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The Determination of Errors in Evaluated Data Using Correlations and the Evaluation of σ_f(U235), α(U235), α(Pu239) and σ_f(Pu239) for the Evaluated Data Library BOYaD-3

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ABSTRACT

A method of estimating values and the errors in them using correlations between the partial errors in different experimental findings has been developed. The method proposed is used for estimating values of $\sigma_f(^{235}U)$, $\alpha(^{235}U)$ and $\alpha(^{239}Pu)$ needed for drawing up a library of evaluated nuclear data.

13 tables, 95 references.

V.A. Kon'shin, E.Sh. Sukhovitskij and V.F. Zharkov

THE DETERMINATION OF ERRORS IN EVALUATED DATA USING CORRELATIONS AND THE EVALUATION OF $\sigma_f(^{235}U)$, $\alpha(^{235}U)$, $\alpha(^{239}Pu)$ AND $\sigma_f(^{239}Pu)$ FOR THE EVALUATED NUCLEAR DATA LIBRARY BOYaD-3

(Preprint)

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1. THE USE OF CORRELATIONS FOR DETERMINING THE ERRORS IN EVALUATED DATA

When obtaining evaluated nuclear data it is important not only to find the actual data, but also to have an idea of the true extent of the errors in them. This information can be used to evaluate the errors in calculated reactor functionals and - which is just as important - to render differential data more accurate using integral experiments.

However, the determination of errors in evaluated data and the individual determination of the weights given to the experimental data points used in evaluation have been given less attention than almost any other topic.

If different measured values for σ_i are obtained with different degrees of accuracy (characterized by the mean-square error $\Delta\sigma_i$), the following mean-weighted one will be the most probable value:

$$\bar{\sigma} = \frac{\sum_i \frac{\sigma_i}{\Delta\sigma_i^2}}{\sum_i \frac{1}{\Delta\sigma_i^2}}$$

However, the use of weights which are the inverse squares of the errors in experimental data is valid only when there are no correlations between errors. In practice the errors in experimental data often correlate strongly as a result of using the same measuring methods. Clearly, the actual errors in evaluated data can be found only if there is detailed information about the correlation characteristics of the errors in the different experimental findings used for the evaluation. The method developed below is based on the use of such information and of the general methods of mathematical statistics [1].

Let there be N measurements of σ_o (the true value of the quantity being measured is unknown to us) which are equal to σ_i (i = I .... N). Each individual measurement of σ_i is a functional of a certain set of actually measured values f_{ik} (k = I, ... M) with an error Δf_{ik}, where M is the total number of parameters necessary for obtaining the value of σ_i.

Thus, if we limit ourselves to the linear approximation, we obtain

$$\sigma_i = \sigma_o + \sum_{k=1}^{M} \frac{\partial\sigma_i}{\partial f_{ik}} \Delta f_{ik} \qquad (1.1)$$

The value $\frac{\partial\sigma_i}{\partial\gamma_{ik}}\Delta\gamma_{ik}$ is part of the error in the i-th experimental result due to the uncertainty with which the k-th measured parameter (below shown as $\Delta\sigma_{ik}$) is known.

Now let the estimated value be obtained by averaging the experimental values which are given the weights a_i^2 such that $\sum_{i=1}^{N} a_i^2 = 1$.

Thus,
$$\sigma_{est} = \sum_{i=1}^{N}\sigma_i a_i^2 \tag{1.2}$$

Summing up Eq. (1.1) with respect to i, we obtain
$$\sum_{i=1}^{N}\sigma_i a_i^2 = \sum_{i=1}^{N}\sigma_o a_i^2 + \sum_{i=1}^{N}\sum_{k=1}^{M}\Delta\sigma_{ik}a_i^2 \quad . \tag{1.3}$$

Thus,
$$\begin{aligned}\overline{|\sigma_{est}-\sigma_o|^2} &= \overline{\left|\sum_{i=1}^{N}\sum_{k=1}^{M}\Delta\sigma_{ik}a_i^2\right|^2} = \sum_{i=1}^{N}\sum_{k=1}^{M}\sum_{j=1}^{N}\sum_{m=1}^{M}a_i^2a_j^2\overline{\Delta\sigma_{ik}\Delta\sigma_{jm}} \\ &= \sum_{i=1}^{N}\sum_{k=1}^{M}\sum_{j=1}^{N}\sum_{m=1}^{M}a_i^2a_j^2K_{ikjm}\sqrt{\overline{|\Delta\sigma_{ik}|^2}}\cdot\sqrt{\overline{|\Delta\sigma_{jm}|^2}} \quad ,\end{aligned} \tag{1.4}$$

where K_{ikjm} is the correlation coefficient determined by the ratio
$$K_{ikjm} = \frac{\overline{\Delta\sigma_{ik}\cdot\Delta\sigma_{jm}}}{\sqrt{\overline{|\Delta\sigma_{ik}|^2}}\sqrt{\overline{|\Delta\sigma_{jm}|^2}}} \tag{1.5}$$

Equation (1.4) gives the error in the estimated value through the mean-square deviation of the partial errors in measurements of $\sqrt{\overline{|\Delta\sigma_{ik}|^2}}$ the coefficient of correlation between these partial errors K_{ikjm} and the weights a_i^2 used for the evaluation.

It would appear to be natural to use the dispersion in the estimate as a criterion of its applicability, i.e. to require that the estimated value should have a minimum dispersion limit. It has been found [2] that with sufficiently general conditions there is a lower limit to the dispersion in estimates. For this it is necessary merely that the function should be doubly differentiated with respect to the unknown distribution parameter.

Let us show that, in the case of complete absence of correlation, this method is equivalent to the least-squares method with weights in inverse proportion to the square of the error.

In this case $K_{ikjm} = \delta_{ikjm}$, where δ_{ikjm} is Kronecker's four-dimensional symbol, and Eq. (1.4) takes the form

$$\overline{|\sigma_{est} - \sigma_0|^2} = \sum_{i=1}^{N} a_i^4 \sum_{k=1}^{N} \overline{|\Delta\sigma_{ik}|^2}$$

and $\sum_{k=1}^{N} \overline{|\Delta\sigma_{ik}|^2} = \overline{|\Delta\sigma_i|^2}$ is the mean-square error in the i-th measurement. Thus,

$$\overline{|\sigma_{est} - \sigma_0|^2} = \sum_{i=1}^{N} a_i^4 \, \overline{|\Delta\sigma_i|^2} \tag{1.6}$$

The values of a_i^2 minimizing $\overline{|\sigma_{est} - \sigma_0|^2}$, can be found from the condition

$$\left\{ \begin{aligned} & \frac{\partial\left(\overline{|\sigma_{est} - \sigma_0|^2}\right)}{\partial a_n^2} = 0 \,, \quad n \neq 1 \\ & \sum_{i=1}^{N} a_i^2 = 1 \,. \end{aligned} \right. \tag{1.7}$$

Let us transform Eq. (1.6), taking the first experiment, as follows:

$$\overline{|\sigma_{est} - \sigma_0|^2} = \sum_{i \neq 1} a_i^4 \, \overline{|\Delta\sigma_i|^2} + a_1^4 \, \overline{|\Delta\sigma_1|^2}$$

and substitute

$$a_1^2 = 1 - \sum_{i \neq 1} a_i^2$$

Thus

$$\begin{aligned} \overline{|\sigma_{est} - \sigma_0|^2} = & \sum_{i \neq 1} a_i^4 \, \overline{|\Delta\sigma_i|^2} + \sum_{i \neq 1} \sum_{m \neq 1} a_i^2 a_m^2 \, \overline{|\Delta\sigma_1|^2} - \\ & - 2 \sum_{i \neq 1} a_i^2 \, \overline{|\Delta\sigma_1|^2} + \overline{|\Delta\sigma_1|^2} \,. \end{aligned} \tag{1.8}$$

Differentiating Eq. (1.8) in terms of a_n^2, n = I, ... N ($n \neq 1$), we obtain (N - I) equations of the type

$$\frac{\partial \overline{|\sigma_{est} - \sigma_o|^2}}{\partial a^2_{n(n\neq 1)}} = 2a_n^2 \overline{|\Delta\sigma_n|^2} - 2\overline{|\Delta\sigma_1|^2} + 2\sum_{i\neq 1} a_i^2 \overline{|\Delta\sigma_1|^2} = 0$$

or

$$a_n^2 \overline{|\Delta\sigma_n|^2} = (1 - \sum_{i\neq 1} a_i^2)\overline{|\Delta\sigma_1|^2} \quad ,$$

from which, using $1 - \sum_{i\neq 1} a_i^2 = a_1^2$, we obtain

$$a_n^2 \overline{|\Delta\sigma_n|^2} = a_1^2 \overline{|\Delta\sigma_1|^2} \quad , \text{ i.e. } \quad \frac{a_n^2}{a_1^2} = \frac{\overline{|\Delta\sigma_1|^2}}{\overline{|\Delta\sigma_n|^2}}$$

Thus, where there are no correlations between errors in experimental values, the weights are in inverse proportion to the squares of the errors.

We shall assume that it is possible to divide up the total error into such small partial error components that $K_{ikjm} = 0$ for $k \neq m$. This assumption means that the errors in any two different parameters needed for finding the cross-section do not correlate with each other. Using the notation $K_{kij} = K_{ikjk}$ we can rewrite Eq. (1.4) in the form

$$\overline{|\sigma_{est} - \sigma_o|^2} = \sum_{i=1}^{N}\sum_{k=1}^{M}\sum_{j=1}^{N} a_i^2 a_j^2 K_{kij} \sqrt{\overline{|\Delta\sigma_{ik}|^2}} \cdot \sqrt{\overline{|\Delta\sigma_{jk}|^2}} \qquad (1.9)$$

When there are correlations, the system (1.7) becomes a system of (N-I) linear equations:

$$\frac{\partial \overline{|\sigma_{est} - \sigma_o|^2}}{\partial a^2_{n(n\neq 1)}} = 2\sum_{k=1}^{M}\sum_{i\neq 1}^{N} a_i^2 \Big(K_{kin}\sqrt{\overline{|\Delta\sigma_{ik}|^2}} \cdot \sqrt{\overline{|\Delta\sigma_{nk}|^2}} - K_{ki1}\sqrt{\overline{|\Delta\sigma_{ik}|^2}}$$

$$\times \sqrt{\overline{|\Delta\sigma_{1k}|^2}} - K_{k1n}\sqrt{\overline{|\Delta\sigma_{1k}|^2}} \cdot \sqrt{\overline{|\Delta\sigma_{nk}|^2}} - K_{k11}\sqrt{\overline{|\Delta\sigma_{1k}|^2}} \cdot \sqrt{\overline{|\Delta\sigma_{1k}|^2}} \Big) +$$

$$+ \sum_{k=1}^{M} \Big(K_{kn1}\sqrt{\overline{|\Delta\sigma_{nk}|^2}} \cdot \sqrt{\overline{|\Delta\sigma_{1k}|^2}} - K_{k11}\sqrt{\overline{|\Delta\sigma_{1k}|^2}} \cdot \sqrt{\overline{|\Delta\sigma_{1k}|^2}} \Big) = 0 \; .$$

Equation (1.9) gives the error in the estimated value for a single point on the curve. Let us determine the correlation coefficient for errors in any two evaluated points n and m as

$$B_{nm} = \frac{\overline{\Delta\sigma_n \cdot \Delta\sigma_m}}{\sqrt{\overline{|\Delta\sigma_n|^2}} \cdot \sqrt{\overline{|\Delta\sigma_m|^2}}} \quad , \qquad (1.10)$$

where the subscripts n and m denote the numbers of the points for which the correlation coefficient is calculated, while $\Delta\sigma_n$ and $\Delta\sigma_m$ are the errors in the estimated values at these points. They are determined as

$$\Delta\sigma_n = \sum_{i=1}^{N} \sum_{k=1}^{M} \Delta\sigma_{ikn} a_{in}^2 \qquad \text{and} \qquad \Delta\sigma_m = \sum_{j=1}^{N} \sum_{k=1}^{M} \Delta\sigma_{jkm} a_{jm}^2 \ ,$$

where a_{jm}^2 is the weight of the j-th experimental result when used in the evaluation at the point m and $\Delta\sigma_{jkm}$ is the k-th partial error in the j-th experiment at the point m.

If the correlation coefficient is determined as

$$K_{kinjm} = \frac{\overline{\Delta\sigma_{jkm} \cdot \Delta\sigma_{ikn}}}{\sqrt{\overline{|\Delta\sigma_{ikn}|^2}} \cdot \sqrt{\overline{|\Delta\sigma_{jkm}|^2}}}$$

and, as before it is assumed that errors of the same type correlate and that the partial errors in the same experimental findings are independent, the coefficients of correlation between the points on the cross-section energy dependence curve will be determined by the expression

$$B_{nm} = \frac{\sum_{k=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{N} a_{in}^2 a_{jm}^2 K_{kinjm} \sqrt{\overline{|\Delta\sigma_{ikn}|^2}} \cdot \sqrt{\overline{|\Delta\sigma_{jkm}|^2}}}{\sqrt{\overline{|\Delta\sigma_n|^2}} \cdot \sqrt{\overline{|\Delta\sigma_m|^2}}} \ . \qquad (1.11)$$

Thus, the coefficient of correlation between the errors in two evaluated points is expressed in terms of the partial errors in the experimental findings used in the evaluations, the weights which these findings were given in the evaluation and the correlation coefficients of partial errors at these points.

In the calculations the correlation coefficient K_{kinjm} was taken to be independent of n and m, i.e. $K_{kinjm} = K_{kji}$. In fact, if the correlation coefficient for partial errors depends on the point (e.g if a parameter for determining the cross-section is measured differently at different points), in formal terms the different results can be considered different references and the difference between the correlation coefficients for different points can be considered a difference between references.

The algorithm described above was incorporated into a computer program which, on the basis of partial errors and the correlations between them, uses the iteration method to determine the weights of experimental data, which minimize the error in an estimated value, the errors in estimated values at different points and the coefficients of correlation between them.

This method was used for evaluating the fission cross-section $\sigma_f(^{235}U)$ in the energy region 0.1 keV-20 MeV, $\alpha(^{235}U)$ in the region 0.1-1000 keV, $\alpha(^{239}Pu)$ in the region 0.1-1000 keV, and $\sigma_f(^{239}Pu)$ in the region 0.1 keV-10 MeV. Using this method, matrices of the coefficients of correlation between the errors in the group-averaged constants for $\sigma_f(^{235}U)$, $\sigma_f(^{239}Pu)$, $\alpha(^{235}U)$ and $\alpha(^{239}Pu)$ were also derived.

2. EVALUATION OF THE FISSION CROSS-SECTION $\sigma_f(^{235}U)$ IN THE ENERGY REGION 0.1 keV-20 MeV BY THE METHOD BASED ON CORRELATIONS BETWEEN THE ERRORS IN DIFFERENT EXPERIMENTAL FINDINGS

Recently, a number of experimental measurements of the fission cross-section $\sigma_f(^{235}U)$ have been published [3-5, 6, 7-13] which differ from those known previously in that the experiments are organized in a more up-to-date fashion and the experimental errors are lower. On the whole these new data give lower values of $\sigma_f(^{235}U)$ than previous data. It has thus become necessary to make a new evaluation of $\sigma_f(^{235}U)$ in which new results are used together with those published earlier. When performing such an evaluation special attention should be paid, in addition to the estimate of σ_f, to the error in the estimate. This is because the errors in many experimental findings correlate fairly strongly since similar methods of measurement and standards are used. A method of evaluation enabling a detailed analysis of the correlations between errors in the experimental findings to be performed has been put forward in this paper and is described in the previous section.

