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STATUS OF THE ENERGY DEPENDENT $\bar{\nu}$-VALUES FOR THE HEAVY ISOTOPES (Z $\geqslant$90) FROM THERMAL TO 15 MEV, AND OF -VALUES FOR SPONTANEOUS FISSION

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Status of the energy dependent $\bar{\nu}$-values for the heavy isotopes (Z > 90) from thermal to 15 MeV, and of the $\bar{\nu}$-values for spontaneous fission

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ABSTRACT

A thorough compilation of all measurements published up to June 1972 on the energy dependent $\bar{\nu}$ -values for prompt and delayed fission neutrons, from thermal to 15 MeV, for the heavy isotopes with Z ≥ 90, as well as for the $\bar{\nu}$ values for spontaneous fission has been performed. This compilation includes not only the numerical data but also the essential physical information related to the measurements; i.e. method of measurement, type of detector and standard used, analysis and corrections carried out as well as errors considered. The experimental data have been renormalized to recommended standards. A weighted least squares orthogonal polynomial fitting analysis was applied to the renormalized data and "best fits" deduced for the energy dependence of the $\bar{\nu}_p$ values of each isotope. Tables of recommended values of $\bar{\nu}_p$ and $\bar{\nu}_t$ as a function of the incident neutron energy are included.

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I. INTRODUCTION

The average number of neutrons per fission, $\bar{\nu}$, and its energy dependence, are quantities of greatest importance for reactor calculations as well as for nuclear fission theory.

$\bar{\nu}$-values are closely related to the neutron multiplication and to the breeding capabilities of fast reactors, hence, it is important to establish the most accurate values of this quantity, particularly for the main fissile and fertile isotopes.

On the other hand, $\bar{\nu}$ values are also of interest because they are a measure of the average excitation energy, $\bar{E}_f^*$ left in the fission fragments immediately after fission, and recent studies have shown that they are strongly correlated with various parameters of the fissioning nucleus, such as A,Z and E_f, the total energy released in the fission process. Therefore a precise systematic knowledge of the average neutron yield both from spontaneous fission and from fission induced by thermal and fast neutrons can help in getting a clearer understanding of the fission process itself.

Finally the implementation of the Non-Proliferation Treaty and the development of safeguards techniques have enhanced nowadays the necessity of a precise knowledge of the energy dependence of the number of delayed neutrons per fission.

As a consequence of the above considerations several reviews or compilations were published during the last years dealing with this subject [1-5].

Recognizing the importance of this subject the Nuclear Data Section of the IAEA, during 1969 - 1970, carried out a critical review of the current status of the energy dependence of $\bar{\nu}$-values for the main fissile isotopes, and of the $\bar{\nu}$-values of several other nuclides used as standards. [6] The results were presented as a working paper at the IAEA Consultants Meeting on $\bar{\nu}$-values for fissile nuclei which took place at Studsvik, Sweden, 10 - 11 June 1970.

The participants of this meeting recommended to the IAEA to continue its compilation effort on $\bar{\nu}$ along the lines of the paper of Konshin and Manero [6] and to take into consideration also the thermal $\bar{\nu}$-values and all those isotopes not yet covered in that paper.

Accordingly a thorough compilation of all experimental $\bar{\nu}$ data published up to June 1972 was made, which includes - in addition to an analysis of the present situation on the thermal $\bar{\nu}_t$ values for the fissile isotopes and of $\bar{\nu}_t$ for the spontaneous fission of ^{252}Cf - the thermal values for all those isotopes not considered in the review of Hanna et al [1], the energy-dependent $\bar{\nu}$ values for prompt and delayed fission neutrons up to an energy of 15 MeV for all isotopes with $Z \geqslant 90$, $\bar{\nu}$ values for resonance fission and $\bar{\nu}$ values for spontaneous fission.

Although similar studies have been performed several times previously [1 - 5], the latest one being that of Davey [60], the present work represents an improvement in the following aspects:

1. It gives a coverage on $\bar{\nu}$ experimental values, which was until now not attained by any other publication, not only because it includes the latest published data but also due to the wider range of subjects treated.

2. A detailed analysis is presented on the present situation of the $\bar{\nu}_t$ values for thermal fission of the fissile isotopes and for the spontaneous fission of ^{252}Cf, which are normally used as standards.

3. The use of a weighted least-squares orthogonal polynomial fitting procedure has allowed an analysis of the experimental data on a purely statistical basis and the deduction of smooth, non-linear fits of the energy-dependent $\bar{\nu}_p$ values for the main fissile isotopes in the energy range from thermal to 15 MeV.

4. Attention has been paid to the problem of the energy dependence of the delayed neutron yields.

5. The problem of the isotopic dependence of $\bar{\nu}$ for spontaneous fission was considered, and its correlation with the thermal $\bar{\nu}$ values analysed.

II. THE ABSOLUTE $\bar{\nu}$-VALUE FOR THE SPONTANEOUS FISSION OF ^{252}Cf

The absolute $\bar{\nu}$-value for the spontaneous fission of ^{252}Cf has a very important influence on the energy dependent $\bar{\nu}$-values for the fissile and fertile isotopes, due to the fact that it has been used as a standard in most of the measurements. Therefore an accurate knowledge of this parameter is needed, but, in spite of the efforts many scientists devoted to this problem, the knowledge of this parameter is far from being satisfactory.

The most recent and most thorough survey published on this problem is the review of Hanna et al.[1], who consider the absolute $\bar{\nu}_t$-value of ^{252}Cf in connection with the 2200 m/s fission parameters (σ_f, σ_γ, σ_a, α, and η) for ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu. The recommended values of this survey are deduced as weighted mean values of re-assessed experimental data through a multi-parameter least-square fitting procedure.

Table 1 reproduces the absolute values of $\bar{\nu}_t$ for ^{252}Cf taken into consideration by Hanna et al. [1] in their review, with the final value of DeVolpi replacing his provisional one. The value of Axton [13], which corresponds to measurements with an old californium sample loaned from EURATOM, and containing only about 30 % of ^{252}Cf, should be considered only as provisional [15]. Axton has re-started new measurements of this parameter with a new sample and the present status of his measurements is as follows [215]: "The results with the new sample appear to lie up to one per cent higher than those with the old sample, giving a value of $\bar{\nu}_t$ of about 3.72. It is planned to measure one more modern sample and to repeat the measurement of the old sample before issuing a final report and value. Also in progress is a comparison of the fission rate per mg of aliquots of the Cf sample, between the Bureau Central de Mesures Nucléaires of EURATOM and the National Physical Laboratory, Teddington. A similar attempt with Argonne National Laboratories, USA, has failed because of source design incompatibilities, and another one with the Research Institute of National Defence, Stockholm, because the gating system employed by this laboratory does not permit an absolute measurement of the fission rate of a sample." Axton expects that the uncertainty of his final result will be between 0.5 and 1.0 per cent, being predominantly systematic.

Boldemann [16,225] has also in progress an absolute measurement of the prompt number of fission neutrons, $\bar{\nu}_p$, for ^{252}Cf using the large liquid scintillator method. The final accuracy of the measurements will be of the order of 0.5 per cent or less. His result (although a few minor corrections have yet to be applied) should be of the order of 3.735, i.e. in agreement with the manganese bath results. He expects to have the final figures in about two months.

It should be mentioned finally that Soleilhac has planned also the measurement of $\bar{\nu}$ for ^{252}Cf [226].

An inspection of the mean values adopted by Hanna et al [1] for the different methods of measurement , as reproduced in Table 1, shows that the published experimental values can be grouped essentially into two sets of results, which differ by about 2% and which are strongly correlated with the methods of measurement. In fact, while the measurements performed with large liquid scintillators give values close to 3.80 neutrons per fission, the results depending on the boron pile and the manganese bath give for $\bar{\nu}_t$ an average value close to 3.70. This spread of values, of the order of three times the reported standard errors, exceeds those to be expected from a Gaussian distribution of statistical errors and cannot be explained by the remaining uncertainties in the several corrections applied to the experimental data, e.g. energy dependence of the neutron detector efficiencies, neutron escape and parasitic and resonance absorption.

This difference between the average value of the liquid scintillator measurements and that obtained from all the remaining absolute measurements have deserved a particular consideration. Two sources of errors have been pointed out as being possibly responsible for this discrepancy. One is the influence on the absolute value of $\bar{\nu}$ of the number of delayed γ-rays from the fission of ^{252}Cf. The other is the so-called "French effect " or dependence of the prompt pulse detection efficiency, $\varepsilon_{\gamma}(n)$, on the number of neutrons detected per fission [17, 18].

As suggested by Soleilhac [17], this effect, which seems to be dependent upon the size and bias of the liquid scintillator, would mean a very small correction to Hopkins' original measurements [8] - neutron efficiency 0.86 -, but a correction of about 1.1% for Asplund-Nilsson's results [7] (neutron efficiency 0.69). Condé et al.[219], who have studied the "French effect" for two different scintillator tanks, cylindrical and spherical, found an estimated correction of 0.6% to the Asplund-Nilsson ^{252}Cf $\bar{\nu}$-value, but they pointed out that the use of a gadolinium loaded scintillator instead of the cadmium-loaded one of Asplund-Nilsson [7] may cause some uncertainty in the application of their results to the previous absolute measurement. They also found out that for neutron efficiencies of the order of 97 - 99% the correction caused by this effect is negligible ($< 0.1\%$). On the other hand according to Mather [17], who repeated the measurements of Soleilhac, the correction to Asplund-Nilsson's results would in fact be less than 0.2%. This result of Mather seems to be confirmed by the measurements of Signarbieux et al. [216] who, in an investigation of possible systematic errors in the $\bar{\nu}$ measurements with a large Gd-loaded liquid scintillator, found that, contrary to their expectations, the experimental value of $\varepsilon_{\gamma}(n)$ for any number of emitted neutrons (i.e. the "French effect") is approximately constant and that the corrections due to this effect are only of the order of 0.1% on the neutron efficiency, ε_n , and therefore cannot explain the above-mentioned discrepancy. They suggested as another possible solution unidentified but nevertheless counted after-pulses or low energy delayed gamma rays.

The result of Signarbieux et al. [216] is in close agreement with the result of Boldeman [16], who in a recent investigation of the French effect found that the systematic error introduced into liquid scintillation measurements by the requirement of a scintillator pulse in coincidence with the fission pulse is only 0.14% for a neutron detection efficiency of 78%. This result confirms that the French effect seems unlikely to explain the existing discrepancy.

With regard to the delayed gamma rays from ^{252}Cf the only published results are those of Guy [19] and Ajitanand [20] for half-lives below 3.4 μs. Their measured yields per fission for the gamma ray of $\sim$383.5 keV, and 3.4 μs half-life, are respectively 0.0073 $\pm$ 0.006 and 0.0039 $\pm$ 0.0009, i.e. of the same order of magnitude as the values of Walton and Sund [21, 217] for ^{235}U and ^{239}Pu. In a recent unpublished measurement of the intensity of the delayed gamma rays accompanying the spontaneous fission of ^{252}Cf, Boldeman [16] has found, with the assumption of the half-lives of Sund and Walton [217], i.e. 3.4, 26.7, 54.0 and 80 μs, and for the same cascades of delayed gamma rays, yields per fission of 0.003, 0.0019, 0.0024 and 0.0034 respectively, which are slightly lower than the corresponding values for ^{235}U and ^{239}Pu. Thus, it can be concluded from these results and the calculations carried out by Hanna et al. [1] and by Boldeman [22] on this correction, that the influence of the delayed gamma rays is almost negligible, being only of the order of 0.2 - 0.3%, and therefore, cannot explain at all the 2 - 3% discrepancy of the published liquid scintillator measurements.

According to De Volpi [23], Hanna's fitted values of the thermal neutron yields for the fissile isotopes and of $\bar{\nu}_t^{sp}(^{252}\mathrm{Cf})$ deviate too much from their input weighted means because they depend strongly on the thermal η and α values for the fissile isotopes. This fact has caused De Volpi to perform a new review of the status of the 2200 m/s fission constants, which includes also the absolute $\bar{\nu}_t^{sp}(^{252}\mathrm{Cf})$ value, in which the points of departure are the acceptance of the more recent low measurements of the ^{233}U and ^{234}U half-lives and of higher weights for some $\bar{\nu}_t^{sp}(^{252}\mathrm{Cf})$ measurements. These hypotheses lead him to a different set of parameters, which differ by about 1% from Hanna's. In particular, by taking $\bar{\nu}_t^{sp}(^{252}Cf) = 3{,}731 \pm 0{,}008$ as input weighted mean of all the measurements without any previous clustering of data, he obtains as adjusted value $\bar{\nu}_t^{sp}(^{252}Cf) = 3{,}735 \pm 0{,}008$ which is 0,94% lower than the Hanna et al. published value [1].

In fact, the fitted values by Hanna et al. [1] suffer from the fact that the low half-lives and resulting high fission cross sections of the uranium isotopes had not yet been confirmed at the time of the review. An increase of the uranium fission cross sections will, through the least squares fitting programme, lower the fitted value of $\bar{\nu}_t^{sp}(^{252}Cf)$ by a few tenths of a percent [207].

The above considerations and the preliminary results of Axton [215] and of Boldeman [225] seem to support a value of $\bar{\nu}_t^{sp}(^{252}Cf)$ lower than that given in [1]. But, until the final results of the new absolute measurements in progress become available, and since a new revision of the thermal neutron constants for the fissile isotopes is also in progress and its results expected in the near future [207], we have adopted in the meantime for our review the value of Hanna et al. [1] as standard value for $\bar{\nu}_t^{sp}(^{252}Cf)$.

It should be pointed out that, in spite of the apparent high accuracy of the value of $\bar{\nu}_t^{sp}(^{252}Cf)$ adopted as standard, its actual uncertainty may be considered as large as $\pm$ 1.2% (namely $\sigma_{\bar{\nu}} = 0.047$), according to the spread in the experimental values. Such an uncertainty should be taken into consideration, therefore, in those measured $\bar{\nu}$ values in which $\bar{\nu}(^{252}Cf)$ was used as standard.

III. THERMAL $\bar{\nu}$-VALUES

1. Thermal $\bar{\nu}$-valu for the fissile isotopes ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu

The continuously increasing importance of the fast breeder reactors has moved to a second place the problem of the thermal parameters, but nevertheless the thermal $\bar{\nu}$-values for the fissile isotopes retain their importance, since they have been used as standard in a number of energy dependent measurements.

As in the case of the absolute $\bar{\nu}_t^{sp}(^{252}Cf)$-value, the most recent and complete published study on this subject is the survey of Hanna et al [1]. They considered the fissile isotopes ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu and we refer to this review for the pertinent bibliography.

After this publication some new results have been published, i.e. the measurements of Nesterov et al. [25] for ^{235}U and ^{239}Pu and of Jaffey et al. [26] for ^{241}Pu, all of them relative to $\bar{\nu}_p^{sp}(^{252}Cf)$. Their ra'.os to $\bar{\nu}_p^{sp}(^{252}Cf)$ agree well with those used in Hanna's review.

As already mentioned above, De Volpi [23] has recently reviewed the 2200 m/s parameters for the fissile isotopes. This study which includes the isotopes ^{233}U, ^{235}U and ^{239}Pu is based upon the following assumptions.

a) The acceptance by the reviewer of the more recently measured low values of the ^{233}U and ^{234}U alpha half-lives.

b) A lower absolute value for $\bar{\nu}_t^{sp}(^{252}Cf)$, with a weight in the fitting process similar to that given to the η and α values.

c) The acceptance of the same value for the product $\bar{\nu}_t \sigma_f = \eta \sigma_a = \eta(1 + \alpha)\sigma_f$, supported by experimental evidence, as that taken by Hanna et al. [1], with allowance for some alternative options for ^{233}U and ^{239}Pu.

The $\bar{\nu}_t$-values obtained by De Volpi are about 1% lower than those of Hanna et al. (which means a similar difference on the related parameters); they are reproduced together with those of Hanna et al. [1] in Table 2.

According to Lemmel [207], the main change in a new least-squares fit of the thermal neutron constants will be an increase of the fission cross-sections due to the new half-life values. Since the product $\bar{\nu}_t \sigma_f$ is rather accurately known (though it will not likely remain constant as De Volpi assumes), an increase in σ_f will result in a decrease of $\bar{\nu}_t$, but it is felt that the change in $\bar{\nu}_t$ is likely not to exceed a few tenths of a percent.

As in the case of $\bar{\nu}_t^{sp}(^{252}Cf)$ the values adopted in this review for the thermal neutron yields of the fissile isotopes are those of Hanna et al. [1].

2. Thermal $\bar{\nu}$-values for the remaining isotopes

The available experimental data for the thermal $\bar{\nu}$-values of the remaining isotopes are very scarce. Almost the whole information is contained in the papers of Jaffey and Lerner [26], and of Zamyatnin et al. [27]. The former authors have measured the prompt neutron yield of ^{232}U, ^{238}Pu, ^{241}Pu, ^{241}Am, ^{242m}Am, ^{243}Cm and ^{245}Cm relative to the prompt thermal $\bar{\nu}$-values of ^{233}U, ^{235}U and ^{239}Pu. In some cases $\bar{\nu}_p^{sp}$ (^{252}Cf) was used also as standard. They used an ionization chamber with an efficiency close to 100% to detect the fission fragments and four Hornyak buttons for detecting the fission neutrons. Their experimental values were corrected for each isotope for random coincidences, neutron-detector drift, isotopic impurities and variation of the counting efficiency with the neutron fission spectrum. Zamyatnin et al. [27] have measured by the time-of-flight method the thermal values of ^{229}Th, ^{238}Pu, ^{242m}Am, ^{245}Cm and ^{249}Cf. The measurements were made relative to ^{235}U assuming $\bar{\nu}_p^{th}$ (^{235}U) = 2.426. The average number of fission neutrons was determined by integrating the measured prompt neutron spectra below 7 MeV. These were determined by the time-of-flight method using a gas-filled scintillation chamber to detect fission fragments and plastic detectors and ^{6}Li-scintillation counters for recording fission neutrons.

We should mention also the measurements of Lebedev and Kalashnikova [28,29] for ^{229}Th and ^{241}Am, relative to $\bar{\nu}_p^{th}$ (^{235}U). They used BF_3 counters embedded in paraffin to detect the fission neutrons and a ionization chamber as fission fragments detector.

We also have the results of Fultz et al. [30] for ^{242}Am, relative to $\bar{\nu}_p^{sp}$ (^{252}Cf), obtained using a spark-chamber as fission detector and 48 high-pressure $B^{10}F_3$ counters embedded in paraffin as fission neutron detector, and the value of von Gunten et al. [31] for ^{245}Cm, deduced from the mass distribution fission yield.

Finally, we have the measurements of Volodin et al. [63], who determined the prompt thermal neutron yield of ^{249}Cf relative to $\bar{\nu}_p$ for the spontaneous fission of ^{252}Cf. They used the method of coincidences. The neutron detector consisted of 24 ^{3}He counters in a paraffin block. The experimental values were corrected for true-coincidences losses and neutron fission spectra differences. In the same experiment an experimental evaluation of $\bar{\nu}_p$ for the spontaneous fission of ^{249}Cf was also obtained.

All the available experimental data have been renormalized to the adopted standards (see next paragraph) and are listed together with the authors' original values in Table 3.

IV. ADOPTED STANDARD $\bar{\nu}$-VALUES

As standards for renormalization of all the experimental values considered in this review, the total $\bar{\nu}$-values of Hanna et al. [1] have been used. As in that paper, the average prompt $\bar{\nu}$-values were deduced from them by substracting the delayed neutron yields given by Keepin et al. [32]. In all cases the errors quoted in our renormalized values do not include the existing uncertainties in the standards. The values used for renormalization were:

Table 4 - Standard $\bar{\nu}$-values

Isotope	$\bar{\nu}_t$	$\bar{\nu}_d$	$\bar{\nu}_p$
^{233}U (1)	2.4866	0.0066	2.480
^{235}U (1)	2.4229	0.0158	2.407
^{239}Pu (1)	2.8799	0.0061	2.874
^{252}Cf (2)	3.765	0.0086	3.756

(1) Thermal value (2) Spontaneous fission

V. PROMPT - $\bar{\nu}$ - VALUES FOR SPONTANEOUS FISSION

The only isotope of which the $\bar{\nu}$-value for spontaneous fission, $\bar{\nu}^{sp}$, was measured absolutely is ^{252}Cf. The $\bar{\nu}$-values for spontaneous fission of all the other isotopes were determined relative to the $\bar{\nu}$-value of another spontaneously fissionable isotope, mainly ^{252}Cf, or the thermal $\bar{\nu}$-value of ^{235}U. Therefore, the final $\bar{\nu}$-value of all the isotopes except ^{252}Cf depends strongly on the values adopted for the standards.

After ^{252}Cf, already considered in detail, the next best studied isotope has been ^{240}Pu, and in a third place ^{238}U, ^{242}Pu and ^{244}Cm. For all the remaining isotopes the knowledge of their $\bar{\nu}$ values for spontaneous fission relies upon the measurements carried out in two or three laboratories. Except for some old measurements for ^{238}U [144 - 148] and the recent measurements of Orth [52] for several isotopes, in which the $\bar{\nu}$-values for spontaneous fission were determined from separate measurements of the neutron and fission rates, all the other determinations of $\bar{\nu}$ were made by the coincidence technique. The neutron detectors used were, with the exception of the measurements of Crane [38], either $^{10}BF_3$-or ^{3}He-counters embedded in a moderator, or a large scintillator tank.

Table 5 includes all the presently available data on $\bar{\nu}_p$ for spontaneous fission. In some early experiments it is not clearly stated if $\bar{\nu}_p$ or $\bar{\nu}_t$ were measured. Since accuracy was relatively poor in these cases, no allowance was made for this distinction and the reported values were considered as $\bar{\nu}_p$.

Besides the authors' original values Table 5 lists the standards originally used and our renormalized values as well as the weighted average value in those cases in which more than one value is available. These average values have been plotted as a function of the mass-number A in Fig. 1.

The present situation for each one of the isotopes is as follows:

^{232}Th. Except for an early work of Pose [149] whioh gives for the average number of neutrons emitted by spontaneous fission a value of about 5.6, the only published value is that of Barclay et al.[33], who determined the spontaneous fission $\bar{\nu}_p$-value of thorium relative to that of uranium. They supposed that the spontaneous fission neutron yield was due only to the ^{238}U content. As fission neutron detector they used eight ^{10}B F_3 counters embedded in paraffin with a sensitivity of 1% as determined by a Ra-Be source. They assumed that the energy spectrum of the neutrons emitted by the two nuclides is approximately the same.

^{236}U. The only published value is that of Condé and Holmberg [34], relative to ^{252}Cf. They measured it together with the $\bar{\nu}_p$-value from the spontaneous fission of ^{238}U. The neutron detector was a spherical scintillation tank. The observed fission rates have been corrected for the effects of bias setting of the neutron and fission detectors and for loss of fission events in the coincidence circuit.

^{238}U. Besides the measurement of Condé and Holmberg [34], already reported, eight more values have been published.

First of all we have the results of Segré [144], Littler [145], Geiger and Rose [146], Richmond et al. [147] and Gerling et al. [148], who determined the $\bar{\nu}$-value for spontaneous fission of ^{238}U from separate measurements of the neutron and fission rates per gram of uranium in unit time.

Kuzminov et al. [35] have determined the $\bar{\nu}^{sp}$-value of ^{238}U relative to $\bar{\nu}^{sp}$ (^{240}Pu). 24 proportional ^{10}B F_3 counters in parallel, embedded in paraffin, were used as neutron detectors. The result of three experimental runs gave the ratio $\bar{\nu}^{sp}(^{238}U)/\bar{\nu}^{sp}(^{240}Pu) = 0.92 \pm 0.03$.

Leroy [36] used an experimental set-up similar to that of Kuzminov to determine the $\bar{\nu}_p^{sp}$-value relative to the thermal $\bar{\nu}_p$-value of ^{235}U. His result was quoted also in reference [130].

Finally we have the measurements of Asplund-Nilsson et al. [37], who measured in the same experiment the $\bar{\nu}_p$-values for the spontaneous fission of ^{238}U and ^{240}Pu relative to $\bar{\nu}_p$ for the spontaneous fission of ^{252}Cf. The measurements were performed with a large liquid scintillator. The results were corrected for random coincidences, different gate lengths in the fission and background channels and energy dependence of the detector efficiency. The reported error is of statistical origin.

Our average value was obtained from the normalized values of Kuzminov, Leroy, Asplund-Nilsson and Condé. The other measured values were not considered because of the lack of information on the standard used.

<u>^{236}Pu and ^{238}Pu</u>. The $\bar{\nu}_p$-values for the spontaneous fission of these isotopes have been measured by Crane et al. [38] together with those of ^{240}Pu, ^{242}Pu, ^{242}Cm, ^{244}Cm, relative to $\bar{\nu}_p$ for the spontaneous fission of ^{252}Cf. The neutron detector was a LiI(Eu) crystal. The reported errors are standard deviations of the total number of events observed. The measured values were corrected for chance coincidences, background and isotopic and chemical contamination, the correction being less than 2.5% in each case.

Much the same isotopes have been considered by Hicks et al. [39]. In fact, they have measured $\bar{\nu}_p$ for spontaneous fission of ^{236}Pu, ^{238}Pu, ^{242}Pu, ^{242}Cm, ^{244}Cm and ^{252}Cf, relative to $\bar{\nu}_p^{sp}$ of ^{240}Pu, together with their neutron number distributions. As fission neutron detector they used a cadmium-loaded liquid scintillator tank.

<u>^{240}Pu</u>. Although all the measurements are relative, the $\bar{\nu}_p$-value for spontaneous fission of this isotope is one of the best known, having been used also as standard on many occasions.

In addition to some old measurements [40 - 46] with $\bar{\nu}$-values grouped around 2.2 n/fission, the renormalization of which is difficult due to the lack of information on the standards, and the measurements of

Asplund-Nilsson [37]and Crane et al. [38] described above, we have the determination of Diven et al. [47] relative to the thermal $\bar{\nu}_p$-value of ^{235}U. In the same experiment they measured also the $\bar{\nu}_p$-values for spontaneous fission of ^{244}Cm and ^{252}Cf and the $\bar{\nu}_p$-values for neutron induced fission at 80 keV of ^{233}U, ^{235}U and ^{239}Pu, together with the respective probability distributions. The measurements were carried out with a large liquid scintillator and the reported errors are standard deviations. They took into consideration the errors due to the counting statistics and to the uncertainty in detector efficiency and in the chance coincidence correction. The measurements were repeated some years later in the same laboratory by Hopkins and Diven [8, 48], who determined $\bar{\nu}_p^{sp}$ for ^{240}Pu, relative to the absolute value of $\bar{\nu}_p^{sp}$ for ^{252}Cf measured in the same experiment. They used a liquid scintillator tank, the efficiency of which was determined by scattering neutrons on protons in a NE 102 plastic scintillator. The reported error is the sum of the statistical error and systematic error, this being composed of the uncertainties in the pile-up correction and in the standard.

A similar technique was used by Moat et al. [10] to determine the $\bar{\nu}_p$-value for spontaneous fission of ^{240}Pu relative to $\bar{\nu}_p^{sp}$ (^{252}Cf) measured absolutely in a separate experiment, together with some $\bar{\nu}_p$-values for the neutron induced fission of ^{235}U and ^{238}U. They used the liquid scintillator tank technique and their result for ^{240}Pu is based on the assumption that the ^{240}Pu and ^{252}Cf fission neutron spectra are identical. The quoted error is compounded of the statistical error of the measurement and the error on $\bar{\nu}_p^{sp}$(^{252}Cf).

Colvin et al. [9] have measured $\bar{\nu}_p$ for spontaneous fission of ^{240}Pu relative to the thermal $\bar{\nu}_p$-value of ^{235}U, determined absolutely in the same experiment, using the boron pile. The error given is that due to statistics – where the larger one of the internal and external errors was considered –, pile stability and error in the efficiency factor.

Baron et al. [49] have used the scintillator tank technique to measure the $\bar{\nu}_p$ value for the spontaneous fission of ^{240}Pu relative to that of ^{252}Cf, together with the respective neutron distribution probabilities. The results have been corrected for background, dead-time and detector efficiency, but no allowance was made for fission spectra differences. The reported error is due mainly to the uncertainty in the standard.

Boldeman [50] has measured the $\bar{\nu}_p$ values for the spontaneous fission of ^{240}Pu and ^{242}Pu relative to the $\bar{\nu}_p$ value for the spontaneous fission of ^{252}Cf. For each isotope the probabilities, P_ν , of emission of $\bar{\nu}$ neutrons per fission event - neutron emission number - were also calculated. He used a large spherical gadolinium-loaded liquid scintillator counter. The experimental data have been corrected for false gates, or chance coincidences between noise in the fission counter and background radiation in the scintillator tank, dead-time and fission spectra differences (= -0.66%). The corrections for impurities were considered negligible and for delayed gamma rays zero. The reported error is composed of the inaccuracy in the corrections and of the statistical error, and does not include any contribution from the accuracy of the assumed value of $\bar{\nu}_p^{sp}$ for ^{252}Cf.

Finally we have the measurements of Prokhorova et al. [61] for the $\bar{\nu}_p$ values for spontaneous fission of ^{240}Pu and ^{244}Cm, relative to $\bar{\nu}_p^{sp}$ of ^{252}Cf. The neutron detector consisted of ^{3}He-counters embedded in paraffin. No information is given about corrections carried out and the origin of the reported error.

Our mean value was obtained from a weighted average of the renormalized values and is determined mainly by the accurate value of Boldeman.

<u>^{242}Pu</u>. In addition to the measurements of Crane et al. [38], Hicks et al. [39] and Boldeman [50] we have the value of Prokhorova et al. [51] measured relative to that for the spontaneous fission of ^{244}Cm. Their neutron detector consisted of a group of twelve ^{3}He counters concentrically

arranged in a cylindrical paraffin block. The neutron detector efficiency was about 12,5%. No information is given on the corrections applied, if any, and on the origin of the reported error.

As in the case of $\bar{\nu}_p^{sp}$ (^{240}Pu) our weighted average value is determined by the accurate value of Boldeman.

<u>^{244}Pu.</u> The only published value is that of Orth [52], who determined it by separately counting neutrons and spontaneous fissions and comparing these counts with similar counts from ^{252}Cf standards. In the same experiment he determined the $\bar{\nu}$-value for spontaneous fission of ^{248}Cm ^{250}Cm, ^{250}Cf and ^{254}Cf. The neutron counting system consisted of a high density polythylene cylinder with eight ^{10}B-lined neutron counters in parallel. The spontaneous fissions were measured with gas proportional counters in 2π geometry. In the case of ^{244}Pu the spontaneous fission rate was calculated from the sample weight and the spontaneous fission half-life, 6.55 $\pm$ 0.32 years. The reported error in $\bar{\nu}$ includes uncertainties in spontaneous fission half-life, neutron counter efficiency, sample weight, and a small difference in delayed neutron contribution per fission compared to ^{252}Cf.

<u>Cm - isotopes.</u> The knowledge on the $\bar{\nu}$-values for spontaneous fission of this element is represented by the measurements for the 5 even-even isotopes with mass numbers ranging from 242 to 250. For some of the isotopes the published information is reduced to the value of only one measurement. Only the $\bar{\nu}$-value for spontaneous fission of ^{244}Cm can be considered relatively well known through seven independent determinations.

Most of the measurements have been described already in this review when dealing with the thermal $\bar{\nu}$-values [26,27] or the $\bar{\nu}$-values for spontaneous fission of other isotopes [38,39,47, and 52].

Hence we should mention now only the following measurements. The $\bar{\nu}_p$ value for spontaneous fission of ^{244}Cm of Hicks et al. [53], relative to ^{252}Cf. In the same experiment the neutron multiplicity distributions of both isotopes were also determined. The result of

Bol'shov et al. [54] for ^{244}Cm, relative to $\bar{\nu}_p^{sp}$ (^{240}Pu). The neutron detector consisted of a group of boron counters arranged concentrically inside a cylindrical paraffin block. No information is given about the origin of the reported error. Finally we have the measurement of Thompson [55] for ^{246}Cm, relative to ^{252}Cf, who determined the $\bar{\nu}_p$ value for spontaneous fission from the measured emission rate and from the half-life.

Our reported mean values were obtained by a weighted average of the renormalized values. In those cases in which the $\bar{\nu}$ value for spontaneous fission of ^{240}Pu was used as standard, our weighted average value was used in the renormalization.

<u>^{249}Bk</u>. The only measurement is that of Pyle [56], relative to $\bar{\nu}^{sp}$(^{240}Pu), reported by Bondarenko [57] at the 2nd Geneva Conference. In the same measurement the $\bar{\nu}$ values for spontaneous fission of ^{246}Cf and ^{254}Cf were also determined.

<u>Cf-isotopes</u>. In addition to the absolute $\bar{\nu}$-value for the spontaneous fission of ^{252}Cf, already analysed in detail in paragraph II, a few measurements exist also for the isotopes of mass-number 246, 249, 250 and 254 [52, 56, 63]. The experimental details of the measurements have been considered above and are not repeated here.

<u>^{254}Fm</u>. The $\bar{\nu}$-value for spontaneous fission was measured by Choppin et al. [58] relative to $\bar{\nu}^{sp}$ (^{252}Cf) using a cadmium-loaded scintillation tank and a parallel-plate ionization chamber. The fission chamber pulses triggered an oscilloscope and the fission, prompt-gamma ray and neutron capture pulses were recorded photographically. The results have been corrected for resolution and background. The reported error is standard deviation.

<u>^{257}Fm.</u> It is the heaviest isotope of which the $\bar{\nu}$-values for spontaneous fission have been reported. This was measured by Cheifetz et al. [201], using a large gadolinium-loaded scintillator, relative to the value of $\bar{\nu}_p^{sp}$ for ^{252}Cf. Both fission sources were measured simultaneously.

The fission fragments were detected by solid-state detectors. No indication is given about corrections and about the origin of the reported error.

