14(1961)85
RATIO FISSION CROSS SECTIONS U238/PU239
NORM. TO 0.4407 AT 14.0 MEV

ENERGY(MEV)	RATIO	PERCENTAGE ERROR
13.4000	0.4363	0.0198
14.0000	0.4407	0.0100
14.4000	0.4543	0.0206
14.9000	0.4843	0.0220
15.3000	0.4790	0.0217
16.0000	0.5124	0.0233
16.5000	0.5247	0.0238
16.9000	0.5310	0.0240
17.5000	0.5374	0.0366
18.0000	0.5578	0.0380
18.4000	0.5578	0.0380
19.0000	0.5799	0.0395
19.4000	0.5799	0.0395

T.CZYZEWSKI
REPORT INR-688/I/PH (1966)

RATIO FISSION CROSS SECTIONS U238/PU239

ENERGY(MEV)	RATIO	PERCENTAGE ERROR
13.1000	0.4360	4.2000
13.5000	0.4420	3.7200
14.2000	0.4740	4.0800
14.8000	0.5180	3.7200
15.3000	0.5440	4.2200

G.HANSEN,S.MCGUIRE AND R.K.SMITH
PRIVATE COMMUNICATION FROM DR. L.STEWART(1970)

RATIO FISSION CROSS SECTIONS U238/PU239

ENERGY(MEV)	RATIO	PERCENTAGE ERROR
2.0000	0.2520	4.2000
2.5000	0.2640	4.1000
3.0000	0.2600	4.1000
3.5000	0.2790	4.2000
4.0000	0.2920	4.2000
4.5000	0.2990	4.2000
5.0000	0.3060	4.2000
5.5000	0.3100	4.1000
6.0000	0.3290	4.1000
6.2500	0.3480	4.5000
6.5000	0.4030	4.2000
7.0000	0.4500	4.2000
7.5000	0.4440	4.2000
8.0000	0.4330	4.1000
8.5000	0.4330	4.2000
9.0000	0.4290	4.7000
9.5000	0.4170	6.0000
10.0000	0.4220	7.3000
12.7000	0.3970	4.6000
14.1000	0.4290	4.3000
14.8000	0.4670	4.3000
16.0000	0.5050	4.3000
17.0000	0.5000	4.4000
18.0000	0.5080	4.3000
19.0000	0.5130	4.3000
20.0000	0.5380	4.4000

W.D.ALLEN AND A.T.G.FERGUSON
PROC. PHYS. SOC. 70A(1957)573

RATIO FISSION CROSS SECTIONS PU239/U235

ENERGY(MEV)	RATIO
0.0300	0.8270
0.0600	0.8530
0.1200	0.9640
0.1500	1.0300
0.1750	1.0260
0.2000	1.0610
0.2200	1.1080
0.2400	1.0850
0.2750	1.1960
0.3000	1.2100
0.3300	1.2040
0.3500	1.2500
0.4450	1.2730
0.5000	1.3330
0.5500	1.3230
0.6500	1.4120
1.0000	1.4750
1.5000	1.4510
2.0000	1.3360
2.5000	1.3170
3.0000	1.4150

R.K.SMITH,R.L.HENKEL AND R.A.NOBLES
BULL.AM.PHYS.SOC. 2(1957)196 AND PRIVATE COMMUNICATICN FROM DR.L.STEWART
LOS ALAMOS (1970)

RATIO FISSION CROSS SECTIONS PU239/U235

ENERGY(MEV)	RATIO	PERCENTAGE ERROR
0.5100	1.4400	5.2000
1.0000	1.5100	4.4000
1.5100	1.6300	4.3000
1.6000	1.6100	4.2000
2.0000	1.6000	4.5000
2.5000	1.6100	4.2000
3.0000	1.6100	4.2000
3.5000	1.6200	4.2000
4.0000	1.6600	4.5000
4.2200	1.5800	4.5000
4.5000	1.6500	4.3000
4.8600	1.5700	4.3000
5.0600	1.6700	6.9000
5.4500	1.5600	4.4000
5.7800	1.5100	5.2000
6.0000	1.6700	4.3000
6.1400	1.7600	6.2000
6.2100	1.7100	4.7000
6.5300	1.5200	4.2000
6.6100	1.3900	5.8000
6.8400	1.4400	4.4000
7.0500	1.3500	4.3000
7.1700	1.4100	6.6000

S.P.KALININ AND V.M.PANKRATOV
PROC. GENEVA CONF. PEACEFUL USES AT. ENER. (1958)VOL.16,P.136

RATIO FISSION CROSS SECTIONS PU239/U235

ENERGY(MEV)	RATIO
3.0000	1.5600
3.6000	1.6300
4.1000	1.6300
4.8000	1.6000
5.2500	1.6700
5.7000	1.6500
6.1000	1.5600
6.5000	1.4600
6.9000	1.4300
7.3000	1.4000
7.7500	1.3800
8.0000	1.3700
8.2500	1.3200