An evaluation of $\sigma_f(^{235}U)$ was made in two energy regions: between 100 eV and 100 keV, where the experimental cross-section data have a distinct structure, and between 100 keV and 20 MeV, where the fission cross-section can be represented by a smooth curve.

The experimental data obtained in the thermal energy region should be renormalized in a consistent fashion. Errors due to a shift in the energy scale and a difference in the energy resolution can be reduced to a minimum by normalization over a wide energy range. The energy range chosen was that of 100 eV-1 keV.

An evaluation of $\sigma_f(^{235}U)$ in the energy region below 1 eV was made recently by Leonard [14], who obtained σ_f = 583.54 $\pm$ 1.7 barn at 0.0253 eV. This agrees with the value obtained by Lemmel [15]: σ_f = 583.5 $\pm$ 1.3 barn at 0.0253 eV.

Deruytter and Wagemans [16] proposed that the fission integral between 7.8 and 11 eV obtained by them should be used for renormalization of experimental data. An analysis of these data performed by Leonard [14] showed that there was a certain systematic deviation in the data of Ref. [16] from the evaluated curve, which may be due to a variation in the analyser channel width in this region. Thus, normalization to these data alone may be inappropriate. Fortunately, other measurements have been performed in the thermal energy region - those obtained by Czirr and Sidhu [6], Gwin et al. [3], de Saussure et al. [17], Bowman et al. [18], Shore and Sailor [19], Michaudon et al. [20], and Van Shi-Di et al. [21]. After renormalization of these data on σ_f = 583.5 barn at 0.0253 eV, the fission integral from 7.8 to 11 eV was calculated. The evaluated fission integral from 7.8 to 11 eV given by Leonard [14] is 241.24 $\pm$ 6.75 barn · eV, which was obtained as a mean-weighted value from the data of Deruytter and Wagemans [16], Czirr and Sidhu [6], Gwin et al. [3] and de Saussure et al. [17]. The data of Bowman et al. [18] were used with the weight reduced by a factor of three because of the considerable discrepancy with other data; the data of Shore and Sailor were not used because they were obtained only in the region up to 10 eV, and the data of Michaudon et al. [20] and Van Shi-Di et al. [21] were not used because of the considerable differences in the shape of the curves and a systematic difference in the thermal region. A fission integral from 7.8 to 11 eV of 241.24 barn · eV was used by us for renormalizing data extending into the thermal region [17, 6, 3, 7, 22].

In the energy region 0.1-1.0 keV there are five series of experimental data which can be considered as being absolute data [17, 6, 3, 7, 22]. After correction of these data for the up-to-date value of the $^{10}B(n,\alpha)$ and $^{6}Li(n,\alpha)$ reaction cross-sections using the data of Ref. [23] and their renormalization in the region 7.8-11 eV, a mean-weighted value for the fission integral in the region 0.1-1.0 keV of 11 864 barn · eV was obtained. The absolute data of Refs [24] and [25] need to be corrected for the angular distribution of alpha particles from the $^{6}Li(n,\alpha)$ reaction, which is in any case small at these energies. The data of Refs [24] and [25], when used to find the mean-weighted fission integral between 0.1 and 1.0 keV, yielded a value of 11 883 $\pm$ 446 barn · eV. When the error in renormalization in the eV region is taken into account, the uncertainty in the latest experimental data [6, 7, 22] is approximately 3.8%. The relative experimental data of Refs [20, 26, 27, 28, 21, 29, 5] were renormalized to the integral 11 883 barn · eV in the region 0.1-1.0 keV. The relative data of Refs [30, 4, 31] were renormalized in the region 10-30 keV to the mean fission integral in this region, equal to 45 580 $\pm$ 2280 barn · eV, which was obtained from the absolute data of Gwin et al. [3] and Czirr et al. [6].

In the energy range 10-100 keV the time-of-flight data of Gwin et al. [3] and Czirr et al. [6] and the measurements at individual points of Refs [32-34] agree on the whole to within $\pm 3\%$, while in the region 100-200 keV the discrepancy reaches 6% (e.g. in the data of Refs [30] and [8]). In the range 200 keV-1 MeV the bulk of the data [32-37, 8] agree to within $\pm 3\%$, with the exception of the data of Refs [31] and [6]. The data of Czirr et al. [6] lie approximately 10% lower than the data of Refs [35, 32, 8, 34]. A fundamental divergence of the order of $\pm 5\%$ is observed in the region 250-300 keV, where the data recently obtained by Wasson for hydrogen [31] are lower than most other measurements. There is also a discrepancy in the region 500-800 keV as regards both the shape and the absolute values between the data of Käppeler [38] and most other measurements.

In the energy range above 1 MeV the latest data [36, 37, 32, 8, 34, 33] generally agree to within $\pm 3\%$, although in the region 1-1.3 MeV the data of Barton et al. [36] are 4% higher than those of Refs [32, 8, 34], and at 5.4 MeV White's data [33] are approximately 5% lower than those of Barton et al. [36] and Czirr et al. [37]. The reason for this discrepancy may be that White did not correct for the angular distribution of protons from the (n,p) reaction, which may amount to approximately 2%. More particularly, the ratio of the fission cross-section at 14 MeV and 5.4 MeV measured by White contradicts the data obtained in other relative measurements [12] and [37]. Because of this, when performing the evaluation, the error in White's data point at 5.4 MeV was increased by 5%.

In an analysis of data on the total errors in experimental measurements of σ_f the following partial errors were identified:

k = 1 - error in determination of the number of ^{235}U nuclei;

k = 2 - error in extrapolation of the fission fragment spectrum to zero pulse height;

k = 3 - error from fission fragment absorption in the foil;

k = 4 - error from scattering in the chamber walls, foil backing and target structure;

k = 5 - error from neutron attenuation in air;

k = 6 - error in determination of the neutron flux;

k = 7 - error in the experimental background;

k = 8 - error in the efficiency of fission detection;

k = 9 - error in the geometrical factor;

k = 10 - error in the standard (hydrogen cross-section);

k = 11 - statistical error;

k = 12 - error in normalization.

This division of the total error into partial components was performed on the basis of the information on errors provided by authors. Where this information was not available (mainly in older studies), the division was based on analysis of the experimental method in terms of the errors inherent in the given method taken.

Correlations were used in the evaluation of $\sigma_f(^{235}U)$ by analysing the experimental methods involved in the evaluation. The following correlations between experimental findings were found.

k = 1 (determination of the number of ^{235}U nuclei)

In papers by Szabo (measurements in the region 17 keV–1 MeV) [35] and White (in the region 40 keV–14 MeV) [33] the same ^{235}U foil was used. These findings therefore correlate totally. Szabo's findings in Ref. [32] differ from the above in that another foil was added to the one used in the other experiments. Refs [35] and [32] therefore correlate partially. Szabo's findings in Ref. [8] do not in any way differ from Ref. [35] as far as this partial error is concerned and they thus correlate entirely.

For drawing up a table of correlations we use the following rules:

(a) If two sets of findings correlate entirely but separately with a third, they correlate entirely with each other. Consequently, we find that Refs [33] and [8] correlate entirely, which is not in contradiction with the physical consideration of this partial error. Partial correlations between Refs [32] and [33, 32, 8] follow directly from the application of the second rule;

(b) If one set of findings (Ref. [35]) correlates with another (Ref. [32]) partially but with a third totally (Ref. [33]), the second [32] should also correlate partially with the third [33].

The partial correlations between Refs [12] and [33, 10, 11] with K = 0.3 are transferred to this partial error from k = 12 (error in normalization). This is because Ref. [12] was normalized by us to the mean-weighted value from Refs [33, 10, 11], but these findings do not have a partial error in normalization, since they are "absolute". In this case a situation arises in which it is necessary to take account of the correlation between partial errors. However, this approach complicates the problem considerably, especially where an additional correlation is to be made on top of that already used for a given partial error. Clearly, in such cases correlations should not be used additively.

As mentioned above, the model we use for taking correlations into account presupposes that there are no correlations between partial errors, which is true in most cases. In those few instances in which the correlation between partial errors is introduced artificially (as a result of normalization, for example) the correlation can be used in the partial error making the greatest contribution to the total error in the experimental values. This approach does not distort the adopted model and enables fuller use to be made of existing correlations.

<u>k = 2</u> (extrapolation of the fission fragment spectrum to zero pulse height)

It may be assumed that in Refs [35, 33, 8] the error in extrapolation of the fission fragment spectrum to zero pulse height is totally correlated since the same foil material was used. In addition, Ref. [35] correlates with Ref. [32] partially since in Ref. [32], another foil was added to the foil used above. The application of rule (b) requires Ref. [32] to correlate partially with Refs [33] and [8].

<u>k = 3</u> (fission fragment absorption in the foil)

As for k = 2, Refs [35, 38, 3] correlate entirely, while Refs [35] and [32] correlate partially.

<u>k = 4</u> (scattering in the chamber wall, foil backing and target structure)

In the experiments of Szabo [35] and White [33] the same fission chamber was used, and these findings therefore correlate totally. On the basis of the information available we might have assumed that the same chamber had been used in Ref. [8] as in Ref. [33]. Since, however, we know this not to be the case we shall assign to Refs [33] and [8] partial correlation. Thus, Ref. [35] correlates partially with Ref. [8].

k = 5 (neutron attenuation in the air)

No correlations have been found for this partial error.

k = 6 (determination of the neutron flux)

References [21, 26, 20, 29, 3-5] correlate entirely with each other because in all the experiments described in them a chamber with ^{10}B was used for determining the neutron flux. In Ref. [30] the neutron flux was determined by the use of chambers with ^{10}B and ^{6}Li at the same time, hence all the above-mentioned results should correlate partially with Ref. [30].

In another set of experiments [24, 25, 27, 6, 7], ^{6}Li was used for determining the neutron flux, and these findings therefore correlate completely with each other and partially with Ref. [30]. We consider that the set of experiments using ^{10}B does not correlate with the ^{6}Li experiments.

In a third set of experiments [33, 31, 12] the neutron flux was determined in terms of the hydrogen scattering cross-section. All these findings correlate totally with each other. Moreover, in Ref. [35], in addition to the neutron recoil technique, two other methods were used - one using a magnesium tank and the other using associated particles - for determining the neutron flux. For this reason Ref. [35] correlates with Refs [33, 31, 12] partially.

References [32 and 8] are identical for determination of the neutron flux, and consequently correlate entirely. In these experiments two of the three methods of determining the neutron flux (the magnesium tank and associated particle methods) are the same as those used in Ref. [35]. It can therefore be stated that Ref. [35] correlates with Refs [32] and [8] with a coefficient $K_{6,35,32} = K_{6,35,8} = 0.7$.

k = 7 (experimental background)

There are no correlations.

k = 8 (efficiency of fission detection)

No correlations were found.

k = 9 (uncertainty in the geometrical factor)

No correlations were found.

k = 10 (standard (hydrogen cross-section))

In Refs [12, 31, 33, 35-39] the hydrogen cross-section was used as a standard. All these findings correlate entirely with each other.

k = 11 (statistical error)

There are no correlations.

k = 12 (error in normalization)

The findings of Refs [17, 3, 6, 7] were renormalized by us to the fission integral in the energy region 0.1-1 keV and on the thermal point. Errors in normalization in these papers correlate entirely. References [24] and [25] were normalized to the same fission integral from 0.1 to 1 keV and therefore these correlate entirely. The relative measurements [26, 20, 27, 21, 29, 5] were also normalized to the fission integral from 0.1 to 1 keV and consequently correlate entirely. Above 10 keV the data of Ref. [30] were renormalized to the data of Ref. [17] in the region 2-10 keV. In addition, the data of Ref. [17] were normalized to the fission integral in the range 0.1-1 keV. Thus, Ref. [30] correlates entirely with all the findings mentioned above. References [4, 31] were renormalized to the integral between 10 and 30 keV which was obtained from Refs [3, 6]. From this it follows that Refs [4, 31] are also normalized to the integral between 0.1 and 1 keV and to the thermal point. Finally, as a result of our normalization, Refs [3-7, 17, 20, 21, 24-27, 29-31] correlate entirely with each other. In addition, the results of Poenitz [34] correlate entirely with those of Czirr et al. [37] since the latter were normalized to the data of Ref. [34].

As mentioned above (see k = 1), the correlations between Ref. [12] and Refs [33, 10, 11] are transferred to k = 1. This correlation occurs because the data of Ref. [12] were renormalized by us to the mean-weighted value from Refs [10, 11, 33]. The correlation $K_{12,33,12} = K_{12,10,12} = K_{12,11,12} = 0.3$ can also remain in k = 12, since for absolute findings [10, 11, 33] this error in normalization is zero.

Optimized weights calculated by a computer program for instances in which there is no correlation (K = 0), i.e. where the weights are in inverse proportion to the square of the total error in the experimental findings, correlation attributed in accordance with what has been said above (K) and total correlation (K = 1) between partial errors in experimental findings for all energy ranges examined, are shown in Table 2.1. These optimized weights for the different experimental values were obtained by solving the system of equations (1.7).

From Table 2.1 it can be seen that, as a result of the analysis performed on partial errors in experimental findings and their correlations in the region 0.1-1 keV, the weights of the experimental data of de Saussure et al. [17], Czirr et al. [6], Wasson [7] and, to a certain extent (in the range 0.6-1.0 keV), those of Gwin et al. [3], have been increased while the weights of the data of Blons [26], Perez et al. [29] and Michaudon et al. [20] have been reduced since they are relative data which correlate strongly with other data. In the region 1-30 keV the weights of the same data of de Saussure et al. [17], Gwin et al. [3], Wasson [7] and Czirr et al. [6] were increased while those of the data of Refs [20, 26, 29] and of Gayther [4] have been reduced.

In the energy region above 30 keV the weights of time-of-flight measurements, in particular, those of Gwin et al. [3] and Gayther [4] are reduced, while those of the data obtained by Szabo et al. [32], White [33] and Poenitz [34] and also the absolute data of Davis et al. [9] are increased. The weight of the findings of Szabo in Ref. [35] is considerably reduced because of the strong correlation with Refs [32] and [33], and it is for practical purposes unnecessary to use them in the evaluation. It would, however, be very difficult to state this firmly before performing the calculations, and even more difficult to ignore these data in the evaluation since they are relatively exact, although they do correlate with some other findings.

In the region 350-750 keV the evaluated curve is determined by means of the data of Szabo et al. [32], White [33] and Poenitz [34], which are given approximately equal weights. In the region above 750 keV the weights of the experimental data of Refs [9, 32-34, 36] remained virtually unchanged.

Tables 2.2-2.4 show the coefficients of correlation between energy ranges B_{nm} calculated in accordance with Eq. (1.11) for cases in which there are no correlations between errors, attributed correlations or total correlation.

Table 2.5 shows values for $\sigma_f(^{235}U)$ estimated in accordance with the method described above and errors in the evaluation with and without the use of correlations for optimum weight. The errors in the evaluated curve shown for energies above 30 keV are mean values for the correlation ranges shown in Table 2.2.