VI. THE SYSTEMATICS OF THERMAL AND SPONTANEOUS FISSION $\bar{\nu}_p$ VALUES.

In considering the operation of high flux reactors, a precise knowledge of the contribution coming from the heavy isotopes, produced by irradiation in the reactor core, is of the utmost importance to the knowledge of the total number of fissions in the reactor. But unfortunately the value of $\bar{\nu}$ is not known for many of these fissionable materials and cannot be measured easily with the presently available experimental techniques. As, on the other hand, the present status of the fission theory does not allow a precise quantitative calculation of this parameter, this gap should be filled by systematizing the available $\bar{\nu}$ data. One way of doing it is by using the theory to deduce semi-empirical expressions, which give $\bar{\nu}$ as a function of the nuclear parameters. In the following paragraphs the different approaches to the solution of this problem are outlined briefly.

1. Correlation between thermal and spontaneous fission $\bar{\nu}_p$ values.

Gordeeva and Smirenkin [59] have shown that if the fission takes place slowly and statistical equilibrium is established during the entire time of the process, then the kinetic energy of the fragments, E_k, should be the same for spontaneous and neutron induced fission of the same compound nucleus, and in particular, the condition

$$\bar{\nu}^{th} = \bar{\nu}^{sp} + B_n \frac{d\bar{\nu}}{dE} \qquad (1)$$

should be satisfied, B_n being the binding energy of the nucleus undergoing fission.

Eq. (1) gives a correlation between the two sets of values $\bar{\nu}^{th}$ and $\bar{\nu}^{sp}$ which allows the prediction of the thermal $\bar{\nu}_p$ value of an isotope from the measured $\bar{\nu}_p$ value for spontaneous fission of the same compound nucleus.

The problem is then reduced to the election of a suitable value for $d\bar{\nu}/dE$. The values reported in the literature range - depending upon the nuclide and the energy range in which the fitting was made - from 0.033 n/MeV [92] to about 0.19 n/MeV [60]. Hence, the choice of one or other of these values of $d\bar{\nu}/dE$ can change the deduced value of $\bar{\nu}_p^{th}$ by as much as $\sim 6\%$.

Nevertheless, Tables 2 - 5 show that we know the values of $\bar{\nu}_p$ both for spontaneous and neutron induced fission of six fissioning nuclei, and therefore we may deduce, by a comparison of these 6 couples of values, a value of $d\bar{\nu}/dE_n$, suitable for use in Eq. (1).

In Table 6 are listed the average $\bar{\nu}_p$ values for spontaneous and neutron-induced fission of the six couples of fissioning nuclei, taken from Tables 2 - 5, as well as the differences $\bar{\nu}_p^{th} - \bar{\nu}_p^{sp}$ and the deduced values of $d\bar{\nu}/dE$. The average value of $d\bar{\nu}/dE$ is in good agreement with the values obtained by fitting the existing experimental data in the energy region below 2 MeV [4, 92, 204, 211].

We conclude then that the expression

$$\bar{\nu}_p^{th} = \bar{\nu}_p^{sp} + 0.101\ B_n \qquad (2)$$

can be used, in principle, to obtain the $\bar{\nu}_p$ value for thermal fission of any fissioning nuclei, if the corresponding $\bar{\nu}_p$ value for spontaneous fission is known.

Table 7 lists the $\bar{\nu}_p^{th}$- values obtained using Eq. (2). For B_n the values of Wapstra et al. [62] have been used. The error assigned to the deduced thermal $\bar{\nu}_p$ values is such that it represents the same percentage error as the error reported for the experimental spontaneous fission $\bar{\nu}_p$-values. The fifth column of Table 7 lists all the available experimental or deduced $\bar{\nu}_p^{th}$ values. These have been plotted as a function of A in Fig. 2. In all those cases in which the experimental thermal $\bar{\nu}_p$ value was known, this was the value adopted.

2. Dependence of $\overline{\nu}_p^{th}$ on Z, A

In theory, the number of neutrons emitted per fission can be calculated from the relationship which gives the total energy released in fission, i.e. the energy-balance equation

$$\overline{E}_F = \overline{E}_K + \overline{\nu}_p \overline{E}_\nu + \overline{E}_\gamma$$

where $\overline{E}_F$ is the prompt energy released in fission, $\overline{E}_K$ is the mean kinetic energy of the fission fragments, $\overline{E}_\nu$ is the average energy of separation of the neutron from the fragments and $\overline{E}_\gamma$ is the total energy of the prompt gamma rays.

Unfortunately neither the energy terms in Eq. (3) are known with precision, nor is there a perfect theory capable of predicting quantitatively the energy and mass distribution in the fission process. Hence the theory has been used as a qualitative guide to develop empirical relationships between $\overline{\nu}_p$ and the parameters Z and A of the nucleus undergoing fission [59, 64].

Several approaches were made to this problem. In one of these, due to Gordeeva and Smirenkin [59], it is assumed that, in a first approximation and for N = A - Z 152, all the fission parameters, such as $\overline{E}_F$, $\overline{E}_K$, $\overline{E}_\nu$, $\overline{E}_\gamma$, and therefore $\overline{\nu}_p^{th}$ can be expressed as a lineal function of Z and A, with some minor corrections for odd-even effects, i.e.

$$\overline{\nu}_p = C_1 Z + C_2 A + C_3 + \delta \qquad (4)$$

where $\delta = 0.09\,\xi$, and $\xi = +1, -1, 0$ for odd-odd, even-even and odd-A target nuclei respectively.

By using all the experimental data on $\overline{\nu}_p$ for thermal fission available at that time they deduced the coefficients of expression (4).

We have recalculated the coefficients of Eq. (4) including all the experimental thermal $\overline{\nu}_p$ values of Table 7-except $\overline{\nu}_p$ for ^{232}U because of its large deviation from the general trend - as well as with all thermal values, experimental and deduced - with the exception of ^{231}Th and ^{232}U - of the same Table. A weighted least squares fit gave respectively,

$$\bar{\nu}_p^{th} = 0.2418\ Z + 0.0347\ A - 20.6550 + \delta \qquad (5)$$

for the experimental thermal values only, and

$$\bar{\nu}_p^{th} = 0.2625\ Z + 0.0093\ A - 23.923 + \delta \qquad (6)$$

for all the values.

A comparison of our results with that of Gordeeva et al. [59] shows that the more nuclides were included in the fitting, the better is the general agreement between the deduced values and the experimental ones. Thus while for the fit of Gordeeva et al. the discrepancy for the Cf-isotopes reaches about 17%, this discrepancy is reduced to about 8.5 % when a greater range of A is considered, as in the case of Eq.(6). This equation allows then predicting the value of $\bar{\nu}_p^{th}$ in the range $229 \leq A \leq 256$ with an accuracy better than about 10%. The last column of Table 7 lists the values of $\bar{\nu}_p^{th}$ obtained with Eq.(6).

Another approach to the problem of correlating $\bar{\nu}_p^{th}$ with the parameter Z and A of the fissioning nucleus is that of Ping- Shiu Tu and Prince [64]. Their starting point was the functional relationship between $\bar{E}_K$ and $\bar{\nu}_p$ given by Eq. (4) and the results of Terrell [65], Viola et al. [66], Bolshov et al. [54] and Okolovich et al. [67], who showed that $\bar{E}_K$ can be correlated with the parameter $Z^2/Z^{1/3}$ [65, 67, 54] and also with $Z^2\sqrt{A}$ [67], where Z and A refer to the fissioning nucleus.

By means of least-squares fittings to 16 experimental and pseudo-experimental $\bar{\nu}_p$ thermal values (the latter ones deduced through Eq.(1) by assuming three different values for the slope $d\bar{\nu}/dE$, viz, 0.085, 0.10 and 0.13 n/MeV respectively) they were able to derive sets of third-order polynomial equations which correlated $\bar{\nu}_p^{th}$ with the average kinetic energy of the fission fragments, $\bar{E}_K$, and also with the parameters $Z^2/A^{1/3}$ and $Z^2\sqrt{A}$ respectively.

The equations they give for the case of $d\bar{\nu}p/dE = 0.1$ were:

$$\bar{\nu}_p = 1.4942314\ (10)^2 - 3.0594702\ (10^{-1})(Z^2/A^{1/3}) + 2.0575406\ (10^{-4})(Z^2/A^{1/3})^2 - 4.4341263.(10^{-8})(Z^2/A^{1/3})^3 \qquad (7)$$

and

$$\bar{\nu}_p = 3.5358585\ (10) - 7.3102037\ (10^{-4})\ (Z^2\sqrt{A}) + 4.9648254\ (10^{-9})\ (Z^2\sqrt{A})^2 - 9.9093852\ (10^{-15})\ (Z^2\sqrt{A})^3 \quad (8)$$

The data used by Ping-Shiu Tu and Prince [64] in their calculations are relatively old, since the $\bar{\nu}_p$ values for thermal neutron induced fission were published before 1968 [2, 7, 30, 59] and those for spontaneous fission were taken from the book of Hyde et al. [208] published in 1964. Therefore we have considered it interesting to repeat their calculations with our more recent and more complete set of experimental and pseudoexperimental $\bar{\nu}_p^{th}$ values of Table 7. Accordingly a weighted least-squares orthogonal polinomial fitting procedure [68] was applied to the experimental average $\bar{\nu}_p^{th}$ values only, as well as to all data - experimental and pseudoexperimental - of the fifth column of Table 7 taking both parameters $Z^2/A^{1/3}$ and $Z^2\sqrt{A}$ as independent variables.

This analysis showed that, at a 95% statistical confidence level, the experimental thermal $\bar{\nu}_p$ values may be represented by a second-order polynomial in the parameters $Z^2/A^{1/3}$ or $Z^2\sqrt{A}$, while if all data are included, - experimental and pseudoexperimental - the best fits are obtained in both cases for a polynomial of degree three.

Thus for the experimental $\bar{\nu}_p$ values only (excluding ^{232}U because of its large deviation from the general trend) the best fits are given by:

$$\bar{\nu}_p = 3.21761\ (10) - 5.15743(10^{-2})\ (Z^2/A^{1/3}) + 2.17952\ (10^{-5})\ (Z^2/A^{1/3})^2 \quad (9)$$

and

$$\bar{\nu}_p = 1.51931\ (10) - 2.51737\ (10^{-4})\ (Z^2\sqrt{A}) + 1.18252\ (10^{-9})\ (Z^2\sqrt{A})^2 \quad (10)$$

respectively, where in both cases Z and A are the parameters of the nuclei undergoing fission.

If all data - experimental and deduced - of the fifth column of Table 7 are included, with the exception of the $\bar{\nu}_p$ values of ^{231}Th and ^{232}U, which deviate too much from the general trend, the best fits are now given by the following equations:

$$\bar{\nu}_p = 1.78540 \; (10^2) - 3.55231 \; (10^{-1}) \, (Z^2/A^{1/3}) + \\ + 2.31358 \; (10^{-4})(Z^2/A^{1/3})^2 - 4.81013 \; (10^{-8})(Z^2/A^{1/3})^3 \qquad (11)$$

and
$$\bar{\nu}_p = 6.14262 \; (10) - 1.24422 \; (10^{-3}) \, (Z^2\sqrt{A}) + \\ + 8.25569 \; (10^{-9})(Z^2 \sqrt{A})^2 - 1.67270 \, (10^{-14})(Z^2\sqrt{A})^3 \qquad (12)$$

where the variables Z and A have the same meaning as in Eq. (9) and (10) respectively.

The values obtained with Eq. (7) - (12) have been plotted, together with our input values, in Figures 3 and 4. In them are shown in black those nuclides taken into consideration by Ping-Shiu Tu et al. [64] in the deduction of Eq. (7) and (8).

An inspection of Fig. 3 and 4 shows:

(i) Our equations are in good agreement for low Z and A with the relationships obtained by Ping-Shiu Tu et al. [64], for both parameters $Z^2/A^{1/3}$ and $Z^2\sqrt{A}$, but there is a clear discrepancy in the region above the Cm-isotopes. This is due to the relatively high weight in the fitting procedure of the $\bar{\nu}_p^{th}$ values of ^{242m}Am, ^{243}Cm and ^{249}Cf, which were not included in their fits.

(ii) Good agreement exists between the results obtained with the experimental thermal data alone and those including all the data. This agreement could be interpreted as a confirmation of the values obtained with Eq. (2), but it should be pointed out that this agreement may be due partly to the higher weight of the experimental thermal values in the fits.

(iii) An inspection of Fig. 3 shows that the trend of the A-dependent $\bar{\nu}$ values for a constant value of Z is completely opposite to that given by Eq.(9) and 11, and therefore a dependence of $\bar{\nu}_p^{th}$ on the parameter $Z^2/A^{1/3}$ does not seem to be a good representation of the experimental data.

We conclude that in the present situation Eq (12) gives the best fit to the experimental data and may be used to predict any thermal $\bar{\nu}_p$ value, within an accuracy which can be expected to be better than about 10%.

VII. ENERGY DEPENDENT $\bar{\nu}$ VALUES OF FISSILE AND FERTILE ISOTOPES

The amount of experimental information available at present on the energy dependent $\bar{\nu}$ values for the fissile and fertile isotopes varies strongly from one isotope to the other. While for some of them (^{235}U, ^{238}U and ^{239}Pu) the published data cover the whole energy range from thermal to 15 MeV, for all the remaining isotopes a large gap exists between about 5 and 14 MeV where no measurement has been reported, and in two cases (^{234}U and ^{241}Pu) the whole information is reduced to four or five points from only one measurement.

All the available experimental data have been compiled in Tables 8 to 16. These have been arranged in order of increasing Z and A, and include, besides the reference, the year of publication, neutron bombarding energy, the author's original values, the standard used and our renormalized prompt and total values. The symbol p or t attached to the standard indicates also whether the authors have measured prompt $\bar{\nu}$ or total $\bar{\nu}$, and accordingly the character of the values listed in the column headed $\bar{\nu}_{exp}$. In those cases in which no information is available in this respect the index was omitted, but the published numerical value was considered as including the delayed neutrons.

The total $\bar{\nu}$ values of the last column of Tables (8) to (16) were obtained by adding to our renormalized $\bar{\nu}_p$ values the delayed-neutron yield as given in paragraph VIII.

It should be pointed out, also in connection with the values listed under $\bar{\nu}_{exp}$, that the errors quoted are only statistical, if these were made available by the authors. In those cases in which no indication was given of the type of error reported, it was assumed as statistical and as such quoted.

In the following paragraphs a short description, grouped by isotopes, of each one of the measurements is given, in which the type of detector is briefly indicated and the error analysis and corrections applied particularly outlined. With respect to the method of measurement we should say that - except for a few measurements in which the $\bar{\nu}$ values were obtained from the average kinetic energy of the fission fragments by making use of the energy balance equation [78, 90, 119, 120], and for some old measurements in which $\bar{\nu}$ was determined by measuring the flux increase produced in the neutron beam when it passed through the samples [86,106] - in all the remaining measurements the $\bar{\nu}$-values were determined by recording coincidences between pulses from the neutron detector and pulses from the fission fragments. Except for a few cases, the neutron detector used was either a large liquid scintillator loaded with Cd or Gd, or an array of BF_3 or ^{3}He counters embedded in a moderator.

1. Energy dependent measurement of $\bar{\nu}$ for ^{232}Th

The available published experimental data on $\bar{\nu}$ for ^{232}Th amount to 30 points, all, except one, being published before 1968. Most of them are below 4 MeV, and there is a large gap between 4 and 14 MeV where only one point was reported. Moreover the precision of the measurements in the 14 - 15 MeV area is in general very poor. The experimental details for each one of the measurements are as follows:

Kuzminov et al. [70] have determined the average number of prompt neutrons from the fission of ^{232}Th, ^{235}U, ^{238}U and ^{237}Np by fast neutrons having an energy spectrum close to that of fission neutrons. The neutrons were detected by $^{10}BF_3$ counters embedded in paraffin. The results were corrected for false gates, for the anisotropic emission of the fission fragments and of the secondary neutrons, and for isotopic impurities.

Smith et al. [71] have measured $\bar{\nu}_p$ of ^{232}Th relative to that of ^{238}U. The neutrons were detected by a Hornyak button in coincidence with a fission chamber. He assumed that the detection efficiency of the button was identical for both ^{232}Th and ^{238}U fission neutrons.

Kuzminov [72] has measured the number of prompt neutrons of ^{232}Th and ^{238}U using the same detection system as in [70]. The reported error is only statistical.

Leroy [36] used an ensemble of $^{10}BF_3$ proportional counters embedded in paraffin to determine $\bar{\nu}_p$ for ^{232}Th, ^{238}U and ^{239}Pu relative to the thermal $\bar{\nu}_p$ value of ^{235}U. He considered the variation of efficiency with the neutron fission spectra negligible. The reported error includes the effect of fission fragment anisotropy.

Vasil'ev et al. [87] have determined the mean number of neutrons per fission of ^{232}Th, ^{233}U and ^{235}U from the energy spectra, which were measured by the time-of-flight method. The neutrons were detected by a scintillation counter placed at 90° to the neutron beam.

Condé et al. [73] have measured $\bar{\nu}_p$ for ^{232}Th between 1.4 and 14.9 MeV. The fission neutron detector was a large liquid scintillator. The primary neutrons were produced by the T (p,n), D(d,n) and T(d,n) reactions and their energy spectrum measured with a stilbene crystal with neutron gamma ray discrimination. The following corrections were applied to the observed $\bar{\nu}$ values:

1. False gates due to random coincidences between spurious fission pulses and background pulses (< 0.2%).

2. Probability of detecting two neutron pulses as one (0.1 - 0.4% depending on energy)

3. Differences in fission neutron spectra of ^{232}Th and the standard (^{252}Cf). The oorrection was calculated using the formula of Terrell [104],

$E = 0.74 + 0.653\ (\bar{\nu} + 1)^{\frac{1}{2}}$. The correction was about 1%.

4. Different escape of fission neutrons from ^{232}Th and ^{252}Cf (~0.1%).

5. Fission foil thickness and anisotropy of fragment angular distribution [(1.1 ± 0.3)%]. The reported errors are due to counting statistics only. The error in the -value due to uncertainties in the corrections was estimated to be less than 0.5%.

Mather et al. [75] have measured $\bar{\nu}_p$ in the neutron-induced fission of ^{232}Th, ^{233}U, ^{234}U, ^{238}U and ^{239}Pu at four incident energies in the range from thermal to 4 MeV, relative to $\bar{\nu}_p^{sp}$(^{252}Cf). They have used a large liquid scintillation counter as neutron detector, and the energy of the incident neutrons was determined by the time-of-flight technique. The observed numbers of neutrons per fission were first corrected for dead-time losses (≈2.5%) and background and then for several other small corrections, which varied from nuclide to nuclide and with the incident neutron energy, and which in the case of ^{232}Th were: Spectral differences (≈ -0.26%), preferential selection of fission events due to the electronic bias (± 0.3%), anisotropy of fission fragment emission (-0.5 to + 0.17%) and false gates produced by random coincidences (~ 3.45 to 5.32%), with a total correction of 3.25 to 5.17 %, depending upon the incident neutron energy. The reported errors are relative errors and do not include the errors in the standard.

Prokhorova et al. [76] have measured $\bar{\nu}_p$ for ^{232}Th between 1.5 and 3.3 MeV and $\bar{\nu}_p$ for ^{238}U from 1.4 to 3.3 MeV, relative to the thermal $\bar{\nu}_p$ value of ^{235}U. An array of 36 $^{10}BF_3$ counters enclosed in a paraffin block was used as neutron detector.

The data were corrected for the dependence of the fission neutron spectrum on excitation energy using the Terrell relation [104], and for the dependence of neutron detection efficiency on the energy and direction of the fission neutrons. No information is given about the origin of the reported errors.

Finally Vorobéva et al. [78] have made use of the energy balance equation to deduce the value of $\bar{\nu}$ of ^{232}Th and ^{238}U at 1.65 MeV and 1.50 MeV respectively. The value was obtained by the least squares method.

All the available published data are listed in Table 8 , together with the renormalized values, and have been plotted as a function of the neutron energy in Figure 5.

2. Energy dependent measurement of $\bar{\nu}$ for ^{233}U

The present knowledge of the energy dependence of $\bar{\nu}$ for ^{233}U is very similar to that of ^{232}Th. There exists also a gap between 5 and 14 MeV in which no measurement has been published, and furthermore the precision of the measurements above 14 MeV is very low.

There is only one modern measurement, that of Boldeman below 2 MeV, all the others were published before 1967. The characteristics of each one of the measurements are as follows:

Diven et al. [47] have measured the average number of prompt neutrons per fission and the respective neutron distribution probabilities for 80 keV neutrons of ^{233}U, ^{235}U and ^{239}Pu, together with the spontaneous fission $\bar{\nu}$ values for some isotopes. The neutrons were detected with a large liquid scintillator, the efficiency of which was determined relative to the thermal $\bar{\nu}$ value of ^{235}U and by scattering neutrons into the scintillator. The data were corrected for random coincidences and background, the errors shown are standard deviations with allowance for counting statistics, uncertainty in the efficiency and uncertainty in the coincidence correction.

Kalashnikova et al. [80] have measured the mean number of neutrons per fission induced in ^{233}U, ^{235}U and ^{239}Pu for a fast neutron spectrum relative to their respective thermal values. The fission neutrons were detected by 24 enriched BF_3 counters embedded in a large cylindrical paraffin block which surrounded the ionization chamber which contained the sample. The reported error is statistical, and the authors estimated that any systematic error which may have been introduced by variations in the neutron detection efficiency should be considerably less than 1%.

Smirenkin et al. [81] have determined the ratio $\bar{\nu}/\bar{\nu}^{th}$ for the fission of ^{233}U, ^{235}U and ^{239}Pu at 4 and 15 MeV. The neutron detector was a double fission chamber. Secondary fission neutrons produced in a fission in one half of the chamber were able to induce a fission in the other half. Such events were recorded by a coincidence technique, the number of coincidences being proportional to $\bar{\nu}$. The data were corrected for the difference in the detector efficiency for secondary fast and slow neutrons, for energy degraded neutrons in the fast beam and for the ^{238}U content of the uranium layers.

Protopopov and Blinov [82] used the same technique as Smirenkin et al. [81] to determine the $\bar{\nu}_p$ value of ^{233}U at 14.8 MeV.

Engle et al.[85] have estimated the average number of neutrons per fission, $\bar{\nu}$, for ^{233}U, ^{235}U, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu and ^{237}Np from reactivity coefficient ratio measurements in the Los Alamos critical assemblies Topsy, Godiva and Jezebel. The reported value is the average of the values of each one of the assemblies.

Flerov and Talizin [86] have determined $\bar{\nu}$ for ^{233}U and ^{239}Pu by measuring the increase in the neutron flux which occurred when 14 MeV neutrons passed through a sample of the fissile element placed in the centre of a graphite prism fast neutron detector. The results were corrected for fission induced by moderated neutrons and the value given was obtained assuming for the non-elastic cross-section a value $\sigma_x = (2.85 \pm 0.10)$ barn .

Vasil'ev et al. [87] have measured $\bar{\nu}$ for ^{233}U at 14.3 MeV. The details of this measurement have been already considered in § VII.1.

Hopkins and Diven [8] have measured $\bar{\nu}_p$ for neutron induced fission of ^{233}U, ^{235}U and ^{239}Pu between zero and 14 MeV relative to the spontaneous fission $\bar{\nu}_p$ of ^{252}Cf measured absolutely in the same experiment. They used a large cadmium-loaded liquid scintillator to detect the neutrons. In its centre was placed the fission detector, a double fission counter, which contained the sample and the standard. They made a detailed investigation of the contribution to the neutron beam coming from degraded-energy neutrons. The data were analysed for $\bar{\nu}$, the neutron emission probabilities, and for the standard deviations due to statistical fluctuations and uncertainties in the α pile-up correction. The error given is the total relative error. The total systematic error, which the authors assumed to be equal to the square root of the sum of the squares of the individual systematic errors is not included in our tabulated errors and amounts to about 1%. Preliminary values of these measurements have been also reported by Diven et al. [48].

Colvin et al. [88] have used the Boron Pile technique(i.e. array of $^{10}BF_3$ counters in a graphite matrix) to determine the $\bar{\nu}_p$ for ^{233}U from 0.5 to 2.58 MeV. The measurements were made relative to the $\bar{\nu}_p$ value for the spontaneous fission of ^{252}Cf.

Mather et al. [75]: The details of this measurement have been already considered when dealing with ^{232}Th. The value of the corrections in the ^{233}U measurement was:fissions induced by energy degraded neutrons (0 to 0.89 %), preferential selection of fission events ($\pm$ 1%), anisotropy of fission fragment emission (0.03 - 0.06%), false gates ($<$ 2.8%), with a total correction ranging from 1.64 to 2.98%. The reported errors are relative and do not include the error in the standard.

Blyumkina et al. [90] have measured the dependence of the average kinetic energy of ^{233}U and ^{235}U fission fragments on the incident neutron energy. The value of $\bar{\nu}_p$ was deduced from the average kinetic energy by means of the energy balance equation.

Kuznetsov and Smirenkin [89] have made use also of the energy balance equation to determine $\bar{\nu}$ for ^{233}U and ^{235}U by assigning absolute values to the results of previous relative measurements.

Boldeman and Walsh [92] have measured $\bar{\nu}_p$ for ^{233}U from thermal to 1.870 MeV, relative to the spontaneous fission $\bar{\nu}_p$ value of ^{252}Cf, using a liquid scintillator detector. Corrections were made for fission spectra differences, (- 0.53 to -0.45)%, with an assigned error in the percentage correction of 0.24 %, dead time losses, (-0.20 ± 0.04)%, thermal contamination, (0.12 ± 0.03)%, preferential detection of fission fragments, (0.05 ± 0.05)%, false gates, (0.05 ±0.02)%, and second neutron group from the Li $(p,n)^7Be$ reaction, (0.06 ± 0.01)%. The correction for sample impurities, fragment anisotropy, electronic errors and delayed gamma rays were considered zero, but an error of 0.03 and 0.10%, respectively was assigned to the two last corrections. The reported error includes together with the statistical error (0.5%) the contribution from the uncertainties in the corrections. Their reported thermal value is the same as that given in [22] and was not included in Table 9.

It should be mentioned also that Howe and Bowman [227] had underway the preparations for the measurement of $\bar{\nu}$ for ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu and possibly ^{238}Pu with the Livermore Electron Linac. They are developing a new concept for the $\bar{\nu}$ measurements which will possess both insensitivity to a changing neutron spectrum and fast time response and which will permit $\bar{\nu}$ studies from 0.1 eV to 15 MeV. The measurements were scheduled to begin in January 1972.

All the published data have been listed in Table 9 and have been plotted as function of the neutron energy in Figures 6 and 7.

3. Energy dependent measurements of $\bar{\nu}$ for ^{234}U

The only published measurement is that of Mather et al. [75], from 0.99 to 4.02 MeV, relative to the spontaneous fission $\bar{\nu}_p$ value of ^{252}Cf. The experimental details have been already considered in para. VII-1. The data were corrected for "thermal" contamination, (0.11 to 0.64)%, spectral differences, (-0.24 to -0.15)%, preferential selection of fission events due to the electronic bias ±(0.6 - 1.0)%, anisotropy of fission fragment emission (0.09%) and false gates (<1.6%), with a total correction of 1.2 to 2.2%. The reported errors are relative and do not include the error on the standard. The values are listed in Table 10 and plotted as function of the energy in Figure 8.

4. Energy-dependent measurements of $\bar{\nu}$ for ^{235}U

The available data on $\bar{\nu}$ for ^{235}U amount to 299 measured values, which correspond to points at 230 different neutron energies. They cover the energy region from thermal to 15 MeV, except for six points between 22 and 28 MeV due to Soleilhac and collaborators, more than half of them being high resolution measurements published during the last years. Thus, the dependence of $\bar{\nu}$ for ^{235}U on the neutron energy is rather well defined, although some controversy still remains about the existence of structure in the low energy region below 2 MeV.

Leaving out some old measurements, most of them unpublished, and in general of very poor precision, the present situation concerning the energy dependence of $\bar{\nu}$ for ^{235}U is as follows:

Diven et al. [47] have measured the $\bar{\nu}_p$ value and neutron probabilities for an energy of 0.08 MeV. The characteristics of the measurement have been already reported in VII.2.

Kuzminov et al. [70] and Kalashnikova et al. [80] have determined $\bar{\nu}$ for ^{235}U in a fast fission spectrum. Details of their measurements can be found in VII.1 and VII.2 respectively.

Smirenkin et al. [81] have determined the $\bar{\nu}_p$ value of ^{235}U, relative to its thermal value, together with those of ^{239}Pu and ^{233}U. The method used and corrections applied can be seen in the paragraph dealing with the ^{233}U values.

Protopopov and Blinov [105] have used the coincidence method, and double back-to-back ^{235}U fission chambers to detect the neutrons, in the measurement of $\bar{\nu}_p$ for ^{235}U at 14.8 MeV, relative to the value for thermal neutron induced fission. The relative measurements were corrected for the effect of background of scattered neutrons (+ 1.4%) and variation of chamber efficiency with energy.

Flerov and Talizin [106] have determined $\bar{\nu}$ for ^{235}U and ^{238}U by measuring the increase in the neutron flux when a beam of 14 MeV neutrons passes through samples of these materials. The observed values were corrected for the increase in the number of neutrons caused by secondary neutron induced fission and for the effect of slow neutron fission of ^{235}U. The $\bar{\nu}$ value for ^{235}U was obtained assuming for the non-elastic and fission cross sections a value of $\sigma_x = (2.85 \pm 0.10)$barn and $\sigma_f = (2.30 \pm 0.15)$ barn, respectively.

Vasil'ev et al [111] have determined $\bar{\nu}$ for ^{235}U and ^{238}U induced by 14.3 MeV neutrons, by integrating the measured fission neutron spectra, with allowance for the absolute scintillation-counter efficiency, $\mathcal{E}$, and the fraction of the spectrum, β, which was beyond the measuring range. ($\approx$ 0.15%) A correction was introduced in the calculation of $\bar{\nu}$ to take account of the moderation of the primary neutrons through scattering in the chamber and target. The error in $\bar{\nu}$ consists mostly of errors in determining the values of $\mathcal{E}$ and β, and, on an average, amounted to $\sim$ 8%.

Moat et al. [10] have measured $\bar{\nu}_p$ for ^{235}U at 3 energies between 75 keV and 14.2 MeV, relative to their own absolute $\bar{\nu}_p$ value for the spontaneous fission of ^{252}Cf. The neutron detector was a 100 l Cd-loaded liquid scintillation counter. The data were corrected for background and dead-time by means of a simulation method in which it was assumed that the pulse width is small compared to the dead-time of the recording instrument. The published errors are compounded from the statistical error and the error on ^{252}Cf. In our tabulated and renormalized values only the statistical error was considered.

Meadows and Whalen [115] have studied the energy dependence of $\bar{\nu}_p$ for ^{235}U over the incident neutron energy range from 0.03 to 1.76 MeV by measuring the ratio of prompt neutrons from neutron induced fission of ^{235}U to those from spontaneous fission of ^{252}Cf, and normalizing the thermal extrapolated value to $\bar{\nu}_p$ for ^{235}U at thermal energies.

The neutron detector consisted of twelve $^{10}BF_3$ proportional counters embedded in polyethylene. A tube passing through the centre of the neutron detector contained the fission detectors. The experimental data were corrected for the second neutron group from the $^{7}Li(p,n)^{7}Be$ reaction, thermal neutron-induced fission, dead-time losses (- 1.3%), asymmetry of the neutron detector (+ 1.4%), energy dependence of the neutron detector efficiency (maximum correction (+1.5 ± 1.0)%, at $E_n = 0$) and fission fragment angular distribution (less than (-0.4 ± 0.3)%). The errors reported are relative errors. Preliminary results of this measurements were reported previously by Butler et al. [112] in 1961.

The measurements of Hopkins and Diven [8, 48] have been already considered in VII.2 and are not repeated here. They cover the range from thermal to 14.5 MeV.

Colvin and Sowerby [9] measured the $\bar{\nu}$ values for fast neutron-induced fission of ^{235}U in the energy range from 100 keV to 2.6 MeV by means of their boron pile. The data were corrected for count-rate effect, neutron pulse overlap, effect of the selective thermal absorption of fission chamber, ion chamber and beam tube on the neutron detector efficiency, neutron captures after the "prompt" gate was closed, variation of chamber efficiency with position in the central channel, effect of impurities in the fission foils and of delayed neutrons. The errors given are due to statistics, pile stability and error in the correction of the effect of selective absorption of the materials placed on the central hole on the efficiency of the boron pile. As statistical error was chosen the larger of the external and internal error.

Blyumkina et al.[90] measured the energy dependence of $\bar{\nu}_t$ for ^{235}U by measuring the ratio of $\bar{\nu}_t(En)$ to a reference value $\bar{\nu}_t(E_n^o)$. In a separate experiment $\bar{\nu}_t(E_n^o)$ was calibrated with respect to the thermal $\bar{\nu}_t$ value. The fission neutrons were detected either by a scintillation stilbene crystal threshold detector with pulse-shape discrimination or a multi-grid thorium fission chamber. The corrections for the anisotropy of fission fragments, for the change of the fission neutron spectrum with the excitation energy of the fissile nucleus and for the multiplication of neutrons in the uranium disc proved to be small. Other effects were considered negligible. The errors given are mainly statistical. According to the authors the reported uncertainties in E_n correspond to the maximum spread of the neutron energy.

The same authors measured also the average kinetic energy of the fission fragments between 0.08 and 2.46 MeV, and calculated from it the value of $\bar{\nu}_p$ by making use of the energy balance equation. Although they reported the existence of a certain structure in the form of a convexity in the region $0 \leqslant E_n \leqslant 0.6$ MeV, an inspection of their published values shows that, except for the three lower energy points at 0.08, 0.28 and 0.35 MeV, for which the value of $\bar{E}_k = \bar{E}_k(En)-\bar{E}_k(E_o)$ is $- 0.38 \pm 0.32$, $- 0.55 \pm 0.23$ and $- 0.71 \pm 0.30$ MeV, respectively, the value of $\Delta \bar{E}_k$ for the remaining points is not statistically different from zero, suggesting therefore according to the energy balance a linear dependence of $\bar{\nu}$ upon E_n between 0.4 and 2.45 MeV.