J.L.PERKIN,P.H.WHITE,P.FIELDHOUSE,E.J.AXTON,P.CROSS AND J.C.ROBERTSON
J.NUCL.ENER. 19(1965)423

RATIO OF FISSION CROSS SECTIONS PU239/J235

ENERGY(KEV)	RATIO
22.8000	0.7030

P.H.WHITE,J.G.HODGKINSON AND G.J.WALL
PROC. IAEA CONF. PHYSICS AND CHEMISTRY OF FISSION(SALZBURG,1965)VOL.1,P.219

RATIO FISSION CROSS SECTIONS PU239/U235

ENERGY(KEV)	RATIO	PERCENTAGE ERROR
40.0000	0.6900	2.2000
67.0000	0.8160	2.2000
127.0000	0.9800	2.2000
312.0000	1.1700	2.2000
505.0000	1.3400	2.2000

W.B.GILBOY AND G.F.KNOLL
KARLSRUHE REPORT KFK-450(1966)
MEAN OF METHOD B AND 0.94 METHOD A RENORMALISED BY A FACTOR 1.149
RATIO FISSION CROSS SECTIONS PU239/J235 (RENORMALISED BY FACTOR 1.149)

ENERGY(KEV)	RATIO
146.1000	0.9730
132.5000	0.9870
120.2000	0.9710
109.0000	0.9370
98.9000	0.9320
89.7000	0.9220
81.3000	0.9190
73.8000	0.9080

66.9000	0.8930
60.7000	0.8740
55.1000	0.8500
49.9000	0.8120
45.3000	0.8030
41.1000	0.7900
37.3000	0.7730
33.8000	0.7580
30.7000	0.7650
27.8000	0.7320
25.2000	0.7390
22.9000	0.7430
20.7000	0.7060
18.8000	0.7140
17.1000	0.6930
15.5000	0.6920
14.0000	0.6780
12.7000	0.6790
11.6000	0.6750
10.5000	0.6490
9.5000	0.6360
8.6000	0.6460
7.8000	0.7010
7.1000	0.6730
6.4000	0.6250
5.8000	0.6470
5.3000	0.6160

D.M.BARTON AND P.G.KOONTZ
PHYS. REV. 162(1967)1070
14.9 MEV POINT NOT USED (SEE TABLE 2(2) APPENDIX 2)
RATIO FISSION CROSS SECTIONS PU239/U235

ENERGY(MEV)	RATIO
3.0000	1.5520
14.9000	1.2020

V.G.NESTEROV AND G.M.SMIRENKIN
SOV.J.AT.ENER. 24(1968)224 AND USSR INFORMATION BULLETIN NUCLEAR DATA CENTRE (1967)
RATIO OF FISSION CROSS SECTIONS 239PU/235U (SERIES 2)

ENERGY(MEV)	RATIO
0.3300	1.2060
0.4000	1.2960
0.4600	1.3720
0.5050	1.3890
0.5600	1.3930
0.6200	1.3750
0.6700	1.3860
0.7200	1.4350
0.7700	1.4350
0.8200	1.4150
0.8750	1.4550
0.9200	1.4330
0.9700	1.4220

1.0000	1.4160
1.0600	1.3970
1.1300	1.3800
1.1700	1.4180
1.2000	1.4610
1.2800	1.4600
1.3200	1.4430
1.3600	1.5090
1.4200	1.4950
1.4700	1.5270
1.5200	1.5100
1.5700	1.5370
1.6300	1.5040
1.6800	1.5270
1.7300	1.5300
1.7800	1.5590
1.8300	1.5130
1.8800	1.4510
1.9300	1.4700
1.9800	1.5150
2.0200	1.5010
2.0800	1.4890
2.1300	1.4750
2.1800	1.5040
2.2200	1.4540
2.2750	1.4300
2.3250	1.4820
2.3900	1.4650
2.4700	1.4650
2.5200	1.4390
2.5750	1.4300

P.H.WHITE AND D.P.WARNER
J. NUCL. ENER. 21(1967)671

RATIO OF FISSION CROSS SECTIONS PU239/J235

ENERGY(MEV)	RATIO	PERCENTAGE ERROR
1.0000	1.4350	2.0000
2.2500	1.5200	2.0000
5.4000	1.5750	2.0000
14.1000	1.1630	2.0000

V.G.NESTEROV AND G.M.SMIRENKIN
SOV.J.AT.ENER. 24(1968)224 AND USSR INFORMATION BULLETIN NUCLEAR DATA CENTRE (1967)
RATIO OF FISSION CROSS SECTIONS 239PU/235U MEASURED BY GLASS METHOD