As can be seen from Table 2.5, the error is relatively strongly dependent on the degree of correlation. Thus, the errors in the estimated value obtained using correlations are approximately twice as high as those in the energy region up to 30 keV without correlations having been used.

When using non-optimized weights, which are in inverse proportion to the square of the error, the error in the evaluated $\sigma_f(^{235}U)$ is on average 10% higher than the errors shown in Table 2.5 for attributed correlations (K) in the region up to 100 keV, and on average 5% higher in the region up to 14 MeV.

The errors in the evaluated $\sigma_f(^{235}U)$ in the energy region below 30 keV shown in Table 2.5 with correlations having been used are 3-4%, which can be regarded as the degree of accuracy attained.

In the energy region above 30 keV the selected energy ranges are excessively wide, so that a large number of findings are evaluated over these intervals. This may cause the error to be evaluated incorrectly as a result of an uneven distribution of experimental points from individual papers within a particular range. Thus, the errors shown in Table 2.5 above 30 keV are merely illustrative. Analysis of the errors in experimental data in this region and the degree of agreement between data suggests that in the range 30 keV-15 MeV the accuracy attained may be $\pm 3\%$.

A comparison of the evaluated data in the present paper with the data of ENDF/B-V [40] shows that they agree to within 1-3% in the energy region 0.1 keV-15 MeV.

In the measurements to be performed in the future it will be necessary to pay attention to the regions 0.25-0.7 and 14-20 MeV in order to eliminate the discrepancies present in experimental data and it will also be necessary to demonstrate the structure of data in the energy region above 100 keV. It may prove worth while performing experiments which are of lower accuracy but which are known not to correlate with other experimental findings already available. Calculations based on the method described in section 1 may be of assistance, when new experiments are being planned, in the search for optimum methods of measuring different parameters in order that the evaluated errors obtained from all the experimental findings already available, together with those of the planned experiment, may be as low as possible.

3. EVALUATION OF $\alpha(^{235}U)$ IN THE ENERGY REGION 0.1-1000 keV BY THE METHOD BASED ON CORRELATIONS BETWEEN ERRORS IN DIFFERENT EXPERIMENTAL FINDINGS

The measurements of $\alpha(^{235}U)$ already made [3, 17, 29, 41-54] are not in good agreement with each other and in some cases differ by a factor of 1.5.

The reasons for the discrepancies between experimental results are as follows:

(a) The experimental findings are not all normalized in a consistent fashion;

(b) The errors in some experimental findings have been underestimated;

(c) There are errors associated with the experimental measurement techniques.

Essentially, all the available measurements of α in the energy region below 20 keV are relative since, in order to determine instrument constants, use is made of normalization to "reference" values, for which values of α for resolved resonances [4], σ_f, σ_a and α in the thermal region [3, 21, 52], fission and capture integrals in different energy regions [29, 42] or values of α at 30 keV [50, 51] are taken. References [46-49] give absolute measurements of α obtained with the use of a scintillation tank with cadmium or gadolinium; this made it possible to renormalize the data of Bandl et al. [50] and Vorotnikov et al. [51] at 30 $\pm$ 10 keV to the mean-weighted value of α which is (0.372 $\pm$ 0.035).

It is difficult to estimate how realistic the errors given by the authors are. In some energy ranges the dispersion between the data is larger than the experimental errors cited by the authors.

The measurement of α consists in measuring the number of fission events N_f and the number of capture events N_γ. The ratio of the effect to the background is higher for N_f than for N_γ, which means that the uncertainty in the background with N_γ causes larger errors in α than the uncertainties in the background with N_f. It is possible to obtain values for σ_f from measurements of N_f and, since the background is small, the results from different experiments should agree. If any given experimental findings contradict the general trend in σ_f, this indicates that there may be errors in the measurement of the background, which will probably also affect the measurement of N_f.

However, a comparison of σ_f values for ^{235}U does not help since it is only in four experiments [3, 17, 21, 29] that the authors give values of σ_f which in general agree satisfactorily with each other and with the results of other authors. In Refs [41, 43, 44] the authors do not give values for σ_f. In Refs [50, 51] no direct measurements of σ_f were given (in Ref. [50] N_f was measured in the case of a thick sample). Moreover, the results of some experiments, for example, those of Kurov et al. [44] are very insensitive to the "σ_f criterion" but, on the other hand, this makes them very sensitive to scattered neutrons. From the measurements of σ_f it would therefore appear that there is no justification for reducing the weights of the experimental data under consideration.

A comparison of the experimental techniques used for measuring $\alpha(^{235}U)$ shows first of all the different sensitivities of the methods (the number of instrument constants). The most sensitive methods are used by Muradyan et al. [43], Kurov et al. [44] and Van Shi-Di et al. [21]. A less sensitive method is that of de Saussure et al. [17] and Perez et al. [29], while the least sensitive methods are those of Czirr and Lindsey [41], Bandl et al. [50] and Vorotnikov et al. [51].

It is worth performing an analysis of possible systematic errors in different experimental findings by testing four different indicators: the operation of gamma and fission detectors, background determinations and energy resolution.

Gamma detectors should be insensitive to variations in the gamma-ray spectra due to capture and fission events and to total fission gamma-ray energy. In the experiment of Czirr and Lindsey a modified detector of the Moxon-Rae type was used with a very low fission-to-capture efficiency ratio $\varepsilon_f/\varepsilon_\gamma = 0.86$ (the expected value is approximately 1.0-1.3). The Moxon-Rae detectors used have a dispersion in the $\varepsilon_f/\varepsilon_\gamma$ ratios of between 0.8 and 1.5. Since it is not known which figure is correct and since this type of total energy detector may also be sensitive to variations in the fission and capture gamma radiation spectra when the detection threshold is raised, the weight of the experimental data of Czirr and Lindsey was reduced by adding a 5% error (quadratically).

The liquid scintillators used in Refs [17, 21, 29, 44] are in theory more sensitive to variations in the capture gamma-ray spectrum than Moxon-Rae detectors, as a result of which there is a danger that in the experiments of Kurov et al. [44], where the coincidence between two half-detectors was used, there might be inconsistency in the efficiency of the detector system over the whole neutron energy range studied. In the experiments of Muradyan et al. and Vorotnikov et al. a certain sensitivity to changes in the capture and fission gamma-ray spectrum is also possible.

The methods used for detecting the number of fission events (N_f) are imperfect in relation to possible sensitivity to variations in fission process characteristics as a function of incident neutron energy. However, errors arising out of this effect are clearly insignificant at energies below 30 keV. These variations in the fission process may be caused by an increase in p-interactions (at 5 keV approximately 25% of fission events are caused by p-neutrons). In principle, there may be an additional error in those experiments in which α depends on $\bar{\nu}$, if $\bar{\nu}$ varies as a function of the spin of a compound nucleus. This possibility arises with the experiments of Czirr and Lindsey, Kurov et al., Van Shi-Di et al., Bandl et al. and Vorotnikov et al. An additional 3% uncertainty was introduced as a result of this effect.

There may be errors associated with self-shielding and multiple-scattering effects. Gwin et al. have shown that for a sample with a thickness of approximately 5.9 x 10^{-4} atoms/barn there is an error of approximately 2% in the mean cross-section in the resonance region as a result of multiple scattering. In the experiments described in Refs [17, 21, 41, 43, 44] the samples were thinner than Gwin's, so that the effects under consideration are insignificant. In Ref. [29] corrections are made for these effects.

The most serious error in the measurement of α is associated with background determination. In order to analyse the background it is necessary to know different components (both those dependent on and those independent of time) and also the rate of variation in the background. Unfortunately, information on each experiment in this respect was not available.

If the background was measured with resonance filters, then clearly the measurements at energies higher than that of the filter are unreliable and should be given a lower weight. Thus, the measurements of Czirr and Lindsey [41] in the region above 3 keV should be given a lower weight (the background was not measured at energies higher than 2.8 keV). In the experiment of Muradyan et al. [43] background measurements proved problematic, especially in the region above 900 eV, and the N_γ count is relatively low. Their results were therefore given a smaller weight.

In the experiments of Kurov et al. [44] and Van Shi-Di et al. [21] there is a high sensitivity to scattered neutrons, which also makes it necessary to give these data a smaller weight.

In the experiments of Bandl et al. and Vorotnikov et al. the greatest errors in background determination occur in the region below 15 keV and the authors show considerable errors in this region, which have not been changed by us.

Errors in experimental findings may occur if delayed fission gamma-rays are recorded as capture events. At energies below 30 keV these gamma-rays may cause an error in α of the order of $\pm$ 0.02 or lower [55]. This systematic error was taken into account by us in all experiments.

The value of α is averaged over ranges of 100 eV in the region below 1 keV, over ranges of 1 keV in the region between 1 and 10 keV, and over ranges of 5 keV or more in the region above 10 keV. Since there is a distinct structure in α the energy resolution is important. It would appear that the minimum number of resolution widths fitting into the averaging ranges should be two (in this case approximately 12% of reactions are caused by neutrons of another energy). On the basis of this, the measurements of Czirr and Lindsey in the region above 5 keV were given a lower weight (at 5 keV $\Delta E \cong 5$ keV); this also applies to the measurements of Kurov et al. (at 5 keV $\Delta E = 0.59$ keV), Van Shi-Di et al. (at 5 keV $\Delta E \cong 0.4$ keV), Bandl et al. in the region above 8 keV (at 8 keV $\Delta E \cong 0.4$ keV), and Vorotnikov et al. in the region above 10 keV (at 10 keV $\Delta E \cong 0.59$ keV).

When evaluating $\alpha(^{235}U)$ the same procedure was used as for $\sigma_f(^{235}U)$, i.e. a table of partial errors in all experimental measurements of α was drawn up and correlations between partial errors in different experimental findings were shown. A method was used for calculating, with a computer program, optimum weights which minimize the error in evaluated data using correlations.

As a result of an analysis of experimental methods and errors, different correlations were shown between partial errors in experimental findings.

For k = 1 (background-energy-dependent) the work of Gwin et al. [3] and that of Perez et al. [29], which was performed on the same accelerator (the ORELA), can be partially correlated in terms of background. Similarly, there must be partial correlation between the work of Kurov et al. [44] and Van Shi-Di et al. [21], since they all made their measurements of α on an IBR fast pulsed reactor.

For k = 2 (statistical errors dependent on energy) there are no correlations.

For k = 3 (error in normalization) there are the following correlations. The work of Gwin et al. [3] (normalized in the thermal energy region) correlates entirely with Refs [21] (normalization to α and σ_f at 2200 m/s in the thermal energy region), [50] and [51] (both sets of results are renormalized to the mean-weighted average α_{av} at 30 $\pm$ 10 keV found by using the data from Refs [3, 46-49]). The latter findings should correlate with each other and with Refs [21, 44, 50, 51] entirely since they were used to obtain the mean-weighted value of α_{av} used for normalization in other papers. References [3] and [44] correlate entirely through Ref. [21] (the results of Ref. [44] were normalized in resonances to α obtained in Ref. [21]).

The experimental findings of de Saussure et al. [17] correlate entirely with Ref. [29] (the results of Ref. [29] are normalized in the region 100-200 eV to the results of Ref. [17]), with Ref. [41] (in Ref. [41] the value of α used in the region 11.45-12.0 eV was taken from Ref. [3]) and with Ref. [42] (the measurements of α in Ref. [42] were normalized in the region 200-1000 eV to the data of Ref. [29]). In Ref. [44] the authors normalize the results to the value of α for 14 resonances of ^{235}U without indicating, however, where these data were taken from. It can be assumed that they were taken from Ref. [17] or Ref. [21], the latter being more likely. Thus, $K_{44,21} \neq 1$, while for Refs [17] and [44] partial correlation is assumed.

Reference [52] should correlate entirely with Refs [3] and [4] since it is known that for calibration purposes the value of α in the thermal region was used in Ref. [52]. But there is no specific information as to where σ_{th} was taken from so we have to attribute only partial correlation to these findings and also to those of Refs [21] and [52].

For k = 4 (uncertainty in the relative neutron flux) Refs [3, 17, 29, 41, 44, 46, 48, 49, 51] correlate entirely with each other since in all these papers a chamber with ^{10}B was used for monitoring the neutron flux. Refs [3, 21, 42, 47] correlate partially since the authors of Refs [42, 44, 47] do not indicate the method used for monitoring flux; it can only be assumed that the monitor used was a counter with ^{10}B. The experimental findings of Refs [3] and [43] are partially correlated since three counters were used in Ref. [43]: two with ^{10}B and one with NaI. In Ref. [50] a counter with ^{6}Li was used, and it does not therefore correlate with any other findings. In Ref. [45] gold foils were used so that these findings do not correlate with any others. In Ref. [52] a lead slowing-down-time spectrometer was used, hence there are no correlations with other findings in this case either.

For k = 5 (determination of the efficiency of the detector system) Refs [17] and [29] correlate entirely since the efficiency of the fission chamber was determined by fitting the data of Ref. [29] to the σ_γ data of Ref. [17] in the region 24-60 eV. The efficiency of the tank for capture detection ε_γ was determined by normalizing the data of Ref. [29] to the data of Ref. [17] for the capture integral in the region 100-200 eV, while the efficiency of the tank for fission detection ε_f was obtained from the data of Ref. [17] for the fission integral from 100 to 200 eV. The fact that in Ref. [29] the efficiency was determined from the results of Ref. [17] had already been taken into account when considering correlations for the partial error k = 3. References [46-49] correlate with each other since extrapolation of the spectrum to zero pulse height was used in them. If it is assumed that the error in extrapolation is weakly dependent on the dimensions of the tank, which are the same only in Refs [46] and [48], the correlation between these findings can be considered to be complete. In addition, an error in determination of the efficiency of the detector system is included in the error in normalization of Refs [50, 51].

The correlations between Refs [46-51] are taken into account under k = 3. However, the effectiveness of so doing is low, since the size of the error under k = 3 is given only in Refs [50] and [51]. Thus, it is better to make use of the total correlation between Refs [46-51] for the partial error k = 5, after transferring the error in normalization from k = 3 to k = 5 and without treating the error in normalization in Refs [50] and [51] separately.

The error in normalization in Ref. [52] also includes the error in determination of the efficiency, since the efficiency of the detector system was determined in the experiment by calibration to a known value of α_{th}. However, in this case, although the partial error k = 5 cannot be singled out, it would be illogical to transfer the error from k = 3 since Ref. [52] correlates under k = 3 with Refs [17, 21, 41], and for all these findings both the error in normalization and the error in the determination of efficiency are given. If we single out the normalization error conditionally in Ref. [52], the correlation can be used both under k = 3 and under k = 5 (as for Refs [17] and [29]). Since we are not making this separation on account of a lack of information we will leave this error in k = 3. In this case, under k = 5 Ref. [52] correlates with no other findings.

For k = 6 (the probability that a fission event will not be accompanied by the detection of fission neutrons) there is a partial error only in Refs [46-49]. References [46] and [48] correlate totally, since the same scintillation tank was used for them.

For k = 7 (uncertainty in ε_{γ} through changes in the gamma-ray spectrum) Ref. [3] correlates entirely with all experimental results for which the same or a similar large liquid scintillation tank was used, i.e. Refs [3, 17, 29, 41, 21, 44, 46-49] correlate totally with each other.