Mather et al. [116] used a large Gd-loaded liquid scintillator counter to measure $\bar{\nu}_p$ for ^{235}U as a function of the incident neutron energy from thermal to 8 MeV. Time-of-flight selection was used above 5 MeV neutron energy. The observed data were corrected for background and dead-time losses by means of a correction matrix of probability coefficients, and then for fission spectra differences (- 0.225 to -0.03%), for energy-degraded neutrons (0.2 - 0.8%), isotopic impurities, (<0.18%), anisotropy of fission neutron emission (+ 0.2% at 7 - 8 MeV and negligible below), and false gates (< 0.25% above 1 MeV) with a total correction ranging from -0.225 at thermal energies to 1.04% at 8 MeV. The errors reported are relative and do not include the error in the standard.

A least square fit to the data showed that the best single curve fit was a second degree polynomial which can be substituted by two linear equations from 0 to 3 MeV and from 3 to 8 MeV respectively. An earlier version of some of the values given here was reported previously by Moat et al. [113] in 1961.

Condé [117] determined the prompt -$\bar{\nu}$-values for ^{235}U at 0.06, 7.5 and 14.8 MeV, using the scintillator tank technique. The observed relative values were corrected for the following effects: pulse pile-up, false gates, different fission neutron spectra, anisotropy of fission neutron emission, fission induced by background neutrons, thickness and impurities of the fissile foil and uncertainty in the primary neutron energy, with total corrections of - 0.5 + 0.9 and + 1.2% respectively. The stated errors include counting statistics and uncertainties in the corrections.

Meadows and Whalen [118] studied the energy dependence of $\bar{\nu}_p$ over the incident neutron energy range from 0.04 to 1.0 MeV by measuring the ratio to $\bar{\nu}_p$ for the spontaneous fission of ^{252}Cf. The experimental set-up was already described in [115]. The number of neutrons detected was corrected for dead-time losses and background to obtain the "detected" ratio, which was then corrected for geometrical asymmetry of the neutron detector, lower energy neutrons, angular and energy dependence of the neutron detector efficiency, fission counter backgrounds and fission losses. The stated errors are relative errors and do not include the error in the standard.

Kuznetsov and Smirenkin [119] have used the energy balance equation to give absolute values to the results of previous ratio measurements of $\bar{\nu}_t$ for ^{235}U from 0.08 to 0.99 MeV. The quoted errors do not include the uncertainty in the standard.

Prokhorova and Smirenkin [76] measured the energy dependence of $\bar{\nu}_p$ for ^{235}U and ^{232}Th. In paragraph VII.1 the method of measurement used and the correction applied were already described.

Nadkarni and Ballal [120] make use of the energy balance equation to determine $\bar{\nu}$ for ^{235}U in the energy range from 0.37 to 2.13 MeV. The kinetic energy distribution of fission fragments was measured with a gridded ionization chamber. The measured $\bar{E}_k$ values were corrected for the centre of mass motion. $\bar{E}_k$ was found to remain constant within about 0.6 % ($\approx$ 1 MeV) in this region, with a slight structure that could be due to statistical fluctuations, but correlates well with the results of Blyumkina [90'] and Mather [116].

Soleilhac et al [121] have measured simultaneously the energy dependence of $\bar{\nu}_p$ for ^{235}U, ^{238}U and ^{239}Pu over the incident energy range from 1.3 to 15 MeV and from 22.7 to 28.3 MeV, relative to $\bar{\nu}_p$ for the spontaneous fission of ^{252}Cf. A time-of-flight selection system was used for all $\bar{\nu}_p$ determinations. The three fissile materials and the standard were contained in the same high speed ionization chamber and the fissions coming from various isotopes were sorted by an electronic logic circuit. The liquid scintillator technique was adopted to detect the neutrons. The collimated beam of neutrons was produced by using a 12 MeV Tandem Van de Graaff and a gaseous target.

The observed number of neutrons per fission was first corrected for background in the neutron detector and electronics dead-time losses, and then for: (a) fission spectra differences ($< \pm$ 0.5%), (b) spurious fissions by thermal neutrons, impurities in fissile deposits or random coincidences, (c) variation of efficiency with fission counter position ($<$ 0.5%), and (d) changes in the counter efficiency with background rate ($<$ 1.5 %). No correction was made for anisotropy of fission neutron emission, because as shown by Mather et al. [75] the maximum correction would be + 0.2 % at 7.5 MeV.

In a private communication to the authors, Soleilhac replaced the values given in reference [121] by a new slightly modified set, in which complementary measurements in the energy range 1.3 - 15 MeV and 22 - 28 MeV had been incorporated. The published error, which corresponds only to the statistical error of measurements, was also increased to take account of the statistical errors due to the correction for degraded energy neutrons and the correction for efficiency. The new values and errors are given in Table 11.

This same group has extended the energy range of the measurements for ^{235}U and ^{239}Pu down to 0.2 MeV [122]. In the new measurements they use the reaction ^{7}Li (p, n) on a thick target to produce a wide energy spectrum of neutrons, from which energy bands were selected by time-of-flight techniques. The measurements were performed simultaneously for the two fissile nuclides, and the observed values corrected for the same effects as in reference [121]. They suggested the existence of some structure in the energy dependent values for both isotopes, but of a weaker nature for ^{239}Pu.

Savin et al [123] have measured $\bar{\nu}_p$ for ^{235}U, ^{239}Pu and ^{240}Pu in the energy range 0.6 - 5 MeV. The measurements were performed on a linear accelerator and the neutron energies selected by time-of-flight. The fission neutrons were counted with a 400 l Cd-loaded liquid scintillator tank divided optically into two equal parts, which were operated in coincidence to reduce the intrinsic background. In calculating $\bar{\nu}$ they take into account: (a) angular correlation between the fission and incident neutrons, (b) fission spectra differences, (c) sample multiplication and (d) isotopic impurities of the samples.

The errors indicated are root-mean-square errors including: (a) statistical fluctuations (0.8 % for ^{235}U and 1% for ^{239}Pu), (b) variations in the neutron counting efficiency (≈ 0.5%), (c) errors due to inaccurate background determinations (≈ 1%) and (d) error in the correction for triggering (≈ 0.5% at 0.7 - 0.9 MeV).

Nesterov et al. [25] measured $\bar{\nu}_p$ for ^{235}U and ^{239}Pu from thermal to 1.6 MeV, relative to $\bar{\nu}_p^{sp}(^{252}Cf)$, by using an electrostatic accelerator and the T (p, n) and Li (p, n) reactions as neutron sources. The neutron detector consisted of 24 ^3He counters embedded in a paraffin block, with an efficiency of 21%, with a through channel to locate the fission fragment detector, which was a multi-layer ionization chamber. The observed ratios were corrected for (a) dependence of neutron detector efficiency on the position of the neutron source in the detector, neutron energy and angular anisotropy, (b) counting bias and losses, (c) background and (d) isotopic impurities. The stated error corresponds to the error of the measurements and does not include the uncertainty in the standard.

Recently the data for ^{239}Pu have been rejected by the authors themselves and should not be taken into consideration [220].

Boldeman and Walsh [24] made accurate measurements of the energy dependence of $\bar{\nu}_p$ for neutron-induced fission of ^{235}U in the energy range from 0 to 2 MeV, relative to $\bar{\nu}_p^{sp}$ (^{252}Cf). Prompt fission neutrons were detected with a 240 l gadolinium-loaded liquid scintillator tank, viewed by 12 photomultiplier tupes arranged in three coincident banks of four tubes, in coincidence with a fission ionization chamber of high efficiency and discrimination against amplifier noise. Incident neutrons were produced by the ^7Li (p, n) ^7Be and T(p,n)^3He reactions in a 3 MeV Van de Graaff accelerator.

The raw data were corrected for: (a) dead time losses, (b) neutron spectra differences (this correction varied from (-0.55 ± 0.22)% at thermal energy to (- 0.48 ± 0.22)% at 1.9 MeV), (c) isotopic impurities in the ^{235}U foil, (d) second neutron group from the ^7Li (p, n) reaction and (e) degraded-energy neutrons, (2.0 ± 0.5)%. No correction was made for fragment anisotropy.

Their reported thermal value was the same as [22] and was not included in Table 11.

The final results inolude all sources of errors except for the standard, which was assumed without error. The relative accuracy of each point with respect to the others is slightly better than that stated, as all errors include a contribution from the error in the correction for fission spectra differences.

Their least-squares fit to the data points shows that they could be adequately represented by a straight line, all the measured points statistically being consistent with the linear fit, with no evidence for any structure. This result was confirmed by the measurements of the average kinetic energy of ^{235}U fission fragments, carried out by Ajitanand and Boldeman [114].

All the published values of for ^{235}U are listed in Table 11, together with the renormalized values, which are plotted as a function of the neutron energy in Figures 9, 10 and 11.

5. Energy dependent measurements of $\bar{\nu}$ for ^{236}U

The only published data on the energy dependence of $\bar{\nu}_p$ for ^{236}U are those of Condé and Holmberg[34], who determined it in the energy range 0.8–6.7 MeV. They used a large liquid scintillator as neutron detector, and although a continuous ion beam was used in the measurements, the energy degradation of the incident neutrons was measured by using a pulsed beam and the time-of-flight technique. The energy spread of the neutron beam was ± 15 keV at 1 MeV incident neutron energy. The observed values were corrected for (a) spontaneous fission (0.3%), (b) thermal induced fission (0.2%), (c) pile-up (0.15%), (d) neutron fission spectra differences (-0.8%), (e) false gates (0.2%) and (f) fission foil thickness (0.3%). The experimental points are well fitted by a straight line.

The $\bar{\nu}$ values are listed in Table 12 and plotted as a function of the neutron energy in Figure 12.

6. Energy dependent measurements of $\bar{\nu}$ for ^{238}U

The presently available information on the energy dependence of $\bar{\nu}$ for ^{238}U is represented by 80 points, which cover the whole energy range from 1.3 to 28 MeV. This number includes some measurements in neutron spectra and the 6 points in the range 22 – 28 MeV, due to Soleilhac and collaborators. The only modern measurement is that of Soleilhac [121], all the others were published before 1965.

Some of the measurements have been considered already when dealing with lower-A fissile nuclei and are not repeated here. The corrections applied, if any, are of the same order of magnitude as for the fissile nuclides already considered.

As for the remaining measurements, leaving out some old ones with low precision, which are only of historical interest because of the impossibility of renormalization, we should consider a point at 1.58MeV by Butler et al [112] , reported also by Meadows et al. [132], relative to the thermal $\bar{\nu}_p$ value of ^{235}U, and also the measurement of Sher and Leroy [130] for a fast neutron spectrum with an effective energy of 3.1 MeV. The $\bar{\nu}$ value was corrected for fission anisotropy and angular dependence of the neutron efficiency $(2.0 \pm 0.5)\%$, for spontaneous fission of ^{238}U, fission fraction due to ^{235}U (17%) and degradation of the neutron spectrum in the beam. The experimental error is mainly statistical.

Finally we have the measurement of Asplund-Nilsson et al. [134], who measured $\bar{\nu}_p$ for ^{238}U between 1.5 and 7.5 MeV and also at 14.8 MeV. The neutron detector was a large Gd-loaded liquid scintillator, the energy of the neutron being selected by time-of-flight techniques. The $\bar{\nu}_p$ values were corrected for gate length differences of the fission-neutron and background counting systems, pulse pile-up (0.5 – 1.5%), false fission events ($<$ 0.2%), foil thickness (1.1%), ^{238}U spontaneous fission (0.3%), fission spectra differences (0.5%), neutron emission anisotropy (0.2%) and background ($<$0.2%).

The stated uncertainties in the $\bar{\nu}_p$ values are due to counting statistics only, and do not take account of the inaccuracy of the standard used, $\bar{\nu}_p^{sp}(^{252}Cf)$.

All the published values on $\bar{\nu}_p$ for ^{238}U are listed in Table 13, together with the renormalized values, which are plotted as a function of the neutron energy in Figure 13.

7. Energy dependent measurements of $\bar{\nu}$ for ^{239}Pu

The knowledge on the energy dependence of $\bar{\nu}$ for ^{239}Pu has improved considerably in the last few years and may be considered relatively well determined by 183 points which cover the whole energy range from thermal to 15 MeV, plus 6 additional points between 22 and 28 MeV, with the interesting feature that all but 30 points were published after 1969. However, although the quoted accuracy of the published values is high, there are still discrepancies as large as 1% among the results of some laboratories.

Most of the measurements were considered already in detail during the analysis of ^{232}Th and the uranium-isotopes, and will not be repeated here. These concern some old non-renormalizable measurements [79,99]; the fast fission spectrum measurements of Auclair et al. [136], Kalashnikova et al. [80], Andreev [137] , Hansen [83,138] and Engle [85]; single point measurements of Diven et al. [47], Leroy [36], Johnstone [69] and Flerov et al. [86]; two values by Smirenkin [81]; the six results by Hopkins et al. [8] between 0.250 and 14.5 MeV; the four points of Mather et al. [75]; the 75 points by Soleilhac and collaborators [121, 122]; and the data of Savin et al. [123] from 0.89 to 4.70 MeV. We should add only that, as for ^{235}U, the values listed in Table 14 from Soleilhac et al. [121], above 1.36 MeV, correspond to the new slightly modified set supplied to us in a private communication.

The measurements not yet considered are:

Condé et al. [139] measured $\bar{\nu}_p$ of ^{239}Pu and ^{241}Pu from 4 to 14.8 MeV and from 0.5 to 14.8 MeV, respectively. The fission detector was a large liquid scintillator. The energy of the incident neutrons was selected by time-of-flight. After subtracting the background from the observed $\bar{\nu}$-values, these were corrected for the contribution from the spontaneous fission (0.4 to 2%), fissions induced by thermal neutrons (0.2 - 2%), pulse pile-up (~ 0.6%), fission spectra differences (~ - 0.2%), false gates, fission foil thickness and anisotropy of fission neutron emission, with a total correction amounting to 1.2% for 4 MeV incident neutron energy. The uncertainty in the published values does not include the inaccuracy in the standard used, which was assumed without error.

Mather et al. [140] used also the large liquid scintillator technique to measure average values of $\bar{\nu}_p$ of ^{239}Pu over 11 energy bands below 1.2 MeV. The energy bands were 40 - 115 keV, 115 - 285 keV and 100 keV wide intervals above 300 keV. In the interval 525 keV to 875 the measurements were repeated with 50 keV wide energy bands. The relative accuracy in both series of measurements was ~1%.

During the experiment the background was measured continuously on a scaler and not by using a second background gate following each genuine one as is usual in this type of measurement. The contributions from low energy neutrons and for ^{240}Pu spontaneous fission were determined experimentally by means of a fission-time sorting technique [116].

The raw neutron multiplicity data were processed to subtract background and correct data for dead time effects, with allowance for the contribution from the ^{240}Pu content, and afterwards corrected for fission spectra differences, using the expression given by Terrell [104], (- 0.36 to 0.3% with an assigned systematic error in the correction of 50%), low energy neutrons ($<$ (0.7 $\pm$ 0.2)%), false gate caused by random coincidences, ($<$(3 $\pm$ 0.15)%), and anisotropy in fission fragment emission ($\ll$0.1% but, according to the authors, an additional error of $\pm$ 0.5% must be assigned for absolute $\bar{\nu}$ values to allow for preferential selection of fissions due to the non-zero bias). No correction was applied for delayed gamma rays.

Errors quoted are standard deviations for relative values and are dominated by counting statistics. According to the authors an additional systematic error of $\pm$ 0.6%, due to uncertainties in the applied correction, should be added to these relative errors to obtain the absolute ones.

The first group of data were well fitted by a straight line, although the addition of the 50 keV wide interval data worsened the fit somewhat.

Condé and Widen [141] measured $\bar{\nu}_p$ of ^{235}U and ^{239}Pu in a fast reactor spectrum. They used a large liquid scintillator as fission neutron detector. The reported values, which have been corrected for spontaneous fission (+2.0%), pile-up (+0.5%), random coincidences (+0.2%) and different neutron spectra (-0.3%), with a total correction of +2.4% should be considered as preliminary.

Finally we have the unpublished results of Boldeman and Walsh [224] below 2.0 MeV, performed with the same technique as the previous measurements for ^{233}U and ^{235}U described above.

Table 14 lists all published data and the renormalized values. The latter ones are plotted as a function of the neutron energy in Figures 14, and 15.

8. Energy dependent measurements of $\bar{\nu}$ for ^{240}Pu

Although there is considerable technological interest in accurate values of $\bar{\nu}$ for ^{240}Pu, as plutonium-fuelled fast reactors are expected to have an initial and equilibrium content of ^{240}Pu of about 20 % of the total plutonium, the available experimental data on the energy dependence of $\bar{\nu}$ for ^{240}Pu is very scarce. In fact, the energy dependence for $\bar{\nu}_p$ is represented mainly by the values of Savin et al. [123], from 1.08 to 3.94 MeV, already considered in VII.4, obtained with a high statistical error owing to the spontaneous fission of ^{240}Pu.

There are also a few measurements carried out with a fast reactor spectrum [83, 85, 142 and 143], two points due to Kuzminov [150], who used a back-to-back ionization chamber, detecting in each half the fission neutrons produced in the other, and finally 3 values by DeVroey et al. [151] below 1.6 MeV, which were obtained using a pulse source of monoenergetic neutrons. The fissile sample was contained in a fission ionization chamber placed close to the source. The neutrons were detected with a plastic scintillator 10 cm in diameter, located at 60 cm from the fission chamber. The $\bar{\nu}$ values were corrected for the effect of neutron-fragment angular correlation, effect of finite foil thickness and isotopic impurities. The errors are mainly statistical. The accuracy of all these measurements is very low.

The published values are listed in Table 15 and plotted in Figure 16 as a function of the neutron energy.

9. Energy dependent measurements of $\bar{\nu}$ for ^{241}Pu

The only available measurement is that of Condé et al. [139], represented by 5 points between 0.5 and 14.8 MeV. The details of the experiment were considered already in VII.7 and are not reproduced here. It should be added only that the correction to the experimental values is dominated by the spontaneous fission contribution, which amounts to 10 - 15 % for this isotope.

The values of $\bar{\nu}_p$ are listed in Table 16 and have been plotted in Figure 17, as a function of the incident neutron energy.

VIII. DELAYED NEUTRONS

The primary practical interest for accurate delayed neutron data lies in the kinetic behaviour and control of reactors, since the delayed neutron emission determines their transient behaviour and stability.

At present, the implementation of the Non-Proliferation Treaty has increased the necessity of accurate delayed neutron emission parameters. In fact, an effective nuclear safeguards and material management system requires direct physical methods of detecting, identifying and quantitatively analysing fissionable materials, and the characteristic differences in yields and time-dependent response of the delayed neutron emission from the various fissionable isotopes, provide an effective and useful method for the non-destructive assay of fissionable elements, by using integral neutron counting [152] or kinetic response methods [153, 154].

On the other hand, there is also a basic interest in the delayed neutron emission studies. This interest stems from its importance in the study of the nuclear structure and fission mechanism, in particular in the neutron-rich region above closed shells.

Since the discovery of the delayed neutrons in 1939 many investigations have been carried out on delayed neutron emission parameters. A comprehensive review of all delayed neutron studies, and in particular of delayed neutron yields, prior to 1956 [170, 228 -239] can be found in the review article of Keepin [155], which was followed by new compilations from the same author [156, 157], and the review papers of Amiel [158, 159] presented at the first and second IAEA Symposia on Physics and Chemistry of Fission. Recognizing the importance of the delayed neutrons the IAEA convened in 1967 a Panel dealing with the various aspects of the Delayed Fission Neutrons [160]. Recently Tomlinson [171] has published a compilation and evaluation of experimental data on delayed neutrons from fission directed towards those concerned with nuclear reactor design and operation. It covers delayed neutron precursors, total number of delayed neutrons per fission, group half-lives and yields, long-lived delayed neutron groups and delayed neutron energy spectra.

The most comprehensive and detailed set of measurements on delayed neutron emission parameters was carried out at Los Alamos, in the first place by Keepin et al. [32], who measured the gross decay rates, group half-lives and group abundances for thermal and fast fission neutrons of thorium and of the uranium and plutonium isotopes, as well as recently by Masters et al. [161] and by Krick and Evans [162, 163], who measured the energy dependence of the total delayed neutron yields per fission for several uranium and plutonium isotopes.

On this subject one should also mention the extensive work carried out in the USSR by Maksyutenko [164 - 168], who measured the energy dependence of total and individual group yields for several thorium, uranium and plutonium isotopes. However, although his values at 2 - 3 MeV incident neutron energy agree with those of other experimenters, his results at 14 MeV are in clear contradiction to what could be expected from theoretical predictions [169], and to the new results of Masters et al [161] and of Krick and Evans [163].

Aside from the measurements of these two laboratories, many other measurements exist which are considered in detail below. The first absolute delayed neutron yield determination was that of Hughes et al. [170], who in 1948 measured the absolute delayed neutron yield per fission of ^{235}U for fission neutrons of the Argonne heavy water pile. He was also able to identify five groups of delayed neutrons, the half-lives of which were used extensively till the more accurate results of Keepin et al [32] became available.

Brunson et al [172] determined the delayed neutron yields for the thermal fission of ^{233}U, ^{235}U and ^{239}Pu as well as for the fast fission of ^{232}Th, ^{233}U, ^{238}U and ^{239}Pu, relative to the fast delayed-neutron yield in ^{235}U. The ratios obtained are based on the four longest periods, and the measurements were made in the Experimental Breeder Reactor using a conventional sample transfer system and a neutron counter comprised of BF_3 tubes surrounded by graphite. In the determination of the individual group yields he used the group periods of Hughes [170].

Keepin et al [32] measured the absolute delayed neutron yields for thermal and fast fission of thorium, uranium and plutonium isotopes. By using short neutron bursts as well as long irradiations to saturation they were able to resolve the multicomponent decay curve into six exponential components by an iterative least squares analysis. "Godiva", the bare ^{235}U metal assembly at Los Alamos, was used as neutron source, and a modified long counter as neutron detector. No spectral dependence was found in the neutron yields. The data were corrected to 100 % isotopic purity.

Rose et al [173] measured the delayed neutron yields from the fast fission of ^{233}U, ^{235}U, ^{238}U, ^{239}Pu and ^{232}Th, relative to the thermal delayed neutron yield of ^{235}U. The samples were irradiated in the natural uranium envelope of the Zephyr reactor in a flux of fast neutrons with an average energy of about 1 MeV. Because of the comparatively poor statistics it was not considered advantageous to analyze the delayed neutron group into both periods and yields. Instead, the half-lives as measured in ^{235}U by Hughes et al [170] were assumed.

Cox et al [174] determined the periods and absolute yields of delayed neutrons for the spontaneous fission of ^{252}Cf. The neutron detector was a shielded BF_3 counter ring embedded in a moderating medium. Delayed-neutron periods of 0.5 ± 0.4, 2.0 ± 0.4 and 20.0 ± 5 sec were found, the experiment being insensitive to delayed neutron periods shorter than 0.25 sec.

Maksyutenko [165] determined the absolute yields of delayed neutrons in the fission of ^{232}Th, ^{235}U and ^{238}U by neutrons of 2.4, 3.3 and 15 MeV, relative to the thermal fission of ^{235}U. He used monoenergetic neutrons from the D(d,n) and T(d,n) reactions in a cascade generator. The neutron detector was a bank of four BF_3 counters connected in parallel and surrounded by paraffin. Five groups of delayed neutrons were resolved. As already indicated, he found that the delayed neutron yields increased by a factor of about 2 when going from fission in the MeV range to 15 MeV.

McGarry et al. [175] determined the number of delayed neutrons per fission of ^{235}U and ^{238}U induced by 14 MeV neutrons. The values obtained agree with those of Maksyutenko [165].

Shpakov et al [176] measured the total yield of delayed neutrons in the fission of ^{232}Th and ^{239}Pu by 14.5 MeV energy neutrons. The neutron detector was composed of 17 boron counters enclosed in a common paraffin block. He found in agreement with Maksyutenko [165] and McGarry [175], that the number of delayed neutrons at 14 MeV is about twice the number of delayed neutrons at thermal energies, in contradiction to the theory.

Cox [177] has measured the total delayed neutron yield resulting from the thermal-neutron induced fission of ^{241}Pu, relative to that of ^{235}U. In the same experiment he determined also the individual group yields and the associated half-lives. Five periods were determined. The neutron detector consisted of 10 BF_3 counters immersed in mineral oil.

Maksyutenko [166] measured the delayed neutron yield of ^{233}U at 15 MeV relative to that at low energies, using the same method as in previous measurements [165]. He found once again that the yield at 15 MeV is about 1.6 times greater than that from the fission by thermal neutrons.

Bucko [178] studied the delayed neutrons arising from the fission of ^{238}U by 14.7 neutrons. He measured the relative group intensities and the ratio of the total delayed neutron yields for bombarding neutron energies of 3 and 14.7 MeV. The measurements were performed using a long counter to detect the neutrons. These results agree with the results of Maksyutenko [165] and McGarry [175].

Herrmann et al [179] have measured the absolute neutron yields of ^{232}Th and ^{238}U by 14 MeV neutrons, using a novel technique which involves no absolute counting of neutron or fission rates. The neutron yields were determined relative to the delayed neutron yield in the fission of ^{235}U by thermal neutrons, by measuring the ^{99}Mo yields in the sample and in the reference reaction. The ^{99}Mo yields were counted with an end-window beta-counter. Decay curves were analysed by the least-squares method using the periods reported by Keepin [32] and by Maksyutenko [164]. His results indicate a decrease of the delayed neutron emission with increasing excitation energy of the fissioning nucleus. Their results which should be considered as preliminary, were modified slightly in a later publication [186].

Notea [184] used a method similar to that of Hermann et al. [179] in the measurement of the delayed neutron yields of ^{233}U and ^{239}Pu for thermal fission and of ^{232}Th and ^{238}U for 14 MeV neutrons. The measurements were made relative to the thermal delayed neutron yield of ^{235}U, and the number of fissions in the samples was determined from the known x-ray peaks of the fission products, measured with a Ge(Li) spectrometer. His results at 14 MeV are in agreement with those of Hermann et al.[179] but his thermal delayed neutron yields are much lower than any other previous measurement.

. Masters et al.[161] measured the absolute and relative delayed-neutron yields of ^{232}Th, ^{233}U, ^{235}U, ^{238}U and ^{239}Pu for neutron-induced fission at 3.1 and 14.9 MeV, using a new method in which a modulated neutron source was operated in antisynchronism with a modified long counter, in which the $^{10}BF_3$ counter was substituted by five ^{3}He detectors. The number of induced fissions was measured with two fission counters sandwiching the sample. The technique used in obtaining the results consisted of first making an absolute yield measurement at 14.9 MeV fission with the long counter, and then a relative measurement at 3.1 and 14.9 MeV. The data were corrected to 100% isotopic purity by making measurements on two samples of different isotopic content. Their results show a strong yield decrease with increasing energy, which as pointed out by the authors, is in accord with expectations based on the behaviour of fission mass and charge distributions as a function of fission energy.

At Los Alamos Scientific Laboratory [180], within the program on Nuclear Safeguards Research, the absolute yield of delayed neutrons per incident source neutron, for an incident energie of 14.9 MeV was measured for the following fissionable isotopes: ^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu and ^{241}Pu. The source neutrons were obtained using a pulsed Cockcroft-Walton accelerator. The absolute number of source neutrons produced was determined through the associated-particle method by counting the alpha particles from the reaction $T(d,n)^4He$. The delayed-neutron yield per fission was obtained by multiplying the absolute delayed-neutron yield per incident source neutron by the fission cross section at 14.9 MeV. The results obtained agree extremely well with the measurements of Masters et al [161]. It is of interest that the yields per fission of ^{240}Pu and ^{241}Pu at 14.9 MeV are roughly a factor of 1.8 below the yield values for thermal or fission spectrum neutrons, shown in Table 17, which corroborates the decrease found by Masters et al. [161] for the other fissionable isotopes.

Krick et al. [162, 163] measured the total delayed neutron yields as a function of energy for ^{233}U, ^{235}U, ^{238}U, ^{239}Pu and ^{242}Pu. The technique used in the measurements was basically that of Masters et al. [161], the data were corrected to 100% isotopic purity, and for self-absorption in the fission chambers and low energy contamination in the source spectrum.

The measurements made on ^{233}U, ^{235}U, and ^{239}Pu from 0.1 to 1.8 MeV and on ^{242}Pu from 0.7 to 1.3 MeV show no variation in yield with neutron energy in agreement with the data of other experimenters [32, 181]. Between 5 and 6.5 MeV a decrease of about 20 to 30% with increasing neutron energy was found in the yields from ^{233}U, ^{235}U and ^{238}U. It should be mentioned that the absolute yields reported are not independent from those obtained by Master et al. [161], since some material and standards are common to both experiments.

Except for ^{242}Pu, sources of error contributing to the uncertainty in the low energy yield values were primarily due to uncertainty in neutron detector efficiency ($\sim$ 6%), uncertainty in neutron flux ($\sim$ 5%), uncertainty in the fission chamber foil masses ($\sim$ 1-4%), statistics and reproducibility ($\sim$ 3%), and uncertainties in miscellaneous corrections ($\sim$ 1%). The net error for the absolute yield of ^{242}Pu is estimated to be $\pm$ 30%. Relative errors for low energy data were determined primarily by reproducibility ($\sim$ 3%), and for the high energy data by statistics and reproducibility ($\sim$ 8%) and by uncertainties in the low energy contamination correction ($\sim$ 1-7%). The numerical values of the measurements are given in Tables 17 and 18.

Cox and Whiting [181] measured the delayed neutron yield from neutron induced fission of ^{232}Th, ^{235}U and ^{238}U. Measurements were made for ^{235}U at various energies from 0.25 to 1.5 MeV. For ^{232}Th and ^{238}U the measurements were made from below the fission threshold to 2.4 MeV. The delayed neutron activity was counted with an array of 11 BF_3 counters placed in a moderating bath of mineral oil, outside the 1.5 ft diam. cylindrical cavity which contained the target and the samples. All data were corrected for effects due to the non-isotropic fission fragment angular distribution and isotope impurities in the samples. The data for all elements were normalized at 1.450 MeV to Keepin's fast neutron determinations. The errors in the individual points are estimated to be $\pm$ 4% based on both the counting statistics and the reproducibility of the measurements. Their results show that for ^{235}U the delayed neutron yield is constant within the experimental errors from thermal up to $\sim$1.5MeV and from below threshold up to 2.4 MeV for ^{238}U and ^{232}Th.

Brown et al. [182] measured the absolute delayed neutron yield of ^{238}U, ^{232}Th and ^{231}Pa for 14.8 MeV neutron induced fission. Delayed neutrons were counted by an array of 20 ^{10}B-enriched BF_3 proportional counters embedded in a cylindrical block of paraffin wax. Neutron flux was determined by measuring the 56 Mn activity from the ^{56}Fe (n,p) ^{56}Mn reaction. Delayed neutron decay curves were resolved into four groups using the half-lives of Maksyutenko. The standard errors of the quoted values are estimated to be 15%.

Conant and Palmedo [183] measured the delayed neutron fractions for thermal fission of ^{233}U, ^{235}U and ^{239}Pu by comparing the neutron production rate of a thin fissile sample in a thermal-neutron beam with the delayed-neutron production after an abrupt termination of the beam. Neutrons were detected with a modified long counter [161]. They used the group half-lives of Keepin et al. [32]. The quoted error includes the experimental error and the uncertainties in delayed neutron precursor half-lives and relative yields. Their results are in excellent agreement with the previously accepted values of delayed neutron fractions.

Finally we have the unpublished measurements of Clifford et al. [185], quoted by Tomlinson [171], for ^{235}U and ^{238}U.

Delayed neutron yields in the photofission of ^{232}Th and ^{238}U have been reported by Moscati and Goldemberg [221] and in the photofission of ^{232}Th, ^{235}U, ^{238}U and ^{239}Pu by Nikotin and Petrzhak [222]. The measurements were made for maximum bremsstrahlung energies of 12 - 20 MeV and 15 MeV respectively. No evidence was found of an energy dependence of the delayed-neutron yields per photo-fission.

Tables 17 and 18 list all at present available values on the total delayed-neutron yields for the fissile and fertile isotopes. These have been plotted as a function of energy in Figures 18 and 19, except for the data of Maksyutenko [165, 166], McGarry [175], Shpakov[176] and Bucko [178] at 14 - 15 MeV because they are in clear contradiction with the more recent results and with the theoretical prediction, and their inclusion could give rise to some confusion in the graphs. In fact, the decrease in the delayed neutron yield above $\sim$ 5MeV occurs at energies corresponding to the onset of the second-chance fission threshold. Since above this threshold fissions occur from a nucleus which is less rich by one neutron, a decrease in delayed-neutron precursors and hence delayed-neutron yield will be expected.

Weighted average yields ($1/\sigma^2$ weighting) have been computed from the data of Table 18 for the three following energy ranges: thermal, 0.1 to 4-5 MeV and 14-15 MeV, respectively, as well as for the photo-fission delayed neutron yields. Since the delayed-neutron yields remain constant over the energy range below 4.5 MeV, weighted averages of the measured values were obtained for each author in this energy region. This average instead of all the discrete measurements has been used to calculate the recommended average fission yields in this energy interval. In those measurements in which only four or five groups were considered, an allowance was made for contributions from shorter half-life groups.

The recommended delayed neutrons yields for the three energy ranges considered are listed in Table 19. These average values were used to draw the delayed-neutron yield versus energy plots of Figures 18 and 19.

An inspection of the values listed in Table 19 shows that there is some systematic dependence of the neutron yield with the parameters Z and A of the fissioning nucleus, in the form of a yield increase with mass number for a given element and also a yield decrease with increasing atomic number of the fissioning nucleus.

To examine in more detail these systematics the average delayed-neutron yields of Table 19 have been plotted versus the mass number A, as well as a function of the empirical parameter A-3Z, [157], where Z and A refer in both cases to the compound nucleus undergoing fission. This choice of representation gives essentially straight lines on a semilogaritmic plot for the delayed-neutron yields of each one of the energy ranges considered.