ENERGY(MEV)	RATIO	ERROR
0.9950	1.3720	0.0290
1.8150	1.4830	0.0320
2.5050	1.5220	0.0330

E.PFLETSCHINGER AND F.KAPPELER
NUCL. SCI. ENG. 40(1970)375

RATIO FISSION CROSS SECTIONS PU239/U235

ENERGY(KEV)	RATIO	PERCENTAGE ERROR
5.2000	0.7110	4.2000
8.2000	0.6630	3.0000
11.1000	0.6780	2.6000
13.6000	0.6360	2.7000
15.5000	0.6930	2.7000
17.5000	0.6740	2.6000
19.5000	0.7370	2.4000
21.4000	0.6860	2.4000
23.8000	0.7360	2.2000
26.8000	0.7140	2.1000
30.0000	0.7540	2.2000
32.6000	0.7910	2.2000
34.9000	0.8000	2.2000
38.2000	0.7890	2.0000
42.0000	0.8130	2.1000
46.4000	0.8120	2.0000
51.5000	0.8360	2.0000
56.2000	0.8530	2.0000
61.7000	0.8700	2.0000
67.9000	0.8600	2.0000
75.1000	0.9090	2.0000
81.3000	0.9240	2.0000
88.3000	0.9200	2.0000
99.1000	0.9630	2.0000
112.1000	0.9720	2.1000
123.5000	0.9680	2.2000
132.1000	1.0350	2.4000
141.7000	1.0100	2.1000
152.3000	1.0140	2.5000
164.2000	1.0040	2.2000
177.6000	1.0570	2.6000
192.6000	1.0240	2.4000
226.0000	1.0510	2.1000
284.0000	1.1360	2.2000
330.0000	1.1550	2.6000
389.0000	1.2120	2.0000
445.0000	1.2580	2.1000
483.0000	1.3290	1.8000
557.0000	1.3310	2.0000
608.0000	1.3790	2.2000
645.0000	1.3540	2.5000
706.0000	1.4000	2.2000
750.0000	1.4400	2.0000
811.0000	1.4530	2.1000
850.0000	1.4140	2.0000
905.0000	1.3570	2.0000
950.0000	1.3160	2.2000
1008.0000	1.3590	2.1000

W.P.POENITZ
NUCL. SCI. ENG. 40(1970)383

RATIO FISSION CROSS SECTIONS PU239/U235

ENERGY(KEV)	RATIO	ERROR
150.0000	0.9580	0.0240
200.0000	1.0720	0.0310
250.0000	1.0800	0.0320
325.0000	1.1910	0.0300
500.0000	1.3200	0.0270
700.0000	1.4290	0.0260
850.0000	1.4610	0.0410
1000.0000	1.3560	0.0310
1200.0000	1.4200	0.0500
1300.0000	1.4180	0.0310
1400.0000	1.4460	0.0290

M.V.SAVIN,YU.A.KHOKHLOV,YU.S.ZAMYATNIN AND I.N.PARAMONOVA.
INDC (CCP)-8/U SOV.J.AT.ENER. 29(1970)938

RATIO FISSION CROSS SECTIONS PU239/U235

ENERGY(MEV)	RATIO	ERROR
5.3500	1.3710	0.1000
4.6600	1.4660	0.0570
4.4300	1.4850	0.0550
4.1700	1.5200	0.0530
3.9400	1.5370	0.0490
3.7200	1.5970	0.0460
3.5300	1.5040	0.0400
3.3500	1.4800	0.0400
3.1800	1.4070	0.0370
3.0200	1.5180	0.0390
2.8800	1.5100	0.0400
2.7500	1.5290	0.0370
2.6100	1.4820	0.0350
2.5000	1.5450	0.0340
2.3900	1.5840	0.0340
2.2900	1.5780	0.0330
2.2000	1.4850	0.0320
2.1100	1.5100	0.0330
2.0200	1.5090	0.0320
1.9200	1.5180	0.0260
1.8100	1.4920	0.0270
1.7100	1.5320	0.0270
1.6200	1.5220	0.0270
1.5400	1.5510	0.0320
1.4500	1.5650	0.0330
1.3900	1.3500	0.0310
1.3100	1.4170	0.0320
1.2300	1.4500	0.0330
1.1500	1.5540	0.0400
1.0800	1.5200	0.0410
1.0200	1.3440	0.0410
0.9700	1.3440	0.0410
0.9100	1.4010	0.0410