For k = 8 (error in $\bar{\nu}$ causing an uncertainty in α) three papers [41, 50, 51] correlate with each other.

For k = 9 (error in the background from delayed fission gamma-rays) all experimental findings were considered to correlate with each other.

For k = 9 (error in the background from delayed fission gamma-rays) all experimental findings were considered to correlate with each other.

For k = 10 (uncertainty in the weight of the sample and in corrections for self-absorption in the foil) no correlations were found.

For k = 11 (uncertainty in corrections for impurities in the sample) Refs [46] and [48] correlate entirely since the same sample with the same isotopic composition was used.

For k = 12 (scattering of neutrons in the sample and in the detector walls) Refs [17] and [29] correlate entirely since the same method of correcting for neutron scattering was used.

For k = 13 (energy resolution) no correlations were found.

Table 3.1 shows calculated weights to be applied when using values of $\alpha(^{235}U)$ measured in each experiment in the cases of lack of correlation (K = 0), attributed correlation (K) and total correlation (K = 1) between the errors in all findings for each energy range.

It will be seen from the table that, as a result of the analysis performed on all partial errors in experimental findings and of the use of the correlations between them, the weights of the experimental data of Gwin et al. [3] increased within practically the whole energy region measured - 0.1-10 keV - and that for the data of de Saussure et al. [17] increased in the region 0.1-3 keV as being the most accurate and independent measurements in this region. The results of Poletaev [49] are also reliable; the weights of these increased in the region between 40 and 400 keV. The weight of the data of Perez et al. [29] was reduced in the region 0.1-3 keV (since they are relative data normalized to Ref. [17] and therefore correlate strongly with them), as was that of the data of Czirr et al. [41] in the region 0.1-3 keV (as a result of correlation with other findings in respect of normalization and measurement of neutron flux) and also of the data of Kurov et al. [44] and Van Shi-Di et al. [21] in the region 0.1-30 keV (as having large experimental errors and correlating strongly with other measurements in respect of a number of partial errors).

Table 3.2 shows estimated values for $\alpha(^{235}U)$ and the errors in them $\Delta\alpha_{est}$ in each energy range when there is no correlation, attributed correlation or total correlation. The values of $\alpha(^{235}U)$ hardly depend at all on the degree of correlation - the difference in the values of α does not amount to more than 3-5% in the cases of absence of correlation and total correlation. However, the errors in the estimated values of α vary in these cases very considerably - by a factor of 1.5-2. Thus, if the correlations between errors in experimental data are ignored, the error in α in the region up to 100 keV is 3-5%, and it increases to 5-8% when the correlations described above occur. In the energy region ~ 1 MeV these differences between errors are much less pronounced because of the small number of measurements and small degree of correlation between them.

The results given above for errors in α were obtained with optimized weights, i.e. weights that minimize the error in the estimated value. Comparisons between the cases of optimized and non-optimized weights (i.e. those in inverse proportion to the squares of the errors) show that in both cases the errors ($\Delta\alpha_{est}$) coincide where correlations are absent, as is to be expected; in the case of the correlations attributed by us the difference in the errors is insignificant (1-7%), and in the case of total correlation the difference is 20-30%. Thus, for purposes of performing an evaluation in practice, when experimental findings correlate only partially rather than entirely, it is necessary first of all to find the correlations between partial errors in the experimental findings and then to use in the evaluation the weights obtained by means of the correlations. When correlations are not extensive, the weights may be applied without optimization.

4. EVALUATION OF $\alpha(^{239}Pu)$ IN THE ENERGY REGION 0.1-1000 keV USING A METHOD BASED ON CORRELATIONS BETWEEN THE ERRORS IN DIFFERENT EXPERIMENTAL FINDINGS

In recent years a number of experimental measurements of $\alpha(^{239}Pu)$ have been made and our knowledge of α has considerably improved [3, 41, 44, 46, 47, 49, 50, 54, 56-67]. All these measurements differ in the experimental techniques and normalization systems employed. The reference values used were values of α for certain well-resolved resonances [44, 58, 61, 67], fission and capture cross-sections in the region 0.05-0.4 eV [3, 56] and values of α for thermal neutrons [59, 64, 66] and at 30 keV [56, 65]. In some papers some of the instrument constants were measured experimentally [46, 47, 49, 54, 62].

In the normalization of measurements it is necessary to take account of the dependence of the efficiency of the detector system on neutron energy. The gamma detectors used in experiments should not be sensitive to variations in the capture and fission gamma-ray spectra or to the total energy of fission gamma-rays. Doubts in this respect may arise in connection with experiments for which small NaI and stilbene crystals [50, 59, 65, 67] and large liquid scintillation tanks in the coincidence mode [28, 44] are used. There may be some uncertainty with regard to non-dependence on total gamma energy when detectors of the Moxon-Rae type [41, 58, 61], which give different ratios of efficiency for fission and capture in three different experimental findings, are used.

The method of detecting fission will not be perfect since it may be sensitive to possible variations in the fission process characteristics as a function of incident neutron energy. For example, the fission chamber may be sensitive to variations in the angular distributions of fission fragments in the energy region in which p-interactions are important. However, in general the errors due to this effect are insignificant at energies below 30 keV.

In experiments in which fission events are detected from fission neutrons [41, 44, 46, 47, 49, 54, 58-60, 62], there is a possibility of sensitivity to variations in $\bar{\nu}$ with incident neutron energy. This sensitivity will be small when low-volume detectors are used [41, 58, 59, 65-67], as mentioned in Ref. [68], since the fission detection efficiency of these detectors is proportional to $\bar{\nu}$ and variations in $\bar{\nu}$ directly affect the result of the measurement of α.

In theory, there may be grave errors in cross-section measurements as a result of self-absorption and multiple scattering effects. In all experimental measurements of α, except for those of Farrell et al. [61] and Kurov et al. [44], a single sample of acceptable thickness ($\sim 10^{-3}$ atoms/barn) was used. Farrell et al. corrected for the self-shielding effect, while Kurov et al. did not make these corrections in the region above 100 eV and so the weight for these measurements has to be reduced.

The most serious errors in experimental determinations of α are those associated with measurement of the background. It is particularly difficult to determine a background which varies as a function of the time-of-flight. The method generally used for measuring the background, involving black resonance filters, does not produce sufficiently reliable measurements of a variable background. Some observations should be made on the determination of the weights of experimental findings in connection with different methods of background measurement. Extrapolation of the measured background to an energy exceeding the filter energy by a factor of two will probably be satisfactory, but at higher measurement energies they should be given a lower weight. Thus, the measurements of Czirr et al. [41] and Belyaev et al. [59] were given a lower weight at energies above 6 keV. Large errors were found in the experimental background measurements of Schomberg et al. [58] in the region 0.8-5.0 keV, and we therefore gave these measurements a lower weight in the energy region concerned.

The data of Farrell et al. [61] in the region above 10 keV should also be given a lower weight since the errors caused by deduction of a large background from fission are high and since there was an additional background in the experiment from the aluminium container of the sample at higher energies.

Additional errors in the experiment can occur if delayed gamma rays from fission are detected as capture events. Walton and Sund [69] showed that for ^{239}Pu in 3.2% of fission events isomers with half-lives of between 3 and 80 μs are produced. The total energy of gamma rays generated during decay of an isomer is less than 2 MeV. It would seem that isomers can have their most serious effect in terms of the formation of a time-dependent background in the gamma detector at high energies. Our evaluations show that an error in α amounting to ± 0.02 or less will be due to delayed gamma rays at neutron energies below 30 keV. In high-accuracy measurements of α to be performed in the future this effect must be carefully studied.

The differences in the energy resolution in different experimental findings, namely of Belyaev et al. [59] and Kurov et al. [44] (220 ns/m) in the region between 400 eV and 1 keV and above 2 keV and of Ryabov [28] and Czirr et al. [41] between 5 and 10 keV have led to a reduction in their weights.

In determining the weights of experimental data for purposes of evaluating α, an error of 5% for each of the observations made above was added quadratically, which in general slightly changed the weight of the experimental findings concerned. Analysis of the experimental methods and errors has resulted in a number of correlations between experimental findings being discovered. The total experimental error in α was divided up into thirteen independent partial errors.

For k = 1 (dependent on background energy) the experimental findings of Gwin et al. [3] and Weston and Todd [57] may be partially correlated since they were obtained on the same accelerator, which may be the source of the energy-dependent background. For the same reason the data of Belyaev et al. [59] and Bolotskij et al. [60, 67] and those of Ryabov et al. [28] and Kurov et al. [44] also correlate where the background is concerned with a coefficient of 0.5

For k = 2 (statistical errors) there are no correlations.

For k = 3 (error in normalization) the findings of Gwin et al. [56] correlate with Refs [3, 57] (normalization in the thermal region), [58] (normalization on Ref. [56]), [41] (normalization with use of α at the thermal point), [60] (normalization to values of α in resonances in the energy region below 50 eV obtained in Refs [28, 44, 56, 58, 59, 63]), [44] (normalization to values of α in resonances obtained in Refs [28, 56, 57]), [28] (normalization to the same values of α as in Ref. [44]) and [63] (normalization to values of α in resonances obtained in Refs [44, 56, 58-60]). There is partial correlation between Refs [56] and [59] (normalization to the thermal value of α obtained from the value of η measured in Ref. [59] and the value of ν at the thermal point) and Refs [56] and [61], (normalization to eight wide 0^+-resonances without any indication having been given about which findings these resonances were taken from). The relative data of Bandl et al. [50] are correlated with the data of Refs [46, 47, 49], since they were renormalized by us to the mean-weighted value of α at 30 $\pm$ 10 keV (0.318 $\pm$ 0.033) obtained from these papers. However, because of the absence of a partial error under k = 3 in Refs [46, 47, 49] it would be more correct to assign this correlation to k = 9 (determination of the efficiency of the detector system). For the paper by Vorotnikov et al. [65], what has been stated above is correct in respect of Ref. [50]. For this reason there is also total correlation between Refs [50] and [65] for k = 9.

For k = 4 (background from delayed fission-gamma rays) we consider that the error caused by the background from delayed fission-gamma rays correlates entirely in all experimental findings.

For k = 5 (uncertainty in the relative neutron flux) Refs [3, 56, 57] correlate entirely with respect to the $^{10}B(n,\alpha)$ reaction cross-section. References [50, 58, 61] correlate entirely with respect to the $^{6}Li(n,\alpha)$ reaction cross-section.

For k = 6 (neutron scattering in the sample and detector walls) Refs [3] and [56] correlate entirely, since the same large liquid scintillation tank was used. References [59, 60, 67] may be correlated since the same method and, it would appear, the same equipment was used.

For k = 7 (uncertainty in detector efficiency as a result of possible variations in the gamma-ray spectrum) we consider that this error correlates entirely in all experimental findings.

For k = 8 (error in $\bar{\nu}$ causing uncertainty in α) Refs [28, 41, 50, 57-60, 65, 67] correlate entirely.

For k = 9 (uncertainty in the efficiency of the detector system) Refs [3] and [56], based on use of the same liquid scintillator, correlate entirely. References [46, 47, 49] contain the same error component caused by uncertainty in extrapolation to zero pulse height and these papers are therefore partially correlated.

For k = 10 (variation in the efficiency of the detector system with time) Refs [3] and [56] correlate entirely since the same scintillation tank was used.

For k = 11 (uncertainty in the correction made for impurities in the sample), k = 12 (probability that a fission event will not be accompanied by detection of fission neutrons) and k = 13 (energy resolution) no correlations were found.

In accordance with the system described in section 1, we calculated the optimum weights to be applied to the measurements of $\alpha(^{239}Pu)$ made in each experiment for absence of correlations (K = 0), the correlations determined above (K), and the total correlation (K = 1). In the region 0.1-6 keV the weight of the data of Gwin et al. [3] and Weston et al. [57] increased by a factor of almost two, which corresponds to the real situation since these two sets of experimental findings are the most complete from the point of view of present-day experimental techniques. They determine the estimated values of α in this energy region (they have a total weight of 0.9). In the relatively narrow band from 6 to 10 keV the weight of Gwin's data [3] is slightly reduced because of the increase in the partial error from the background which is correlated with a coefficient of 0.5 with Ref. [57], and it is the data of Weston et al. [57] and Czirr et al. [41] which determine the evaluated data in this energy region. In the region 0.1-5.0 keV the weight of the data from Refs [28, 44, 56, 58-60, 63, 67] is reduced, while in the region above 5 keV the weight of this data does not vary, although its absolute value remains low (it is approximately one order of magnitude lower than that of the most accurate data). Typically, in some ranges the weight of the data of Bergman et al. [64] increased by a factor of ~2 as a result of the low degree of correlation of these experimental findings with other data.

In the energy region 10-100 keV the evaluated α values are determined by the following: Gwin's data [3], the weight of which increases up to an energy of 70 keV, Weston's data [57], the weight of which is considerable up to an energy of 20 keV and then begins to drop, and those of Poletaev et al. [49], the weight of which increases from an energy of 30 keV and is the determining factor in the second half of this range.

In the energy region above 100 keV, the estimated values of α are determined by absolute data of Poletaev [49], Lottin et al. [46] and Hopkins et al. [47].

Table 4.1 shows estimated values for $\alpha(^{239}Pu)$ obtained by the method described in section 1, and indicates errors in the evaluation for absence of correlations (K = 0), attributed correlation (K) and total correlation (K = 1). The estimated values of α themselves hardly vary at all as a function of the extent of correlation (the variations are not more than 2%), while the errors in the estimated value of α in the region 0.1-10 keV are ~ 3% for K = 0, ~6% for the correlations mentioned above, and ~7-10% for K = 1; in the region 10-500 keV these errors are ~5-9%, 8-11% and 12-16% for 0, K and 1, respectively. Thus, it can be considered that the accuracy attained in measurement of $\alpha(^{239}Pu)$ is 6% in the region 0.1-20 keV, 8-10% in the region 20-100 keV, 13-17% in the region 100-800 keV, and 25% in the region 0.8-1.0 MeV. The difference in the errors $\Delta\alpha_{est}$ for the cases of optimized and non-optimized weights is not more than 5-10% of the error mentioned above, i.e. it is practically negligible.

Since the accuracy attained in measurement of $\alpha(^{239}Pu)$ does not correspond to the accuracy required for reactor calculations (3.6% in the region below 100 keV and 5% in the region up to 0.8 MeV), further measurements of α are needed for which methods which do not correlate with existing ones must be used.

5. EVALUATION OF $\sigma_f(^{239}Pu)$ IN THE ENERGY REGION 0.1 keV-15 MeV WITH THE METHOD USING CORRELATIONS

Experimental values for $\sigma_f(^{239}Pu)$ were divided into four groups for analysis. Into the first group were put data obtained by the time-of-flight method with good resolution [3, 26, 28, 56, 58, 61, 70–74]. Values of $\sigma_f(^{239}Pu)$ obtained with monoenergetic sources in the region 10 keV-15 MeV were divided into four groups: absolute values (in the measurement of $\sigma_f(^{239}Pu)$ no other data were used apart from the well-known standard cross-sections H(n,n), $^{10}B(n,\alpha)$ and σ_f at 2200 m/s), [32, 35, 75–77]; relative values (in normalization of $\sigma_f(^{239}Pu)$ the authors used values of $\sigma_f(^{235}U)$ and $\sigma_f(^{238}U)$ only for one single energy differing from the thermal energy) [78, 79]; "inferred" values (in simultaneous measurement of the ratio $\sigma_f(^{239}Pu/\sigma_f(^{235}U)$ and $\sigma_f(^{235}U)$ at common energies it is possible to obtain $\sigma_f(^{239}Pu))$ [33, 80–83], and direct data for the ratio $\sigma_f(^{239}Pu)/\sigma_f(^{235}U)$ (these data were obtained by the direct method and do not involve any assumptions regarding the shape of the energy dependence of $\sigma_f(^{235}U)$ or $\sigma_f(^{239}Pu))$ [84–88].