Weighted least-squares fits of the average fast and 14 MeV fission data to the functions $N/F = \exp\,[a\,(A-3Z)_{CN} + b]$ and $N/F = \exp\,[c\,A_{CN} + d]$ gave the straight lines plotted in Fig. 20. A t test, carried out to establish whether there are significant differences between the slopes of the fitted lines, gave results consistent with the hypothesis that the fitted lines in Fig. 20 (a) and (b) are parallel, except for the case of 14 MeV data of the plutonium isotopes. There is a general good agreement between the fits obtained and the experimental data, except for the fast fission yield of ^{242}Pu. Therefore the implied systematics shown in Fig.20 provides an useful mean for estimating unknown delayed neutron yields.

IX. NEUTRON MULTIPLICITY MEASUREMENTS FOR RESONANCE FISSION

The analysis of the variations of the average number of prompt fission neutrons in the resonance energy region presents great interest not only from the theoretical point of view, but also in nuclear power engineering.

In fact, measurements over the last few years have shown that some characteristics of the fission process, such as the fission-product mass yield and the kinetic energy of fission, vary from resonance to resonanc for the fissile nuclei [90,187,188]. These results could be interpreted by supposing that the mean number of neutrons per fission varies also systematically among resonances.

On the other hand, the variation from resonance to resonance of the average number of fission neutrons plays an important role in fast breeder reactors, since resonance effects must be accounted for even if only statistically [189], and in the renormalizations, e.g. of α-measurements [209].

All the considerations above have caused several experimenters to carry out detailed measurements on the dependence of the fission neutron multiplicity on the incident neutron energy in the resonance region. The presently available information on this subject is as follows:

<u>Weinstein et al</u> [190,198] investigated the energy variation of the average fission neutron multiplicity, $\bar{\nu}$, for ^{233}U, ^{235}U, and ^{239}Pu in the resolvable resonance region. Their measurements cover the energy region from 0.01 eV to 100 eV for ^{239}Pu, 0.01 eV to 5.5 eV for ^{233}U and 0.01 eV to 25 eV for ^{235}U.

The measurements were carried out at the Rensselaer 100 MeV Electron Linear Accelerator. The neutrons were detected with a 70 cm diam. gadolinium-loaded liquid scintillator tank in coincidence with the fission events of a multiplate fission ion chamber placed at its centre.

The experimental data were corrected for background, spontaneous fission, random coincidences and scaler dead-time. The set of $\bar{\nu}$ data for each nuclide was separately normalized to the standard $\bar{\nu}$ values of Westcott et al. [223]

The results of measurements for 20 resolved resonances in ^{239}Pu show that the $\bar{\nu}$ values appear to fall into two distinct groups, which are strongly correlated with the spins of the individual resonances , with the $J = 0^+$ levels corresponding to high values of $\bar{\nu}$ and the $J = 1^+$ levels corresponding to low values. The average multiplicity for the $J = 0^+$ group is about 3% higher than the average for the $J = 1^+$ group.

In the case of ^{235}U, variations in fission neutron multiplicity were observed in the thermal neutron energy region with a statistically significant decrease of about 0.6% when one goes from the 0.3 to the 0.01 eV resonance. In the resonance region the data have not been completely analysed, but spin assignments were made for 13 of the resonances, and the $\bar{\nu}$ values appear to fall into two groups which could be assigned to $J = 3^-$ (higher values of $\bar{\nu}$) and to $J = 4^-$ (lower values of $\bar{\nu}$).

For ^{233}U data were taken only below 5 eV. Although there is some indication of a grouping of the $\bar{\nu}$ values in the resonances, the statistics are too low to allow firm conclusions to be drawn. The authors concluded that $\bar{\nu}$ is constant within 0.2% over the neutron energy range from 0.01 to 0.2 eV.

The resonance spin assignments for both ^{235}U and ^{239}Pu are in excellent agreement with the results of other experimenters [187, 191-194].

Ryabov et al. [195] made relative measurements of $\bar{\nu}$ for the ^{235}U and ^{239}Pu fission by resonance neutrons. The measurements cover the energy region from 1.14 to 39.5 eV for ^{235}U and 7.9 to 85.7 eV for ^{239}Pu. The measurements were carried out by the time-of-flight method using the pulsed fast reactor at the Joint Institute of Nuclear Research, Dubna, as a neutron source. Fission neutrons were detected with a 500-litre cadmium-loaded liquid scintillator detector in coincidence with a fission chamber. The data were corrected for background, random coincidences and dead-time counting losses. Their spin assignments were taken from Asghar [192]. It should be pointed out that they assigned spin 0^+ to the resonance at 26.37 eV, which should correspond to the 26.2 eV resonance of Asghar, but according to this author the spin value is 1^+, in agreement with the assignments given in [187, 190]. A least-squares analysis of the results obtained showed that the values of $\bar{\nu}_i/\langle\bar{\nu}_i\rangle$, i.e. the ratio of $\bar{\nu}$ of the i^{th}-resonance to the average of all resonances studied, for the different resonances of both ^{235}U and ^{239}Pu could be grouped around two values, one of them greater and the other smaller than unity. Furthermore, $\bar{\nu}_i/\langle\bar{\nu}_i\rangle$ plotted as a function of M_S/M_A, i.e. the relative yield of fragments of symmetrical mass, showed clearly that the values of $\bar{\nu}_i/\langle\bar{\nu}_i\rangle$ are in correlation with the values of M_S/M_A for ^{235}U and in anticorrelation for ^{239}Pu, and are in both cases in correlation with the statistical spin factor, g.

From the correlation between $\bar{\nu}_i/\langle\bar{\nu}_i\rangle$ and g they deduced that the resonance groups with the larger and smaller values of $\bar{\nu}_i/\langle\bar{\nu}_i\rangle$ can be assigned spin values 4^- and 3^- in the case of ^{235}U and 1^+ and 0^+ in that of ^{239}Pu.

Although their results seem to be in agreement with measurements of the energy dependence of the average fragment kinetic energy [90, 196], they are in clear contradiction with the results of Weinstein et al.[190] and with considerations of the characteristics of the exit channel of fission and the results on mass distribution of the fission products [197].

These discrepancies between the results of Weinstein et al. [190] and Ryabov et al. [195] have caused Weston and Todd [189] to perform new measurements on the neutron multiplicity for ^{239}Pu in the resonance fission region below 200 eV. They use a novel method in which fission neutrons from a fission chamber were detected with low efficiency with fast neutron detectors rather than counting thermalized neutrons with high efficiency in a scintillator tank. The Oak Ridge Electron Linear Accelerator (ORELA) was used as source of pulsed neutrons. The fission chamber was identical to that used by Weinstein et al. [190] and the fast neutron detectors were liquid scintillators (NE-213) coupled to 58AVP photomultipliers, in which pulse-shape discrimination was done in order to discriminate between fast neutrons and gamma-rays. The data were normalized to the thermal ^{239}Pu $\bar{\nu}$ value of Westcott et al. [5]. The reported errors are those due to counting statistics, systematic errors not being known which are comparable with or larger than the statistical ones. Spin values were taken from [190] or derived from the summary tables of spin assignments of Derrien et al. [191].

As stated by the authors, the data obtained do not indicate a separation into two groups according to the spin of the resonances but a much weaker correlation. Where previous results showed an average difference of 3 to 5% in $\bar{\nu}$ for resonances of different spins, their results give no difference outside the 1/4% uncertainty of the experiment. They suggest as a possible explanation for the discrepancy between their results and those of previous experimenters that the present technique is not as sensitive to gamma-ray effects as some of the previous techniques, being insensitive to a possible change from resonance to resonance of the prompt gamma-rays from fission. Therefore they deduce that the variation of $\bar{\nu}$ from resonance to resonance should be ignored in reactor calculations and in fission cross section measurements involving the detection of fission neutrons.

Finally it should be mentioned that Reed and Block [199] have in progress a measurement of $\bar{\nu}$ for ^{233}U and ^{235}U below 40 eV, and envision to extend the measurements to the keV region.

Table 19 lists the renormalized data of the resonance $\bar{\nu}$-values of ^{239}Pu, which are plotted as a function of the incident neutron energy in Figure 21. The numerical values of Ryabov et al. [195] have been obtained by multiplying $\bar{\nu}_i/\langle\bar{\nu}_i\rangle$ by $\langle\bar{\nu}_i\rangle$ = 2.873, the average value of all data of Weinstein et al. [198] and Weston et al. [189] for the same energy range.

Weighted least-squares fit to the experimental data enhanced the discrepancies among the three sets of values, although, as shown in Fig.21, the results for the data of Weston et al. [189] and of Weinstein et al.[190] seem to indicate that spin 0^+ resonances tend to higher values of $\bar{\nu}$, in agreement with the measurement of the variation of the mass distribution of fission fragments [187, 197]. However, the resolution of the problem is far from being achieved and much more detailed data would be necessary to predict the magnitude of this effect.

X. RECOMMENDED VALUES OF $\bar{\nu}_p$ AND $\bar{\nu}_t$ FOR THE FISSILE AND FERTILE ISOTOPES

Although the main purpose of this review was to produce a thorough compilation of the $\bar{\nu}$ values of the heavy isotopes - for neutron induced and spontaneous fission - it was considered of the utmost interest to analyse statistically the experimental data in order to derive "best fits" from which recommended values of $\bar{\nu}_p$ and $\bar{\nu}_t$, as a function of the incident neutron energy, can be deduced.

The analysis was performed with a weighted Least-squares Orthogonal Polynomial Fitting computer programme [68, 202], which allows to select, on a purely statistical basis, the best fit to the experimental data, by taking into consideration the statistical weight associated with each individual experimental data point, and to assign statistical confidence limits to the fitted curve, through the point-wise standard deviations given by the programme.

The essential features of the fitting programme are the following:

(i) it uses orthogonal polynomials which allow a high degree of fitting without excessive use of computer time.

(ii) it allows to obtimize the degree, k, of the fitted polynomial from the experimental data. The criterion used is the F ratio at the 95% confidence level, where $F = S_j/\sigma^2$, S_j being the residual sum of squares and σ^2 the variance of the fitted curve.

(iii) The programme provides point-wise values of the fitted function as well as useful statistical information concerning the "quality" of the fitted curve of degree, k.

E.g. it prints out the estimated standard deviation of the fitted curve, $\hat{\sigma}$, the standard deviation of the estimated mean of $\bar{\nu}(Ei)$, z_i, and the standard deviation of $\bar{\nu}(Ei)$ about the estimated mean, $s_i = \sqrt{z_i^2 + \hat{\sigma}^2}$. These allow to define confidence intervals $(\bar{\nu}(E_i) \pm |t_\mu| z_i)$ and $(\bar{\nu}(E_i) \pm |t_\mu| s_i)$ for the expected value of $\bar{\nu}(E_i)$ and for a single predicted value, respectively. Here $|t_\mu|$ is the value of the t of Student at the desired confidence level on $\mu = n - k - 1$ degrees of freedom (n is the number of energy points and k the degree of the fitted polynomial).

Both sets of confidence intervals apply at individual values of E only, and do not apply simultaneously for all E in an energy interval $E_1 \leqslant E \leqslant En$, but it is possible to define a suitable confidence <u>region</u> which will contain the whole curve $\bar{\nu}(E)$ for $E_1 \leqslant E \leqslant En$ by joining the points

$$\bar{\nu}^{(k)}(E_i) \pm z_i \sqrt{(k+1)\, F_{k+1,\mu}} \qquad (13)$$

in a smooth curve. Here $F_{k+1,\mu}$ is the point of the F distribution at the desired confidence level.

The inverse squares of the errors of the individual experimental data points were used as weights. Only the experimental errors, as given in <u>Tables 8 - 16</u>, were taken into account in the calculation of the weights. In those cases in which no indication was given of the type of error reported, this was assumed as statistical in the weight calculations.

No correction was made for systematic effects not taken into account by the authors, as e.g. fission spectra differences. In fact, the value of these corrections is smaller than the remaining uncertainties in the value of the standards used. In any case, those data sets for which corrections should still be applied are old lower accuracy data, the weight of which in the total fitting is negligible. Except for ^{235}U, ^{239}Pu and ^{240}Pu no rejection of data was made in the determination of the "best" values.

The errors listed in the tables of recommended values correspond to the standard deviation of the estimated mean, z_i, and do not include the inaccuracies in the value of the standards. For all the fits values of $\hat{\sigma}$ and μ are also given, which allow to define suitable confidence intervals for the fitted values.

In the following paragraphs the results of the fittings are given, together with a comparison with the results of previous evaluations.

1. Recommended $\bar{\nu}_p$ and $\bar{\nu}_t$ values for ^{232}Th.

The available experimental information on the energy dependence of $\bar{\nu}_p$ for ^{232}Th is old, scarce and in general of low accuracy, which a large gap between 4 and 14 MeV where only one point is available. This makes it useless trying to fit a high degree polynomial to the whole energy range, because it will be determined by the points at both ends of the fitted interval and, therefore, the $\bar{\nu}$ values it will yield in the range between 4 and 14 MeV would be unrealistic.

At energies close to the threshold the experimental data show an increase of $\bar{\nu}_p$ with decreasing energy which, though statistically not significant due to the large errors associated with each individual point, seems to be confirmed by the results of four different experiments.

This low energy region (from fission threshold up to 1.6 MeV) is well represented by the second degree polynomial

$$\bar{\nu}_p\,(E) = 8.0471 - 7.0020\,E + 2.0916\,E^2 \qquad (14)$$

with $\hat{\sigma} = 0.0094$ on 5 degrees of freedom, while the experimental data between 1.6 and 15 MeV could be represented by the straight line

$$\bar{\nu}_p\,(E) = 1.8518 + 0.1513\,E \qquad (15)$$

The estimated value of σ is $\hat{\sigma} = 0.01220$ on 21 degrees of freedom.
A linear fit to all the experimental data from threshold up to 15 MeV gave the result

$$\bar{\nu}_p\,(E) = 1.8743 + 0.1489\,E \qquad (16)$$

with $\hat{\sigma} = 0.0152$ and $\mu = 25$, which deviates from expression (15) by less than 0.8% for the common energy range from 1.6 to 15 MeV. The results obtained agree well with those of Davey [60] who fitted the experimental data by means of two straight lines which intersect at 1.57 MeV. Eq (16) is also in good agreement with the linear fit of Filmore [2] but in clear contradiction to the evaluated data of the UKAEA- Nuclear Data Library [203] which considers also a linear fit but with a slope of only 0.104 n/MeV.

Eq(14) and (15) were considered as best representation of the experimental data. They are plotted in Fig. 5 and the values of $\bar{\nu}_p$ and $\bar{\nu}_t$ listed as a function of energy in Table 21. The errors given represent as already stated pointwise standard deviations, z_i, of the estimated mean of $\bar{\nu}$ (E_i), as given by the fitting programme. The standard variation of any single predited value, $s = \sqrt{z_i^2 + \hat{\sigma}^2}$, remains equal to 0.019 below 5.5 MeV and then increases with energy, with a value $s = 0.046$ at 15 MeV.

The total $\bar{\nu}$ values have been obtained by adding a delayed neutron contribution of 0.0515 n/fission to the $\bar{\nu}_p$ values between threshold and 4.5 MeV (obtained as average value of all published data below this energy), and lower contributions, as given by Fig. 19, above this energy. The shape of the $\bar{\nu}_d$ curve was deduced from a comparison with the results for other fissile isotopes.

2. Recommended $\bar{\nu}_p$ and $\bar{\nu}_t$ values for ^{233}U

The experimental information on the energy dependence of $\bar{\nu}_p$ for ^{233}U is very similar to that of ^{232}Th. The published data are old, scarce, and in general of low accuracy, with the exception of the data of Boldeman [92], below 2 MeV, published in 1971. There is no experimental point between 5 and 14 MeV, hence any high degree polynomial fitting covering the whole energy region will give an unrealistic representation over this energy interval.

Some indication of structure may be guessed in the low energy region, as shown by the data of Kuznetsov et al. [89] and Blyumkina et al.[90], which seems to be supported by the latest measurements of Boldeman et al. [224] of the dependence of the average total fission fragment kinetic energy of ^{233}U on incident neutron energy causing fission, in which strong evidence of channel effects were found.

In search for such a structure a weighted Least-squares Orthogonal Polynomial Fitting analysis was carried out for the energy intervals between thermal and 2 MeV and between thermal and 5 MeV.

The analysis performed seems to confirm the existence of such a structure below 3 MeV, in the form of a step-like dependence of $\bar{\nu}_p$ with the incident neutron energy, which can be represented by a five degree polynomial, but the scarcity and low accuracy of the data above 2 MeV makes it difficult to get a smooth, realistic connection between the fittings for the low and high energy regions. In the present circumstances the following set of equations was considered to give the best representation of the experimental data for the whole energy range between thermal and 15 MeV:

$$\bar{\nu}_p(E) = 2.47810 - 0.05840E + 0.20947E^2 - 0.07297E^3 \qquad (17)$$

between thermal energy and 0.9 MeV, with $\hat{\sigma}_1 = 0.0036$ on $\mu_1 = 20$ degrees of freedom, and

$$\bar{\nu}_p(E) = 2.4276 + 0.12715E \qquad (18)$$

From 0.9 to 15 MeV, the estimated value of σ being $\hat{\sigma}_2 = 0.0038$ on $\mu_2 = 27$ degrees of freedom. The agreement between the results given by both equations in the energy range between 0.5 and 1.5 MeV is better than 0.1%.

Most of the data below ~ 2 MeV appear systematically lower than the fitted curve, but it should be pointed out that they correspond to the low accuracy, indirect measurements of Kuznetsov et al [89] and of Blyumkina et al [90], which therefore enter with much lower weight in the fitting process.

The present evaluation gives a continuous and smooth variation of $\bar{\nu}_p$ with the neutron energy, improving the evaluation of Boldeman [92], who fitted the existing data below 5 MeV, with exception of the Kuznetsov [89] and Blyumkina [90] data, by means of two straight lines which intersect at 0.44 MeV, and also that of Davey [60], which does not include the latest data of Boldeman.

The existence for this isotope of several independent experimental values at the same energy allows a test of the goodness of the fits by means of an estimate of the "internal error variance", σ^{*2}, at these points and a F test of the ratio $(\hat{\sigma}/\sigma^{*})^2$. The test showed that $\hat{\sigma}^2$ was not significantly greater than σ^{*2} and confirmed the goodness of the fits. Therefore, it was possible to combine $\hat{\sigma}^2$ and σ^{*2} in an overall variance estimate, $\bar{\sigma}^2$, which can be used to define suitable confidence intervals for any single point. We have $\bar{\sigma}_1 = 0.0159$ on 28 degrees of freedom (d.f.) below 0.9 MeV and $\bar{\sigma}_2 = 0.0130$ on 29 d.f. above this energy, which means for the standard deviation about the mean, $s = \sqrt{\hat{\sigma}_i^2 + \bar{\sigma}_i^2}$, a value of $\bar{s}_1 \simeq 0.0167$ on 28 d.f. over the low energy region and of $\bar{s}_2 = 0.0135 - 0.0230$ on 29 d.f. above 0.9 MeV.

The recommended values of $\bar{\nu}_p$ and $\bar{\nu}_t$ for ^{233}U are listed in <u>Table 22</u>, and the $\bar{\nu}_p$ values plotted, together with the experimental data, in <u>Fig.6</u> and <u>7</u>. The fits of Boldeman [92] and Davey [60] are also plotted for comparison. The value of Hanna et al. [1] was adopted as recommended value. The difference with the value $\bar{\nu}_p = 2.4781$ obtained from Eq. (17) is less than 0.1%.

Total $\bar{\nu}$ values were obtained by adding a delayed neutron contribution of 0.0072 neutrons/fission below 5.0 MeV (taken from Table 19) and lower contributions, as given in <u>Fig. 18</u>, above this energy, the delayed neutron contribution at 14 MeV being $\bar{\nu}_d = 0.0044$ n/fission.

<u>3. Recommended $\bar{\nu}_p$ and $\bar{\nu}_t$ values for ^{234}U</u>

The whole experimental information on this isotope is reduced to four points below 4.1 MeV. A linear least-squares fitting to these points gave

$$\bar{\nu}_p(E) = 2.351 + 0.1350E \qquad (19)$$

There is no measurement on the delayed neutron yield for this isotope. The semilogaritmic plot of Fig. 20 gives for this isotope $\bar{\nu}_d = 0.010$ n/fission and therefore the total $\bar{\nu}$ value is given by

$$\bar{\nu}_t\ (E) = 2.361 + 0.1350E \qquad (20)$$

for E $\leqslant$ 4.1 MeV.

The coefficient of E in Eq. (20) is in good agreement with those obtained for other isotopes in the energy region up to 15 MeV. Therefore, in the absence of better information, Eq. (20) can be also used in the energy region above 4 MeV.

4. Recommended $\bar{\nu}_p$ and $\bar{\nu}_t$ values for ^{235}U

The experimental information on the energy dependence of $\bar{\nu}_p$ for ^{235}U is fairly abundant and of high accuracy, covering the whole energy range from thermal energy up to 15 MeV, which allows the analysis of the data in terms of the weighted fitting procedure mentioned before.

This analysis is of the utmost importance because of the controversy arisen in the last few years regarding the existence of structure in the low energy region. While Blyumkina et al. [90] suggested the existence of a convexity in the $\bar{\nu}_p$ vs energy curve, - correlated with a minimum in the fission fragment average kinetic energy values, which seemed to be confirmed by the more accurate measurements of Meadows et al [118] - this structure was questioned by Boldeman et al [24] who, in an attempt to confirm it, found that a straight line gave the best fit to their own, statistically excellent, $\bar{\nu}_p$ data from thermal energy up to 2 MeV, as well as to all previous $\bar{\nu}_p$ data of reasonable accuracy in the same energy region, excluding those of Meadows and Whalen [118], which were in complete statistical disagreement with their values in the region from 200 to 700 keV.

Although, according to Boldeman et al [92,225] their data on $\bar{\nu}_p(E)$ and $\bar{E}_k(E)$ for ^{235}U suggest that there are no reasons whatsoever to assume that any structure exists in the energy dependence of $\bar{\nu}_p(E)$ for this isotope, and that, if it is present, must be less than 3/4 percent, in accord with their general explanation of $\bar{\nu}_p(En)$ in terms of the double-humped fission barrier [92], the recent publication of new, very accurate sets of data

[25, 122, 123] seems to support the existenre of a step-like structure: In fact, the weighted least squares analysis carried out to the experimental data in the energy range between thermal energy and 15 MeV revealed the existence of three clearly differentiated regions: from thermal to $\sim$2 MeV, between $\sim$2 MeV and $\sim$7.5 MeV and above this energy. Thus, while the experimental data above 7.5 MeV could be adequately represented by a linear equation, those between $\sim$2 and $\sim$7.5 MeV showed a clear departure from linearity, while still conserving a smooth variation of $\bar{\nu}_p$ with the neutron energy. However, in the region below 2 MeV the fitted curve shows a well defined structure in the form of a step-like variation of $\bar{\nu}_p$ with E.

The analyses performed both for all available data, as well as for those of higher resolution only, - i.e. those data for which the energy resolution is of the order of 50 keV and better, - showed that the maximum degree of the polynomials, which gave the best fits to the experimental data, was in both cases the same for each one of the energy regions considered. Accordingly only the higher resolution data were taken into consideration in the final fittings. These data correspond essentially to measurements carried out after 1961, with the exception of the data of Nadkarni and Ballal [120] which were also excluded.

In conclusion we could state that the energy dependence of $\bar{\nu}_p$ for ^{235}U can most adequately be represented by the following set of equations:

$$\bar{\nu}_p(E) = 2.40591 - 0.01368\,E + 2.45575\,E^2 - 10.86137\,E^3 + 20.80908E^4 - 20.57858E^5 + 10.99438\,E^6 - 3.01762E^7 + 0.33403\,E^8 \tag{21}$$

between thermal and 2.05 MeV, with $\hat{\sigma}_1 = 0.00135$ on $\hat{\mu} = 128$ d.f.,

$$\bar{\nu}_p(E) = 2.20576 + 0.339328E - 0.087402E^2 + 0.014487\,E^3 - 0.76989\,(10^{-3})\,E^4 \tag{22}$$

between 2.05 and 7.5 MeV, with $\hat{\sigma}_2 = 0.00061$ on $\hat{\mu}_2 = 44$ d.f., and

$$\bar{\nu}_p(E) = 2.49238 + 0.135491\,E \tag{23}$$

from 7.5 MeV to 15 MeV, with a standard deviation of $\hat{\sigma}_3 = 0.00129$ on $\hat{\mu}_3 = 21$ degrees of freedom.

In Table 23 are listed the $\bar{\nu}_p$ values obtained from Eq.(21) - (23). The errors reported are point-wise standard deviations of the estimated mean of $\bar{\nu}(E)$, z_i. As in the case of a $\bar{\nu}$ for ^{233}U, the thermal $\bar{\nu}$ value of Hanna et al. [1] was adopted as recommended value.

The total $\bar{\nu}$ values in Table 23 were obtained by adding a delayed neutron contribution of 0.0158 neutrons per fission at thermal energies, 0.0166 neutrons/fission from thermal up to 4.5 MeV - and lower contributions, as given in Fig. 18, above this energy with a value of $\bar{\nu}_d$ = 0.0096 at 10 - 15 MeV.

The $\bar{\nu}_p$ fitted curve has been plotted, together with the experimental values, in Fig. 9 - 11.

The existence of several independent experimental values at the same energy allowed us, as in the case of ^{233}U, to confirm the goodness of the fits and to estimate pooled variances $\bar{\sigma}_i^2 = (\hat{\mu}_i \; \hat{\sigma}_i^2 + \mu_i^* \; \sigma_i^{*2})/(\hat{\mu}_i + \mu_i^*)$ for the energy regions below 7.5 MeV. According to the calculations carried out we have $\bar{\sigma}_1$ = 0.0148 on 163 d.f. for the energy region below 2.05 MeV, which means a standard deviation $\bar{s}_1 \simeq$ 0.0160 for any single estimated value, and $\bar{\sigma}_2$ = 0.0082 on 49 d.f., with $\bar{s}_2 \simeq$ 0.0116, for the energy region between 2.05 and 7.5 MeV. This represents an accuracy for the predicted values of about 1% at the 95% confidence level.

Figure 22 gives our evaluated $\bar{\nu}_t$ values as a function of the incident neutron energy, together with the renormalized results of previous evaluations. An inspection of this figure shows that our results are in good agreement with the histogram obtained by Nesterov et al. [25] for $\bar{\nu}$ values compiled from the references published before 1969, and also with the recent evaluation of Mather and Bampton [204].

In fact, our results agree within 0.4%, in the energy range from thermal to 2 MeV, with those of Mather and Bampton, who have fitted the average $\bar{\nu}_p$ values of 50 keV - wide energy bands by using a cubic spline fitting computer code.

Above 2 MeV our evaluation gives a much smoother energy dependence of $\bar{\nu}_p$ than all previously reported evaluations, in which only linear fits were considered. Thus Mather and Bampton [204] have fitted the experimental data above 1.75 MeV by the following set of straight lines:

$$\bar{\nu}_p(E) = 2.3829 + 0.1262\ E \text{ for } 1.75 \leqslant E \leqslant 3.69 \text{ MeV} \quad (24)$$
$$\bar{\nu}_p(E) = 2.3453 + 0.1364\ E \text{ for } 3.69 \leqslant E \leqslant 4.918 \text{ MeV} \quad (25)$$
$$\bar{\nu}_p(E) = 2.0497 + 0.1965\ E \text{ " } 4.918 \leqslant E \leqslant 7.101 \text{ MeV} \quad (26)$$
$$\bar{\nu}_p(E) = 2.4715 + 0.1371\ E \text{ " } 7.101 \leqslant E \leqslant 15.0 \text{ MeV} \quad (27)$$

They have used the measurements of Soleilhac et al. [121, 122] to determine the position of the "change points", i.e. the energy points where there is a significant change of slope in the curve. The maximum deviation with our evaluation appears at 5 MeV and is of the order of 0.6 %.

Davey [60] has recently carried out an evaluation of $\bar{\nu}_p$ for ^{235}U which include all the available experimental data up to February 1970. He has considered in it the effects of the onset of the (n,n'f) and (n, 2n'f) reactions on the energy dependence of $\bar{\nu}$. By accepting the fits to the data of Soleilhac et al [121, 122] alone as the best definition of the experimental $\bar{\nu}_p$ values he gets the following set of linear equations as the best fit to all the experimental data.

$$\bar{\nu}_p\ (E) = 2.409 + 0.1077 \cdot E \text{ for } 0.50 \leqslant E \leqslant 3.50 \text{ MeV} \quad (28)$$
$$\bar{\nu}_p\ (E) = 2.267 + 0.1488 \cdot E \text{ for } 3.50 \leqslant E \leqslant 5.06 \text{ MeV} \quad (29)$$
$$\bar{\nu}_p\ (E) = 2.012 + 0.1992 \cdot E \text{ for } 5.06 \leqslant E \leqslant 7.56 \text{ MeV} \quad (30)$$
$$\bar{\nu}_p\ (E) = 2.491 + 0.1358 \cdot E \text{ for } 7.56 \leqslant E \leqslant 11.50 \text{ MeV} \quad (31)$$
$$\bar{\nu}_p\ (E) = 2.477 + 0.1365 \cdot E \text{ for } 11.50 \leqslant E \leqslant 15.0 \text{ MeV} \quad (32)$$

The values given by Eq. 28 - 32 have been plotted in Fig. 22, after adding the delayed-neutron contribution. An inspection of Fig. 22 shows that the values given by Eq (28) - (30) are lower than ours by about 1 % in the energy range between 3 and 6.5 MeV. He makes no recommendation on $\bar{\nu}_p$ for the energy region below 0.5 MeV due to the existing discrepancy among different sets of experimental data.

In Fig. 22 are also included the evaluated data from KEDAK [205] and ENDF/B II [206] libraries. Both consider also a set of straight lines and are based on the evaluations of J.J.Schmidt [4]. The maximum difference with ENDF/B is 2 % at 8 MeV.

From the above considerations we conclude that Eq.(21) - (23) give a most adequate representation of the energy dependence of $\bar{\nu}_p$ for ^{235}U in the energy range from thermal to 15 MeV.

5. Recommended $\bar{\nu}_p$ and $\bar{\nu}_t$ values for ^{236}U

Only the measurements of Condé and Holmberg [34], published in 1971, are available for this isotope. They cover the energy range between 0.77 and 6.7 MeV. A weighted least-squares analysis showed that the best fit to the experimental data is the linear equation:

$$\bar{\nu}_p(E) = 2.3162 + 0.13082\ E \qquad (33)$$

with $\hat{\sigma} = 0.008411$ on 19 d.f. The standard deviation of the estimated mean, z_i, decreases from 0.013 to 0.0084 when going from 0.7 to 2.8 MeV and then increases, with a value $z_i = 0.022$ at 6.7 MeV, which means for s_i a value of 0.015, 0.012 and 0.023 at 0.7, 2.8 and 6.7 MeV respectively.

There is no delayed neutron yield measurement for this isotope. If we take $\bar{\nu}_d = 0.021$ neutrons per fission, as given by the systematic displayed by the uranium isotopes in Fig. 20, the total $\bar{\nu}$ value will be given by

$$\bar{\nu}_t\ (E) = 2.3382 + 0.13082\ E \qquad (34)$$

for $E < 7$ MeV.

For the same reasons as those already stated when dealing with the $\bar{\nu}_t$ values of ^{234}U, Eq.(34) can be also used in the energy region up to 15MeV.

6. Recommended $\bar{\nu}_p$ and $\bar{\nu}_t$ values for ^{238}U

The available experimental information on the energy dependence of $\bar{\nu}_p$ for ^{238}U is represented by measurements which cover the whole energy range from 1.3 to 15 MeV.

Previous evaluations [2,4,73,121,213,214] showed that these $\bar{\nu}_p$ experimental points could be adequately represented by a single straight line with intercept around 2.29 neutrons and a slope of ~ 0.15 neutrons/MeV. Therefore, and before investigating more complicated fits, a weighted linear fitting was made to all the experimental data over the whole energy range from 1.3 to 15 MeV. The equation obtained was

$$\bar{\nu}_p(E) = 2.2939 + 0.15129\ E \tag{35}$$

which is plotted as a function of the neutron energy in Fig. 13.

An inspection of this figure shows that the experimental values present systematic deviations from this linear fit, which suggest that these points can be more adequately represented by a higher degree polynomial.

Accordingly the weighted least-squares analysis was applied to all the energy-dependent experimental $\bar{\nu}_p$-values, in order to determine the degree of such polynomial. The analysis showed that the energy dependence of $\bar{\nu}_p$ for ^{238}U can be described by the following equation

$$\begin{aligned}\bar{\nu}_p(E) = {} & 2.52761 - 0.077662E + 0.0729372E^2 - 0.01017318E^3 + \\ & + 0.648299\ (10^{-3})\ E^4 - 0.154627(10^{-4})\ E^5\end{aligned} \tag{36}$$

where E is given in MeV.

In Table 24 are listed the $\bar{\nu}_p$ values obtained from Eq.(36). The errors reported are point-wise standard deviations of the estimated mean of $\bar{\nu}(E)$, as given by the fitting programme. The estimated standard deviation of the fitted curve is $\hat{\sigma} = 0.004515$ on 50 degrees of freedom, which means a value s = 0.010 – 0.025 for the standard deviation of any single predicted point. The value of $\hat{\sigma}^2$ obtained was consistent with the value deduced for the internal error variance, σ^{*2}. The combined standard deviation of $\hat{\sigma}$ and σ^* gives $\bar{\sigma} = 0.0191$ on 55 d.f., which means for the $\bar{\nu}(E)$ values an accuracy better than 2% at the 95% confidence level.

The total $\bar{\nu}$ values of Table 24 were obtained by adding a delayed neutron contribution of 0.0430 neutrons per fission from 1.35 MeV up to 4.5 MeV – obtained as average value of all reported measurements in this energy region – and smaller contributions, as given by Fig. 18, above this energy, with a value of 0.0278 neutrons per fission for the energy interval from 10 to 15 MeV. The values of $\bar{\nu}_d$ between 4.5 and 9 MeV were obtained by renormalizing the values of Krick et al. [162] to our average value below 4.5 MeV.

In figure 13 is plotted the recommended $\bar{\nu}_p$ fitted curve given by Eq. (36), as well as the experimental values.