0.8600	1.3860	0.0560
0.8200	1.3920	0.0600

M.SOLEILHAC,J.FREHAUT,J.GAURIAU AND G.MOSINSKI
PROC. IAEA CONF. NUCLEAR DATA FOR REACTORS(HELSINKI,1970)VOL.2,P.145

RATIO FISSION CROSS SECTIONS PU239/U235

ENERGY(MEV)	RATIO	ERROR
1.3600	1.2770	0.0200
1.3750	1.2030	0.0820
1.3250	1.3100	0.0690
1.2750	1.4190	0.0670
1.2250	1.2910	0.0550
1.1750	1.3070	0.0500
1.1250	1.3210	0.0450
1.0750	1.3510	0.0450
1.0250	1.3760	0.0430
0.9750	1.3510	0.0330
0.9250	1.3890	0.0330
0.8750	1.3970	0.0300
0.8250	1.3970	0.0290
0.7750	1.3890	0.0260
0.7250	1.3720	0.0240
0.6900	1.3790	0.0340
0.6700	1.3890	0.0330
0.6500	1.3820	0.0300
0.6300	1.3700	0.0300
0.6100	1.3540	0.0280
0.5900	1.3260	0.0270
0.5700	1.3080	0.0260
0.5500	1.3230	0.0270
0.5300	1.3560	0.0300
0.5100	1.2880	0.0280
0.4900	1.2650	0.0290
0.4700	1.2860	0.0330
0.4500	1.2430	0.0330
0.4300	1.2710	0.0380
0.4100	1.2340	0.0390
0.3900	1.2270	0.0410
0.3700	1.2160	0.0430
0.3500	1.2280	0.0440
0.3300	1.2470	0.0460
0.3100	1.2400	0.0490
0.2900	1.1790	0.0530
0.2700	1.1580	0.0580
0.2500	1.1550	0.0710
0.2300	1.0920	0.0780
0.2100	0.8910	0.0950

I.SZABO,G.FILIPPI,J.L.HUET,J.L.LEROY AND J.P.MARQUETTE
PROC.KNOXVILLE CONF. ON NEUTRON CROSS SECTIONS AND TECH. P573 (1971)
NOT USED IN EVALUATION AS 239 AND 235 DATA INDEPENDENTLY CONSIDERED
RATIO OF FISSION CROSS SECTIONS PU239/U235

ENERGY(KEV)	RATIO	ERROR
11.5000	0.6590	0.0220
15.0000	0.7180	0.0210

22.5000	0.7880	0.0300
33.0000	0.8050	0.0200
46.0000	0.8750	0.0240
58.0000	0.8670	0.0230
78.0000	0.9290	0.0270
83.5000	0.9450	0.0240
93.0000	1.0350	0.0260
103.5000	1.0250	0.0240
116.0000	1.0170	0.0220
135.0000	1.0550	0.0340
150.0000	1.0370	0.0300
172.0000	1.0370	0.0260
199.0000	1.0620	0.0270

K.K.HARRIS,H.A.GRENCH,R.G.JOHNSON,F.J.VAUGHN,J.H.FERZIGER AND R.SHER
NUCL. PHYS. 69(1965)37. REVISED(1970)

CAPTURE CROSS SECTION AU197 (MILLIBARNS)

ENERGY(KEV)	SIG NG
13.1000	1252.0000
23.2000	761.0000
36.0000	623.0000
41.6000	548.0000
53.5000	440.0000
69.7000	384.0000
89.4000	359.0000
129.3000	290.7998
168.8000	278.7000
232.3000	267.2000
284.2000	222.3000
372.0999	181.5000
508.5999	130.0000
555.2000	115.5000
691.2000	92.8000

W.P.POENITZ,D.KOMPE AND H.O.MENLOVE
J.NUCL. ENER. 22(1968)505

CAPTURE CROSS SECTION AU197 (MILLIBARNS)

ENERGY(KEV)	SIG NG
24.7000	676.0000
25.0000	639.0000
30.8000	591.0000
36.0000	488.0000
44.6000	459.0000
47.4000	457.0000
50.9000	447.0000
58.3000	422.0000
61.9000	397.0000
82.3000	340.0000
88.8000	318.0000
103.3000	328.0000
134.0000	294.0000
153.0000	275.0000
171.0000	273.0000
179.0000	268.0000
184.0000	265.0000
191.0000	263.0000
227.0000	250.0000
280.0000	209.0000
342.0000	185.0000
473.0000	142.0000

J.C.ROBERTSON,T.B.RYVES,E.J.AXTON,I.GOODIER AND A.WILLIAMS
J. NUCL. ENER. 23(1969)205

CAPTURE CROSS SECTION AU197

ENERGY(KEV)	SIG NG
966.0000	0.0960

M.P.FRICKE,W.M.LOPEZ,S.J.FRIESENHAN,A.D.CARLSON AND D.G.COSTELLO
PROC. IAEA CONF. NUCLEAR DATA FOR REACTORS(HELSINKI,1970)VOL.2,P.265
CORRECTED FOR NON 1/V B-10(N,ALPHA) BELOW 80 KEV
AVERAGE CAPTURE CROSS SECTION AU197

ENERGY(KEV) AV	SIG NG
1.5000	5.5830
2.5000	3.3860
3.5000	2.5140
4.5000	2.2930
5.5000	1.9880
6.5000	1.8220
7.5000	1.6970
8.5000	1.4360
9.5000	1.1850
15.0000	0.9540
25.0000	0.6390
35.0000	0.5280
45.0000	0.4710
55.0000	0.4370
65.0000	0.4130
75.0000	0.3690
85.0000	0.3760
95.0000	0.3520

M.P.FRICKE,W.M.LOPEZ,S.J.FRIESENHAN,A.D.CARLSON AND D.G.COSTELLO
PROC. IAEA CONF. NUCLEAR DATA FOR REACTORS(HELSINKI,1970)VOL.2,P.265
RELATIVE ERROR GIVEN. TOTAL SYSTEMATIC UNCERTAINTY IS 10.0%
CAPTURE CROSS SECTION AU197