The following sequence was used for the evaluation of $\sigma_f(^{239}Pu)$:

(a) Tables were drawn up of the partial errors in all experimental measurements of σ_f (including relative measurements);

(b) The correlations between partial errors in different experimental findings were identified;

(c) The method described above for calculating the errors in evaluated data using correlations was applied;

(d) The PREDA program was used for processing the results in the energy region above 30 keV - where there are generally only measurements at single points - separately from absolute $\sigma_f(^{239}Pu)$ data and from the ratio $\sigma_f(^{239}Pu)/\sigma_f(^{235}U)$ in such a way that these figures could be used to obtain a value of $\sigma_f(^{235}U)$ which could then be compared with the fission cross-section for ^{235}U evaluated in Section 2 in order to achieve agreement between values of $\sigma_f(^{239}Pu)$, $\sigma_f(^{239}Pu)/\sigma_f(^{235}U)$ and $\sigma_f(^{235}U)$.

By analysing the experimental data it was possible to single out from the total error twelve partial errors and to identify a number of correlations between experimental findings.

k = 1 (determination of the number of ^{239}Pu nuclei): Refs [32, 35, 75] correlate entirely, since they represent series of experimental findings obtained in different years by the same authors. In Refs [32, 35, 75] the same ^{239}Pu foil was used. In Ref. [80] the same fission chamber was used as in Ref. [35], but they do not correlate entirely. This is because, unlike the absolute measurements of $\sigma_f(^{239}Pu)$ of Ref. [35], in Ref. [80] the ratio $\sigma_f(^{239}Pu)/\sigma_f(^{235}U)$ was measured, while in Ref. [33] ^{235}U was measured absolutely using the same foil. Thus, Refs [35, 80, 33] correlate partially.

k = 2 (extrapolation of the fission fragment spectrum to zero pulse height): Refs [32, 35, 75] correlate entirely with each other, while Ref. [35] correlates partially with Refs [80] and [33] for the reasons mentioned above.

k = 3 (fission fragment absorption in the foil): the correlations are the same as for k = 2.

k = 4 (scattering in the chamber walls, foil backing and target structure): Refs [38] and [80] correlate entirely since the same fission chamber was used. There is also a correlation between Refs [32] and [75]. However, since they do not give measurements for a common energy region they should be considered as not correlating.

k = 5 (neutron attenuation in the air): Refs [35] and [32] correlate entirely (the experiments were performed on the same device), as do Refs [35] and [75] in the common region 800-972 keV.

k = 6 (determination of the neutron flux): Refs [3, 28, 56, 58, 70, 71, 73, 74] correlate entirely for the $^{10}B(n,\alpha)$ reaction cross-section, while Refs [35] and [32] correlate only in the region 800-972 keV (two energy points).

k = 7 (experimental background): Refs [61] and [72] can be considered to correlate partially in terms of background, since an underground nuclear explosion was used for measuring the cross-sections; Refs [35] and [32] and [35] and [75] correlate entirely in the common energy range.

k = 8 (efficiency of fission detection): there is total correlation between Refs [61] and [72], where the same method was used for detecting fission fragments.

k = 9 (uncertainty in the geometrical factor): no correlations were found.

k = 10 (standard cross-section (hydrogen)): Refs [35] and [32] correlate entirely since they used the same chamber, which differs only for k = 4; there is total correlation between Refs [35, 80] and [82], since Ref. [82] correlates in respect of the standard (the hydrogen cross-section) with Ref. [35] and in the region 0.5-1 MeV in terms of the standard cross-section $\sigma_f(^{235}U)$ with Ref. [80].

k = 11 (statistical errors): there are no correlations.

k = 12 (error in normalization): Refs [3, 28, 56, 58, 71, 73, 74] correlate entirely. This is because the results of Refs [56] and [3] are normalized to the thermal point, those of Ref. [58] are normalized to the data in Refs [56] and [73], while the results of Ref. [71] are normalized to Ref. [73], i.e. also to the thermal point; the results of Ref. [28] are also normalized to the thermal point. Ref. [74] is normalized to the evaluation of Sowerby et al. [89] in the range 10-30 keV, i.e. to the data of Refs [56, 61, 72, 73], which determine the absolute value in the range 0.1-1.0 keV, and to the data of Refs [58, 70] and [71], which were used by Sowerby et al., in addition to the first four papers, for determining the shape of the σ_f curve in the region below 30 keV. Refs [82-88, 79] correlate entirely since the value of $\sigma_f(^{235}U)$ from our own evaluation was used as a standard.

The calculations for the weights which should be applied to measurements of $\sigma_f(^{239}Pu)$ when there are correlations between partial errors from different experimental findings show that in the region 0.1-1 keV the weight of the experimental data hardly varies, in the region 1-10 keV the weight of the data of Refs [30, 70] rose by a factor of 1.5-2, and the weight of the data of Refs [28, 58, 61, 71, 74] dropped by a factor of approximately two. In the region 10-30 keV the weight of the data of Refs [3, 32, 58, 85, 86], which determine the evaluated data in this energy region, increased by a small amount (approximately 10-15%), while the weight of the data of Refs [61, 70, 71] was reduced by approximately 20%. In the energy region above 30 keV the weight of data varied little, and the data with the greatest weight are the absolute measurements of Refs [3, 32, 35, 75] and the measured ratios, first of all, of Ref. [88] and, secondly, of Refs [81, 85, 86, 90].

Errors in $\sigma_f(^{239}Pu)$ are equal to 2.2-2.8% in the regions 0.1-30 keV when correlations are used (1.5 and 2.4% when they are not) and approximately 3.5-4% in the energy region up to 10 MeV. The evaluated $\sigma_f(^{239}Pu)$ data, the ratio $\sigma_f(^{239}Pu)/\sigma_f(^{235}U)$ and earlier evaluations of $\sigma_f(^{235}U)$ provide a set of data which agree among themselves to within 1-3%. Table 5.1 gives estimated values for $\sigma_f(^{239}Pu)$.

6. MATRICES OF COEFFICIENTS OF CORRELATION BETWEEN THE ERRORS IN GROUP-AVERAGED CONSTANTS FOR $\sigma_f(^{235}U)$, $\sigma_f(^{239}Pu)$, $\alpha(^{235}U)$ and $\alpha(^{239}Pu)$

In the literature several different approaches are followed for drawing up a covariance matrix of group-averaged constants [91, 92]. Dragt et al. [91] calculated the uncertainties in group-averaged cross-sections of fission fragment capture, starting from mean resonance parameters and errors in them and taking account of some correlations between data for different isotopes. Bazazyants et al. [92] give calculated correlation coefficients for group-averaged values of $\sigma_f(^{235}U)$ in the energy region above 2 keV and a covariance matrix of group-averaged capture cross-sections for ^{238}U in a uranium-plutonium medium in the region 0.4-200 keV, obtained on the basis of the sensitivities of blocks of group-averaged constants to mean resonance parameters.

In Ref. [93] a method of rendering evaluated nuclear constants more accurate is developed; this uses data of integral experiments on critical assemblies. The input information consists of nuclear constants, their errors and the coefficients of correlation between them. Since the method of Ref. [93] is applied by means of the computer program of Ref. [94] for a group-averaged approximation of reactor calculations, it becomes necessary to present evaluated constants, their errors and the coefficients $B_{n,m}$ in a standard group-averaged form. The method described in section 1 can be used to calculate these values in the correct sequence.

The procedure for obtaining group-averaged constants from evaluated data is well known [95]. Thus, we shall describe only the method of evaluating errors in group-averaged constants and the coefficients of correlation between them.

The error in an evaluated group-averaged constant is determined in the group in the following way:

$$\Delta\sigma_n = \int_{\Delta E_n} \Delta\sigma(E) f(E) dE \quad ,$$

where f(E) is the weighting function used for averaging. It is assumed that the function of f(E) is normalized in such a way that the integral for the group ΔE_n is equal to

$$\int_{\Delta E_n} f(E) dE = 1 \quad ; \qquad (6.1)$$

The mean-square error in the group is determined as follows:

$$\overline{|\Delta\sigma_n|^2} = \int_{\Delta E_n}\int_{\Delta E_n} \overline{\Delta\sigma(E)\Delta\sigma(E')}\, f(E)f(E')dEdE' =$$

$$= \int_{\Delta E_n}\int_{\Delta E_n} \sqrt{\overline{|\Delta\sigma(E)|^2}}\cdot\sqrt{\overline{|\Delta\sigma(E')|^2}}\cdot K_{E,E'} f(E)f(E')dEdE', \tag{6.2}$$

where $K_{E,E}$ is the coefficient of correlation between the errors in estimated values at the points E and E', while $\sqrt{\overline{|\Delta\sigma(E)|^2}}$ is the mean-square error at the point E. These values can be found by means of the method described in section 1, with account having been taken of correlations between errors in the experimental data used in the evaluation.

The coefficient of correlation between the errors at any two evaluated points n and m has the following form:

$$B_{nm} = \frac{\overline{\Delta\sigma_n\Delta\sigma_m}}{\sqrt{\overline{|\Delta\sigma_n|^2}}\cdot\sqrt{\overline{|\Delta\sigma_m|^2}}} \tag{6.3}$$

since the denominator of this formula is determined by Eq. (6.2), it is necessary to find only the numerator:

$$\overline{\Delta\sigma_n\Delta\sigma_m} = \int_{\Delta E_n}\int_{\Delta E_m} \overline{\Delta\sigma(E)\Delta\sigma(E')}\, f(E)f(E')dEdE' =$$

$$= \int_{\Delta E_n}\int_{\Delta E_m} \sqrt{\overline{|\Delta\sigma(E)|^2}}\cdot\sqrt{\overline{|\Delta\sigma(E')|^2}}\cdot K_{EE'} f(E)f(E')dEdE' . \tag{6.4}$$

Equations (6.2), (6.3) and (6.4) were used for calculating the errors in group-averaged constants and coefficients of correlation between their errors. The estimated values, their errors and correlations between the errors were obtained earlier and are described in previous sections.

The calculations for values of $\alpha(^{235}U)$, $\alpha(^{239}Pu)$, $\sigma_f(^{235}U)$ and $\sigma_f(^{239}Pu)$ were performed using a computer program. The relative accuracy of integration in calculations was 10%, which is higher than the accuracy with which the errors and correlation coefficients were determined. The evaluated errors in group-averaged constants and correlation coefficients differ by less than 10% when averaged over the spectra I/E and E = const., which is less than the error associated with the input information.

Tables 6.1-6.4 show correlation matrices for the errors in values of $\alpha(^{235}U)$, $\alpha(^{239}Pu)$, $\sigma_f(^{235}U)$ and $\sigma_f(^{239}Pu)$ and group-averaged constants for σ_f and $\sigma\gamma$.

The values of $\sigma_f(^{235}U)$, $\alpha(^{235}U)$, $\sigma_f(^{239}Pu)$ and $\alpha(^{239}Pu)$ estimated in this paper have been incorporated into the third version of the Soviet Evaluated Nuclear Data Library for ^{235}U and ^{239}Pu (BOYaD-3). The evaluated $\sigma_f(^{235}U)$ and $\sigma_f(^{239}Pu)$ data were examined at a meeting of the Fission Group and they were recommended for use.

In conclusion, the authors wish to express their gratitude to Academician A.K. Krasin of the Byelorussian Academy of Sciences for discussion of the results.

Table 2.1.

Optimized weights for different experimental findings in absence of correlation (K = 0), attributed correlation (K) and full correlation (K = 1)

REFERENCE	E, keV														
	0,I - 0,3			0,3 - 0,4			0,4 - 0,6			0,6 - 0,8			0,8 - I,0		
	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I
/ I7 / De Saussure	0,III	0,I50	0,000	0,I5I	0,206	0,000	0,I2I	0,223	0,000	0,I88	0,380	0,705	0,I97	0,432	0,705
/ 26 / Blons	0,093	0,000	0,000	0,I27	0,000	0,000	0,I02	0,000	0,000	0,I58	0,000	0,000	0,I65	0,000	0,000
/ 24 / Lemley	0,040	0,039	0,000	0,055	0,000	0,000	0,044	0,0I0	0,000	0,068	0,098	0,000	0,063	0,000	0,000
/ 20 / Michaudon	0,045	0,000	0,000	0,062	0,000	0,000	0,050	0,000	0,000	0,077	0,000	0,000	0,08I	0,000	0,000
/ 25 / Brown	0,03I	0,00I	0,000	0,009	0,000	0,000	0,033	0,000	0,000	0,060	0,062	0,000	0,057	0,064	0,000
/ 27 / Patrick	0,042	0,000	0,000	0,058	0,000	0,000	0,046	0,000	0,000	0,072	0,000	0,000	0,070	0,000	0,000
/ 2I / Van Shi-Di	0,032	0,000	0,000	0,043	0,000	0,000	0,034	0,000	0,000	0,054	0,000	0,000	0,049	0,000	0,000
/ 29 / Perez	0,047	0,000	0,000	0,II9	0,000	0,000	0,095	0,000	0,000	0,I48	0,I09	0,000	0,I35	0,004	0,000
/ 3 / Gwin	0,09I	0,000	0,000	0,I40	0,II0	0,000	0,II2	0,026	0,000	0,I75	0,35I	0,295	0.1[illegible]	0.402	0.295
/ 5 / Mostovaya	0,066	0,000	0,000	-	-	-	-	-	-	-	-	-	-	-	-
/ 6 / Czirr	0,I74	0,267	0,378	0,236	0,684	I,0	0,I90	0,396	0,666	-	-	-	-	-	
/ 7 / Wasson	0,I88	0,543	0,622	-	-	-	0,I73	0,345	0,334	-	-	-	-	-	-