Our evaluation for ^{238}U gives a continuously variable dependence of $\bar{\nu}_p$ on the neutron energy, while in the latest evaluations of Davey [60] and of Mather and Bampton [210] the experimental data were fitted by sets of straight lines.

Thus, according to Davey [60], the experimental $\bar{\nu}_p$ data for ^{238}U are given by

$$\bar{\nu}(E) = 2.230 + 0.1596\ E \qquad \text{for } 1.0 \leqslant E \leqslant 5.0 \text{ MeV} \qquad (37)$$
$$\bar{\nu}(E) = 2.226 + 0.1642\ E \qquad \text{for } 5.0 \leqslant E \leqslant 7.0 \text{ MeV} \qquad (38)$$
$$\bar{\nu}(E) = 2.306 + 0.1505\ E \qquad \text{for } 7.0 \leqslant E \leqslant 12.0 \text{ MeV} \qquad (39)$$
$$\bar{\nu}(E) = 2.458 + 0.1385\ E \qquad \text{for } 12.0 \leqslant E \leqslant 15.0 \text{ MeV} \qquad (40)$$

Eq. (37) - (40) were obtained by considering that the data of Soleilhac et al. [121] alone were sufficient to deduce the best fit to all experimental data over the entire energy range. The number of linear equations fitted and the energy interval they cover were taken similar to those used in the case of $\bar{\nu}_p$ for ^{235}U and ^{239}Pu.

Mather and Bampton [210] have covered the whole energy range with only three straight lines with "change points", i.e. points where the slope changes, at 3 and 5 MeV. They split all the experimental data points into three groups, viz., the data of Soleilhac et al. [121], the data of Condé and collaborators [73, 134] and all the others. They used the data of Soleilhac et al. to determine the position of the change points. The slope and zero energy intercept of the three fitted linear equations were obtained as average value of the individual parameters of the groups taken into consideration in each energy interval. These parameters were derived by means of least-squares linear fits.

By assuming $\bar{\nu}_p$ = 3.7567 for the spontaneous fission of ^{252}Cf, they get the following set of equations

$$\bar{\nu}_p(E) = 2.4002 + 0.1041\ E \qquad \text{for } E \leqslant 3.0 \text{ MeV} \qquad (41)$$
$$\bar{\nu}_p(E) = 2.1818 + 0.1769\ E \qquad \text{for } 3.0 \leqslant E \leqslant 5.01 \text{ MeV} \qquad (42)$$
$$\bar{\nu}_p(E) = 2.3096 + 0.1514\ E \qquad \text{for } 5.01 \leqslant E \leqslant 15.0 \text{ MeV} \qquad (43)$$

Figure 23 gives our evaluated $\bar{\nu}_t$ values as a function of the neutron energy together with the results of the evaluations of Davey [60], Mather and Bampton [210] and of the KEDAK Library [218].

An inspection of the figure shows that there exists good agreement between our evaluation and those of Mather et al [210] and of Davey [60], especially in the energy interval between 3 and 9 MeV. Above 9 MeV the values given by Eq. (36) and Eq (43) diverge, the maximum deviation being 1.3 % at 15 MeV.

Below 3 MeV the evaluation of Davey is in clear disagreement with ours, as well as with that of Mather et al [210]. The discrepancy increases with decreasing energy, the difference being of about 5% at 1 MeV.

We conclude then that Eq (36) gives a most adequate representation of the experimental $\bar{\nu}_p$ values for ^{238}U over the neutron energy range up to 15 MeV.

7. Recommended $\bar{\nu}_p$ and $\bar{\nu}_t$ values for ^{239}Pu

The available experimental data on $\bar{\nu}_p$ for ^{239}Pu cover smoothly the whole energy range from thermal to 15 MeV, and, already stated in § VII.7, most of the measurements were published after 1969.

All previous evaluation [4, 17, 60, 121, 211, 212] showed clearly that the $\bar{\nu}_p$ experimental data for this isotope could not be fitted by a single linear equation over the whole energy range from thermal to 15 MeV, but that a set of straight lines gave a good representation. The number of energy intervals considered was four in general, the change points being determined in almost all the cases by the data of Soleilhac et al. [121].

Therefore we tried from the beginning a higher degree polynomial fitting. The analysis carried out showed that the experimental $\bar{\nu}_p$ data for ^{239}Pu can be represented by the following set of high degree polynomials:

$$\bar{\nu}_p(E) = 2.86999 + 0.09823E + 0.044129E^2 - 0.015334E^2 + 0.0022321E^4 - 0.0001134E^5 \qquad (44)$$

from thermal to 3.8 MeV with $\hat{\sigma}_2 = 0.00196$ on 103 d.f, and

$$\bar{\nu}_p(E) = 2.86240 + 0.134784E + 0.34692(10^{-2})E^2 - 0.18820(10^{-3})E^3 \qquad (45)$$

from 3.8 to 15 MeV, with $\hat{\sigma}_2 = 0.00183$ on 43 d.f.

A weighted least squares fit was made to all data in the energy interval from thermal to 2 MeV alone. This showed that the $\bar{\nu}_p$ experimental data can be adequately represented by a second degree polynomial, which gives values of $\bar{\nu}_p$ which coincide with those given by Eq. (44) within 0.1%. We deduce therefore that Eq. (44) was the best representation of all the experimental $\bar{\nu}_p$ values below 3.8 MeV.

The $\bar{\nu}_p$ fitted curve has been plotted, together with the experimental values in Fig. 14 and 15.

An inspection of these figures shows that, unlike ^{235}U. the energy dependent $\bar{\nu}_p$ values for ^{239}Pu do not present any structure in the lower energy region below 2 MeV., although certainly a clear departure from linearity.

In Table 25 are listed the recommended $\bar{\nu}_p(E)$ and $\bar{\nu}_t(E)$ values for this isotope. The reported errors correspond, as in all previous cases, to the standard deviation of the estimated mean value of $\bar{\nu}_p(E)$. The ν_t values were obtained by adding $\bar{\nu}_d = 0.0065$ neutrons/fission below 5 MeV and lower values, as given by Fig. 19, above this energy with $\nu_d = 0.0043$ n/f between 10 and 15 MeV.

There are several experimental values at the same energy below 4 MeV for this isotope, which allow an estimation of the internal error variance σ^{*2}. The value obtained was $\sigma^{*2} = 0.001719$ on 19 d.f., which means for the pooled standard deviation a value $\bar{\sigma} = 0.0164$ on 122 d.f. i.e. of the order of 1%.

In Figure 24 our evaluated $\bar{\nu}_t$ values are plotted together with the results of previous evaluations [60, 92, 211, 212]. The following main evaluations have been considered:

Davey [60] made, as with ^{235}U, a series of linear fits to the data of Soleilhac et al [121] alone and to all the data, choosing breakpoints that correspond both to energies at which measurements have been made by Solcilhac et al., and close to the onset of the (n, n'f) and (n, 2n'f) reactions. This evaluation, which did not include the measurements published after 1969, i.e. those of Soleilhac et al. [122], Savin et al. [123], Mather et al . [140] and Boldeman [224], gave as best fit to the experimental data the following set of linear equations:

$$(E) = 2.835 + 0.1506\,E \quad \text{for } 1.50 \leqslant E \leqslant 5.00 \text{ MeV} \qquad (46)$$
$$(E) = 2.816 + 0.1560\,E \quad " \quad 5.00 \leqslant E \leqslant 7.50 \text{ MeV} \qquad (47)$$
$$(E) = 2.866 + 0.1495\,E \quad " \quad 7.50 \leqslant E \leqslant 11.50 \text{ MeV} \qquad (48)$$
$$(E) = 2.954 + 0.1398\,E \quad " \quad 11.50 \leqslant E \leqslant 15.00 \text{ MeV} \qquad (49)$$

Mather et al. [211] have incorporated in their evaluation, in addition to their own values, the latest values of Soleilhac et al. below 1.3 MeV, and also those of Savin et al. [123], but not the measurements of Boldeman [224]. They used the data of Soleilhac et al. to determine the shape of the variation of $\bar{\nu}_p$ with the incident neutron energy. The whole energy range from thermal to 15 was fitted with four straight lines with changing points at 1.225, 6.0 and 12.0MeV. The slopes and intercepts of the evaluated lines in the energy intervals between thermal and 1.225 MeV and 1.225 - 6.00 MeV were obtained as simple means of the values of the parameters derived in the fits made separately to each of the three groups in which they divided the available data in each interval, viz., Soleilhac et al., Mather and "others", and Soleilhac et al., Savin et al., and "others" respectively. The fitted lines above 6.00 MeV are given by the data of Soleilhac et al.

The equations obtained for each one of the intervals were:

$$\bar{\nu}_p(E) = 2.8746 + 0.1341\,E \quad \text{for} \quad 0 \leqslant E \leqslant 1.225 \text{ MeV} \qquad (50)$$
$$\bar{\nu}_p(E) = 2.8588 + 0.1470\,E \quad " \quad 1.225 \leqslant E \leqslant 6.00 \text{ MeV} \qquad (51)$$
$$\bar{\nu}_p(E) = 2.8300 + 0.1518\,E \quad " \quad 6.00 \leqslant E \leqslant 12.00 \text{ MeV} \qquad (52)$$
$$\bar{\nu}_p(E) = 3.0652 + 0.1322\,E \quad " \quad 12.00 \leqslant E \leqslant 15.00 \text{ MeV} \qquad (53)$$

The estimated standard error of the evaluated $\bar{\nu}_p$ values are 1%, 1.5 - 2 %, 1% and < 1% respectively for each of the intervals.

The new KEDAK evaluation [212] is only a revision of the previous calculations of Schmidt [4], and includes the measurements of Soleilhac et al. above 1.36 MeV [121] and those of Condé et al. [139] but does not take into consideration any measurement published after 1969. After addition of the delayed neutron contribution a linear least squares fit was carried out for the data of Soleilhac et al. and of Condé et al. above 3.4 MeV under the condition that the linear equation passes at 3.4 MeV through the previous KEDAK value of 3.3448 MeV. The experimental data were previously renormalized to the standard value used in previous KEDAK calculations, viz., $\bar{\nu}_p^{sp}(^{252}Cf) = 3.764$. As delayed neutron contribution they took $\bar{\nu}_d = 0.006$ n/fission below 10 MeV and $\bar{\nu}_d = 0.013$ above this energy.

The energy dependence of $\bar{\nu}_t$ for ^{239}Pu is described by the following set of equations:

$$\bar{\nu}_t\,(E) = 2.89200 + 0.12791\,E + 0.00189\,E^2 - 0.00010\,E^3 \qquad (54)$$

from thermal to 3.4 MeV, as given by [4], and which was determined by the requirement that the $\bar{\nu}_p^{sp}$ (^{240}Pu) best value be exactly reproduced; and

$$\bar{\nu}_t\,(E) = 2.81908 + 0.15463\,E \qquad (55)$$

from 3.4 to 15 MeV.

Finally, Walsh and Boldeman [92] have fitted all data below 5 MeV by means of two linear equations which intercept at 0.64 MeV. These equations, renormalized to our standard $\bar{\nu}_p^{sp}(^{252}Cf)$ value, are

$$\bar{\nu}_p\,(E) = (2.869 \pm 0.007) + (0.107 \pm 0.014)\,E \qquad (56)$$

for $0. \leq E \leq 0.64$ MeV, and

$$\bar{\nu}_p\,(E) = (2.841 \pm 0.006) + (0.151 \pm 0.003)\,E \qquad (57)$$

for $0.64 \leq E \leq 5$ MeV.

An inspection of Fig. 2 shows that our evaluation is in good agreement with the results of previous evaluations, in particular in the energy region above 2 MeV. Below 2 MeV we are in excellent agreement with the evaluation of Boldeman [92], but our values are systematically lower than that of Mather et al. [211], the maximum difference being 0.7 %. This discrepancy should arise from the fact that the evaluation of Mather et al. [211] did not include the data of Boldeman[224] in this energy region.

The deviation shown by the KEDAK evaluation above 10 MeV is to be expected due to the delayed neutron yield value adopted in this energy region.

We conclude that Eq. (44) - (45) give the best fit to the energy dependence of $\bar{\nu}_p$ for ^{239}Pu over the energy range from thermal to 15 MeV.

8. Recommended $\bar{\nu}_p$ and $\bar{\nu}_t$ values for ^{240}Pu

The available experimental information on $\bar{\nu}_p$ for this isotope is scarce and of low precision. Except for one measurement at 15 MeV all the values correspond to points below 4 MeV. Therefore the only possible fit for the whole energy range from 0 to 15 MeV is a linear equation, and even this fit is exposed to some ambiguity due to the extremely low value of the measurement of Kuzminov [150] at 15 MeV.

In fact a weighted linear least-squares fit to all data gives

$$\bar{\nu}_p\,(E) = 2.9955 + 0.1025E \tag{58}$$

It can be seen that the slope of the linear equation [64] is in complete disagreement with the values found for all the other isotopes when the whole energy interval was considered.

On the other hand, a linear fit to the data of Savin et al [123] alone, gives

$$\bar{\nu}_p\,(E) = 2.870 + 0.172\,E \tag{59}$$

The coefficient of E is in this case too large compared with those found for the other isotopes. Therefore we decided to fit all data, below 5 MeV, excluding then the value of Kuzminov at 15 MeV, by means of a linear equation. The resulting fit was

$$\bar{\nu}_p(E) = 2.8887 + 0.1562\ E \qquad (60)$$

with $\hat{\sigma} = 0.0170$ on 26 degrees of freedom. Eq (60), which is in principle defined for $E < 4$ MeV, is in good agreement with the results obtained for all the other isotopes.

The standard deviations of the estimated means of $\bar{\nu}(E)$, z_i, range from 0.047 to 0.017, with the lowest value in the middle of the fitted interval, i.e. at an incident neutron energy of 2 MeV. This means for the standard deviations about the mean, $s = \sqrt{z_i^2 + \hat{\sigma}^2}$, values of 0.050 and 0.024 respectively.

If we take $\bar{\nu}_d = 0.0088$, as given in Table 19, the total $\bar{\nu}$ value for ^{240}Pu is given by

$$\bar{\nu}_t = 2.8975 + 0.1562\ E \qquad (61)$$

This equation is in principle defined only for the energy range below 4 MeV, but in our opinion and in the absence of better information it can be used also in the region above this energy.

As previous evaluations for this isotope we have those contained in the KEDAK file [218], where $\bar{\nu}_t$ is given by a linear equation with intercept at 3.0000 and slope of 0.101 n/MeV and the evaluation of Davey [60]. This author, who did not include the data of Savin et al. in his evaluation, made use of the first-, second-, and third chance fission model to derive the best $\bar{\nu}_p$ values for this isotope. For the low energy range these are given by

$$\bar{\nu}_p = 2.81 + 0.186\ E \qquad 0 \leqslant E \leqslant 6.5\ \text{MeV} \qquad (62)$$

It is worth pointing out the large value of $\frac{d\bar{\nu}}{dE}$ in Eq (62) which, although supported by data of Savin et al. [123], is in clear contradiction with the values found for the other isotopes, and also with the predictions of Howerton [240] for this isotope in terms of the second- and third chance fission formalism.

In view of the above considerations we conclude that Eq (60) and (61) give the best representations of the $\bar{\nu}$ values for ^{240}Pu.

9. Recommended $\bar{\nu}_p$ and $\bar{\nu}_t$ values for ^{241}Pu

Besides the recommended thermal value of Hanna et al. [1], only four more points, due to Condé et al. [139], exist for this isotope.

Weighted linear least-squares fits, both excluding and including the thermal value, gave

$$\bar{\nu}_p(E) = 2.8913 + 0.1465\ E \qquad (63)$$

and

$$\bar{\nu}_p(E) = 2.9203 + 0.1431\ E \qquad (64)$$

respectively. The estimated standard deviation of the fitted values is about 2 %. The maximum difference between the values given by Eq. (63) and (64) is 0.7 % at thermal energies, i.e. less than the error associated with each value, and therefore both equations can be considered as equivalent.

If we take Eq (64) as the best representation of $\nu_p(E)$ from thermal to 15 MeV and $\nu_d = 0.0110$ as mean delayed-neutron contribution in this energy interval, the total $\bar{\nu}$ values for ^{241}Pu will be given by

$$\bar{\nu}_t = 2.9313 + 0.1431\ E \qquad (65)$$

for the whole energy range up to 15 MeV.

At thermal energies the value of Hanna et al [1] is recommended, viz. $\bar{\nu}_t = 2.934 \pm 0.012$.

As in the case of ^{240}Pu, Davey [60] made use of the first-, second and third-chance fission model to deduce best values of $\bar{\nu}_p$ for this isotope. In the range from 0 to $\sim$5.5 MeV these are given by the linear equation

$$\bar{\nu}_p\ (E) = 2.781 + 0.1771\ E \qquad (66)$$

Besides the large value of the coefficient of E in Eq (66), the difference between the thermal value obtained with this equation and the value of Hanna et al. amount to 5%, and therefore Eq (66) cannot be considered as a good representation of the experimental $\bar{\nu}$ values for ^{241}Pu.

Within the general subject of the evaluation and prediction of the energy dependence of the $\bar{\nu}$ values for the heavy isotopes, we should mention finally the attempts made to describe the variation of $\bar{\nu}$ with energy in terms of the second and third chance fission [111, 240, 241]. In this context, by revising the formalism developed by Schuster et al. [241] in 1963, Howerton [240] was able to establish an equation which can be used to predict $\bar{\nu}$ (E,A,Z) for the thorium, uranium and plutonium isotopes in terms of Z,A and $E-E_{th}$, where E_{th} is the threshold energy for the fission process of the nucleus considered. According to that author the equation obtained predicts the measured values of $\bar{\nu}$ (E,A,Z) to better than 0.5 % with standard deviations better than 1.5 % about the central point of the measurements, which suggests that such formalism can be used to predict the $\bar{\nu}$ values of those isotopes having no measurement.

XI. CONCLUSIONS AND RECOMMENDATIONS

In spite of the large effort devoted by many scientists in the last few years and the large amount of high accuracy measurements published recently on the different aspects of the energy dependence of $\bar{\nu}$ for the fissile and fertile isotopes, the present situation of this problem is, except for a few cases, far from being satisfactory. Among the problems still awaiting an adequate solution we can mention the following:

The absolute $\bar{\nu}$(E) values of the fissile and fertile isotopes are strongly linked to the absolute value of the standards used in the measurements, viz., the thermal $\bar{\nu}$ values of the main fissile isotopes and the $\bar{\nu}$ value for the spontaneous fission of ^{252}Cf. As shown in chapter II. an uncertainty as large as ≈1.2% still remains on the absolute value of $\bar{\nu}_t$ for the spontaneous fission of ^{252}Cf and therefore on those energy dependent $\bar{\nu}$ values for which $\bar{\nu}_p^{sp}(^{252}Cf)$ was used as standard. This uncertainty arises from the discrepancy between the $\bar{\nu}$ value obtained in the measurements performed with large liquid scintillators and the value obtained with other methods. Although the preliminary result of the $\bar{\nu}_p^{sp}(^{252}Cf)$ liquid scintillator measurement of Boldeman [225] is in agreement with the value obtained with other methods, the discrepancy with the previous liquid scintillator measurements remains still unresolved. The two possible sources of error pointed out as responsible for this discrepancy, viz., the influence on $\bar{\nu}$ of the delayed γ-rays from the fission of ^{252}Cf and the dependence of the prompt pulse detection efficiency on the number of neutrons detected per fission, ("French effect"), were unable to account for this discrepancy.

The present knowledge of the systematics of the thermal $\bar{\nu}_p$ values for the heavy isotopes does not allow the prediction of the thermal $\bar{\nu}_p$ value of any nuclide, and specially of the transplutonium isotopes, with an accuracy of better than about 10%.

Only for the nuclides ^{235}U, ^{238}U and ^{239}Pu the published experimental data points allow to define the shape of the energy dependence of $\bar{\nu}_p$ over the MeV energy range up to 15 MeV. For all the other isotopes a large gap exists between about 5 MeV and 14 MeV. For the two nuclides ^{234}U and ^{241}Pu the only data available are four and five points respectively. Therefore for these isotopes the knowledge of $\bar{\nu}_p$ above about 5 MeV relies on the extrapolation of the fits obtained in the low energy region and on the systematics for isotopes with the same atomic number Z.

The problem of the existence of structure in the MeV region remains still unresolved for most of the nuclides. Only in the case of ^{235}U the available information seems adequate to draw definitive conclusions, but even in this case the step-like structure found, which seems to be correlated with a number of characteristics of the fission process, viz. fission cross sections, angular anisotropy of fission and relative yield of symmetric fission [243], is questioned by Boldeman [225] in accordance with his own measurements of $\bar{\nu}_p$ (E) and $\bar{E}_k$ (E) for this isotope. On the other hand no conclusion can be drawn on this problem from the doublehumped potential barrier model of Strutinsky [242], because unfortunately, it is not known at present which of the two humps is higher for the compound nucleus ^{236}U [92]. In the case of ^{233}U some structure seems also to be present, in agreement with the results of Boldeman [225] and the predictions of the theory, since for the compound nucleus ^{234}U there is reasonable evidence to suggest that the second potential barrier is higher [242]. In the case of ^{239}Pu, unlike ^{233}U and ^{235}U, there does not appear to be any kind of structure which seems to be in agreement with the fact that for nuclei with $A > 239$ the first barrier is higher [92,242]. For all the remaining isotopes the scarcity of data in the low energy region does not allow any kind of conclusion to be drawn.

For the important isotopes the values of $\bar{\nu}$ from thermal up to a few hundred keV are of the greatest importance in fast reactor design but, unfortunately, precise and reliable measurements do not exist in this energy range. The several measurements carried out for ^{235}U and ^{239}Pu are in clear disagreement with respect to the existence of structure in and correlation of with the spin of the resonances.

Now it seems to be confirmed that, in agreement with the prediction of theory, the delayed neutron yields decrease with increasing incident neutron energy when going from about 4.5 MeV to 14 MeV. However, the experimental information on the shape of this dependence is scarce. In fact there is no measurement of the energy dependence of $\bar{\nu}_d$ for ^{232}Th and the plutonium isotopes above 3 MeV, and for the uranium isotopes between 6 and 14 MeV.

The calculations carried out here on the energy dependence of $_p$ for the fissile and fertile isotopes are consistent with the results of recently published evaluations [60, 204, 206, 210-212], which suggest that a good agreement has been reached between evaluators on the reliability of the existing differential data. Further evaluations will not solve the existing discrepancies, but more measurements are needed. In this context the $\bar{\nu}$ measurements planned by Howe and Bowman [227] are of the greatest interest.

In accordance with the output of the fitting programme and the spread amongst different experimental data sets, as given by the internal error variance, the present accuracy of the energy dependent $\bar{\nu}_p$ values can be assessed as follows: for the most measured nuclides, i.e. ^{235}U and ^{239}Pu, a standard deviation of 0.7 - 1.0 % is realistic, whilst for ^{238}U 2% is appropriate. For the other less measured nuclides it would be 2 to 4%, in view of the lack of experimental information over some energy ranges. These accuracies can still not meet some of the requirements for fast reactor calculations [226], since accuracies as high as 0.5% for ^{235}U and ^{239}Pu are requested over the whole energy range from thermal to 14 MeV.

As a result of this analysis the following recommendations are made with regard to future measurements:

1. More measurements should be performed on the absolute $\bar{\nu}$ value for the spontaneous fission of ^{252}Cf, and new efforts should be made to resolve the discrepancies among the $\bar{\nu}^{sp}$ (^{252}Cf) values obtained by different methods of measurement, and also between those directly measured and the one deduced from thermal neutron parameters [1].

2. For all isotopes, except ^{235}U, ^{238}U and ^{239}Pu, precise measurements should be made at sufficiently narrow intervals on the energy dependence of $\bar{\nu}_p$ above 4 to 5 MeV.

3. Further more precise measurements are needed below 2.5 MeV for most of the isotopes in order to confirm the existence of structure in $\bar{\nu}(E)$. If such structure is shown to exist, its shape should be investigated in detail.

4. Precise measurements should be made in the resonance region for all isotopes in order to solve the existing discrepancies relating to possible correlation between $\bar{\nu}$ and the spin of the resonances.

5. Precise measurements are needed for the energy dependence of the delayed neutron yield over the whole energy range for ^{232}Th and the plutonium isotopes. These measurements are also needed for the uranium isotopes for energies above 6 MeV.

6. Further measurements should be made to determine the thermal values of the transplutonium isotopes.

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TABLE 1

Total neutron yield per fission ($\overline{\nu}_t$) for ^{252}Cf spontaneous fission.

Reference	Year	Reassessed value	Adopted mean++
<u>Liquid scintillator</u>			
Asplund-Nilsson et al [7]	1963	3.830 ± 0.037	3.807 ± 0.024
Hopkins and Diven [8]	1963	3.793 ± 0.031	
<u>Boron pile calibrated with d(γ, n)p reactions</u>			
Colvin and Sowerby [9]	1965	3.713 ± 0.015 *	3.713 ± 0.024
<u>Dependent on NPL manganese bath</u>			
Moat et al [10]	1961	3.727 ± 0.056	3.713 ± 0.024
Colvin et al [11]	1966	3.700 ± 0.031 *	
White and Axton [12]	1967	3.796 ± 0.031 *	
Axton [13]	1969	3.700 ± 0.020 *	
<u>ANL Manganese bath</u>			
De Volpi and Porges [14]	1969	3.725 ± 0.017 *	3.725 ± 0.024
		Present weighted mean + :	3.740 ± 0.016
		Hanna's weighted mean :	3.743 ± 0.016
		Hanna's fitted value :	3.765 ± 0.010

+ Mean value obtained taking into consideration the final value of De Volpi quoted in this table.

* Authors' values.

++ The errors of the adopted mean values were assigned by Hanna et al [1] artificially as to give each method equal weights.

TABLE 2

Recommended $\bar{\nu}_t$-values for 2200 m/s neutrons

Isotope	Hanna et al [1]	De Volpi [23]		
		Input values(1)	Adjustment A(2)	Adjustment B(3)
^{233}U	2.4866 ± 0.0069	2.464 ± 0.005 (- 1.0%) *	2.453 ± 0.007 (- 1.4%) *	2.454 (- 1.3%) *
^{235}U	2.4229 ± 0.0066	2.393 ± 0.008 (- 1.2%) *	2.400 ± 0.007 (-0.92%) *	-
^{239}Pu	2.8799 ± 0.0090	2.854 ± 0.008 (- 1.0%) *	2.877 (- 0.10%) *	2.854 ± 0.007 (- 0.91%) *
^{241}Pu	2.934 ± 0.012			

(1) Weighted means of experimental data

(2) For $\bar{\nu}_t \sigma_f$ [^{233}U] = 1319.5 and $\nu_t \sigma_f$ [^{239}Pu] = 2136.2 as in Hanna et al [1]

(3) For the alternative optional values $\bar{\nu}_t \sigma_f$ [^{233}U] = 1316.6 and $\bar{\nu}_t \sigma_f$ [^{239}Pu] = 2119.1

(*) In parentheses are percentage differences with input-experimental and output-adjusted data of Hanna et al [1]

TABLE 3

Average prompt $\bar{\nu}$ values for thermal neutrons

Isotope	Reference		Year	$\bar{\nu}_{exper.}$	Standard	$\bar{\nu}_{renormal.}$	Weighted mean value
^{229}Th	Lebedev et al Zamyatnin et al	[28] [27]	1958 1970	2.13 ± 0.03 2.05 ± 0.10	$\bar{\nu}^{th}(^{235}U) = 2.47$ $\bar{\nu}_p^{th}(^{235}U) = 2.426$	2.08 ± 0.02 2.03 ± 0.10	2.08 ± 0.02
^{232}U	Jaffey et al	[26]	1970	3.132 ± 0.060	(1)	3.132 ± 0.060	3.132 ± 0.060
^{238}Pu	Jaffey et al Zamyatnin et al	[26] [27]	1970 1970	2.889 ± 0.027 2.92 ± 0.12	(1) $\bar{\nu}_p^{th}(^{235}U) = 2.426$	2.889 ± 0.027 2.90 ± 0.12	2.889 ± 0.023
^{241}Am	Lebedev et al Jaffey et al	[29] [26]	1958 1970	3.14 ± 0.03 2.219 ± 0.038	$\bar{\nu}_p^{th}(^{235}U) = 2.47$ (1)	3.06 ± 0.03 3.214 ± 0.037	3.121 ± 0.023
^{242m}Am	Fultz et al Jaffey et al Zamyatnin et al	[30] [26] [27]	1966 1970 1970	3.24 ± 0.12 3.264 ± 0.024 3.28 ± 0.10	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.48$ (1) $\bar{\nu}_p^{th}(^{235}U) = 2.426$	3.22 ± 0.12 3.258 ± 0.024 3.25 ± 0.10	3.257 ± 0.023
^{243}Cm	Jaffey et al	[26]	1970	3.430 ± 0.047	(1)	3.426 ± 0.047	3.426 ± 0.047
^{245}Cm	Von Gunten et al Jaffey et al Zamyatnin et al	[31] [26] [27]	1967 1970 1970	4 ± 1 3.832 ± 0.034 3.83 ± 0.16	- (1) $\bar{\nu}_p^{th}(^{235}U) = 2.426$	4 ± 1 3.826 ± 0.033 3.80 ± 0.16	3.825 ± 0.032
^{249}Cf	Zamyatnin et al Volodin et al	[27] [63]	1970 1972	4.60 ± 0.21 4.06 ± 0.04	$\bar{\nu}_p^{th}(^{235}U) = 2.426$ $\bar{\nu}_p^{sp}(^{252}Cf) = 3.756$	4.56 ± 0.21 4.06 ± 0.04	4.08 ± 0.04

(1) $\bar{\nu}_p^{th}(^{233}U) = 2.478 \pm 0.007$ $\bar{\nu}_p^{th}(^{235}U) = 2.407 \pm 0.005$ and $\bar{\nu}_p^{th}(^{239}Pu) = 2.884 \pm 0.007$ were used as standards.

TABLE 5

Available experimental data on $\bar{\nu}_p$ for the spontaneous fission of the heavy isotopes

Isotope	Reference	Year	$\bar{\nu}_p$ experimental	Standard	$\bar{\nu}_p$ renormalized
^{232}Th	Barclay et al [33]	1952	1.07 ± 0.10	$\bar{\nu}^{sp}(^{238}U) = 1$	2.13 ± 0.20
^{236}U	Condé et al. [34]	1971	1.90 ± 0.05	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.756$	1.90 ± 0.05
^{238}U	Segré [144]	1952	2.2 ± 0.3	-	
	Littler [145]	1952	2.5 ± 0.2	calibrated source	
	Geiger et al. [146]	1954	2.26 ± 0.16	-	
	Richmond [147]	1957	2.14 ± 0.07	-	
	Kuzminov et al. [35]	1959	2.1 ± 0.1	$\bar{\nu}^{sp}(^{240}Pu) = 2.26$	1.98 ± 0.06
	Gerling [148]	1960	1.7	-	
	Leroy [36]	1960	2.10 ± 0.08	$\bar{\nu}_p^{th}(^{235}U) = 2.47$	2.05 ± 0.08
	Asplund-Nilsson et al. [37]	1963	1.97 ± 0.07	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.80$	1.95 ± 0.07
	Condé et al. [34]	1971	2.00 ± 0.05	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.756$	2.00 ± 0.05
				Average value =	2.00 ± 0.03
^{236}Pu	Crane et al. [38]	1956	1.89 ± 0.20	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.52$	2.03 ± 0.21
	Hicks et al. [39]	1956	2.30 ± 0.19	$\bar{\nu}_p^{sp}(^{240}Pu) = 2.257$	2.19 ± 0.18
				Average value =	2.12 ± 0.13
^{238}Pu	Crane et al [38]	1956	2.04 ± 0.13	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.52$	2.18 ± 0.14
	Hicks et al [39]	1956	2.33 ± 0.08	$\bar{\nu}_p^{sp}(^{240}Pu) = 2.257$	2.22 ± 0.07
				Average value =	2.21 ± 0.07
^{240}Pu	Segré [40]	1946	2.31 ± 0.3	-	
	Barclay et al [41]	1951	2.84 ± 0.26	Ra-Be Source	
	Carter [42]	1953	2.22 ± 0.11	-	
	Martin et al [43]	1954	2.20 ± 0.05	-	
	Sanders [44]	1955	0.759 ± 0.028	$\bar{\nu}^{th}(^{239}Pu) = 1$	2.181 ± 0.080
	Carter et al [45]	1956	2.20 ± 0.03	-	
	Kalashnikova et al [46]	1956	2.20 ± 0.09	Calibrated n.source	
	Johnstone [69]	1956	2.21 ± 0.13	Calibrated n.source	
	Crane et al [38]	1956	2.09 ± 0.11	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.53$	2.22 ± 0.12
	Diven et al [47]	1956	2.257 ± 0.045	$\bar{\nu}_p^{th}(^{235}U) = 2.46$	2.208 ± 0.044
	Moat et al [10]	1961	2.13 ± 0.05	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.69$	2.16 ± 0.05
	Diven et al [48]	1961	2.187 ± 0.036 (*)	$\bar{\nu}_p^{th}(^{235}U) = 2.414$	2.180 ± 0.036
	Asplund-Nilsson et al [37]	1963	2.154 ± 0.028	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.80$	2.130 ± 0.028
	Hopkins et al [8]	1963	2.189 ± 0.026	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.771$	2.181 ± 0.026
	Colvin et al [9]	1965	0.888 ± 0.005	$\bar{\nu}_p^{th}(^{235}U) = 1$	2.137 ± 0.012
	Baron et al [49]	1966	2.153 ± 0.020	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.782$	2.139 ± 0.020
	Boldeman [50]	1968	2.168 ± 0.009	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.784$	2.153 ± 0.009
	Prokhorova et al [61]	1971	2.161 ± 0.016	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.782$	2.146 ± 0.016
				Average value $\bar{\nu}_p^{sp}$ =	2.150 ± 0.008
^{242}Pu	Crane et al [38]	1956	3.32 ± 0.16	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.53$	2.47 ± 0.17
	Hicks et al [39]	1956	2.18 ± 0.09	$\bar{\nu}_p^{sp}(^{240}Pu) = 2.257$	2.08 ± 0.09
	Boldeman [50]	1968	2.157 ± 0.009	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.784$	2.142 ± 0.009
	Prokhorova et al [51]	1968	2.13 ± 0.05	$\bar{\nu}_p^{sp}(^{244}Cm) = 2.71$	2.12 ± 0.05
				Average value =	2.141 ± 0.009

(*) Preliminary value. Same as [8] and therefore not included in the final average value.