ENERGY(KEV)	SIG NG	PERCENTAGE ERROR
104.7000	0.3230	7.0000
113.3000	0.3300	7.0000
123.0000	0.3110	6.0000
133.8000	0.3350	6.0000
146.3000	0.2950	6.0000
160.6000	0.2790	5.0000
176.9000	0.2780	5.0000
196.1000	0.2610	5.0000
218.5000	0.2670	5.0000
245.1000	0.2550	4.0000
276.5000	0.2440	4.0000
314.7000	0.2120	4.0000
361.3999	0.1810	4.0000
418.7998	0.1730	4.0000
491.7000	0.1590	4.0000
585.2000	0.1280	4.0000
708.5000	0.1060	4.0000
835.5000	0.0910	5.0000
1107.5000	0.0820	10.0000

S.J.BAME AND R.L.CUBITT
PHYS. REV. 113(1959)256

RATIO AU197(N,GAMMA)/U235(N,F)

ENERGY(KEV)	RATIO
180.0000	0.1990

B.C.DIVEN ,J.TERREL AND A.HEMMENDINGER
PHYS. REV. 120(1960)556

RATIO AU197(N,GAMMA)/U235(N,F)

ENERGY(KEV)	RATIO
175.0000	0.2100
250.0000	0.1880
400.0000	0.1570
600.0000	0.1140
800.0000	0.0940
900.0000	0.0810
1000.0000	0.0800

J.A.MISKEL,K.V.MARSH,M.LINDNER AND R.J.NAGLE
PHYS. REV. 128(1962)2717

RATIO AU197(N,GAMMA)/U235(N,F)

ENERGY(KEV)	RATIO
32.0000	0.3560
42.0000	0.3400
59.0000	0.3769
69.0000	0.2990
84.0000	0.2690
112.0000	0.2250
118.0000	0.2320
176.0000	0.2407
240.0000	0.2430
247.0000	0.2548
255.0000	0.1910
430.0000	0.1630
580.0000	0.1480
710.0000	0.0949
790.0000	0.1270
850.0000	0.0769
870.0000	0.1030
990.0000	0.1020
1000.0000	0.0857
1610.0000	0.0720
1790.0000	0.0595
2000.0000	0.0480
2720.0000	0.0267
3000.0000	0.0239
3650.0000	0.0175
3970.0000	0.0164

J.F.BARRY
J. NUCL. ENER. 18(1964)491

RATIO AU197(N,GAMMA)/U235(N,F)

ENERGY(MEV)	RATIO
0.1270	0.2080
0.1620	0.2100
0.2090	0.2100
0.3140	0.1780
0.4060	0.1500
0.5070	0.1370
0.6000	0.1090
0.7460	0.0950
1.0140	0.0810
1.3080	0.0720
1.7890	0.0570

H.A.GRENCH,K.L.COOP,H.O.MENLOVE AND F.J.VAUGHN
WASH 1068 (1966)

RATIO AU197(N,GAMMA)/U235(N,F)

ENERGY(KEV)	RATIO
143.0000	0.2210
223.0000	0.2050
318.0000	0.1820
426.0000	0.1430
525.0000	0.1230
609.0000	0.1040
724.0000	0.0930
824.0000	0.0860
926.0000	0.0770
1027.0000	0.0658
1085.0000	0.0666
1223.0000	0.0629

APPENDIX 2

This section lists the experiments we have rejected together with our reasons. While every attempt has been made to investigate the reliability of all published data between about 1955 and October 1971, there may be work which we have overlooked. However, we believe that we have considered all the significant measurements.

Table 2(1)