REFERENCE	E, keV														
	I - 2			2 - 4			4 - 5			5 - I0			I0 - 20		
	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I
/ I7 / De Saussure	0,I09	0,202	0,000	0,I52	0,4I5	0,705	0,I29	0,253	0,000	0,I29	0,353	0,425	-	-	-
/ 26 / Blons	0,09I	0,000	0,000	0.128	0,0I3	0,000	0,I08	0,000	0,000	0,I00	0,000	0,000	0,088	0,004	0,000
/ 24 / Lemley	0,035	0,000	0,000	0,048	0,097	0,000	0,04I	0,0I5	0,000	0,046	0,I2I	0,000	0,062	0,000	0,000
/ 20 / Michaudon	0,045	0,000	0,000	0,063	0,006	0,000	0,053	0,000	0,000	0,049	0,000	0,000	-	-	-
/ 25 / Brown	0,032	0,000	0.000	0,044	0,064	0,000	0,038	0,037	0,000	0,038	0,05I	0,000	-	-	-
/ 27 / Patrick	0,039	0,000	0.000	0,054	0.007	0,000	0,046	0,000	0,000	0,053	0,006	0,000	0,074	0,000	0,000
/ 2I / Van Shi-Di	0,027	0,000	0,000	0,054	0,000	0,000	0,032	0,000	0,000	0,03I	0,000	0,000	-	-	-
/ 29 / Perez	0,075	0,000	0,000	0,104	0,000	0,000	0,088	0,000	0,000	0,I05	0,072	0,000	-	-	-
/ 3 / Gwin	0,I0I	0,118	0,000	0.141	0.398	0.295	0,I20	0,224	0,000	0,I3I	0,342	0,544	0,I6I	0,274	0,000
/ 4 / Gayther	0,049	0,000	0,000	0.069	0,000	0,000	0,058	0,000	0,000	0,079	0,000	0,000	0,113	0,000	0,000
/ 5 / Mostovaya	0,060	0,000	0.000	0.086	0.000	0,000	0,07I	0,000	0,000	0,094	0,000	0,000	-	-	-
/ 6 / Czirr	0,169	0.340	0.500	-	0.000	0.000	-	0,000	0,000	-	-	-	0.279	0.722	1.00
/ 7 / Wasson	0.168	0.340	0.500	-	-	-	0,168	0,47I	I,000	-	-	-	-	-	-
/ 30 / Perez	-	-		0.057	0.000	0.000	0.048	0,000	0,000	0,057	0.000	0.000	0.075	0.000	0.000
/ 31 / Wasson	-	-	-	-	-	-	-	-	-	0,097	0,055	0.031	0,148	0.0	0.0

Table 2.1 (continued)

REFERENCE	E, keV 20 - 30 K=0	20 - 30 K	20 - 30 K=I	30 - II0 K=0	30 - II0 K	30 - II0 K=I	II0 - 350 K=0	II0 - 350 K	II0 - 350 K=I	350 - 750 K=0	350 - 750 K	350 - 750 K=I	750 - I500 K=0	750 - I500 K	750 - I500 K=I
/ 26 / Blons	0,09I	0,040	0,000	-	-	-	-	-	-	-	-	-	-	-	-
/ 24 / Lemley	0,064	0,000	0,000	0,024	0,000	0,000	-	-	-	-	-	-	-	-	-
/ 27 / Patrick	0,076	0,000	0,000	-	-	-	-	-	-	-	-	-	-	-	-
/ 30 / Perez	0,08I	0,000	0,000	0,025	0,000	0,000	-	-	-	-	-	-	-	-	-
/ 3 / Gwin	0,I67	0,306	0,000	0,043	0,026	0,000	0,030	0,000	0,000	-	-	-	-	-	-
/ 4 / Gayther	0,II7	0,000	0,000	0,044	0,005	0,000	0,033	0,00I	0,000	0,037	0,050	0,000	0,0I7	0,0I5	0,000
/ 35 / Szabo	[illegible]	0,000	0,000	0,I59	0,0I3	0,000	0,077	0,003	0,000	0,I9I	0,048	0,304	0,083	0,025	0,000
/ 32 / Szabo	-	-	-	0,2I6	0,3I5	0,80I	0,I67	0,I87	0,0	0,I7I	0,2I3	0,0	0,082	0,087	0,000
/ 33 / White	-	-	-	0,I93	0,282	0,I00	0,I84	0,203	0,I58	0,2I4	0,268	0,5I8	0,I09	0,II6	0,000
/ 34 / Poenitz	-	-	-	0,I75	0,255	0,003	0,I36	0,I50	0,0	0,I63	0,203	0,I32	0,077	0,082	0,000
/ 38 / Käppeler	-	-	-	-	-	-	-	-	-	0,I24	0,I54	0,048	0,074	0,079	0,000
/ 39 / Diven	-			-	-	-	-	-	-	0,030	0,037	0,000	0,0I4	0,0I5	0,000
/ 6 / Czirr	0,254	0,654	I,000	0,068	0,I00	0,000	0,024	0,027	0,000	0,0I9	0,023	0,000	-	-	-
/ 3I / Wasson	0,I50	0,000	0,000	0,054	0,004	0,096	0,046	0,050	0,034	0,05I	0,004	0,000	0,023	0,024	0,000
/ 9 / Davis	-	-	-	-	-	-	0,30I	0,379	0,808	-	-	-	0,I60	0,I7I	0,000
/ I2 / Leugers	-	-	-	-	-	-	-	-	-	-	-	-	0,0I0	0,0I2	0,000
/ 36 / Barton	-	-	-	-	-	-	-	-	-	-	-	-	0,283	0,302	0,899
/ 37 / Czirr	-	-	-	-	-	-	-	-	-	-	-	-	0,068	0,072	0,I0I

REFERENCE	E, MeV I,5 - 3,0 K=0	I,5 - 3,0 K	I,5 - 3,0 K=I	3,0 - 5,0 K=0	3,0 - 5,0 K	3,0 - 5,0 K=I	5,0 - I2,0 K=0	5,0 - I2,0 K	5,0 - I2,0 K=I	I2 - I4 K=0	I2 - I4 K	I2 - I4 K=I	I4,I - I5 K=0	I4,I - I5 K	I4,I - I5 K=I	I5 - 20 K=0	I5 - 20 K	I5 - 20 K=I
/ 32 / Szabo	0,I50	0,I65	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
/ 33 / White	0,084	0,092	0,000	-	-	-	0,I59	0,I33	0,000	0,2I8	0,226	0,I79	0,256	0,256	0,220	-	-	-
/ 34 / Poenitz	0,093	0,I02	0,000	0,I76	0,I83	0,000	-	-	-	-	-	-	-	-	-	-	-	-
/ 39 / Diven	0,0I7	0,0I9	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
/ 36 / Barton	0,499	0,536	0,948	0,5I7	0,538	0,876	0,528	0,575	0,976	-	-	-	-	-	-	-	-	-
/ 37 / Czirr	0,080	0,077	0,052	0,I50	0,I56	0,I20	0,I53	0,I67	0,I20	0,II4	0,II8	0,2I0	-	-	-	0,860	0,875	0,956
/ 8 / Szabo	0,068	0,009	0,000	0,III	0,I75	0,004	0,II2	0,I22	0,004	-	-	-	-	-	-	-	-	-
/ I2 / Leugers	0,0I9	0,000	0,000	0,046	0,008	0,000	0,048	0,003	0,000	0,035	0,000	0,000	-	-	-	0,I40	0,I25	0,0[illegible]
/ I0 / Cance	-	-	-	-	-	-	-	-	-	0,333	0,345	0,6II	0,39I	0,39I	0,753	-	-	-
/ II / Alkhazov	-	-	-	-	-	-	-	-	-	0,300	0,3II	0,000	0,353	0,353	0,027	-	-	-

Table 2.2.

Matrix of coefficients of correlation between energy ranges B_{nm} in absence of correlations between errors

n,m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1,00	0,94	0,95	0,74	0,74	[illegible]	0,73	0,83	0,69	0,51	0,50	0,18	0,03	0,04	0,00	0,00	0,00	0,00	0,00	0.00	0.00
2		1,00	0,90	0,86	0,35	0,83	0,76	0,69	0,70	0,62	0,61	0,22	0,12	0,05	0,00	0,00	0,00	0,00	0,00	0.00	0.00
3			1,00	0,80	0,90	0,94	0,70	0,81	0,65	0,55	0,54	0,20	0,10	0,04	0,00	0,00	0,00	0,00	0,00	0.00	0.00
4				1,00	1,00	0,74	0,98	0,81	0,92	0,40	0,41	0,12	0,06	0,00	0,00	0,00	0,00	0,00	0,00	0.00	0.00
5					1,00	0,74	0,88	0,81	0,82	0,41	0,42	0,12	0,07	0,00	0,00	0,00	0.00	0,00	0,00	0.00	0.00
6						1,00	0,72	0,93	0,74	0,59	0,58	0,23	0,14	0,08	0,03	0,00	0,00	0,00	0,00	0.00	0.00
7							1,00	0,91	[illegible]	0,51	0,52	0,20	0,11	0,05	0,03	0,00	0,00	0,00	0,00	0.00	0.00
8								1,00	0,36	0,47	0,48	0,18	0,10	0,05	0,03	0,00	0.00	0,00	0,00	0.00	0.00
9									1,00	0,70	0,64	0,27	0,18	0,13	0,08	0,00	0,00	0,00	0,00	0.00	0.00
10										1,00	0,92	0,45	0,28	0,21	0,10	0,00	0,00	0,00	0,00	0.00	0.00
11											1,00	0,45	0,29	0,21	0,10	0,00	0,00	0,00	0,00	0.00	0.00
12												1,00	0,30	0,85	0,53	0,42	0,18	0,17	0.19	0.21	0.00
13													1,00	0,71	0,67	0,39	0,15	0,19	0.18	0.20	0.00
14														1,00	0,65	0,42	0,17	0,19	0.20	0.22	0.00
15															1,00	0,71	0,62	0,60	0.26	0.16	0.27
16																1,00	0,82	0,92	0.25	0.14	0.30
17																	1,00	0,83	0.17	0.00	0.42
18																		1,00	0.35	0.19	0.43
19																			1.00	0.92	0.37
20																				1.00	0.00
21																					1.00

n,m		n,m		n,m	
1	0,1 - 0,3 keV	8	4,0 - 5,0 keV	15	0,75 - 1,5 MeV
2	0,3 - 0,4 keV	9	5,0 -10,0 keV	16	1,5 - 3,0 MeV
3	0,4 - 0,6 keV	10	10,0 -20,0 keV	17	3,0 - 5,0 MeV
4	0,6 - 0,8 keV	11	20,0 -30,0 keV	18	5,0 -12,0 MeV
5	0,8 - 1,0 keV	12	30,0 -110 keV	19	12,0 -14,0 MeV
6	1,0 - 2,0 keV	13	110 -350 keV	20	14,1 -15,0 MeV
7	2,0 - 4,0 keV	14	350 -750 keV	21	15,0 - 20,0 MeV

Table 2.3.

Matrix of coefficients of correlation between energy ranges B_{nm} with attributed correlations between errors

n.m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1,00	0,92	0,98	0,93	0,90	0,97	0,81	0,94	0,92	0,85	0,83	0,29	0,27	0,25	0,18	0,00	0,00	0,00	0,00	0,00	0,00
2		1,00	0,96	0,97	0,96	0,97	0,96	0,89	0,97	0,96	0,95	0,34	0,29	0,27	0,18	0,00	0,00	0,00	0,00	0,00	0,00
3			1,00	0,86	0,84	0,99	0,84	0,95	0,85	0,90	0,88	0,31	0,28	0,26	0,18	0,00	0,00	0,00	0,00	0,00	0,00
4				1.00	1,00	0,89	1,00	0,91	0,99	0,93	0,83	0,28	0,23	0,24	0,17	0,00	0,00	0,00	0,00	0,00	0.00
5					1,00	0,88	1,00	0.90	0,93	0,92	0,92	0,27	0,22	0,24	0,17	0,00	0,00	0,00	0.00	0.00	0,00
6						1.00	[illegible]	0,96	0,88	0,92	0,91	0,32	0,28	0,26	0,19	0,00	0,00	0,00	0.00	0,00	0.00
7							1,00	0,91	0,99	0,89	0,89	0,28	0,22	0,24	0,17	0,00	0,00	0,00	0,00	0,00	0.00
8								1,00	0,90	0,94	0,93	0,29	0,25	0,24	0,13	0,00	0,00	0,00	0,00	0,00	0,00
9									1,00	0,83	0,93	0,29	0,23	0,26	0,18	0,01	0,00	0,01	0,01	0.01	0,01
10										1,00	[illegible]	0.35	0,28	0,27	0,16	0,00	0,00	0,00	0,00	0,00	0,00
11											1,00	[illegible]	0,27	0,26	0,17	0,00	0,00	0,00	0,00	0,00	0,00
12												1,00	0,77	0,89	0,52	0,60	0,37	0,33	0,27	0,28	0,14
13													1,00	0,71	0,71	0,48	0.30	0,29	0,22	0,23	0,12
14														1,00	0,70	0,52	0,37	0,36	0,29	0,30	0,16
15															1,00	0,82	0,68	0,73	0,37	0,28	0,41
16																1,00	0,84	0,84	0,32	0,23	0,39
17																	1,00	0,87	0,25	0,10	0,43
18																		1.00	0.37	0.24	0.51
19																			1.00	0.94	0.45
20																				1,00	0,15
21																					1.00

Table 2.4.

Matrix of coefficients of correlation between energy ranges B_{nm} with full correlation between errors

n,m	I	2	3	4	5	6	7	8	9	I0	II	I2	I3	I4	I5	I6	I7	I8	I9	20	21
I	I,00	0,93	0,98	0,88	0,88	0,98	0,88	0,96	0,86	0,90	0,88	0,56	0,47	0,5I	0,64	0,58	0,64	0,64	0,70	0,39	0,93
2		I,00	0,98	0,94	0,94	0,98	0,94	0,97	0,93	0,99	0,96	0,68	0,52	0,62	0,55	0,50	0,55	0,55	0,72	0,44	0,88
3			I,00	0,95	0,95	0,I0	0,95	0,95	0,93	0,97	0,95	0,68	0,55	0,62	0,64	0,57	0,64	0,64	0,75	0,46	0,94
4				I,00	I,00	0,93	I,00	0,9I	0,99	0,96	0,95	0,83	0,74	0,74	0,73	0,64	0,75	0,75	0,83	0,60	0,92
5					I,00	0,93	I,00	0,9I	0,99	0,96	0,95	0,83	0,74	0,74	0,73	0,64	0,75	0,75	0,83	0,60	0,92
6						I,00	0,93	0,95	0,92	0,96	0,94	0,66	0,52	0,6I	0,64	0,59	0,64	0,64	0,74	0,44	0,23
7							I,00	0,9I	0,99	0,96	0,95	0,83	0,74	0,74	0,73	0,64	0,75	0,75	0,83	0,60	0,92
8								I,00	0,89	0,98	0,86	0,68	0,6I	0,60	0,77	0,69	0,79	0,79	0,76	0,48	0,97
9									I,00	0,96	0,94	0,83	0,73	0,74	0,72	0,64	0,74	0,74	0,8I	0,58	0,90
I0										I,00	0,97	0,77	0,59	0,70	0,6I	0,54	0,6I	0,6I	0,75	0,50	0,88
II											I,00	0,9I	0,63	0,75	0,64	0,59	0,63	0,63	0,85	0,64	0,83
I2												I,00	0,87	0,96	0,77	0,74	0,78	0,78	0,87	0,84	0,62
I3													I,00	0,8I	0,83	0,76	0,85	0,85	0,76	0,73	0,57
I4														I,00	0,79	0,8I	0,76	0,75	0,85	0,96	0,49
I5															I,00	0,97	0,99	0,99	0,8I	0,72	0,66
I6																I,00	0,93	0,93	0,72	0,74	0,54
I7																	I,00	I,00	0,8I	0,70	0,70
I8																		I,00	0,8I	0,70	0,70
I9																			I,00	0,92	0,68
20																				I,00	0,36
2I																					I,00

Table 2.5.