TABLE 5 (continued)

Isotope	Reference	Year	$\bar{\nu}_p$ experiment	Standard	$\bar{\nu}_p$ renormalized
^{244}Pu	Orth [52]	1971	2.30 ± 0.19	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.77	2.29 ± 0.19
^{242}Cm	Crane et al [38]	1956	2.33 ± 0.11	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.53	2.48 ± 0.12
	Hicks et al [39]	1956	2.65 ± 0.09	$\bar{\nu}_p^{sp}$ (^{240}Pu) = 2.257	2.52 ± 0.08
	Jaffey et al [26]	1970	0.933 ± 0.043	$\bar{\nu}_p^{sp}$ (^{244}Cm) = 1	2.51 ± 0.15
				Average value	= 2.51 ± 0.06
^{244}Cm	Hicks et al [53]	1955	2.66 ± 0.11	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.53	2.83 ± 0.12
	Hicks et al [39]	1956	2.84 ± 0.09	$\bar{\nu}_p^{sp}$ (^{240}Pu) = 2.257	2.70 ± 0.08
	Crane et al [38]	1956	2.61 ± 0.13	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.53	2.67 ± 0.14
	Diven et al [47]	1956	2.810 ± 0.059	$\bar{\nu}_p^{sp}$ (^{240}Pu) = 2.257	2.678 ± 0.056
	Bolshov et al [54]	1964	2.71 ± 0.04	$\bar{\nu}_p^{sp}$ (^{240}Pu) = 2.17	2.68 ± 0.04
	Jaffey et al [26]	1970	2.692 ± 0.024	(1)	2.693 ± 0.024
	Zamyatnin et al [27]	1970	2.77 ± 0.08	$\bar{\nu}_p^{sp}$ (^{235}U) = 2.426	2.75 ± 0.08
	Prokhorova et al [61]	1971	2.690 ± 0.015	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.782	2.671 ± 0.015
				Average value	= 2.681 ± 0.011
^{246}Cm	Thompson [55]	1970	3.20 ± 0.22	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.79	3.17 ± 0.22
^{248}Cm	Orth [52]	1971	3.11 ± 0.09	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.77	3.10 ± 0.09
^{250}Cm	Orth [52]	1971	3.31 ± 0.08	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.77	3.30 ± 0.08
^{249}Bk	Pyle [56]	1958	3.72 ± 0.16	$\bar{\nu}_p^{sp}$ (^{240}Pu) = 2.23	3.59 ± 0.16
^{246}Cf	Pyle [56]	1958	2.92 ± 0.19	$\bar{\nu}_p^{sp}$ (^{240}Pu) = 2.23	2.81 ± 0.19
^{249}Cf	Volodin et al [63]	1972	3.4 ± 0.4	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.756	3.4 ± 0.4
^{250}Cf	Orth [52]	1971	3.53 ± 0.09	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.77	3.52 ± 0.09
^{252}Cf	Hanna et al [1]	1970	Adjusted value		= 3.756 ± 0.012
^{254}Cf	Pyle [56]	1958	3.90 ± 0.14	$\bar{\nu}_p^{sp}$ (^{240}Pu) = 2.23	3.76 ± 0.14
	Orth [52]	1971	3.93 ± 0.05	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.77	3.91 ± 0.05
				Average value	= 3.89 ± 0.05
^{254}Fm	Choppin et al [58]	1956	4.05 ± 0.19	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.82	3.98 ± 0.14
^{257}Fm	Cheifets et al [201]	1971	3.97 ± 0.13	$\bar{\nu}_p^{sp}$ (^{252}Cf) = 3.72	4.01 ± 0.13

(1) For standards used see Table 3

TABLE 6

Comparison of $\bar{\nu}_p$ for spontaneous and thermal fission.

Fissioning nucleus	$\bar{\nu}_p^{th}$ (1)	$\bar{\nu}_p^{sp}$ (2)	$\bar{\nu}_p^{th} - \bar{\nu}_p^{sp}$	B_n(MeV) (3)	$\frac{d\bar{\nu}}{dEn}$
^{236}U	2.407 ± 0.007	1.90 ± 0.05	0.507	6.545	0.077
^{240}Pu	2.874 ± 0.007	2.150 ± 0.008	0.724	6.533	0.111
^{242}Pu	2.921 ± 0.012	2.141 ± 0.009	0.780	6.301	0.124
^{244}Cm	3.426 ± 0.047	2.681 ± 0.011	0.745	6.799	0.109
^{246}Cm	3.825 ± 0.032	3.17 ± 0.22	0.655	6.451	0.102
^{250}Cf	4.08 ± 0.04	3.52 ± 0.09	0.56	6.619	0.085
			Average value	=	0.101

(1) Average thermal $\bar{\nu}_p$ values taken from Tables 2 - 4.
(2) Average $\bar{\nu}_p$ values for spontaneous fission taken from Table 5.
(3) Taken from [62]

TABLE 7

Experimental and deduced thermal $\bar{\nu}_p$-values

Target (Z,A)	$\bar{\nu}_p^{th}(Z,A)$ (1)	$\bar{\nu}_p^{sp}(Z,A+1)$ (1)	$\bar{\nu}_p^{sp} + 0.101\,B_n$	$\bar{\nu}_p^{th}$ (2)	$\bar{\nu}_p^{th}$ (3)
^{229}Th	2.08 ± 0.02			2.080 ± 0.020	1.842
^{231}Th		2.13 ± 0.20	2.780 ± 0.260	2.780 ± 0.260	1.861
^{232}U	3.132 ± 0.060			3.132 ± 0.060	2.395
^{233}U	2.480 ± 0.007			2.480 ± 0.007	2.404
^{235}U	2.407 ± 0.007	1.90 ± 0.05	2.561 ± 0.082	2.407 ± 0.007	2.423
^{237}U		2.00 ± 0.03	2.620 ± 0.040	2.620 ± 0.040	2.442
^{235}Pu		2.12 ± 0.13	2.863 ± 0.175	2.863 ± 0.175	2.948
^{237}Pu		2.21 ± 0.07	2.917 ± 0.092	2.917 ± 0.092	2.967
^{238}Pu	2.889 ± 0.023			2.889 ± 0.023	2.886
^{239}Pu	2.874 ± 0.007	2.150 ± 0.008	2.810 ± 0.011	2.874 ± 0.007	2.985
^{241}Pu	2.921 ± 0.012	2.141 ± 0.009	2.777 ± 0.012	2.921 ± 0.012	3.004
^{243}Pu		2.29 ± 0.19	2.898 ± 0.285	2.898 ± 0.285	3.022
^{241}Am	3.121 ± 0.023			3.121 ± 0.023	3.266
^{242}Am	3.257 ± 0.023			3.257 ± 0.023	3.366
^{241}Cm		2.51 ± 0.06	3.214 ± 0.077	3.214 ± 0.077	3.529
^{243}Cm	3.426 ± 0.047	2.681 ± 0.011	3.368 ± 0.023	3.426 ± 0.047	3.548
^{245}Cm	3.825 ± 0.032	3.17 ± 0.22	3.821 ± 0.108	3.825 ± 0.032	3.566
^{247}Cm		3.10 ± 0.09	3.727 ± 0.094	3.727 ± 0.094	3.585
^{249}Cm		3.30 ± 0.08	3.884 ± 0.096	3.884 ± 0.096	3.603
^{248}Bk		3.59 ± 0.16	4.218 ± 0.185	4.218 ± 0.185	3.857
^{245}Cf		2.81 ± 0.19	3.553 ± 0.238	3.553 ± 0.238	4.091
^{248}Cf		3.4 ± 0.4	4.110 ± 0.485	4.110 ± 0.485	4.029
^{249}Cf	4.08 ± 0.04	3.52 ± 0.09	4.188 ± 0.107	4.080 ± 0.040	4.128
^{251}Cf		3.756 ± 0.012	4.379 ± 0.014	4.379 ± 0.014	4.147
^{253}Cf		3.89 ± 0.05	4.494 ± 0.057	4.494 ± 0.057	4.166
^{253}Fm		3.98 ± 0.14	4.638 ± 0.163	4.638 ± 0.163	4.691
^{256}Fm		4.01 ± 0.13	4.511 ± 0.146	4.511 ± 0.146	4.718

(1) Experimental values

(2) Experimental value <u>or</u> deduced value from Eq (2)

(3) From Eq. (6).

TABLE 8

Available experimental data on the energy dependence of $\overline{\nu}$ for ^{232}Th

Reference		Year	Energy (MeV)	$\overline{\nu}_{exp}$	Standard	$\overline{\nu}_{p}$ renormalized	$\overline{\nu}_t = \overline{\nu}_p + \overline{\nu}_d$
Johnstone	[69]	1956	14.1	3.55 ± 0.28	–		3.55 ± 0.28
Kuzminov	[70]	1958	3.5 **	2.35 ± 0.07	$\overline{\nu}_p^{th}(^{235}U)$ = 2.47	2.29 ± 0.07	2.34 ± 0.07
Smith et al	[71]	1959	1.4	2.58 ± 0.20	$\overline{\nu}_p^{1.4}(^{238}U)$ = 2.63	2.48 ± 0.20	2.53 ± 0.20
Kuzminov	[72]	1959	2.3	2.26 ± 0.10	$\overline{\nu}_p^{th}(^{235}U)$ = 2.47	2.20 ± 0.10	2.25 ± 0.10
			3.75	2.43 ± 0.09	–"–	2.37 ± 0.09	2.43 ± 0.09
			15.7	4.25 ± 0.13	–"–	4.14 ± 0.13	4.17 ± 0.13
Leroy	[36]	1960	14.2	4.64 ± 0.20	$\overline{\nu}_p^{th}(^{235}U)$ = 2.47	4.52 ± 0.20	4.55 ± 0.20
Vasil'ev et al.	[87]	1962	14.3	3.68 ± 0.25	-		3.68 ± 0.25
Condé et al	[73]	1965	1.42 ± 0.02	2.205 ± 0.060	$\overline{\nu}_p^{sp}(^{252}Cf)$ = 3.775	2.194 ± 0.060	2.245 ± 0.060
			1.61 ± 0.01	2.084 ± 0.037	–"–	2.074 ± 0.037	2.125 ± 0.037
			1.80 ± 0.01	2.119 ± 0.055	–"–	2.108 ± 0.055	2.159 ± 0.055
			2.23 ± 0.01	2.180 ± 0.049	–"–	2.169 ± 0.049	2.220 ± 0.049
			2.64 ± 0.01	2.273 ± 0.052	–"–	2.262 ± 0.052	2.213 ± 0.052
			3.6 ± 0.3	2.41 ± 0.10	–"–	2.40 ± 0.10	2.45 ± 0.10
			7.45 ± 0.05	3.028 ± 0.060	–"–	3.013 ± 0.060	3.054 ± 0.060
			14.8 ± 0.2	4.065 ± 0.060	–"–	4.045 ± 0.060	4.076 ± 0.060
			14.9 ± 0.03	4.32 ± 0.13	–"–	4.30 ± 0.13	4.33 ± 0.13
Meadows et al	[74]	1961	1.6	2.160 ± 0.042	$\overline{\nu}_p^{th}(^{235}U)$ = 2.43	2.139 ± 0.042	2.190 ± 0.042
Mather et al	[75]	1965	1.39 ± 0.160	2.319 ± 0.076	$\overline{\nu}_p^{sp}(^{252}Cf)$ = 3.782	2.303 ± 0.076	2.354 ± 0.076
			1.98 ± 0.145	2.211 ± 0.034	–"–	2.196 ± 0.034	2.247 ± 0.034
			3.00 ± 0.115	2.286 ± 0.095	–"–	2.270 ± 0.095	2.321 ± 0.095
			4.02 ± 0.095	2.400 ± 0.067	–"–	2.394 ± 0.067	2.445 ± 0.067
Prokhorova et al	[76]	1968	1.48 ± 0.03	2.179 ± 0.096	$\overline{\nu}_p^{th}(^{235}U)$ = 2.414	2.173 ± 0.096	2.224 ± 0.096
			1.56 ± 0.05	2.096 ± 0.073	–"–	2.090 ± 0.073	2.141 ± 0.073
			1.64 ± 0.07	2.132 ± 0.072	–"–	2.126 ± 0.072	2.177 ± 0.072
			2.05 ± 0.06	2.142 ± 0.069	–"–	2.136 ± 0.069	2.187 ± 0.069
			2.46 ± 0.06	2.221 ± 0.052	–"–	2.214 ± 0.052	2.265 ± 0.052
			2.86 ± 0.05	2.213 ± 0.054	–"–	2.206 ± 0.054	2.237 ± 0.054
			3.27 ± 0.04	2.416 ± 0.074	–"–	2.409 ± 0.074	2.460 ± 0.074
Vorobëva et al	[78]	1970	1.65	2.118 +	-	2.118	2.169

** Average energy of the fast neutron beam.

+ Deduced from the energy balance equation

TABLE 9

Available experimental data on the energy dependence of $\bar{\nu}$ for ^{233}U

Reference	Year	Energy (MeV)	$\bar{\nu}$ exp	Standard	$\bar{\nu}_p$ renormalized	$\bar{\nu}_t = \bar{\nu}_p + \bar{\nu}_d$
Graves [79]	1954	4.00	2,998±0,12	-		2,998±0,12
Diven et al [47]	1956	0.08	2,585±0.062	$\bar{\nu}_p^{th}(^{235}U)=2,46$	2,530±0,062	2.537±0,062
Johnstone [69]	1956	14.1	3.78 ±0.28	-		3.86 ±0.27
Kalashnikova [80]	1957	1.8++	2,69 ±0,06			
Smirenkin et al [81]	1958	4.0	3.00 ±0.11	$\bar{\nu}_p^{th}(^{233}U)=2,55$	2,92 ±0,11	2.93 ±0.11
		15.0	4.33 ±0.16	-"-	4.21 ±0.16	4.22 ±0.16
Protopopov et al [82]	1958	14.8	4.35 ±0.40	$\bar{\nu}_p^{th}(^{233}U)=2,52$	4.28 ±0.40	4.29 ±0.40
Engle et al [85]	1960	1.45	2.71 ±0,08	—		2,71 ±0,08
Hansen [83]	1958	1.40+	2,68 ±0.02	$\bar{\nu}^{E}(^{235}U)=2,56$		2.68 ±0,02
		1.67+	2,69 ±0,02	" =2,58		2,69 ±0,02
Flerov et al [86]	1961	14,0	4,23 ± 0,24	$\sigma_{in}(^{233}U)=2,85$ barns	4.23 ± 0,24	4,23 ± 0,24
Vasil'ev et al [87]	1962	14.3	4,20 ± 0.30	—		4.20 ± 0.30
Hopkins et al [8]	1963	0,280±0,090	2.489± 0.033	$\bar{\nu}_p^{sp}(^{252}Cf)= 3,771$	2,479±0.033	2,486±0.033
		0,440±0,080	2,502± 0,033	-"-	2.492±0.033	2,499±0.033
		0,980±0,050	2,553± 0,035	-"-	2,543±0.035	2,550±0.035
		1.080±0,050	2,510± 0,030	-"-	2.500±0.030	2.507±0.030
		3,930±0,290	2,983± 0,040	-"-	2,971±0.040	2,978±0.040
Colvin et al [88]	1965	0,58	2.47 ± 0.05	$\bar{\nu}_p^{sp}(^{252}Cf) = 3,780$	2,45 ±0,05	2,46 ±0,05
		0,93	2,56 ± 0.05	-"-	2,54 ±0.05	2,55 ±0,05
		1,49	2,52 ± 0,10	-"-	2,50 ±0,10	2,51 ±0,10
		2,12	2,575± 0,050	-"-	2,56 ±0,05	2,57 ±0,05
		2,58	2,81 ± 0,06	-"-	2,79 ±0,06	2,80 ±0,06
Mather et al [75]	1965	0,960±0,205	2,532± 0,036	$\bar{\nu}_p^{sp}(^{252}Cf)=3,782$	2.515±0,036	2,522±0,036
		1,980±0,145	2,639± 0,033	-"-	2,621±0,033	2,628±0,033
		3,000±0,115	2,855± 0,038	-"-	2,835±0,038	2.842±0,038
		4,000±0,090	2,923± 0,043	-"-	2,903±0,043	2,910+0,043
Blyumkina et al [90]	1964	0,30±0,09			2,414 ± 0,044**	2,421 ± 0,044
		0,40±0,09			2,452 ± 0,042**	2,459 ± 0,042
		0.50±0,09			2,458 ± 0,059**	2,465 ± 0.059
		0,60±0,09			2,538 ± 0,035**	2,545 ± 0.035
		0,76±0.09			2,578 ± 0,042**	2,585 ± 0.042
		0.95±0.09			2,519 ± 0,054**	2,526 ± 0,054
		1,09±0,09			2,551 ± 0,049**	2,558 ± 0,049
		1,28±0,09			2,555 ± 0,047**	2,562 ± 0,047
		1.53±0,10			2,591 ± 0.042**	2,598 ± 0,042
		1,75±0.10			2,607 ± 0,045**	2,614 ± 0,045
		1,92±0,10			2,602 ± 0,065**	2,609 ± 0,065
		2,16±0,11			2,642 ± 0,064**	2,649 ± 0,064
		4,7 ±0,7			3,050 ± 0,086**	3,057 ± 0,086
Kuznetsov et al [89]	1967	0,08	2,489± 0.030	$\bar{\nu}^{0.4MeV}(^{233}U)=2.462$	2,473 ± 0.030	2,481 ± 0,030
		0,20	2.467± 0.031	$\bar{\nu}^{th}/\bar{\nu}^{0.4MeV}=1.010$	2.452 ± 0,031	2,459 ± 0.031
		0,30	2,442± 0,027	-"-	2,427 ± 0,027	2,434 ± 0.027
		0.40	2.462± 0,025	-"-	2,447 ± 0,025	2,454 ± 0.025
		0.50	2.472± 0,027	-"-	2,457 ± 0.027	2,464 ± 0,027
		0,60	2,491± 0,028	-"-	2.476 ± 0.028	2,483 ± 0,028
		0,70	2,516± 0,029	-"-	2,501 ± 0.029	2,508 ± 0.029

**Deduced from the average kinetic energy of fission fragments through the energy balance equation

+ Average energy of neutron spectrum, not including effects of $\sigma_f(E)$

++ Average energy of neutron spectrum

TABLE 9 (continued)

Reference	Year	Energy (MeV)	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_p$ renormalized	$\bar{\nu}_t = \bar{\nu}_p + \bar{\nu}_d$
Boldeman et al.[92]		0.300±0.025	2.502±0.014	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.782$	2.484±0.014	2.491±0.014
		0.485±0.031	2.508±0.010	-"-	2.490±0.010	2.497±0.010
		0.600±0.032	2.546±0.012	-"-	2.528±0.012	2.535±0.012
		0.700±0.025	2.546±0.011	-"-	2.528±0.011	2.535±0.011
		0.917±0.033	2.564±0.012	-"-	2.546±0.012	2.553±0.012
		1.500±0.050	2.645±0.019	-"-	2.626±0.019	2.633±0.019
		1.870±0.050	2.684±0.022	-"-	2.665±0.022	2.673±0.022

TABLE 10

Available experimental data on the energy dependence of $\bar{\nu}$ for ^{234}U

Reference	Year	Energy	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_p$ renormalized	$\bar{\nu}_t = \bar{\nu}_p + \bar{\nu}_d$
Mather et al [75]	1965	0.99 ± 0.185	2.471±0.046	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.782$	2.454 ± 0.046	2.464 ± 0.046
		0.98 ± 0.145	2.678±0.033	-"-	2.659 ± 0.033	2.669 ± 0.033
		3.00 ± 0.115	2.730±0.043	-"-	2.711 ± 0.043	2.721 ± 0.043
		4.02 - 0.095	2.925±0.046	-"-	2.905 ± 0.056	2.915 ± 0.046

TABLE 11

Available experimental data on the energy dependence of $\bar{\nu}$ for ^{235}U

Reference		Year	Energy (MeV)	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_p$ renormalized	$\bar{\nu} = \bar{\nu}_p + \bar{\nu}_d$
Blair	[93]	1945	0.2	2.39 ± 0.15	–	–	2.39 ± 0.15
Blair	[94]	1945	1.5	2.57 ± 0.12	$\bar{\nu}^{th}(^{235}U) = 2.47$	2.53 ± 0.12	2.53 ± 0.12
Graves	[79]	1954	14.0	4.10 ± 0.15	$\bar{\nu}^{th}(^{235}U) = 2.47$	4.05 ± 0.15	4.03 ± 0.15
Fowler	[96]	1954	14.0	1.99 ± 0.23	$\bar{\nu}_p^{th}(^{235}U) = 1$	4.79 ± 0.53	4.80 ± 0.56
Ford	[97]	1954	5 *	3.1	–		3.1
			14 *	4.8	–		4.8
Terrel et al	[98]	1955	0.7	1.02 ± 0.02	$\bar{\nu}_p^{th}(^{235}U) = 1$	2.46 ± 0.05	2.48 ± 0.05
Bethe et al	[99]	1955	4	3.13 ± 0.31	$\bar{\nu}^{th}(^{235}U) = 2.47$	3.07 ± 0.031	3.07 ± 0.31
			4.5	3.26 ± 0.31	-"-	3.20 ± 0.31	3.20 ± 0.31
Fowler	[100]	1955	1.0	1.15 ± 0.12	$\bar{\nu}_p^{th}(^{235}U) = 1$	2.77 ± 0.29	2.79 ± 0.29
			1.9	1.24 ± 0.22	-"-	2.99 ± 0.53	3.01 ± 0.53
			4	1.26 ± 0.14	-"-	3.03 ± 0.34	3.05 ± 0.34
			5	1.31 ± 0.14	-"-	3.15 ± 0.34	3.17 ± 0.34
Diven et al	[47]	1956	0.08	2.47 ± 0.03	$\bar{\nu}^{th}(^{235}U) = 2.46$	2.40 ± 0.03	2.44 ± 0.03
Hanna et al	[101]	1956	0.74	2.48 ± 0.05	$\bar{\nu}^{th}(^{235}U) = 2.47$	2.44 ± 0.05	2.44 ± 0.05
			1.3	2.61 ± 0.09	-"-	2.57 ± 0.09	2.57 ± 0.09
			1.6	2.58 ± 0.05	-"-	2.54 ± 0.05	2.54 ± 0.05
			2.5	3.04 ± 0.20	-"-	2.99 ± 0.20	2.99 ± 0.20
Diven et al	[102]	1957	1.25	2.65 ± 0.07	$\bar{\nu}_p^{th}(^{235}U) = 2.47$	2.58 ± 0.07	2.60 ± 0.07
			4.8	3.20 ± 0.08	-"-	3.12 ± 0.08	3.14 ± 0.08
Johnstone	[69]	1956	2.5	2.64 ± 0.19	Old Harwell calibrated Unat source	2.64 ± 0.19	2.66 ± 0.19
			14.1	4.52 ± 0.32		4.52 ± 0.32	4.53 ± 0.32
Kalashnikova et al	[80]	1957	1.8**	1.10 ± 0.01	$\bar{\nu}_p^{th}(^{235}U) = 1$	2.65 ± 0.03	2.66 ± 0.03
Beyster	[103]	1958	1.8 **	1.05 ± 0.03	$\bar{\nu}^{th}(^{235}U) = 1$	2.55 ± 0.07	2.55 ± 0.07
Kuzminov et al	[70]	1958	1.20**	1.05 ± 0.01	$\bar{\nu}_p^{th}(^{235}U) = 1$	2.53 ± 0.02	2.54 ± 0.02
Smirenkin et al	[81]	1958	4	1.22 ± 0.04	$\bar{\nu}_p^{th}(^{235}U) = 1$	2.94 ± 0.09	2.95 ± 0.09
			15	1.82 ± 0.07	-"-	4.38 ± 0.17	4.39 ± 0.17
Protopopov & Blinov	[105]	1958	14.8	1.80 ± 0.18	$\bar{\nu}_p^{th}(^{235}U) = 1$	4.33 ± 0.43	4.34 ± 0.43
Flerov & Talyzin	[106]	1958	14.1	4.13 ± 0.24	–	4.13 ± 0.24	4.13 ± 0.24
Usachev & Trubitsyn	[107]	1958	0.7	2.52 ± 0.06	$\bar{\nu}^{th}(^{235}U) = 2.47$	2.48 ± 0.06	2.48 ± 0.06
			1.0	2.84 ± 0.35		2.79 ± 0.35	2.79 ± 0.35
Andreev	[108]	1958	2.0	2.80 ± 0.15	$\bar{\nu}^{th}(^{235}U) = 2.47$	2.76 ± 0.15	2.76 ± 0.15
Wahl	[109]	1958	14.0	5.2 ± 0.5	–	5.2 ± 0.5	5.2 ± 0.5
Saelay	[110]	1960	1.6	2.59 ± 0.05	–	2.59 ± 0.05	2.59 ± 0.05
Vasil'ev et al	[111]	1960	14.3	4.17 ± 0.30	–	4.17 ± 0.30	4.17 ± 0.30
Engle et al	[85]	1960	1.45	2.60 ± 0.10	–	2.60 ± 0.10	2.60 ± 0.10
Moat et al.	[10]	1961	0.075	2.39 ± 0.05	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.69$	2.43 ± 0.03	2.45 ± 0.03
			2.50	2.60 ± 0.08	-"-	2.65 ± 0.06	2.67 ± 0.06
			14.20	4.28 ± 0.08	-"-	4.36 ± 0.06	4.38 ± 0.06
Meadows & Whalen	[115]	1962	0.03	2.421± 0.025	$\bar{\nu}_p^{th}(^{235}U) = 2.414$	2.414± 0.025	2.430± 0.025
			0.20	2.436± 0.016	-"-	2.429± 0.016	2.445± 0.016
			0.62	2.470± 0.019	-"-	2.463± 0.019	2.479± 0.019
			1.11	2.520± 0.018	-"-	2.513± 0.018	2.529± 0.018
			1.58	2.580± 0.020	-"-	2.573± 0.020	2.589± 0.020
			1.76	2.575± 0.021	-"-	2.568± 0.021	2.584± 0.021
Hopkins & Diven	[8]	1963	0.280±0.090	2.438± 0.022	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.771$	2.428± 0.022	2.444± 0.022
			0.470±0.080	2.456± 0.022	-"-	2.446± 0.022	2.462± 0.022
			0.815±0.060	2.471± 0.026	-"-	2.461± 0.026	2.477± 0.026
			1.080±0.050	2.530± 0.026	-"-	2.520± 0.026	2.536± 0.026
			3.930±0.290	2.937± 0.030	-"-	2.926± 0.030	2.942± 0.030
			14.50 ±1.00	4.626± 0.075	-"-	4.608± 0.075	4.618± 0.075

* Derived from fission fragment charge distribution

** Fission spectrum average

<u>TABLE 11</u> (continued)

Reference	Year	Energy (MeV)	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_{renormalized}$	$\bar{\nu}_t = \bar{\nu}_p + \bar{\nu}_d$
Colvin & Sowerby [9]	1963	0.101 ± 0.060	2.478 ± 0.047	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.76$	2.466 ± 0.047	2.482 ± 0.047
		0.514 ± 0.054	2.524 ± 0.044	-"-	2.509 ± 0.044	2.525 ± 0.044
		0.571 ± 0.156	2.511 ± 0.026	-"-	2.497 ± 0.026	2.513 ± 0.026
		0.572 ± 0.015	2.501 ± 0.029	-"-	2.488 ± 0.029	2.504 ± 0.029
		0.604 ± 0.053	2.519 ± 0.023	-"-	2.501 ± 0.023	2.517 ± 0.023
		0.946 ± 0.128	2.534 ± 0.020	-"-	2.515 ± 0.020	2.531 ± 0.020
		1.497 ± 0.109	2.583 ± 0.020	-"-	2.573 ± 0.020	2.599 ± 0.020
		2.123 ± 0.095	2.668 ± 0.021	-"-	2.664 ± 0.021	2.680 ± 0.021
		2.572 ± 0.085	2.717 ± 0.024	-"-	2.708 ± 0.024	2.724 ± 0.024
Blyumkina et al. [90]	1964	0.08 ± 0.05	2.439 ± 0.024*	$\bar{\nu}(0.3 MeV) = 1.023\, \bar{\nu}_t^{th}(^{235}U)$ $\bar{\nu}_t^{th}(^{235}U) = 2.430$	2.416 ± 0.024	2.432 ± 0.024
		0.31 ± 0.04	2.483 ± 0.022*	-"-	2.460 ± 0.022	2.476 ± 0.022
		0.39 ± 0.05	2.491 ± 0.017*	-"-	2.468 ± 0.017	2.484 ± 0.017
		0.55 ± 0.05	2.441 ± 0.022*	-"-	2.418 ± 0.022	2.434 ± 0.022
		0.67 ± 0.05	2.471 ± 0.022*	-"-	2.448 ± 0.022	2.464 ± 0.022
		0.78 ± 0.06	2.471 ± 0.025*	-"-	2.448 ± 0.025	2.464 ± 0.025
		0.99 ± 0.06	2.503 ± 0.029*	-"-	2.480 ± 0.029	2.496 ± 0.029
		0.08 ± 0.05	2.391 ± 0.035	- " -	2.368 ± 0.035	2.384 ± 0.035
		0.19 ± 0.09	2.448 ± 0.038	- " -	2.425 ± 0.038	2.441 ± 0.038
		0.29 ± 0.04	2.483 ± 0.034	- " -	2.460 ± 0.034	2.476 ± 0.034
		0.46 ± 0.05	2.493 ± 0.037	- " -	2.470 ± 0.037	2.486 ± 0.037
		0.64 ± 0.05	2.468 ± 0.038	- " -	2.445 ± 0.038	2.461 ± 0.038
Blyumkina et al, [90]	1964	0.08 ± 0.05			2.466 ± 0.053**	2.482 ± 0.053
		0.28 ± 0.09			2.514 ± 0.046**	2.530 ± 0.046
		0.35 ± 0.09			2.544 ± 0.057**	2.560 ± 0.057
		0.48 ± 0.09			2.479 ± 0.043**	2.495 ± 0.043
		0.68 ± 0.09			2.473 ± 0.054**	2.489 ± 0.054
		0.77 ± 0.09			2.464 ± 0.054**	2.480 ± 0.054
		0.87 ± 0.09			2.510 ± 0.046**	2.526 ± 0.046
		1.09 ± 0.09			2.541 ± 0.072**	2.457 ± 0.073
		1.45 ± 0.10			2.573 ± 0.051**	2.589 ± 0.051
		1.90 ± 0.10			2.657 ± 0.070**	2.673 ± 0.070
		2.46 ± 0.11			2.738 ± 0.083**	2.754 ± 0.083
		5.00 ± 0.7			3.073 ± 0.081**	3.089 ± 0.081
Mather et al [116]	1964	0.040	2.420 ± 0.014	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.782$	2.403 ± 0.014	2.419 ± 0.014
		0.140 ± 0.040	2.423 ± 0.042	- " -	2.406 ± 0.042	2.422 ± 0.042
		0.230 ± 0.025	2.490 ± 0.022	- " -	2.473 ± 0.022	2.489 ± 0.022
		0.330 ± 0.115	2.478 ± 0.021	- " -	2.461 ± 0.021	2.477 ± 0.021
		0.430 ± 0.115	2.475 ± 0.020	- " -	2.458 ± 0.020	2.474 ± 0.020
		0.700 ± 0.145	2.457 ± 0.016	- " -	2.440 ± 0.016	2.456 ± 0.016
		0.840 ± 0.070	2.529 ± 0.021	- " -	2.511 ± 0.021	2.527 ± 0.021
		0.930 ± 0.190	2.499 ± 0.020	- " -	2.482 ± 0.020	2.498 ± 0.020
		1.170 ± 0.175	2.557 ± 0.021	- " -	2.539 ± 0.021	2.555 ± 0.021
		1.470 ± 0.130	2.583 ± 0.020	- " -	2.565 ± 0.020	2.581 ± 0.020
		1.940 ± 0.135	2.656 ± 0.021	- " -	2.638 ± 0.021	2.654 ± 0.021
		2.440 ± 0.120	2.689 ± 0.022	- " -	2.671 ± 0.022	2.687 ± 0.022
		2.960 ± 0.110	2.751 ± 0.016	- " -	2.732 ± 0.016	2.748 ± 0.016
		3.870 ± 0.580	2.933 ± 0.022	- " -	2.913 ± 0.022	2.929 ± 0.022
		4.910 ± 0.385	3.074 ± 0.027	- " -	3.053 ± 0.037	3.069 ± 0.037
		5.940 ± 0.270	3.273 ± 0.025	- " -	3.251 ± 0.025	3.265 ± 0.025
		6.960 ± 0.210	3.490 ± 0.022	- " -	3.466 ± 0.022	3.478 ± 0.022
		7.960 ± 0.205	3.666 ± 0.037	- " -	3.641 ± 0.037	3.651 ± 0.037
Condé [117]	1965	0.06	2.416 ± 0.023	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.767$	2.409 ± 0.023	2.425 ± 0.023
		7.50	3.49 ± 0.06	- " -	3.480 ± 0.060	3.496 ± 0.060
		14.80	4.47 ± 0.09	- " -	4.458 ± 0.090	4.468 ± 0.090

* Data taken from [90] were later on corrected as given in DASTAR-00363, 2nd version, June 1969.
** Data deduced from the average kinetic energy of fission fragments by means of the energy balance equation

TABLE 11 (continued)