Rejected measurements of the U-238(n,γ) cross-section

Authors	Reason for Rejection
A.I. Leipunsky, O.D. Kazochkovsky, G.Y. Artyukhov, A.I. Baryshnikov, T.S. Belanova, V.N. Galkov, Yu. Ya Stavisskii, E.A. Stumbur and L.E. Sherman Proc. 2nd Geneva Conf. PUAE (1958) Vol.15, p.50	Discrepant and not well documented
E. Broda and D.H. Wilkinson Report BR-574 Reported by B. Rose, AERE-NP/R-1743 (1955)	Old measurement, techniques not considered reliable
R.L. Macklin, N.H. Lazar and W.S. Lyon Phys. Rev. 107 (1957) 504	Thick sample used. Energy spectrum of Sb-Be source uncertain. Measurements made relative to Iodine
W.S. Lyon and R.L. Macklin Phys. Rev. 114 (1959) 1619	Thick sample, uncertain neutron spectrum relative to Indium. Large error
E.G. Bilpuch, L.W. Weston and H.W. Newson Ann. Phys. 10 (1960) 455	Disagrees in shape with the later more reliable data
I. Bergquist Arkiv fur Fysik 23 (1963) 425	Measured relative to Ag(n,γ). Rejected because of uncertainty in this cross-section
R.L. Macklin, J.H. Gibbons and P.J. Pasma WASH-1046, p.88 (1963)	Measured relative to Ta(n,γ). Rejected because of uncertainty in this cross-section
H. Miessner and E. Arai Proc. IAEA Conf. Nuclear Data for Reactors (Paris, 1966), Vol.1, p.502	Measurement of effective (resonance shielded) cross-section. Not a measurement of the absolute cross-section at a given energy
Yu. G. Panitkin, V.A. Tolstikov and Yu. Ya Stavisskii Proc. IAEA Conf. Nuclear Data for Reactors (Helsinki, 1970) Vol.2, p.57	Not considered reliable because measured relative to U-235(n,f) and normalised in a region of large structure
Yu. Ya Stavisskii, V.A. Tolstikov, V.B. Chelnokov, A.A. Bergman and A.E. Samsonov Proc. IAEA Conf. Nuclear Data for Reactors (Helsinki, 1970) Vol.2, p.51	Not corrected for self-screening. Measurements with lead slowing down spectrometer not considered to give high accuracy data
B.C. Diven, J. Terrell and H.A. Hemmendinger Phys. Rev. 120 (1960) 556	Data discrepant. Data rejected because of uncertainty in detector efficiency for active sample. Measurement of Au-197(n,γ) accepted
R.J. Nagle, J.H. Landrum and M. Lindner Proc. Knoxville Conf. on Neutron Cross-sections and Technology, Vol.1, p.259 (1971)	Only preliminary data available

Table 2(2)

Rejected measurements of the fission cross-sections of U-235, Pu-239, U-238 and their ratios

Quantity Measured	Reference	Reason for Rejection
Pu-239(n,f), U-235(n,f), U-238(n,f) and ratios	D.L. Allan and M.J. Poole Report AERE N/R 957 (1952)	Early measurement of low accuracy. No scattering correction
Pu-239(n,f)/U-238(n,f), Pu-239(n,f)/U-235(n,f), Pu-239(n,f), U-235(n,f)	D. Szteinsznaider, V. Naggiar and F. Netter Proc. 1st Geneva Conf. (1955) Vol.4, p.245	Ratio values and cross-sections very much different from the later measurements
U-235(n,f)	M.L. Yeater, W.R. Mills and E.R. Gaerttner Phys. Rev. 104 (1956) 479	Poor resolution in energy region of interest
U-235(n,f)	M.L. Yeater, P.L. Kelley and E.R. Gaerttner Report KAPL-1109 (1954)	Poor resolution. Not considered reliable
U-235(n,f)	R.L. Henkel Reports LA-2114 (1957) and LA-2122 (1957)	Data revised several times and documentation insufficient
U-235(n,f),Pu-239(n,f)	G.A. Dorofeev and Y.P. Dobrynin J. Nucl. Energy 5 (1957) 217	Used neutron sources with energies between 22 keV and ~ 5 MeV. Rejected because source spectra uncertain
U-235(n,f), Pu-239(n,f), U-238(n,f)	W.D. Allen and A.T.G. Ferguson Proc. Phys. Soc. 70A (1957) 573	Rejected the relative absolute cross-sections because results possibly sensitive to fission fragment ang. dist. (see Ref. 3)
Pu-239(n,f)	F. Netter, J. Julien, C. Corge and R. Ballini Le Journal de Physique et le Radium 17 (1956) 565	Inaccurate. Relative to long counter with doubtful efficiency characteristics
U-235(n,f)	E. Melkonian, V. Perez-Mendez, M.L. Melkonian, W.W. Havens, Jr., and L.J. Rainwater Nucl. Sci. Eng. 3 (1958) 435	Poor resolution. Not considered reliable at energies considered in this evaluation
U-235(n,f), Pu-239(n,f)	G.N. Smirenkin, V.G. Nesterov and I.I. Bondarenko Sov. J. At. Ener. 13 (1963) 366	Measurement designed to look for structure in cross-sections corresponding to changes in angular distribution and not as an absolute cross-section measurement
Pu-239(n,f)	S.M. Dubrovina and V.A. Shigin Sov. Phys. Doklady 9 (1965) 579	Insufficient documentation. Poor agreement with later more accurate measurements
Pu-239(n,f)	B.H. Patrick, M.G. Schomberg, M.G. Sowerby and J.E. Jolly Proc. IAEA Conf. Nuclear Data for Reactors (Paris, 1966) Vol.2, p.117	Some doubts about scattering correction applied. Correction in process of being re-examined
Pu-239(n,f)/U-235(n,f)	D.M. Barton and P.G. Koontz Phys. Rev. 162 (1967) 1070	14.9 MeV point rejected for 14 MeV evaluation as energy dependence of ratio not well known and error relatively large
U-235(n,f)	M.G. Cao, E. Migneco, J.P. Theobald, J.A. Wartena and J. Winter J. Nucl. Energy 22 (1968) 211	Data cover a relatively small energy range only. Uncertainties due to presence of permanent molybdenum filter in beam
U-235(n,f)/U-238(n,f) Pu-239(n,f)/U-238(n,f)	R.H. Iyer and R. Sampathkumar Proc. Symp. (Roorkee) Vol.2, p.289 (1969) and Report BARC-474	Low accuracy (15%). No scattering corrections
Pu-239(n,f)/U-235(n,f)	W.K. Lehto Nucl. Sci. Eng. 39 (1970) 361	Lead slowing down spectrometer. Poor resolution. Given zero weight in evaluation though plotted in Fig. 2. Not considered to be a good technique for obtaining accurate data
U-235(n,f)	E.G. Silver, G. de Saussure, R.B. Perez and R.W. Ingle Proc. Conf. Neut. Cross-sections and Tech. (Knoxville, 1971) Vol.2, p.728	Data still preliminary
U-235(n,f), Pu-239(n,f) and ratio	A.E. Samsonov, Yu. Ya Stavisskii, V.A. Tolstikov and V.B. Chelnokov Atomnaya Energiya 31 (1971) 103	Lead slowing down spectrometer. Poor resolution. Not considered to be a good technique for obtaining accurate data
U-238(n,f)/U-235(n,f)	A. Phillips, L. Rosen and R.F. Taschek Report LAMS-774 (1948)	Early low accuracy value. Over two standard deviations from evaluated ratio
U-238(n,f)	W. Nyer Report LA-719 (1948)	No error quoted
U-238(n,f)	M. Mangialajo, F. Merzari and P.G. Sona Nucl. Phys. 43 (1963) 124	Not considered a reliable measurement of the absolute cross-section
U-238(n,f)	Lieu-Sheng Chuang Nucl. Sci. Taiwan 3 (1964) 1	Not seen
U-238(n,f)	V. Emma, S. Lo Nigro, C. Milone and R.Ricamo Nucl. Phys. 63 (1965) 641	Thick samples used with no correction for scattering effects
U-238(n,f)	J. Turkiewicz Reports INR-83 /I/PL (1967) and INR-970 (1969)	Low accuracy
U-238(n,f)	M.G. Silbert and D.W. Bergen Phys. Rev. C, 4 (1971) 220	Subthreshold fission. Cross-section too low to warrant inclusion