Estimated values of $\sigma_f(^{235}U)$ and errors in estimated data with and without use of correlations for optimum weights

Energy, keV	$\sigma_f(^{235}U)$, barn	Errors $\Delta\sigma_f$, %		
		K=0	K	K=1
I	2	3	4	5
0,I - 0,2	20,7I	I,44	3,08	3,22
0,2 - 0,3	20,I9			
0,3 - 0,4	I2,88	I,68	3,24	3,44
0,4 - 0,5	I3,34	I,50	3,I6	3,39
0,5 - 0,6	I4,69			
0,6 - 0,7	II,20	I,87	3,70	4,27
0,7 - 0,8	I0,80			
0,8 - 0,9	7,92	I,9I	3,7I	4,27
0,9 - I,0	7,34			
I,0 - 2,0	7,I0	I,42	3,I5	3,39
2,0 - 3,0	5,27	I,68	3,7I	4,27
3,0 - 4,0	4,73			
4,0 - 5,0	4,I5	I,55	3,35	3,80
5,0 - 6,0	3,70	I,69	3,94	4,58
6,0 - 7,0	3,3I			
7,0 - 8,0	3,26			
8,0 - 9,0	2,89			
9,0 - I0	3,03			
I0 - 20	2,44	2,02	3,56	3,82
20 - 30	2,I0	2,05	3,70	4,07
30 - 40	2,00	I,25	I,57	2,65
40 - 50	I,9I5			
50 - 60	I,823			
60 - 70	I,749			
70 - 80	I,677			
80 - 90	I,6I7			
90 - I00	I,575			
I00	I,555	I,II	I,25	I,99
II0	I,545			

Table 2.5 (continued)

I	2	3	4	5
I20	I,522			
I30	I,50I			
I40	I,478			
I50	I,458			
I60	I,438			
I70	I,4I9			
I80	I,399			
I90	I,380			
200	I,366			
220	I,336			
240	I,3II			
260	I,289			
280	I,270			
300	I,250			
320	I,233			
340	I,22I			
360	I,2I5	I,2I	I,45	2,57
380	I,2I4			
400	I,2I2			
450	I,I9I			
500	I,I66			
550	I,I46			
600	I,I28			
650	I,II3			
700	I,I05			
750	I,I04	0,83	I,00	I,53
800	I,II7			
850	I,I44			
900	I,I20			
950	I,204			
I000	I,2I5			
I,I MeV	I,220			
I,2	I,226			
I,4	I,239			

Table 2.5 (continued)

I	2	3	4	5
I,6	I,258	0,92	I,02	I,30
I,8	I,276			
2,0	I,284			
2,5	I,248			
3,0	I,205			
3,5	I,I77			
4,0	I,I47			
4,5	I,II7			
5,0	I,087	I,27	I,39	I,7I
5,5	I,052			
6,0	I,I39			
6,5	I,386			
7,0	I,600			
7,5	I,755			
8,0	I,820			
8,5	I,824			
9,0	I,8I2			
9,5	I,800			
I0,0	I,786			
II,0	I,770			
I2,0	I,768	I,I0	I,I3	I,73
I3,0	I,922			
I4,I	2,07I	3,40	3,43	3,64
I5,0	2,I08			

Table 3.1. Optimized weights of experimental findings in absence of correlations (K=0), attributed correlation (K) and total correlation (K=1)

Reference	E, keV																	
	0,I - 0,2			0,2 - 0,3			0,3 - 0,4			0,4 - 0,5			0,5 - 0,6			0,6 - 0,7		
	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I
[3] Gwin	0,289	0,443	I,000	0,269	0,368	I,000	0,270	0,370	I,000	0,29I	0,425	I,000	0,298	0,4I7	I,000	0,287	0,407	I,000
[17] De Saussure	0,250	0,382	0,000	0,234	0,202	0,000	0,225	0,I94	0,000	0,275	0,39I	0,000	0,263	0,369	0,000	0,26I	0,370	0,000
[29] Perez	0,I98	0,000	0,000	0,I80	0,I56	0,000	0,I88	0,I62	0,000	0,I99	0,000	0,000	0,203	0,000	0,000	0,207	0.000	0.000
[41] Czirr	0,I00	0,000	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
[42] Corvi	-	-	-	0,III	0,096	0,000	0,II3	0,098	0,000	0,I2I	0,I55	0,000	0,I23	0,I72	0,000	0,I25	0,I77	0.000
[43] Muradyan	0,095	0,I74	0,000	0,086	0,074	0,000	0,030	0,078	0,000	-	-	-	-	-	-	-	-	-
[44] Kurov	0,056	0,000	0,000	0,05I	0,044	0,000	0,054	0,046	0,000	0,056	0,000	0,000	0,057	0,000	0,000	0,058	0,000	0,000
[21] Van Shi-Di	0,0I2	0,00I	0,000	0,025	0,02I	0,000	0,022	0,0I9	0,000	0,027	0,000	0,000	0,029	0,00I	0,000	0,033	0,00I	0,000
[52] Bluhm	-	-	-	0,044	0,039	0,000	0,038	0,033	0,000	0,03I	0,029	0,000	0,027	0,04I	0,000	0,029	0,015	0.000

Reference	E, keV																	
	0,7 - 0,8			0,8 - 0,9			0,9 - I,0			I - 2			2 - 3			3 - 4		
	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I
[3] Gwin	0,287	0,425	I,000	0,292	0,396	I,000	0,306	0,42I	I,000	0,238	0,357	0,000	0,I28	0,I54	0,000	0,289	0.338	0.055
[17] De Saussure	0,269	0,387	0,000	0,282	0,382	0,000	0,266	0,366	0,000	0,248	0,372	I,000	0,243	0,29I	0,537	-	-	-
[29] Perez	0,207	0,002	0,000	0,2I9	0,000	0,000	0,224	0,008	0,000	0,I44	0,000	0,000	0,I43	0,034	0,000	0,326	0,4I3	0,649
[41] Czirr	-	-	-	-	-	-	-	-	-	0,098	0,000	0,000	0,09I	0,022	0,000	0,256	0.165	0.296
[42] Corvi	0,119	0,I55	0,000	0,I27	0,172	0,000	0,I28	0,I76	0,000	0,II4	0,028	0,000	-	-	-	-	-	-
[43] Muradyan	-	-		-	-		-	-	-	0,063	0,I3I	0,000	0,059	0,070	0,000	-	-	-
[44] Kurov	0,056	0,000	0,000	0,0II	0,000	0,000	0,0I3	0,000	0,000	0,042	0,006	0,000	0,047	0,000	0,000	0,063	0,041	0,000
[21] Van Shi-Di	0,034	0,004	0,000	0,036	0,001	0,000	0,037	0,00I	0,000	0,03I	0,004	0,000	0,032	0,002	0,000	0,024	0,0I5	0,000
[52] Bluhm	0,028	0,027	0,000	0,033	0,049	0,000	0,026	0,028	0,000	0,022	0,032	0,000	0,0I8	0,0I5	0,000	0.042	0,028	0.000
[45] Dvukhsherstnov	-	-	-	-	-		-	-		-	-	-	0,239	0,412	0,463	-	-	-

Reference	E, keV																	
	4 - 5			5 - 6			6 - 7			7 - 8			8 - 9			9 - I0		
	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I
[3] Gwin	0,394	0,507	0,862	0,406	0,496	I,000	0,260	0,257	0,008	0,42I	0,496	0,840	0,383	0,452	I,000	0,366	0,427	I,000
[29] Perez	0,297	0,336	0,I38	-	-	-	0,350	0,346	0,992	0,333	0,344	0,I60	0,I53	0,I73	0,000	0,267	0,337	0,000
[41] Czirr	0,I20	0,06I	0,000	0,26I	0,279	0,000	0,I36	0,I35	0,000	0,I00	0,065	0,000	0,I57	0,I27	0,000	0,II8	0,076	0,000
[44] Kurov	0,094	0,048	0,000	0,I42	0,096	0,000	0,092	0,09I	0,000	0,023	0,0I5	0,000	0,047	0,038	0,000	0,0I3	0,008	0,000
[21] Van Shi-Di	0,06I	0,03I	0,000	0,068	0,046	0,000	0,074	0,073	0,000	0,023	0,0I5	0,000	0,043	0,035	0,000	0,037	0,024	0,000
[51] Vorotnikov	-	-	-	0,052	0,035	0,000	0,047	0,047	0,000	0,059	0,038	0,000	0,088	0,07I	0,000	0,083	0,053	0,000
[52] Bluhm	0,034	0,0I7	0,000	0,07I	0,048	0,000	0,04I	0,05I	0,000	0,04I	0,027	0,000	0,039	0,032	0,000	0,036	0,024	0,000
[50] Bandl	-	-	-	-	-	-	-	-	-	-	-	-	0,090	0,072	-	0,090	0,05I	-

Reference	E, keV																	
	I0 - 20			20 - 30			30 - 40			40 - 50			50 - 60			60 - 70		
	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I
[3] Gwin	0,405	0,536	I,000	0,I7I	0,294	0,43I	0,220	0,520	0,454	0,I54	0,280	0,I93	0,I97	0,404	0,44I	0,283	0,432	0,470
[42] Corvi	0,I68	0,24I	0,000	0,073	0,I9I	0,000	-	-	-	-	-	-	-	-	-	-	-	-
[44] Kurov	0,062	0,032	0,000	0,04I	0,030	0,000	-	-	-	-	-	-	-	-	-	-	-	-
[21] Van Shi-Di	0,048	0,025	0,000	0,023	0,0I6	0,000	-	-	-	-	-	-	-	-	-	-	-	-
[46] Lottin	-	-	-	0,I47	0,I00	0,244	0,23I	0,I42	0,546	0,225	0,390	0,807	0,2I0	0,028	0,472	0,260	0,050	0,000
[47] Hopkins	-	-	-	0,II9	0,08I	0,000	-	-	-	-	-	-	0,I82	0,265	0,000	-	-	-
[48] Weston	-	-	-	0,085	0,058	0,000	0,I3I	0,08I	0,000	0,I58	0,000	0,000	0,II6	0,000	0,000	0,I63	0,03I	0,000
[49] Poletaev	0,06I	0,032	0,000	0,I03	0,070	0,000	0,206	0,I27	0,000	0,228	0,320	0,000	0,207	0,303	0,087	0,294	0,487	0,530
[50] Bandl	0,I02	0,053	0,000	0,058	0,039	0,000	0,890	0,055	0,000	0,I05	0,0I0	0,000	0,088	0,000	0,000	-	-	-
[51] Vorotnikov	0,I54	0,08I	0,000	0,I80	0,I2I	0,325	0,I22	0,075	0,000	0,I30	0,000	0,000	-	-	-	-	-	-

Reference	E, keV																	
	70 - 80			90 - I00			I00 - 200			200			250			300		
	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I
[3] Gwin	0,2I9	0,254	0,244	0,306	0,259	0,09I	0,044	0,040	0,000	-	-	-	-	-	-	-	-	-
[46] Lottin	0,284	0,234	0,000	-	-	-	-	-	-	0,7I8	0,994	I,000	-	-	-	0,440	0,654	I,000
[48] Weston	0,I78	0,I48	0,000	0,694	0,74I	0,909	0,I58	0,007	0,000	0,282	0,006	0,000	0,387	0,3II	0,000	0,234	0,000	0,000
[49] Poletaev	0,3I9	0,364	0,756	-	-	-	0,250	0,325	0,226	-	-	-	-	-	-	0,326	0,346	0,000
[45] Dvukhsherstnov	-	-	-	-	-	-	0,I44	0,294	0,I60	-	-	-	-	-	-	-	-	-
[47] Hopkins	-	-	-	-	-	-	0,260	0,334	0,6I4	-	-	-	0,6I3	0,689	I,000	-	-	-
[51] Vorotnikov	-	0,000	0,000	-	-	-	0,I44	0,000	0,000	-	-	-	-	-	-	-	-	-

Reference	E, keV																	
	400			500			600			750			900			I000		
	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I	K=0	K	K=I
[46] Lottin	0,3I8	0,3I4	0,767	0,585	0,604	0,992	0,425	0,473	0,050	-	-	-	-	-	-	-	-	-
[47] Hopkins	0,30I	0,298	0,233	-	-	-	0,450	0,527	0,950	0,63I	0,689	I,000	0,624	0,654	I,000	0,66I	0,7I9	I,000
[48] Weston	0,I60	0,I58	0,000	-	-	-	0,I25	0,000	0,000	-	-	-	-	-	-	-	-	-
[49] Poletaev	0,22I	0,230	0,000	0,4I5	0,336	0,008	-	-	-	0,369	0,3II	0,000	0,376	0,346	0,000	0,339	0,28I	0,000

Table 3.2 Estimated values of α (^{235}U) and errors in the evaluation using optimized weights in absence of correlation (K = 0), attributed correlation (K) and full correlation (K = 1)

Range No.	Energy, keV	α_{est}			Error in evaluation, %		
		K=0	K	K=1	K=0	K	K=1
1	0,1 - 0,2	0,61	0,63	0,63	3,52	5,21	6,54
2	0,2 - 0,3	0,47	0,46	0,46	3,36	5,25	6,48
3	0,3 - 0,4	0,52	0,52	0,52	3,43	5,31	6,60
4	0,4 - 0,5	0,36	0,36	0,35	3,55	5,32	6,57
5	0,5 - 0,6	0,30	0,31	0,29	3,57	5,37	6,55
6	0,6 - 0,7	0,41	0,41	0,42	3,59	5,41	6,71
7	0,7 - 0,8	0,43	0,44	0,45	3,57	5,38	6,67
8	0,8 - 0,9	0,50	0,52	0,51	3,71	5,44	6,86
9	0,9 - 1,0	0,64	0,66	0,68	3,74	5,51	6,76
10	1 - 2	0,40	0,43	0,43	3,49	5,30	6,98
11	2 - 3	0,39	0,41	0,39	3,47	4,72	6,77
12	3 - 4	0,34	0,34	0,30	5,23	7,24	8,84
13	4 - 5	0,36	0,36	0,37	4,96	6,76	7,86
14	5 - 6	0,34	0,34	0,38	7,05	8,65	11,00
15	6 - 7	0,39	0,39	0.36	5,42	7,47	9,17
16	7 - 8	0,41	0,41	0,43	5,28	6,91	8,10
17	8 - 9	0,45	0,46	0,51	5,21	7,22	8,43
18	9 - 10	0,39	0,40	0,42	4,99	6,98	8,24
19	10 - 15	0,39	0,40	0,39	7,36	8,66	12,06
20	15 - 20	0,38	0,37	0,36	6,64	10,13	12,69
21	10 - 20	0,40	0,40	0,40	5,31	7,07	8,35
22	20 - 25	0,37	0,36	0,36	6,54	7,83	9,60
23	25 - 30	0,35	0,35	0,35	7,32	10,41	12,30
24	20 - 30	0,37	0,38	0,39	3,68	6,56	8,35
25	30 - 40	0,37	0,37	0,37	4,56	8,14	8,84
26	40 - 50	0,35	0,35	0,35	4,69	8,25	9,30
27	50 - 60	0,33	0,32	0,32	4,30	7,58	8,75
28	60 - 70	0,31	0,30	0,29	5,13	7,96	8,70
29	70 - 90	0,31	0,31	0,29	5,32	8,40	9,14
30	90 - 100	0,29	0,29	0,30	10,41	11,30	12,40
31	100 - 200	0,24	0,23	0,23	5,25	7,52	10,13
32	200	0,23	0,25	0,25	8,46	9,99	9,99
33	250	0,20	0,20	0,21	8,69	10,18	11,10
34	300	0,20	0,21	0,22	6,62	9,39	9,99
35	400	0,16	0,16	0,16	5,87	9,11	10,38
36	500	0,16	0,15	0,15	7,95	9,68	10,39
37	600	0,13	0,14	0,14	7,37	9,49	10,97
38	750	0,13	0,13	0,13	8,54	9,75	11,75
39	900	0,10	0,10	0,10	9,74	10,84	12,34
40	1000	0,086	0,086	0,087	8,91	11,27	12,63