Reference	Year	Energy (MeV)	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_{p\,renormalized}$	$\bar{\nu}_t = \bar{\nu}_p + \bar{\nu}_d$
Meadows & Whalen [118]	1967	0.039 ± 0.050	2.422 ± 0.017	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.782$	2.405 ± 0.017	2.421 ± 0.017
		0.046 ± 0.050	2.423 ± 0.016	- " -	2.406 ± 0.016	2.422 ± 0.016
		0.150 ± 0.032	2.462 ± 0.018	- " -	2.445 ± 0.018	2.461 ± 0.018
		0.225 ± 0.030	2.480 ± 0.018	- " -	2.463 ± 0.018	2.479 ± 0.018
		0.265 ± 0.028	2.470 ± 0.022	- " -	2.453 ± 0.022	2.469 ± 0.022
		0.298 ± 0.027	2.472 ± 0.022	- " -	2.455 ± 0.022	2.471 ± 0.022
		0.325 ± 0.027	2.514 ± 0.018	- " -	2.496 ± 0.018	2.512 ± 0.018
		0.358 ± 0.025	2.436 ± 0.018	- " -	2.419 ± 0.018	2.435 ± 0.018
		0.375 ± 0.025	2.477 ± 0.022	- " -	2.460 ± 0.022	2.476 ± 0.022
		0.405 ± 0.025	2.468 ± 0.022	- " -	2.451 ± 0.022	2.467 ± 0.022
		0.425 ± 0.025	2.534 ± 0.017	- " -	2.516 ± 0.017	2.532 ± 0.017
		0.476 ± 0.024	2.512 ± 0.019	- " -	2.494 ± 0.019	2.510 ± 0.019
		0.548 ± 0.021	2.489 ± 0.017	- " -	2.472 ± 0.017	2.488 ± 0.017
		0.675 ± 0.018	2.514 ± 0.017	- " -	2.496 ± 0.017	2.512 ± 0.017
		0.785 ± 0.021	2.527 ± 0.014	- " -	2.509 ± 0.014	2.525 ± 0.014
		1.000 ± 0.020	2.561 ± 0.016	- " -	2.544 ± 0.016	2.560 ± 0.016
Kuznetsov & Smirenkin [119]	1967	0.08	2.456 ± 0.022	$\bar{\nu}_t(0.39 MeV) = 1.025 \cdot \bar{\nu}_t^{th}(^{235}U)$ $\bar{\nu}_t^{th}(^{235}U) = 2.430$	2.432 ± 0.022	2.448 ± 0.022
		0.20	2.523 ± 0.023	- " -	2.499 ± 0.023	2.515 ± 0.023
		0.30	2.511 ± 0.023	- " -	2.487 ± 0.023	2.503 ± 0.023
		0.40	2.491 ± 0.017	- " -	2.467 ± 0.017	2.483 ± 0.017
		0.50	2.486 ± 0.022	- " -	2.462 ± 0.022	2.478 ± 0.022
		0.60	2.478 ± 0.022	- " -	2.455 ± 0.022	2.471 ± 0.022
		0.70	2.476 ± 0.022	- " -	2.453 ± 0.022	2.469 ± 0.022
Prokhorova & Smirenkin [76]	1967	0.37 ± 0.10	2.474 ± 0.017	$\bar{\nu}_p(0.39 MeV) = 1.025\ \bar{\nu}_p^{th}(^{235}U)$, $\bar{\nu}_p^{th}(^{235}U) = 2.414$	2.467 ± 0.017	2.483 ± 0.017
		0.59 ± 0.10	2.471 ± 0.035	- " -	2.464 ± 0.035	2.480 ± 0.035
		0.81 ± 0.09	2.461 ± 0.035	- " -	2.454 ± 0.035	2.470 ± 0.035
		1.02 ± 0.08	2.538 ± 0.027	- " -	2.531 ± 0.027	2.547 ± 0.027
		1.23 ± 0.08	2.556 ± 0.037	- " -	2.549 ± 0.037	2.565 ± 0.037
		1.44 ± 0.07	2.564 ± 0.037	- " -	2.557 ± 0.037	2.573 ± 0.037
		1.64 ± 0.07	2.589 ± 0.036	- " -	2.582 ± 0.036	2.598 ± 0.036
		1.85 ± 0.07	2.619 ± 0.034	- " -	2.612 ± 0.034	2.628 ± 0.034
		2.05 ± 0.06	2.607 ± 0.031	- " -	2.600 ± 0.031	2.616 ± 0.031
		2.25 ± 0.06	2.678 ± 0.037	- " -	2.670 ± 0.037	2.686 ± 0.037
		2.46 ± 0.06	2.760 ± 0.042	- " -	2.752 ± 0.042	2.768 ± 0.042
		2.76 ± 0.06	2.815 ± 0.038	- " -	2.808 ± 0.038	2.824 ± 0.038
		3.06 ± 0.05	2.825 ± 0.050	- " -	2.817 ± 0.059	2.833 ± 0.059
		3.25 ± 0.05	2.852 ± 0.046	- " -	2.844 ± 0.046	2.860 ± 0.046
Nadkarni & Ballal [120]	1967	0.37 ± 0.15	2.57 ± 0.11		2.52 ± 0.11 *	2.54 ± 0.11
		0.43 ± 0.14	2.53 ± 0.11		2.49 ± 0.11 *	2.51 ± 0.11
		0.49 ± 0.14	2.49 ± 0.11		2.46 ± 0.11 *	2.48 ± 0.11
		0.54 ± 0.14	2.49 ± 0.11		2.46 ± 0.11 *	2.48 ± 0.11
		0.65 ± 0.13	2.37 ± 0.07		2.38 ± 0.07 *	2.40 ± 0.07
		0.76 ± 0.13	2.50 ± 0.10		2.47 ± 0.10 *	2.49 ± 0.10
		0.82 ± 0.13	2.60 ± 0.10		2.56 ± 0.10 *	2.58 ± 0.10
		0.87 ± 0.12	2.65 ± 0.10		2.59 ± 0.10 *	2.61 ± 0.10
		0.92 ± 0.12	2.64 ± 0.10		2.58 ± 0.10 *	2.60 ± 0.10
		0.98 ± 0.12	2.62 ± 0.09		2.56 ± 0.09 *	2.58 ± 0.09
		1.03 ± 0.12	2.59 ± 0.09		2.54 ± 0.05 *	2.56 ± 0.05
		1.09 ± 0.12	2.56 ± 0.05		2.52 ± 0.05 *	2.54 ± 0.05
		1.24 ± 0.11	2.54 ± 0.105		2.59 ± 0.10 *	2.61 ± 0.10
		1.40 ± 0.11	2.68 ± 0.10		2.56 ± 0.10 *	2.58 ± 0.10
		1.51 ± 0.10	2.72 ± 0.10		2.64 ± 0.10 *	2.66 ± 0.10
		1.61 ± 0.10	2.63 ± 0.08		2.57 ± 0.08 *	2.59 ± 0.08
		1.71 ± 0.10	2.75 ± 0.10		2.67 ± 0.10 *	2.69 ± 0.10
		1.82 ± 0.10	2.74 ± 0.10		2.65 ± 0.10 *	2.66 ± 0.10
		1.92 ± 0.09	2.83 ± 0.10		2.72 ± 0.10 *	2.74 ± 0.10
		2.02 ± 0.09	2.85 ± 0.10		2.74 ± 0.10 *	2.76 ± 0.10
		2.13 ± 0.09	2.79 ± 0.10		2.69 ± 0.10 *	2.71 ± 0.10

* Values corrected by making use of the energy balance equation.

TABLE 11 (continued)

Reference	Year	Energy, MeV	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_p$ renormalized	$\bar{\nu}_t = \bar{\nu}_p + \bar{\nu}_d$
Soleilhac et al [122]	1969	1.36 ± 0.165	2.565 ± 0.017	$\bar{\nu}_p^{sp}(^{252}Cf)$=3.782	2.547 ± 0.017	2.563 ± 0.017
		1.87 ± [illegible]	2.631 ± 0.022	- " -	2.613 ± 0.022	2.629 ± 0.022
		2.45 ± 0.125	2.668 ± 0.022	- " -	2.669 ± 0.022	2.685 ± 0.022
		3.05 ± 0.105	2.757 ± 0.018	- " -	2.738 ± 0.018	2.754 ± 0.018
		3.52 ± 0.100	2.804 ± 0.023	- " -	2.784 ± 0.023	2.800 ± 0.023
		4.03 ± 0.090	2.890 ± 0.019	- " -	2.870 ± 0.019	2.886 ± 0.019
		4.54 ± 0.080	2.984 ± 0.022	- " -	2.963 ± 0.022	2.979 ± 0.022
		5.06 ± 0.070	3.040 ± 0.019	- " -	3.019 ± 0.019	3.035 ± 0.019
		5.57 ± 0.070	3.163 ± 0.028	- " -	3.141 ± 0.028	3.155 ± 0.028
		6.08 ± 0.065	3.254 ± 0.029	- " -	3.234 ± 0.029	3.244 ± 0.029
		6.57 ± 0.170	3.422 ± 0.022	- " -	3.398 ± 0.022	3.309 ± 0.022
		7.00 ± 0.065	3.428 ± 0.029	- " -	3.404 ± 0.029	3.414 ± 0.029
		7.48 ± 0.160	3.521 ± 0.016	- " -	3.496 ± 0.016	3.506 ± 0.016
		7.99 ± 0.145	3.582 ± 0.017	- " -	3.567 ± 0.017	3.577 ± 0.017
		8.49 ± 0.130	3.658 ± 0.018	- " -	3.632 ± 0.018	3.642 ± 0.018
		9.00 ± 0.120	3.731 ± 0.018	- " -	3.705 ± 0.018	3.715 ± 0.018
		9.49 ± 0.110	3.800 ± 0.020	- " -	3.782 ± 0.020	3.792 ± 0.020
		9.74 ± 0.110	3.850 ± 0.021	- " -	3.823 ± 0.021	3.833 ± 0.021
		9.98 ± 0.100	3.882 ± 0.014	- " -	3.855 ± 0.014	3.865 ± 0.014
		10.47 ± 0.095	3.937 ± 0.020	- " -	3.909 ± 0.020	3.919 ± 0.020
		10.96 ± 0.090	3.972 ± 0.019	- " -	3.944 ± 0.019	3.954 ± 0.019
		11.44 ± 0.085	4.074 ± 0.020	- " -	4.045 ± 0.020	4.055 ± 0.020
		11.93 ± 0.080	4.136 ± 0.021	- " -	4.107 ± 0.021	4.117 ± 0.021
		12.42 ± 0.080	4.202 ± 0.020	- " -	4.172 ± 0.020	4.182 ± 0.020
		12.88 ± 0.080	4.257 ± 0.024	- " -	4.227 ± 0.024	4.257 ± 0.024
		13.36 ± 0.075	4.345 ± 0.022	- " -	4.315 ± 0.022	4.325 ± 0.022
		13.84 ± 0.075	4.411 ± 0.022	- " -	4.380 ± 0.022	4.490 ± 0.022
		14.31 ± 0.070	4.481 ± 0.023	- " -	4.450 ± 0.023	4.460 ± 0.023
		14.79 ± 0.070	4.506 ± 0.023	- " -	4.476 ± 0.023	4.486 ± 0.023
		22.79 ± 0.140	5.511 ± 0.049	- " -	5.472 ± 0.049	5.482 ± 0.049
		23.94 ± 0.115	5.654 ± 0.054	- " -	5.614 ± 0.054	5.624 ± 0.054
		25.05 ± 0.105	5.693 ± 0.054	- " -	5.653 ± 0.054	5.663 ± 0.054
		26.15 ± 0.090	5.789 ± 0.042	- " -	5.748 ± 0.042	5.758 ± 0.042
		27.22 ± 0.080	5.986 ± 0.062	- " -	5.944 ± 0.062	5.954 ± 0.062
		30.28 ± 0.075	6.108 ± 0.090	- " -	6.065 ± 0.090	6.075 ± 0.090
Soleilhac et al [122]	1970	0.21 ± 0.010	2.4307±0.0525	$\bar{\nu}_p^{sp}(^{252}Cf)$=3.782	2.4139±0.0533	2.4304±0.0533
		0.23 ± 0.010	2.4471±0.0410	-"-	2.4302±0.0408	2.4467±0.0408
		0.25 ± 0.010	2.4635±0.0371	-"-	2.4465±0.0369	2.4630±0.0369
		0.27 ± 0.010	2.4930±0.0307	-"-	2.4758±0.0305	2.4923±0.0305
		0.29 ± 0.010	2.4607±0.0292	-"-	2.4437±0.0290	2.4602±0.0290
		0.31 ± 0.010	2.4699±0.0257	-"-	2.4529±0.0255	2.4694±0.0255
		0.33 ± 0.010	2.4455±0.0242	-"-	2.4286±0.0240	2.4451±0.0240
		0.35 ± 0.010	2.5165±0.0237	-"-	2.4991±0.0235	2.5156±0.0235
		0.37 ± 0.010	2.4736±0.0232	-"-	2.4565±0.0230	2.4730±0.0230
		0.39 ± 0.010	2.4788±0.0229		2.4617±0.0227	2.4[illegible]±0.0227
		0.41 ± 0.010	2.5326±0.0212	-"-	2.5151±0.0210	2.5316±0.0210
		0.43 ± 0.010	2.4969±0.0206	-"-	2.4797±0.0204	2.4962±0.0204
		0.45 ± 0.010	2.4764±0.0184	-"-	2.4593±0.0182	2.4758±0.0182
		0.47 ± 0.010	2.4562±0.0179	-"-	2.4393±0.0177	2.4558±0.0177
		0.49 ± 0.010	2.5004±0.0163	-"-	2.4831±0.0161	2.4996±0.0161
		0.51 ± 0.010	2.4960±0.0162	-"-	2.4788±0.0160	2.4954±0.0160
		0.53 ± 0.010	2.5140±0.0155	-"-	2.4967±0.0153	2.5132±0.0153
		0.55 ± 0.010	2.4725±0.0146	-"-	2.4554±0.0144	2.4719±0.0144

TABLE 11 (continued)

Reference	Year	Energy(MeV)	$\overline{\nu}_{exp}$	Standard	$\overline{\nu}_{p}$ renormalized	$\nu_t = \nu_p + \nu_d$
Soleilhac et al [122]	1970	0.57 ± 0.010	2.4885±0.0143	$\overline{\nu}_p^{sp}(^{252}Cf) = 3.782$	2.4713±0.0141	2.4878±0.0141
		0.59 ± 0.010	2.4725±0.0142	-"-	2.4554±0.0140	2.4714±0.0140
		0.61 ± 0.010	2.4928±0.0168	-"-	2.4756±0.0166	2.4921±0.0166
		0.63 ± 0.010	2.4921±0.0162	-"-	2.4749±0.0160	2.4914±0.0160
		0.65 ± 0.010	2.5108±0.0167	-"-	2.4935±0.0165	2.5100±0.0165
		0.67 ± 0.010	[illegible]±0.0168	-"-	2.4826±0.0166	2.4991±0.0166
		0.690± 0.010	[illegible]±0.0195	-"-	2.4756±0.0193	2.4921±0.0193
		0.725± 0.025	2.4958±0.0129	-"-	2.4786±0.0127	2.4951±0.0127
		0.775± 0.025	2.5215±0.0136	-"-	2.5041±0.0134	2.5206±0.0134
		0.825± 0.025	2.5347±0.0151	-"-	2.5172±0.0149	2.5337±0.0149
		0.875± 0.025	2.5472±0.0166	-"-	2.5297±0.0164	2.5462±0.0164
		0.925± 0.025	2.5498±0.0173	-"-	2.5322±0.0171	2.5487±0.0171
		0.975± 0.025	2.5539±0.0194	-"-	2.5363±0.0192	2.5528±0.0192
		1.025± 0.025	2.5471±0.0233	-"-	2.5295±0.0231	2.5460±0.0231
		1.075± 0.025	2.5782±0.0242	-"-	2.5604±0.0240	2.5769±0.0240
		1.125± 0.025	2.5786±0.0277	-"-	2.5608±0.0275	2.5773±0.0275
		1.175± 0.025	2.5769±0.0292	-"-	2.5559±0.0290	2.5724±0.0290
		1.225± 0.025	2.5779±0.0300	-"-	2.5601±0.0298	2.5706±0.0298
		1.275± 0.025	2.6378±0.0396	-"-	2.6196±0.0394	2.6361±0.0394
		1.325± 0.025	2.5588±0.0399	-"-	2.5411±0.0397	2.5576±0.0397
		1.375± 0.025	2.5826±0.0317	-"-	2.5648±0.0315	2.5813±0.0315
		1.360± 0.025	2.5650±0.0100	-"-	2.5473±0.0100	2.5638±0.0100
Savin et al [123]	1970	0.65	2.432 ± 0.039	$\overline{\nu}_p^{sp}(^{252}Cf) = 3.772$	2.422 ± 0.039	2.438 ± 0.039
		0.68	2.447 ± 0.039	- " -	2.437 ± 0.039	2.453 ± 0.039
		0.71	2.472 ± 0.039	- " -	2.461 ± 0.039	2.477 ± 0.039
		0.73	2.473 ± 0.039	- " -	2.462 ± 0.039	2.468 ± 0.039
		0.79	2.478 ± 0.039	- " -	2.467 ± 0.039	2.483 ± 0.039
		0.82	2.491 ± 0.040	- " -	2.480 ± 0.040	2.496 ± 0.040
		0.87	2.474 ± 0.039	- " -	2.463 ± 0.039	2.479 ± 0.039
		0.91	2.499 ± 0.040	- " -	2.488 ± 0.040	2.504 ± 0.040
		0.97	2.484 ± 0.039	- " -	2.473 ± 0.039	2.489 ± 0.039
		1.01	2.491 ± 0.039	- " -	2.480 ± 0.039	2.496 ± 0.039
		1.06	2.539 ± 0.038	- " -	2.528 ± 0.038	2.544 ± 0.038
		1.15	2.575 ± 0.038	- " -	2.564 ± 0.038	2.560 ± 0.038
		1.25	2.578 ± 0.038	-"-	2.567 ± 0.038	2.583 ± 0.038
		1.35	2.613 ± 0.039	-"-	2.602 ± 0.039	2.618 ± 0.039
		1.41	2.618 ± 0.039	-"-	2.607 ± 0.039	2.622 ± 0.039
		1.48	2.636 ± 0.039	-"-	2.625 ± 0.039	2.641 ± 0.039
		1.63	2.641 ± 0.039	-"-	2.630 ± 0.039	2.646 ± 0.039
		1.80	2.641 ± 0.039	-"-	2.630 ± 0.039	2.646 ± 0.039
		1.97	2.645 ± 0.039	-"-	2.634 ± 0.039	2.650 ± 0.039
		2.09	2.661 ± 0.040	-"-	2.650 ± 0.040	2.666 ± 0.040
		2.18	2.700 ± 0.033	-"-	2.688 ± 0.033	2.704 ± 0.033
		2.26	2.713 ± 0.035	-"-	2.701 ± 0.035	2.717 ± 0.035
		2.39	2.748 ± 0.035	-"-	2.736 ± 0.035	2.752 ± 0.035
		2.55	2.711 ± 0.035	-"-	2.699 ± 0.035	2.715 ± 0.035
		2.68	2.763 ± 0.033	-"-	2.751 ± 0.033	2.767 ± 0.033
		2.85	2.812 ± 0.034	-"-	2.800 ± 0.034	2.816 ± 0.034
		2.94	2.806 ± 0.034	-"-	2.794 ± 0.034	2.810 ± 0.034
		3.05	2.800 ± 0.034	-"-	2.788 ± 0.034	2.804 ± 0.034
		3.28	2.833 ± 0.043	-"-	2.821 ± 0.043	2.837 ± 0.043
		3.71	2.871 ± 0.043	-"-	2.859 ± 0.043	2.875 ± 0.043

TABLE 11 (continued)

Reference	Year	Energy, MeV	$\overline{\nu}_{exp}$	Standard	$\overline{\nu}_p$ renormalized	$\overline{\nu}_t = \overline{\nu}_p + \overline{\nu}_d$
Savin et al [123]	1970	4.23	2.903 ± 0.044	$\overline{\nu}_p^{sp}(^{252}Cf) = 3.772$	2.891 ± 0.044	2.907 ± 0.044
		4.57	2.937 ± 0.058	-"-	2.924 ± 0.058	2.940 ± 0.058
		4.90	3.032 ± 0.061	-"-	3.019 ± 0.061	3.035 ± 0.061
		5.32	3.095 ± 0.072	-"-	3.082 ± 0.072	3.097 ± 0.072
		5.60	3.110 + 0.082	-"-	3.097 ± 0.082	3.111 ± 0.082
		5.94	3.234 ± 0.106	-"-	3.220 ± 0.105	3.238 ± 0.105
		6.60	3.373 ± 0.111	-"-	3.359 ± 0.110	3.371 + 0.110
Nesterov et al [25]	1970	0.0	2.412 ± 0.014	$\overline{\nu}_p^{sp}(^{252}Cf) = 3.782$	2.395 ± 0.014	2.411 ± 0.014
		0.080	2.404 + 0.014	-"-	2.387 ± 0.014	2.403 ± 0.014
		0.214 ± 0.040	2.466 + 0.020	-"-	2.449 ± 0.020	2.465 ± 0.020
		0.322 ± 0.043	2.457 ± 0.020	-"-	2.440 ± 0.020	2.456 ± 0.020
		0.408 ± 0.042	2.474 ± 0.024	-"-	2.457 ± 0.024	2.473 ± 0.024
		0.510 ± 0.039	2.484 ± 0.027	-"-	2.467 ± 0.027	2.483 ± 0.027
		0.604 ± 0.039	2.452 ± 0.025	-"-	2.435 ± 0.025	2.451 ± 0.025
		0.810 ± 0.036	2.514 ± 0.020	-"-	2.497 ± 0.020	2.513 ± 0.020
		0.910 ± 0.037	2.518 ± 0.026	-"-	2.500 ± 0.026	2.516 ± 0.026
		1.002 ± 0.062	2.558 ± 0.025	-"-	2.540 ± 0.025	2.556 ± 0.025
		1.112 ± 0.035	2.578 ± 0.022	-"-	2.560 ± 0.022	2.576 ± 0.022
		1.314 ± 0.035	2.574 ± 0.024	-"-	2.556 ± 0.024	2.572 ± 0.024
		1.515 ± 0.035	2.572 ± 0.025	-"-	2.554 ± 0.025	2.570 ± 0.025
Boldeman & Walsh [24]	1970	0.110 ± 0.070	2.417 ± 0.021	$\overline{\nu}_p^{sp}(^{252}Cf) = 3.782$	2.400 ± 0.021	2.416 ± 0.021
		0.220 ± 0.033	2.445 ± 0.015	-"-	2.428 ± 0.015	2.444 ± 0.015
		0.300 ± 0.032	2.448 ± 0.017	-"-	2.431 ± 0.017	2.447 ± 0.017
		0.350 ± 0.032	2.456 ± 0.016	-"-	2.439 ± 0.016	2.455 ± 0.016
		0.460 ± 0.032	2.439 ± 0.016	-"-	2.422 ± 0.016	2.438 ± 0.016
		0.485 ± 0.025	2.456 ± 0.011	-"-	2.439 ± 0.011	2.455 ± 0.011
		0.750 ± 0.020	2.456 ± 0.014	-"-	2.439 ± 0.014	2.455 ± 0.014
		0.485 ± 0.025	2.474 ± 0.010	-"-	2.457 ± 0.010	2.473 ± 0.010
		0.540 ± 0.032	2.456 ± 0.013	-"-	2.439 ± 0.013	2.455 ± 0.013
		0.600 ± 0.032	2.476 ± 0.014	-"-	2.459 ± 0.014	2.475 ± 0.014
		0.700 ± 0.032	2.492 ± 0.014	-"-	2.475 ± 0.014	2.491 ± 0.014
		1.000 ± 0.032	2.537 ± 0.014	-"-	2.519 ± 0.014	2.535 ± 0.014
		1.500 ± 0.050	2.589 ± 0.018	-"-	2.571 ± 0.018	2.587 ± 0.018
		1.900 ± 0.050	2.625 ± 0.016	-"-	2.607 ± 0.016	2.623 ± 0.016

TABLE 12

Available experimental data on the energy dependence of $\bar{\nu}$ for ^{236}U

Reference	Year	Energy (*) (MeV)	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_p$ renormalized	$\bar{\nu}_t = \bar{\nu}_p + \bar{\nu}_d$
Condé and Holmberg [34]	1971	0.77	2.45 ± 0.06	$\bar{\nu}_p^{sp}(^{252}Cf) = 3.756$	2.45 ± 0.06	2.47 ± 0.06
		0.82	2.40 ± 0.05	-"-	2.40 ± 0.05	2.42 ± 0.05
		0.08	2.44 ± 0.05	-"-	2.44 ± 0.05	2.46 ± 0.05
		0.98	2.47 ± 0.05	-"-	2.47 ± 0.05	2.49 ± 0.05
		1.08	2.43 ± 0.05	-"-	2.43 ± 0.05	2.45 ± 0.05
		1.29	2.50 ± 0.04	-"-	2.50 ± 0.04	2.52 ± 0.04
		1.50	2.56 ± 0.04	-"-	2.56 ± 0.04	2.58 ± 0.04
		1.69	2.52 ± 0.05	-"-	2.52 ± 0.05	2.54 ± 0.05
		1.90	2.55 ± 0.04	-"-	2.55 ± 0.04	2.57 ± 0.04
		2.21	2.55 ± 0.04	-"-	2.55 ± 0.04	2.57 ± 0.04
		2.29	2.69 ± 0.05	-"-	2.69 ± 0.05	2.71 ± 0.05
		2.51	2.59 ± 0.04	-"-	2.59 ± 0.04	2.61 ± 0.04
		2.59	2.67 ± 0.05	-"-	2.67 ± 0.05	2.69 ± 0.05
		2.79	2.67 ± 0.05	-"-	2.67 ± 0.05	2.69 ± 0.05
		2.99	2.72 ± 0.05	-"-	2.72 ± 0.05	2.74 ± 0.05
		3.29	2.78 ± 0.05	-"-	2.78 ± 0.05	2.80 ± 0.05
		3.79	2.81 ± 0.05	-"-	2.81 ± 0.05	2.83 ± 0.05
		4.17	2.85 ± 0.04	-"-	2.85 ± 0.04	2.87 ± 0.04
		5.50	2.96 ± 0.06	-"-	2.96 ± 0.06	2.98 ± 0.06
		6.20	3.12 ± 0.04	-"-	3.12 ± 0.04	3.14 ± 0.04
		6.70	3.26 ± 0.05	-"-	3.26 ± 0.05	3.28 ± 0.05

(*) The energy spread was ± 15 keV at 1 MeV incident neutron energy

TABLE 13

Available experimental data on the energy dependence of $\bar{\nu}$ for ^{238}U

Reference	Year	Energy(MeV)	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_p$ renormalized	$\bar{\nu}_t = \bar{\nu}_p + \bar{\nu}_d$
Martin et al [43]	1954	1.5	2.58 ± 0.09	-		2.58 ± 0.09
Beyster [103]	1954	4.5	3.31 ± 0.3	-		3.31 ± 0.3
Graves [79]	1954	4.0	3.05 ± 0.10	-		3.05 ± 0.10
		14.0	3.43 ± 0.15	-	-	3.43 ± 0.15
Bethe et al [99]	1955	4.25	3.10 ± 0.40	$\bar{\nu}_p^{th}(^{235}U)$ = 2.47	3.02 ± 0.39	3.06 ± 0.39
Johnstone [69]	1956	2.5	2.35 ± 0.18	Harwell source	2.35 ± 0.18	2.39 ± 0.18
Diven et al [102]	1957	1.5	2.65 ± 0.09	-		2.65 ± 0.09
Cuninghame [124]	1957	14.	4 ± 0.5	-		4 ± 0.5
Hansen [125]	1958	2.6	1.11 ± 0.04	$\bar{\nu}^{th}(^{235}U)$ = 1	2.67 ± 0.10	2.71 ± 0.10
Nargundkar et al [127]	1958	3*	3.1 ± 0.2	$\bar{\nu}^{th}(^{235}U)$ = 2.47	3.02 ± 0.2	3.06 ± 0.2
Kuzminov et al [70]	1958	3.1*	1.17 ± 0.02	$\bar{\nu}^{th}(^{235}U)$ = 1	2.82 ± 0.05	2.86 ± 0.05
		3.1*	1.15 ± 0.04	"	2.77 ± 0.10	2.81 ± 0.10
		3.1*	1.16 ± 0.02	"	2.79 ± 0.05	2.83 ± 0.05
Flerov et al [106]	1958	14	4.50 ± 0.32	-		4.50 ± 0.32
Flerov, Tamanov [128]	1958	14	4.45 ± 0.35			4.45 ± 0.35
Smirenkin et al [129]	1958	4.0	3.11 ± 0.10	$\bar{\nu}^{th}(^{235}U)$ = 2.47	3.03 ± 0.10	3.07 ± 0.10
Hansen [83]	1958	1.40+	2.69 ± 0.10	$\bar{\nu}^{F}(^{235}U)$ = 2.56	-	2.69 ± 0.10
		1.47+	2.82 ± 0.10	" = 2.58	-	2.82 ± 0.10
		1.67+	2.74 ± 0.10	" = 2.59	-	2.74 ± 0.10
Kuzminov [72]	1959	2.3	2.72 ± 0.08	$\bar{\nu}_p^{th}(^{235}U)$ = 2.47	2.65 ± 0.08	2.69 ± 0.08
		3.75	3.02 ± 0.10	"	2.94 ± 0.10	2.98 ± 0.10
Engle et al [85]	1960	3.01*	2.61 ± 0.17	-		2.61 ± 0.17
Vasil'ev et al [111]	1960	14.3	4.28 ± 0.30	-		4.28 ± 0.30
Leroy [36]	1960	14.2	4.55 ± 0.15	$\bar{\nu}_p^{th}(^{235}U)$ = 2.47	4.43 ± 0.15	4.46 ± 0.15
Sher, Leroy [130]	1960	3.1*	2.93 ± 0.075	$\bar{\nu}_p^{th}(^{235}U)$ = 2.47	2.85 ± 0.075	2.89 ± 0.075
Zysin [131]	1960	14	5.0 ± 0.6	-		5.0 ± 0.6
Condé et al [73]	1961	3.6 ± 0.03	2.79 ± 0.09	$\bar{\nu}_p^{sp}(^{252}Cf)$ = 3.79	2.76 ± 0.09	2.80 ± 0.09
		14.9 ± 0.3	4.75 ± 0.12	"	4.71 ± 0.12	4.74 ± 0.12
Butler et al [112]	1961	1.58	2.56 ± 0.03	$\bar{\nu}_p^{th}(^{235}U)$ = 2.42	2.55 ± 0.03	2.59 ± 0.03
Moat et al [1 0]	1961	14.2	4.44 ± 0.09	$\bar{\nu}_p^{sp}(^{252}Cf)$ = 3.69	4.52 ± 0.09	4.55 ± 0.09
Chuang et al [133]	1963	14	4.36 ± 0.34	-		4.36 ± 0.34
Asplund-Nilsson et al [134]	1964	1.49 ± 0.01	2.520 ± 0.056	$\bar{\nu}_p^{sp}(^{252}Cf)$ = 3.775	2.507 ± 0.056	2.550 ± 0.056
		2.40 ± 0.01	2.671 ± 0.051	-"-	2.658 ± 0.051	2.701 ± 0.051
		3.50 ± 0.02	2.864 ± 0.049	-"-	2.850 ± 0.049	2.893 ± 0.049
		4.88 ± 0.05	3.068 ± 0.049	-"-	3.052 ± 0.049	3.095 ± 0.049
		5.63 ± 0.15	3.159 ± 0.059	-"-	3.143 ± 0.059	3.184 ± 0.059
		6.32 ± 0.06	3.269 ± 0.059	-"-	3.252 ± 0.059	3.289 ± 0.059
		6.83 ± 0.06	3.379 ± 0.054	-"-	3.362 ± 0.054	3.397 ± 0.054
		7.45 ± 0.05	3.518 ± 0.053	-"-	3.500 ± 0.053	3.531 ± 0.053
		14.8 ± 0.2	4.563 ± 0.067	-"-	4.540 ± 0.067	4.568 ± 0.067
Mather et al [75]	1965	1.41 ± 0.160	2.570 ± 0.034	$\bar{\nu}_p^{sp}(^{252}Cf)$ = 3.782	2.552 ± 0.034	2.595 ± 0.034
		1.98 ± 0.145	2.658 ± 0.022	-"-	2.639 ± 0.022	2.682 ± 0.022
		3.00 ± 0.115	2.788 ± 0.024	-"-	2.768 ± 0.024	2.811 ± 0.024
		4.02 ± 0.095	2.973 ± 0.025	-"-	2.952 ± 0.025	2.995 ± 0.025

* Average energy of neutron spectrum

\+ Average energy of neutron spectrum not including effects of $\sigma_f(E)$

TABLE 13 (continued)