APPENDIX 3

The cross-sections given in the Tables 3(1), 3(2), 3(3) and 3(4) were used in making the following data files U-235 (DFN 271D), Pu-239 (DFN 269D) and U-238 (DFN 272A). The cross-sections have been discussed in an earlier note (AERE - M 2497) and in the tables the values that are different to those recommended in the main body of this report are marked with an asterisk. It should be noted that the actual data files contain more energy points than listed here. The extra points were obtained from smooth curves drawn through the evaluated data.

Table 3(1)

Originally evaluated average U-235 fission cross-sections below 100 keV

Energy Range (keV)	$\langle\sigma_{nf}\rangle$ (barns)	Energy Range (keV)	$\langle\sigma_{nf}\rangle$ (barns)	Energy Range (keV)	$\langle\sigma_{nf}\rangle$ (barns)
0.1-0.2	21.31	30-31	2.117	68-69	1.795
0.2-0.3	20.79	31-32	2.155	69-70	1.817
0.3-0.4	13.46	32-33	2.026	70-71	1.798
0.4-0.5	13.75	33-34	2.023	71-72	1.773
0.5-0.6	15.14	34-35	1.968	72-73	1.720
0.6-0.7	11.63	35-36	1.963	73-74	1.686
0.7-0.8	11.15	36-37	1.969	74-75	1.743
0.8-0.9	8.399	37-38	1.959	75-76	1.778
0.9-1.0	7.762	38-39	1.948	76-77	1.774
1-2	7.455	39-40	1.979	77-78	1.605
2-3	5.486	40-41	2.110	78-79	1.580
3-4	4.866	41-42	1.932	79-80	1.684
4-5	4.391	42-43	1.949	80-81	1.730
5-6	3.943	43-44	1.896	81-82	1.725
6-7	3.477	44-45	1.859	82-83	1.712
7-8	3.373	45-46	1.820	83-84	1.707
8-9	3.071	46-47	1.868	84-85	1.728
9-10	3.165	47-48	1.854	85-86	1.657
10-11	2.868	48-49	1.899	86-87	1.590
11-12	2.785	49-50	1.897	87-88	1.603
12-13	2.565	50-51	1.876	88-89	1.692
13-14	2.748	51-52	1.895	89-90	1.666
14-15	2.573	52-53	1.911	90-91	1.644
15-16	2.393	53-54	1.890	91-92	1.614
16-17	2.376	54-55	1.837	92-93	1.612
17-18	2.333	55-56	1.848	93-94	1.621
18-19	2.507	56-57	1.851	94-95	1.566
19-20	2.349	57-58	1.881	95-96	1.704
20-21	2.111	58-59	1.799	96-97	1.643
21-22	2.166	59-60	1.926	97-98	1.601
22-23	2.336	60-61	1.876	98-99	1.628
23-24	2.080	61-62	1.858	99-100	1.689
24-25	2.195	62-63	1.843		
25-26	2.111	63-64	1.720		
26-27	2.091	64-65	1.766		
27-28	2.105	65-66	1.825		
28-29	2.204	66-67	1.801		
29-30	2.084	67-68	1.787		