<u>Table 4.1</u> Estimated values of $\alpha(^{239}Pu)$ and errors in the evaluation using optimized weights in absence of correlation (K = 0), attributed correlation (K) and full correlation (K = 1)

Range No.	Energy, keV	α_{est}			Error in evaluation, %		
		K=0	K	K=I	K=0	K	K=I
1	0,I - 0,2	0,857	0,853	0,871	3,07	5,43	6,36
2	0,2 - 0,3	0,929	0,932	0,929	3,03	5,37	6,II
3	0,3 - 0,4	I,I6I	I,127	I,150	3,I6	5,5I	6,43
4	0,4 - 0,5	0,488	0,446	0,426	3,7I	5,64	6,33
5	0,5 - 0,6	0,728	0,717	0,718	3,30	5,56	6,40
6	0,6 - 0,7	I,524	I,553	1,488	3,I3	5,54	6,44
7	0,7 - 0,8	0,962	0,932	0,890	3,I5	5,63	6,40
8	0,8 - 0,9	0,804	0,796	0,790	3,45	5,66	6,46
9	0,9 - I,0	0,7I7	0,693	0,675	3,47	5,56	6,36
10	I - 2	0,886	0,849	0,802	3,38	6,05	7,I0
II	2 - 3	I,044	I,008	0,972	3,47	6,03	7,I5
12	3 - 4	0,8I8	0,794	0,738	3,67	5,90	7,I8
13	4 - 5	0,852	0,843	0,83I	3,56	5,92	7,22
14	5 - 6	0,812	0,843	0,807	3,7I	6,I3	7,I9
15	6 - 7	0,794	0,773	0,745	3,76	6,07	7,II
16	7 - 8	0,642	0,640	0,642	3,82	6,26	II,90
17	8 - 9	0,559	0,552	0,537	3,76	6,I6	II,57
18	9 - I0	0,600	0,603	0,606	3,88	6,I2	II,95
19	I0 -I5	0,5I5	0,518	0,447	6,53	8,33	I4,85
20	15 - 20	0,446	0,445	0,4I9	7,27	8,81	I5,75
21	10 - 20	0,473	0,476	0,486	4,22	6,08	II,03
22	20 - 30	0,356	0,356	0,350	4,68	7,I6	I3,07
23	30 - 40	0,288	0,286	0,282	5,63	8,59	12,38
24	40 - 50	0,256	0,257	0,243	5,66	8,42	I2,36
25	50 - 60	0,225	0,225	0,225	6,55	8,6I	13,2I
26	60 - 70	0,I96	0,I97	0,193	7,48	8,93	13,00
27	70 - 80	0,I78	0,I77	0,I72	8,00	9,3I	14,26
28	80 - 90	0,213	0,214	0,220	II,98	I3,67	16,52
29	90 - I00	0,I49	0,I49	0,I45	12,I2	I3,01	19,56
30	100 - 200	0,I4I	0,I4I	0,I39	8,45	9,82	14,77
31	250	0,I06	0,106	0,I06	I6,74	I6,74	16,74
32	300	0,II6	0,II6	0,II9	II,77	I3,08	16,25
33	400	0,0852	0,0856	0,0890	9,45	II,I7	15,80
34	500	0,0784	0,078I	0,0690	I3,24	I4,54	18,39
35	600	0,0558	0,056I	0,0650	I5,09	I5,83	20,66
36	750	0,0670	0,0674	0,0800	I6,70	I7,44	23,12
37	900	0,0378	0,0378	0,0372	25,03	25,55	33,34
38	1000	0,0270	0,0270	0,0270	25,95	25,95	25,95

Table 5.1 Estimated values of $\sigma_f(^{239}Pu)$

E, keV	$\frac{\sigma_f(^{239}Pu)}{\sigma_f(^{235}U)}$	$\sigma_f(^{239}Pu)$ barn	E, MeV	$\frac{\sigma_f(^{239}Pu)}{\sigma_f(^{235}U)}$	$\sigma_f(^{239}Pu)$ barn
0,I - 0,2		I8,22	0,25	I,I554	I,502
0,2 - 0,3		I7,50	0,30	I,2090	I,5I0
0,3 - 0,4		8,56	0,40	I,2822	I,554
0,4 - 0,5		9,46	0,50	I,36I9	I,588
0,5 - 0,6		I5,70	0,60	I,4I84	I,600
0,6 - 0,7		4,58	0,75	I,48I9	I,636
0,7 - 0,8		5,45	0,90	I,4458	I,706
0,8 - 0,9		5,I0	I,0	I,4230	I,729
0,9 - I,0		7,99	I,2	I,4943	I,832
I - 2		4,45	I,4	I,5464	I,9I6
2 - 3		3,3I	I,6	I,5476	I,947
3 - 4		3,05	I,8	I,5376	I,962
4 - 5		2,37	2,0	I,5296	I,964
5 - 6		2,35	2,5	I,5272	I,906
6 - 7		2,05	3,0	I,5386	I,854
7 - 8		2,II	3,5	I,5472	I,82I
8 - 9		2,20	4,0	I,5554	I,784
9 - I0		I,92	4,5	I,5685	I,752
I0 - 20	0,680	I,659	5,0	I,5823	I,720
20 - 30	0,738	I,550	5,5	I,6I4I	I,698
30 - 40	0,785	I,570	6,0	I,5540	I,770
40 - 50	0,826	I,582	6,5	I,4567	2,0I9
50 - 60	0,860	I,568	7,0	I,3500	2,I60
60 - 70	0,888	I,553	7,5	I,2650	2,220
70 - 80	0,9II	I,528	8,0	I,2396	2,256
80 - 90	0,932	I,507	8,5	I,2500	2,280
90 - I00	0,953	I,500	9,0	I,2655	2,293
I00	0,9697	I,508	9,5	I,2789	2,302
I20	0,99I5	I,509	I0,0	I,29I2	2,306
I40	I,0203	I,508	II,0	I,2893	2,282
I60	I,0473	I,506	I2,0	I,2557	2,220
I80	I,075I	I,504	I3,0	I,I8II	2,270
200	I,I000	I,503	I4,0	I,I294	2,330
			I5,0	I,II20	2,344

Table 6.1 Correlation matrix of the errors in $\alpha(^{235}U)$ and group-averaged constants for $\sigma_\gamma(^{235}U)$

E, keV	n	5	6	7	8	9	IO	II	I2	I3	I4	I5	I6	I7	Δd_{est}, %	$\sigma_{\gamma}(^{235}U)$ barn
800 - I400	5	I,00													I0,57	0,I00
400 - 800	6	0,89	I,00												8,95	0,I64
200 - 400	7	0,79	0,98	I,00											9,02	0,263
I00 - 200	8	0,90	0,80	0,75	I,00										7,52	0,333
46,5- I00	9	0,65	0,84	0,87	0,7I	I,00									8,30	0,552
21,5- 46,5	I0	0,63	0,82	0,84	0,69	0,98	I,00								7,40	0,732
I0- 2I,5	II	0,52	0,66	0,68	0,59	0,83	0,92	I,00							6,75	0,970
4,65- I0,0	I2	0,37	0,48	0,50	0,47	0,73	0,80	0,80	I,00						7,00	I,3I5
2,I5- 4,65	I3	0,33	0,42	0,44	0,48	0,65	0,7I	0,76	0,96	I,00					5,83	I,8I4
I,0 - 2,I5	I4	0,33	0,42	0,44	0,53	0,58	0,65	0,7I	0,8I	0,90	I,00				4,70	3,I22
0,465-I,0	I5	0,39	0,48	0,50	0,44	0,68	0,75	0,83	0,87	0,89	0,89	I,00			5,40	4,574
0,215-0,465	I6	0,38	0,48	0,50	0,44	0,66	0,73	0,80	0,84	0,88	0,94	0,97	I,00		5,20	7,500
0,I00-0,2I5	I7	0,39	0,49	0,50	0,44	0,66	0,7I	0,75	0,82	0,82	0,94	0,92	I,00	I,00	5,20	II,975

Table 6.2 Correlation matrix of the errors in $\alpha(^{239}Pu)$ and group-averaged constants for $\sigma_{\gamma}(^{239}Pu)$

E, keV	n	5	6	7	8	9	I0	II	I2	I3	I4	I5	I6	I7	Δd_{est}, %	$\sigma_{\gamma}(^{239}Pu)$ barn
800 - I400	5	I,00													20,63	0,047
400 - 800	6	0,84	I,00												I2,72	0,III
200 - 400	7	0,83	0,96	I,00											II,23	0,I63
100 - 200	8	0,67	0,67	0,68	I,00										9,8I	0,2I3
46,5- I00	9	0,25	0,46	0,45	0,8I	I,00									9,25	0,3II
21,5- 46,5	I0	0,32	0,59	0,59	0,76	0,94	I,00								7,53	0,484
10- 21,5	II	0,25	0,44	0,46	0,73	0,87	0,92	I,00							6,35	0,834
4,65 - 10,0	I2	0,I5	0,26	0,29	0,60	0,7I	0,7I	0,88	I,00						5,92	I,572
2,15 - 4,65	I3	0,I2	0,2I	0,23	0,60	0,70	0,66	0,83	0,98	I,00					5,90	2,709
1,0 - 2,15	I4	0,II	0,20	0,22	0,57	0,65	0,62	0,82	0,97	0,98	I,00				6,00	4,478
0,465- 1,0	I5	0,I0	0,I9	0,2I	0,59	0,68	0,63	0,8I	0,95	0,99	0,98	I,00			5,57	6,85I
0,215- 0,465	I6	0,I2	0,I9	0,2I	0,60	0,68	0,63	0,8I	0,94	0,98	0,96	I,00	I,00		5,67	II,3I6
0,100- 0,215	I7	0,I0	0,I9	0,2I	0,59	0,68	0,64	0,8I	0,92	0,96	0,94	0,99	I,00	I,00	5,65	I6,636

Table 6.3 Correlation matrix of errors and group-averaged constants for $\sigma_f(^{235}U)$

E, keV	n	I	2	3	4	5	6	7	8	9	10	I1	I2	I3	I4	I5	I6	I7	$\sigma_f(^{235}U)$ barn
6500 - I0500	I	I,00																	I,072
4000 - 6500	2	0,99	I,00																I,II7
2500 - 4000	3	0,83	0,83	I,00															I,200
I400 - 2500	4	0,82	0,82	0,82	I,00														I,266
800 - I400	5	0,64	0,64	0,62	0,7I	I,00													I,205
400 - 800	6	0,I8	0,I8	0,I7	0,42	0,65	I,00												I,I46
200 - 400	7	0,I8	0,I8	0,I6	0,4I	0,66	0,79	I,00											I,274
100 - 200	8	0,I8	0,I9	0,I5	0,39	0,67	0,7I	0,86	I,00										I,470
46,5 - I00	9	0,I7	0,I7	0,I8	0,42	0,53	0,68	0,82	0,80	I,00									I,7I8
2I,5 - 46,5	I0	0,08	0,08	0,09	0,2I	0,32	0,53	0,53	0,54	0,72	I,00								2,0II
I0 - 2I,5	II	0,00	0,00	0,00	0,00	0,I0	0,2I	0,24	0,28	0,45	0,72	I,00							2,444
4,65 - I0,0	I2	0,00	0,00	0,00	0,00	0,06	0,09	0,I2	0,I4	0,22	0,48	0,69	I,00						3,373
2,15 - 4,65	I3	0,00	0,00	0,00	0,00	0,03	0,05	0,08	0,I5	0,I9	0,46	0,65	0,9I	I,00					4,862
1,0 - 2,I5	I4	0,00	0,00	0,00	0,00	0,03	0,06	0,09	0,I2	0,22	0,46	0,66	0,85	0,88	I,00				6,927
0,465 - I,0	I5	0,00	0,00	0,00	0,00	0,00	0,03	0,06	0,09	0,I5	0,39	0,57	0,8I	0,83	0,82	I,00			II,I33
0,215 - 0,465	I6	0,00	0,00	0,00	0,00	0,00	0,04	0,08	0,II	0,2I	0,49	0,70	0,77	0,80	0,82	0,87	I,00		I6,I43
0,100 - 0,2I5	I7	0,00	0,00	0,00	0,00	0,00	0,04	0,06	0,09	0,I8	0,34	0,50	0,76	0,78	0,84	0,8I	0,90	I,00	20,578

Table 6.4 Correlation matrix of errors and group-averaged constants for $\sigma_f(^{239}Pu)$

E, keV	n	2	3	4	5	6	7	8	9	I0	II	I2	I3	I4	I5	I6	I7	$\sigma_f(^{239}Pu)$, barn
4000 - 6500	2	I,00																I,753
2500 - 4000	3	0,79	I,00															I,848
1400 - 2500	4	0,76	0,80	I,00														I,947
800 - 1400	5	0,7I	0,72	0,88	I,00													I,774
400 - 800	6	0,73	0,58	0,74	0,93	I,00												I,599
200 - 400	7	0,70	0,54	0,72	0,90	0,94	I,00											I,5I4
I00 - 200	8	0,67	0,49	0,69	0,87	0,94	0,97	I,00										I,507
46,5 - 100	9	0,70	0,52	0,64	0,84	0,90	0,94	0,96	I,00									I,54I
21,5 - 46,5	I0	0,70	0,52	0,64	0,84	0,90	0,94	0,96	0,99	I,00								I,562
I0,0 - 2I,5	II	0,49	0,5I	0,48	0,68	0,68	0,70	0,72	0,73	0,73	I,00							I,643
4,65 - I0,0	I2	0,II	0,I3	0,I0	0,36	0,37	0,40	0,44	0,44	0,44	0,80	I,00						2,I80
2,I5 - 4,65	I3	0,00	0,00	0,00	0,I8	0,2I	0,25	0,28	0,26	0,26	0,68	0,86	I,00					3,00I
I,0 - 2,I5	I4	0,00	0,00	0,00	0,I8	0,2I	0,25	0,28	0,26	0,26	0,68	0,86	0,99	I,00				5,775
0,465 - I,0	I5	0,00	0,00	0,00	0,I2	0,I5	0,20	0,26	0,24	0,24	0,59	0,80	0,9I	0,9I	I,00			8,540
0,2I5 - 0,465	I6	0,00	0,00	0,00	0,I2	0,I5	0,20	0,26	0,24	0,24	0,50	0,80	0,90	0,90	0,99	I,00		I2,35I
0,I00 - 0,2I5	I7	0,00	0,00	0,00	0,I6	0,20	0,23	0,26	0,24	0,24	0,66	0,85	0,96	0,96	0,87	0,8I	I,00	I8,989

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