Table 3(2)

Originally evaluated Pu-239 average fission cross-sections below 100 keV

Energy Range (keV)	$\langle\sigma_{nf}\rangle$ (barns)	Energy Range (keV)	$\langle\sigma_{nf}\rangle$ (barns)
0.1-0.2	19.04 *	10-15	1.80*
0.2-0.3	18.07 *	15-20	1.68*
0.3-0.4	8.862*	20-25	1.60*
0.4-0.5	9.474*	25-30	1.57*
0.5-0.6	15.38 *	30-35	1.63
0.6-0.7	4.559*	35-40	1.57
0.7-0.8	5.628*	40-45	1.61
0.8-0.9	4.945*	45-50	1.56
0.9-1.0	7.914*	50-55	1.63
1-2	4.253*	55-60	1.63
2-3	3.189*	60-65	1.63
3-4	2.910*	65-70	1.62
4-5	2.300*	70-75	1.63
5-6	2.135*	75-80	1.59
6-7	1.946*	80-85	1.63
7-8	2.076*	85-90	1.55
8-9	2.223*	90-95	1.56
9-10	1.852*	95-100	1.60

Table 3(3)

Originally evaluated U-238 average capture cross-sections from 1 to 100 keV

Energy Interval (keV)	Evaluated $\sigma_{n\gamma}$ (barns)
1 - 2	2.020*
2 - 3	1.534*
3 - 4	1.279*
4 - 5	1.000*
5 - 6	0.979*
6 - 7	0.880*
7 - 8	0.832*
8 - 9	0.755*
9 - 10	0.754*
10 - 20	0.616*
20 - 30	0.491*
30 - 40	0.436*
40 - 50	0.374*
50 - 60	0.321*
60 - 70	0.275*
70 - 80	0.233*
80 - 90	0.220*
90 - 100	0.208*

Table 3(4)

Originally evaluated cross-sections above 100 keV

Energy (MeV)	U-235(n,f) (barns)	Pu-239(n,f) (barns)	U-238(n,f) (barns)	U-238(n,γ) (barns)
0.100	1.599*	1.540*		0.201*
0.130	1.531*	1.501*		0.179*
0.170	1.433*	1.462*		0.160*
0.200	1.371*	1.444*		0.151*
0.250	1.304*	1.438*		0.139*
0.300	1.268*	1.463*		0.131*
0.350	1.236*	1.488*		0.125*
0.400	1.204*	1.494*		0.122*
0.500	1.137*	1.508*		0.122
0.600	1.111*	1.536*	0.0010	0.133
0.700	1.139*	1.619*	0.0008	0.145*
0.800	1.164*	1.675*	0.0026	0.149*
0.900	1.207*	1.686	0.0082	0.149*
0.950	1.224*	1.690*	0.0122	0.147*
1.000	1.242*	1.691*	0.0122*	0.145*
1.20	1.276*	1.824*	0.0395*	0.133*
1.40	1.281*	1.848*	0.129	0.103*
1.60	1.318*	1.999*	0.372	0.0817*
1.80	1.356	2.061	0.487	0.0705
2.00	1.319	2.016	0.522	0.0581
2.20	1.286	1.968	0.525	0.0489
2.40	1.246	1.910	0.515	0.0411
2.60	1.214	1.870	0.507	0.0352
2.80	1.193	1.848	0.503	0.0298
3.00	1.174	1.830	0.502	0.0258
3.5	1.127	1.799	0.506	0.0195
4.0	1.093	1.754	0.512	0.0151
4.5	1.066	1.714	0.513	0.0119
5.0	1.047	1.679	0.514	0.0097
5.5	1.037	1.684	0.540	0.0083
6.0	1.115	1.806	0.613	0.0072
6.5	1.273	1.917	0.753	0.0067
7.0	1.465	2.015	0.874	0.0064
8.0	1.674	2.213	0.956	0.0059
9.0	1.748	2.252*	0.957	0.0054
10.0	1.753	2.288*	0.952	0.0049
11.0	1.725	2.344*	0.954	0.0045
12.0	1.725*	2.415*	0.966	0.0041
13.0	2.000*	2.477*	1.008	0.0038
14.0	2.138*	2.520*	1.130*	0.0034
15.0	2.187*	2.541*	1.245*	0.0031
16.0	2.224*	2.498*	1.294*	0.0029
17.0	2.189*	2.484*	1.346*	0.0026
18.0	2.121*	2.358*	1.330*	0.0024
19.0	2.120*	2.273*	1.332*	0.0022
20.0	2.100*	2.389*	1.450*	0.0020