Reference	Year	Energy(MeV)	$\bar{\nu}$ exp	Standard	$\bar{\nu}_p$ renormalized	$\nu_t = \nu_p + \bar{\nu}_d$
Soleilhac et al [121]	1969	1.36 ± 0.165	2.552 ± 0.030	$\bar{\nu}_p^{sp}(^{252}Cf)=3.782$	2.534 ± 0.030	2.577 ± 0.030
		1.87 ± 0.150	2.597 ± 0.030	-"-	2.579 ± 0.030	2.622 ± 0.030
		2.45 ± 0.125	2.641 ± 0.030	-"-	2.622 ± 0.030	2.665 ± 0.030
		2.98 ± 0.105	2.678 ± 0.023	-"-	2.659 ± 0.023	2.702 ± 0.023
		3.50 ± 0.100	2.799 ± 0.029	-"-	2.779 ± 0.029	2.822 ± 0.029
		4.03 ± 0.090	2.884 ± 0.023	-"-	2.864 ± 0.023	2.907 ± 0.023
		4.54 ± 0.080	2.960 ± 0.027	-"-	2.939 ± 0.027	2.982 ± 0.027
		5.06 ± 0.070	3.080 ± 0.024	-"-	3.058 ± 0.024	3.101 ± 0.024
		5.57 ± 0.070	3.140 ± 0.035	-"-	3.118 ± 0.035	3.158 ± 0.035
		6.08 ± 0.065	3.234 ± 0.034	-"-	3.211 ± 0.034	3.249 ± 0.034
		6.97 ± 0.170	3.403 ± 0.025	-"-	3.379 ± 0.025	3.412 ± 0.025
		7.09 ± 0.065	3.401 ± 0.032	-"-	3.377 ± 0.032	3.410 ± 0.032
		7.48 ± 0.165	3.440 ± 0.022	-"-	3.416 ± 0.022	3.447 ± 0.022
		7.99 ± 0.145	3.545 ± 0.021	-"-	3.520 ± 0.021	3.550 ± 0.021
		8.49 ± 0.130	3.596 ± 0.022	-"-	3.571 ± 0.022	3.599 ± 0.022
		9.00 ± 0.120	3.695 ± 0.022	-"-	3.669 ± 0.022	3.697 ± 0.022
		9.49 ± 0.110	3.748 ± 0.024	-"-	3.722 ± 0.024	3.750 ± 0.024
		9.74 ± 0.110	3.792 ± 0.026	-"-	3.765 ± 0.026	3.793 ± 0.026
		9.98 ± 0.100	3.865 ± 0.020	-"-	3.838 ± 0.020	3.866 ± 0.020
		10.47 ± 0.095	3.882 ± 0.024	-"-	3.855 ± 0.024	3.883 ± 0.024
		10.96 ± 0.090	3.978 ± 0.022	-"-	3.950 ± 0.022	3.978 ± 0.022
		11.44 ± 0.085	4.052 ± 0.025	-"-	4.024 ± 0.025	4.052 ± 0.025
		11.93 ± 0.080	4.146 ± 0.024	-"-	4.117 ± 0.024	4.145 ± 0.024
		12.41 ± 0.080	4.200 ± 0.024	-"-	4.171 ± 0.024	4.199 ± 0.024
		12.88 ± 0.080	4.258 ± 0.026	-"-	4.228 ± 0.026	4.256 ± 0.026
		13.36 ± 0.075	4.344 ± 0.027	-"-	4.313 ± 0.027	4.341 ± 0.027
		13.84 ± 0.075	4.445 ± 0.025	-"-	4.414 ± 0.025	4.442 ± 0.025
		14.31 ± 0.070	4.496 ± 0.026	-"-	4.464 ± 0.026	4.492 ± 0.025
		14.79 ± 0.070	4.498 ± 0.025	-"-	4.466 ± 0.025	4.494 ± 0.025
		22.79 ± 0.140	5.531 ± 0.043	-"-	5.492 ± 0.043	5.520 ± 0.043
		23.94 ± 0.115	5.723 ± 0.045	-"-	5.683 ± 0.045	5.711 ± 0.045
		25.05 ± 0.105	5.778 ± 0.046	-"-	5.737 ± 0.046	5.765 ± 0.046
		26.15 ± 0.090	5.846 ± 0.038	-"-	5.805 ± 0.038	5.833 ± 0.038
		27.22 ± 0.080	6.127 ± 0.051	-"-	6.084 ± 0.051	6.112 ± 0.051
		28.28 ± 0.075	6.166 ± 0.067	-"-	6.123 ± 0.067	6.151 ± 0.067
Vorobëva et al [78]		1.50	2.540	-	2.540	2.583

TABLE 14

Available experimental data on the energy dependence of $\bar{\nu}$ for ^{239}Pu

Reference		Year	Energy (MeV)	ν_{exp}	Standard	$\bar{\nu}_p$ renormalized	$\bar{\nu}_t = \bar{\nu}_p + \bar{\nu}_d$
Graves	[79]	1954	4.0	3.36 ± 0.11	-	-	3.36 ± 0.11
			14.0	4.12 ± 0.15	-		4.12 ± 0.15
Bethe et al	[99]	1955	1.75	3.01 ± 0.15	-		3.01 ± 0.15
			4.25	3.66 ± 0.40	-		3.66 ± 0.40
Diven et al	[47]	1956	0.000	3.048 ± 0.079	$\bar{\nu}_p^{th}(^{235}U)=2.46$	2.982 ± 0.078	2.988 ± 0.078
Allen et al	[135]	1956	0.5	1.3 ± 0.2	$\bar{\nu}^{th}(^{235}U)=1$		3.156 ± 0.48
			1.0	1.3 ± 0.2	-"-		3.156 ± 0.48
Johnstone	[69]	1956	14.1	4.85 ± 0.50	-		4.85 ± 0.50
Auclair et al	[136]	1956	1.75**	1.065 ± 0.02	$\bar{\nu}^{th}(^{239}Pu)=1$		3.067 ± 0.058
Kalashnikova et al	[80]	1957	1.8**	1.11 ± 0.01	$\bar{\nu}_p^{th}(^{239}Pu)=1$	3.190 ± 0.029	3.196 ± 0.029
Andreev	[137]	1958	2.1**	3.12 ± 0.015	-		3.12 ± 0.015
Hansen	[138]	1958	1.3**	3.08 ± 0.05	-		3.08 ± 0.05
Hansen	[83]	1958	1.40+	3.09 ± 0.02	$\bar{\nu}^{E}(^{235}U)=2.56$		3.09 ± 0.02
			1.47+	3.06 ± 0.02	" =2.58		3.06 ± 0.02
			1.67+	3.09 ± 0.02	" =2.59		3.09 ± 0.02
Smirenkin	[81]	1958	4 ±0.3	3.34 ± 0.11	$\bar{\nu}^{th}(^{239}Pu)=2.91$		3.38 ± 0.11
			15 ±0.5	4.71 ± 0.20	"		4.64 ± 0.20
Leroy	[36]	1960	14.2	4.75 ± 0.4	$\bar{\nu}_p^{th}(^{235}U)=2.47$	4.63 ± 0.39	4.63 ± 0.39
Engle et al	[85]	1960	1.58**	3.08 ± 0.09	-	-	3.08 ± 0.09
Flerov et al	[86]	1961	14	4.62 ± 0.28	-		4.62 ± 0.28
Hopkins et al	[8]	1963	0.250±0.050	2.931±0.039	$\bar{\nu}_p^{sp}(^{252}Cf)=3.771$	2.920 ± 0.039	2.926 ± 0.039
			0.420±0.110	2.957±0.046	-"-	2.946 ± 0.046	2.952 ± 0.046
			0.610±0.070	2.904±0.041	-"-	2.893 ± 0.041	2.899 ± 0.041
			0.900±0.080	3.004±0.041	-"-	2.993 ± 0.041	2.999 ± 0.041
			3.90 ±0.29	3.422±0.039	-"-	3.409 ± 0.039	3.414 ± 0.039
			14.5 ±1.0	4.942±0.119	-"-	4.924 ± 0.119	4.930 ± 0.119
Mather et al	[75]	1965	0.99 ±0.185	3.103±0.053	$\bar{\nu}_p^{sp}(^{252}Cf)=3.782$	3.082 ± 0.053	3.088 ± 0.053
			1.99 ±0.035	3.170±0.040	-"-	3.149 ± 0.040	3.155 ± 0.040
			3.00 ± 0.105	3.243±0.049	-"-	3.221 ± 0.049	3.227 ± 0.049
			4.02 ± 0.095	3.325±0.050	-"-	3.303 ± 0.050	3.309 ± 0.050
Condé et al	[139]	1968	4.22 ± 0.02	3.47 ± 0.07	$\bar{\nu}_p^{sp}(^{252}Cf)=3.764$	3.46 ± 0.07	3.47 ± 0.07
			5.91 ± 0.12	3.74 ± 0.07	-"-	3.73 ± 0.07	3.74 ± 0.07
			6.77 ± 0.10	3.94 ± 0.10	-"-	3.93 ± 0.10	3.94 ± 0.10
			7.51 ± 0.09	3.97 ± 0.06	-"-	3.96 ± 0.06	3.97 ± 0.06
			14.8 ± 0.20	4.98 ± 0.09	-"-	4.97 ± 0.09	4.97 ± 0.09

(**) Effective neutron energy of a fission spectrum

\+ Average energy of a neutron spectrum, not including effects of $\sigma_f(E)$

TABLE 14 (continued)

Reference	Year	Energy (MeV)	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_p$ renormalized	$\nu_t = \bar{\nu}_p + \bar{\nu}_d$
Soleilhac et al [121]	1969	1,36 ± 0,165	3,071 ± 0,018	$\bar{\nu}_p^{sp}(^{252}Cf)=3,782$	3.051 ± 0,018	3.057 ± 0,018
		1,87 ± 0,150	3.152 ± 0.021	-"-	3.131 ± 0,020	3.136 ± 0.020
		2,45 ± 0.125	3.222 ± 0,022	-"-	3.201 ± 0,021	3.207 ± 0,021
		2,98 ± 0.105	3.311 ± 0.016	-"-	3.289 ± 0,016	3.295 ± 0.016
		3,50 ± 0.100	3.372 ± 0.022	-"-	3.350 ± 0,021	3.356 ± 0,021
		4.03 ± 0.090	3.467 ± 0,017	-"-	3,444 ± 0,017	3.450 ± 0.017
		4.54 ± 0,080	3,562 ± 0,022	-"-	3.538 ± 0,021	3,544 ± 0,021
		5,06 ± 0,070	3,628 ± 0,017	-"-	3.604 ± 0,017	3,610 ± 0.017
		5,57 ± 0,070	3,688 ± 0.027	-"-	3.664 ± 0,026	3,670 ± 0,026
		6,08 ± 0.075	3.791 ± 0,028	-"-	3.766 ± 0,027	3,772 ± 0.027
		6,97 ± 0,170	3,937 ± 0,022	-"-	3.911 ± 0,021	3.916 ± 0,021
		7.09 ± 0,065	3,970 ± 0,029	-"-	3,944 ± 0,028	3.949 ± 0.028
		7,48 ± 0,165	3,998 ± 0,018	-"-	3.972 ± 0,018	3.977 ± 0,018
		7,99 ± 0,145	4,090 ± 0,018	-"-	4.063 ± 0,018	4,068 ± 0.018
		8,49 ± 0,130	4,176 ± 0,020	-"-	4.148 ± 0,020	4,153 ± 0,020
		9,00 ± 0,120	4.249 ± 0,020	-"-	4,221 ± 0,020	4.225 ± 0.020
		9,49 ± 0,110	4,324 ± 0,023	-"-	4.298 ± 0,022	4,302 ± 0,022
		9,74 ± 0,110	4,334 ± 0.021	-"-	4.305 ± 0,021	4.309 ± 0,021
		9,98 ± 0,100	4,421 ± 0,016	-"-	4,391 ± 0,016	4,395 ± 0,016
		10,47 ± 0,095	4.462 ± 0.022	-"-	4.432 ± 0,021	4.436 ± 0.021
		10,96 ± 0,090	4,542 ± 0,021	-"-	4.512 ± 0,020	4,516 ± 0.020
		11,44 ± 0,085	4,620 ± 0,023	-"-	4,589 ± 0,022	4,593 ± 0,022
		11.93 ± 0,080	4,683 ± 0,023	-"-	4,652 ± 0,022	4,656 ± 0,022
		12,41 ± 0,080	4,697 ± 0.024	-"-	4,666 ± 0,023	4,670 ± 0.023
		12.88 ± 0,080	4,804 ± 0,025	-"-	4.772 ± 0,024	4.776 ± 0.024
		13,36 ± 0,075	4,859 ± 0,026	-"-	4,827 ± 0,025	4,831 ± 0,025
		13,84 ± 0,075	4,939 ± 0,025	-"-	4,906 ± 0,024	4,910 ± 0.024
		14.31 ± 0,070	4,997 ± 0,029	-"-	4,964 ± 0,028	4,968 ± 0,028
		14.79 ± 0,070	5,048 ± 0,027	-"-	5,015 ± 0,026	5,019 ± 0,026
		22,79 ± 0,140	6.026 ± 0,077	-"-	5,986 ± 0,075	5,990 ± 0,075
		23,94 ± 0,115	6,127 ± 0,064	-"-	6,086 ± 0,062	6,090 ± 0,062
		25,05 ± 0,105	6.170 ± 0,086	-"-	6,129 ± 0,084	6.133 ± 0,084
		26,15 ± 0,090	6.296 ± 0,056	-"-	6.254 ± 0,054	6.258 ± 0.054
		27,22 ± 0,080	6.457 ± 0,076	-"-	6.414 ± 0,074	6.418 ± 0.074
		28,28 ± 0,075	6,513 ± 0,104	-"-	6,470 ± 0,101	6,474 ± 0,101
Soleilhac et al [122]	1970	0,21 ± 0,010	2,8969 ± 0,0941	$\bar{\nu}_p^{sp}(^{252}Cf)=3,782$	2,8778 ± 0,0935	2.8843 ± 0.0935
		0,23 ± 0.010	2,9185 ± 0.0588	-"-	2.8992 ± 0,0584	2,9057 ± 0,0584
		0,25 ± 0.010	2,8537 ± 0,0493	-"-	2,8349 ± 0.0490	2,8414 ± 0,0490
		0,27 ± 0,010	2,8883 ± 0,0420	-"-	2.8692 ± 0,0417	2,8757 ± 0.0417
		0,29 ± 0.010	2,8795 ± 0,0359	-"-	2.8605 ± 0.0358	2,8700 ± 0.0358
		0,31 ± 0.010	2,9307 ± 0,0324	-"-	2,9113 ± 0,0324	2,9178 ± 0.0358
		0,33 ± 0,010	2,9576 ± 0,0306	-"-	2,9381 ± 0.0304	?,9446 ± 0,0304
		0,35 ± 0,010	2,9467 ± 0,0300	-"-	2.9272 ± 0.0300	2,9337 ± 0,0300
		0,37 ± 0,010	2,9367 ± 0,0295	-"-	2.9173 ± 0.0294	2,9338 ± 0,0294
		0,39 ± 0.010	2,9592 ± 0,0270	-"-	2.9397 ± 0,0269	2.9462 ± 0.0269
		0,41 ± 0.010	2,9345 ± 0,0275	-"-	2.9151 ± 0.0274	2,9216 ± 0,0274
		0,43 ± 0,010	2,9641 ± 0,0249	-"-	2.9445 ± 0.0247	2,9510 ± 0,0247
		0,45 ± 0,010	2,9366 ± 0,0228	-"-	2,9172 ± 0,0226	2,9237 ± 0,0226
		0,47 ± 0,010	2,9577 ± 0,0220	-"-	2,9382 ± 0,0219	2,9447 ± 0,0219
		0,49 ± 0,010	2,9202 ± 0,0193	-"-	2,9009 ± 0,0193	2,9074 ± 0,0193

TABLE 14 (continued)

Reference	Year	Energy(MeV)	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_p$ renormalized	$\bar{\nu}_t = \nu_p + \bar{\nu}_d$
Soleilhac et al [122]	1970	0,51 ± 0,010	2,9[illegible]3 ± 0,0176	$\nu_p^{sp}(^{252}Cf)$ - 3,782	2,9487 ± 0.0175	2,9552 ± 0,0175
		0,53 ± 0.010	2,9281 ± 0,0173	-"-	2,9088 ± 0,0172	2,9153 ± 0.0172
		0,55 ± 0,010	2,9600 ± 0,0169	-"-	2,9405 ± 0.0168	2,9470 ± 0,0168
		0,57 ± 0,010	2.9605 ± 0,0164	-"-	2,9410 ± 0,0164	2,9475 ± 0,0164
		0,59 ± 0,010	2,9358 ± 0.0178	-"-	2,9164 ± 0,0177	2,9259 ± 0,0177
		0,61 ± 0,010	2,9702 ± 0.0162	-"-	2.9506 ± 0,0161	2,9571 ± 0,0161
		0,63 ± 0.010	2,9686 ± 0.0181	-"-	2,9490 ± 0,0180	2,9555 ± 0,0180
		0,65 ± 0.010	2,9562 ± 0,0184	-"-	2.9367 ± 0,0183	2,9432 ± 0.0183
		0,67 ± 0.010	2,9719 ± 0,0190	-"-	2,9523 ± 0.0189	2,9588 ± 0,0189
		0,69 ± 0.010	2,9781 ± 0,0189	-"-	2,9584 ± 0.0188	2,9649 ± 0,0188
		0,725 ± 0.025	2,9712 ± 0,0145	-"-	2,9516 ± 0,0145	2,9581 ± 0,0145
		0,775 ± 0,025	2,9912 ± 0,0153	-"-	2,9714 ± 0.0152	2,9779 ± 0,0152
		0,825 ± 0.025	2,9674 ± 0.0180	-"-	2,9478 ± 0.0179	2,9543 ± 0,0179
		0,875 ± 0,025	3,0035 ± 0,0176	-"-	2.9837 ± 0,0175	2,9902 ± 0,0175
		0,925 ± 0.025	2,9858 ± 0,0209	-"-	2.9661 ± 0,0208	2,9726 ± 0.0208
		0,975 ± 0,025	2,9885 ± 0,0206	-"-	2,9688 ± 0.0205	2,9753 ± 0,0205
		1,025 ± 0,025	3,0177 ± 0,0263	-"-	2,9978 ± 0.0261	3,0043 ± 0,0261
		1.075 ± 0,025	3.0457 ± 0,0307	-"-	3.0276 ± 0.0305	3,0341 ± 0,0305
		1,125 ± 0.025	3,0614 ± 0,0288	-"-	3.0412 ± 0.0286	3,0477 ± 0,0286
		1.175 ± 0.025	3,0310 ± 0.0343	-"-	3.0100 ± 0,0341	3,0165 ± 0.0341
		1.225 ± 0.025	3,0835 ± 0,0406	-"-	3,0631 ± 0,0404	3,0696 ± 0,0404
		1.275 ± 0,025	3,1027 ± 0,0381	-"-	3.0822 ± 0,0380	3,0887 ± 0,0380
		1.325 ± 0.025	3,1439 ± 0.0473	-"-	3.1231 ± 0,0471	3.1296 ± 0.0471
		1,375 ± 0,025	3,0446 ± 0,0421	-"-	3,0245 ± 0,0420	3,0310 ± 0,0420
		1,36 ± 0,025	3.0708 ± 0.0100		3,0493 ± 0.0100	3.0553 ± 0,0100
Savin et al [123]	1970	0,89	3,026 ± 0,070	$\bar{\nu}_p^{sp}(^{252}Cf)$=3,772	3,013 ± 0,070	3,019 ± 0,070
		0,96	3,005 ± 0,060	-"-	2.992 ± 0,060	2,998 ± 0,060
		0,99	3,011 ± 0 060	-"-	2,998 ± 0.060	3,004 ± 0,060
		1,03	3,049 ± 0,046	-"-	3.036 ± 0,046	3,042 ± 0.046
		1,07	3.009 ± 0,046	-"-	2,996 ± 0,046	3,002 ± 0.046
		1,10	3,053 ± 0,046	-"-	3,040 ± 0,046	3,046 ± 0,046
		1.14	3,089 ± 0.047	-"-	3.076 ± 0.047	3,082 ± 0,047
		1,17	3,066 ± 0,046	-"-	3.053 ± 0,046	3,059 ± 0,046
		1,22	3,061 ± 0,046	-"-	3,048 ± 0,046	3,054 ± 0,046
		1,26	2,984 ± 0.045	-"-	2,971 ± 0,045	2,977 ± 0.045
		1,30	3.021 ± 0,045	-"-	3.008 ± 0,045	3,014 ± 0.045
		1,34	3,129 ± 0,047	-"-	3,116 ± 0,047	3,122 ± 0,047
		1,39	3,118 ± 0.047	-"-	3.105 ± 0.047	3,111 ± 0,047
		1,49	3,138 ± 0.047	-"-	3.125 ± 0.047	3,131 ± 0,047
		1,54	3.165 ± 0.047	-"-	3.151 ± 0.047	3,157 ± 0,047
		1,60	3,135 ± 0.045	-"-	3.122 ± 0,045	3,128 ± 0,045
		1,66	3,100 ± 0,045	-"-	3,087 ± 0,045	3,093 ± 0,045
		1,72	3,142 ± 0.047	-"-	3.129 ± 0,047	3,135 ± 0,047
		1,78	3.203 ± 0.048	-"-	3.189 ± 0.048	3,195 ± 0,048
		1,85	3,217 ± 0,048	-"-	3,203 ± 0,048	3,209 ± 0,048
		1,91	3,220 ± 0.048	-"-	3.206 ± 0,048	3,212 ± 0,048
		1,97	3.243 ± 0.048	-"-	3.229 ± 0,048	3,235 ± 0,048
		2,05	3,163 ± 0.047	-"-	3,149 ± 0,047	3,155 ± 0.047
		2.14	3,176 ± 0.047	-"-	3,162 ± 0.047	3,168 ± 0,047
		2,23	3,230 ± 0.048	-"-	3,216 ± 0,048	3,224 ± 0,048
		2,36	3.227 ± 0,048	-"-	3,213 ± 0,048	3,219 ± 0.048
		2,49	3,310 ± 0,049	-"-	3,296 ± 0,049	3,302 ± 0,049
		2,59	3,304 ± 0,049	-"-	3,290 ± 0.049	3,296 ± 0.049
		2,67	3.338 ± 0,057	-"-	3,324 ± 0,057	3,330 ± 0.057
		2,79	3.320 ± 0,056	-"-	3.306 ± 0,056	3,312 ± 0,056
		3,01	3,364 ± 0,057	-"-	3,350 ± 0,057	3.356 ± 0,057
		3,21	3,415 ± 0,061	-"-	3,400 ± 0,061	3,406 ± 0,061

TABLE 14 (continued)

Reference	Year	Energy(MeV)	ν_{exp}	Standard	$\bar{\nu}_{renormalized}$	$\bar{\nu}_t = \bar{\nu}_p + \bar{\nu}_d$
Savin et al [123]	1970	3.34	3.395 ± 0,061	$\bar{\nu}_p^{sp}(^{252}Cf)=3,772$	3,381 ± 0,061	3,387 ± 0.061
		3,52	3,387 ± 0,061	-"-	3,373 ± 0,061	3,379 ± 0.061
		3,72	3,379 ± 0,067	-"-	3,365 ± 0,067	3,371 ± 0.067
		3,94	3,439 ± 0,075	-"-	3,424 ± 0,075	3,430 ± 0.075
		4,05	3,579 ± 0,078	-"-	3,564 ± 0,078	3,570 ± 0,078
		4,23	3,558 ± 0,089	-"-	3,543 ± 0,089	3,549 ± 0,089
		4,35	3,551 ± 0,089	-"-	3,536 ± 0,089	3,542 ± 0,089
		4,49	3,661 ± 0,091	-"-	3,645 ± 0,091	3,651 ± 0,091
		4,70	3,684 ± 0,110	-"-	3,668 ± 0,109	3,674 ± 0,109
Nesterov et al [25]	1970	0,0 *	2,872 ± 0,025*	$\bar{\nu}_p^{sp}(^{252}Cf)=3,782$		
		0,400 ± 0,051*	2,904 ± 0,031*	-"-		
		0,677 ± 0,048*	2,871 ± 0,035*	-"-		
		0,902 ± 0,045*	2,882 ± 0,037*	-"-		
		1,103 ± 0,045*	2,926 ± 0,043*	-"-		
		1,306 ± 0,043*	3,034 ± 0,039*	-"-		
		1,404 ± 0,043*	3,115 ± 0,040*	-"-		
		1,483 ± 0,042*	3,128 ± 0,039*	-"-		
		1,507 ± 0,042*	3,138 ± 0,055*	-"-		
Mather et al [140]	1970	0,0775 ± 0,0375	0,7650 ± 0,0072	$\bar{\nu}_p^{sp}(^{252}Cf)=1$	2,874 ± 0,027	2,880 ± 0,027
		0,200 ± 0,085	0,7754 ± 0,0077	-"-	2,913 ± 0,029	2,919 ± 0,029
		0,350 ± 0,050	0,7738 ± 0,0073	-"-	2,915 ± 0,027	2,923 ± 0,027
		0,450 ± 0,050	0,7933 ± 0,0077	-"-	2,980 ± 0,029	2,986 ± 0,029
		0,550 ± 0,050	0,7964 ± 0,0075	-"-	2,992 ± 0,028	2,998 ± 0,028
		0,650 ± 0,050	0,8023 ± 0,0076	-"-	3,014 ± 0,028	3,020 ± 0,028
		0,750 ± 0,050	0,7795 ± 0,0073	-"-	2,929 ± 0,027	2,935 ± 0,027
		0,850 ± 0,050	0,7969 ± 0,0078	-"-	2,994 ± 0,029	3,000 ± 0,029
		0,950 ± 0,050	0,8046 ± 0,0074	-"-	3,023 ± 0,028	3,029 ± 0,028
		1,050 ± 0,050	0,8070 ± 0,0075	-"-	3,032 ± 0,028	3,038 ± 0,028
		1,150 ± 0,050	0,8134 ± 0,0075	-"-	3,056 ± 0,028	3,062 ± 0,028
		0,550 ± 0,025	0,7889 ± 0,0101	$\bar{\nu}_p^{sp}(^{252}Cf)=1$	2,964 ± 0,038	2,970 ± 0,038
		0,600 ± 0,025	0,7715 ± 0,0102	-"-	2,898 ± 0,038	2,904 ± 0,038
		0,650 ± 0,025	0,8158 ± 0,0120	-"-	3,065 ± 0,045	3,071 ± 0,045
		0,700 ± 0,025	0,8114 ± 0,0110	-"-	3,048 ± 0,038	3,054 ± 0,038
		0,750 ± 0,025	0,7917 ± 0,0122	-"-	2,974 ± 0,046	2,980 ± 0,046
		0,800 ± 0,025	0,7928 ± 0,0108	-"-	2,978 ± 0,041	2,984 ± 0,041
		0,850 ± 0,025	0,7874 ± 0,0106	-"-	2,958 ± 0,040	2,964 ± 0,040
Condé et al. [141]	1970	0 - 10	2.902 ± 0.055+	$\bar{\nu}_p^{sp}(^{252}Cf)=3.756$	2.902 ± 0.055	2.908 ± 0.055
		0 - 0.0674	2.704 ± 0.051++	-"-	2.704 ± 0.051	2.710 ± 0.051
Boldeman et al. [224]	1972	0.200 ± 0.055	2.893 ± 0.013	$\bar{\nu}_p^{sp}(^{252}Cf)=3.782$	2.873 ± 0.013	2.879 ± 0.013
		0.350 ± 0.052	2.914 ± 0.016	-"-	2.894 ± 0.016	2.900 ± 0.016
		0.550 ± 0.036	2.938 ± 0.017	-"-	2.917 ± 0.017	2.923 ± 0.017
		0.700 ± 0.036	2.960 ± 0.017	-"-	2.939 ± 0.017	2.945 ± 0.017
		0.900 ± 0.048	2.984 ± 0.014	-"-	2.963 ± 0.014	2.969 ± 0.014
		1.300 ± 0.050	3.022 ± 0.020	-"-	3.001 ± 0.020	3.007 ± 0.020
		1.600 ± 0.050	3.076 ± 0.021	-"-	3.054 ± 0.021	3.060 ± 0.021
		1.900 ± 0.050	3.150 ± 0.019	-"-	3.128 ± 0.019	3.134 ± 0.019

\+ Integral value over the total reactor spectrum (provisional value)

++ Calculated value (provisional value)

* These data have to be considered invalid as rejected by the authors themselves. [220]

TABLE 15

Available experimental data on the energy dependence of $\bar{\nu}$ for ^{240}Pu

Reference	Year	Energy (MeV)	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_p$ renormalized	$\bar{\nu}_t = \bar{\nu}_p + \bar{\nu}_d$
Hansen [83]	1958	1.47(*)	3.26 ± 0.21	$\bar{\nu}$ (^{235}U) = 2.58		3.26 ± 0.21
		1.67(*)	3.37 ± 0.10	$\bar{\nu}$ (^{235}U) = 2.59		3.37 ± 0.10
Sanders [142]	1958	2.1 (**)	3.15 ± 0.20	-		3.15 ± 0.20
Engle [85]	1960	2.13(**)	3.6 ± 0.5	-		3.6 ± 0.5
Barton et al [143]	1961	2.0 (*)	3.32 ± 0.14	-		3.32 ± 0.14
Kuzminov [150]	1962	3,69	3,25 ± 0,15	$\bar{\nu}_p^{th}$(^{239}Pu) = 2,90	3,22 ± 0,14	3,23 ± 0.14
		15,0	4.4 ± 0,2	-"-	4,36 ± 0,20	4,37 ± 0.20
De Vroey et al [151]	1966	0,1	2,89 ± 0,19	$\bar{\nu}_p^{th}$(^{235}U) = 2,414	2,88 ± 0,19	2,89 ± 0,19
		1,0	2,55 ± 0,35	-"-	2,54 ± 0,35	2.55 ± 0,35
		1,6	3,26 ± 0,12	-"-	3,05 ± 0,12	3,06 ± 0.12
Savin et al [123]	1970	1,08	3,138± 0,156	$\bar{\nu}_p^{sf}$(^{252}Cf) = 3,772	3,125± 0,155	3,134± 0.155
		1,15	3,221± 0,161		3,207± 0.160	3,216± 0,160
		1,23	3,018± 0,120	-"-	3,005± 0,129	3,014± 0.119
		1,31	3,038± 0,106	-"-	3,025± 0,105	3,034± 0.105
		1,39	3,037± 0,106	-"-	3,024± 0,105	3,033± 0,105
		1,46	3,051± 0,112	-"-	3,038± 0,111	3,047± 0,111
		1,54	3,192± 0,102	-"-	3,178± 0,101	3,187± 0,101
		1,62	3,260± 0,097	-"-	3,246± 0,096	3,255± 0,096
		1,71	3,170± 0,095	-"-	3,156± 0,095	3,165± 0,095
		1,81	3,264± 0,091	-"-	3,250± 0,091	3,259± 0.091
		1,92	3,238± 0,090	-"-	3,224± 0,089	3,233± 0,089
		2,02	3,175± 0,104	-"-	3,161± 0,103	3,170± 0,103
		2,15	3,151± 0,104	-"-	3,138± 0,103	3,147± 0,103
		2,29	3,280± 0,114	-"-	3,266± 0,113	3,275± 0,113
		2,39	3,262± 0,114	-"-	3,248± 0,113	3,257± 0,113
		2,50	3,435± 0,127	-"-	3,420± 0,126	3,429± 0,126
		2,62	3,367±0,134	-"-	3,353±0,133	3,362±0,133
		2,74	3,327±0,133	-"-	3,313±0,132	3,322±0,132
		2,88	3,450±0,138	-"-	3,435±0,137	3,444±0,137
		3,02	3,423±0,143	-"-	3,408±0,142	3,417±0,142
		3,18	3,484±0,156	-"-	3,469±0,155	3,478±0,155
		3,53	3,501±0,157	-"-	3,486±0,156	3,495±0,156
		3,73	3,406±0,170	-"-	3,391±0,169	3,400±0,169
		3,94	3,507±0,200	-"-	3,492±0,199	3,501±0.199

(*) Average energy of neutron spectrum, not including effect of σ_f (E)

(**)Average energy of neutron spectrum

TABLE 16

Available experimental data on the energy dependence of $\bar{\nu}$ for ^{241}Pu

Reference	Year	Energy (MeV)	$\bar{\nu}_{exp}$	Standard	$\bar{\nu}_p$ renormalized	$\nu_t = \bar{\nu}_p + \bar{\nu}_d$
Condé et al [139]	1968	0,52 ± 0,02	2,89 ± 0,11	$\bar{\nu}_p^{sf}$(^{252}Cf) = 3,764	2,88 ± 0,11	2,89 ± 0,11
		2.71 ± 0.01	3,37 ± 0,11	-"-	3,36 ± 0.11	3.37 ± 0,11
		4,19 ± 0,02	3,50 ± 0,10	-"-	3.49 ± 0,10	3,49 ± 0,10
		5,88 ± 0,12	3,84 ± 0,12	-"-	3.83 ± 0.12	3.83 ± 0,12
		14,8 ± 0,2	5,02 ± 0,14	-"-	5,01 ± 0,14	5,01 ± 0,14

TABLE 17

Delayed Neutron Yields [a]

Reference	Year	Energy (MeV)	Neutron yield ($n/10^4$ fissions)								
			^{232}Th	^{233}U	^{235}U	^{238}U	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{252}Cf
Brunson et al [172]	1955	Thermal		65±5(e)	168±18(e)		59±4(e)				
		Fast (b)	510±87 (e)	68±5(e)		368±28(e)	67±5(e)				
Keepin et al [32]	1957	Thermal		66±3	158±5		61±3				
		Fast (c)	496±20	70±4	165±5	412±17	63±3	88±6			
Rose et al [173]	1957	Fast (d)	380±80(f)	74±6(f)	174±14(f)	370±40(f)	70±6(f)				
		"	365±44(g)	71±4(g)		363±25(g)	67±4(g)				
Cox et al [174]	1958	Spont									86±10
Maksyutenko [165]	1960	2.4	537±44(h)		163±8 (h)	408±22(h)					
		3.3	502±41(h)		156±8 (h)	387±27(h)					
		15.0	807±60(h)		294±9 (h)	727±44(h)					
McGarry et al [175]	1960	14.0			220±50	660±170					
Shpakov et al [176]	1961	14.5	750±60				130±15				
Cox [177]	1961	Thermal							154±15		
Maksyutenko [166]	1963	15		123±10(4)							
Bucko [178]	1966	14.7				650±65					
Notea [184]	1969	thermal		54±13⁺			50±19⁺				
		14	140±50⁺			160±50⁺					
Masters et al [161]	1969	3.1	600±60	77±8	180±20	490±50	69±7				
		14.9	310±30	43±4	95±8	286±25	43±4				
Los Alamos [180	1969	14.9	300±30 (i)	46±5(i)	96±8(i)	270±22(i)	44±4(i)	57±5(i)	84±8(i)		
Cox et al [181]	1970	0.25			171±5 *						
		0.60			170±5 *						
		0.90				437±30*					
		1.00			167±5 *	390±40*					
		1.10				400±20*					
		1.20			167±5 *	396±20*					
		1.30	465±30*			375±20*					
		1.35	490±25*								
		1.40	540±20*			396±10*					
		1.50	505±20*		165±3 *	406±10*					
		1.60	530±25*			406±20*					
		1.76				406±30*					
		1.85				418±25*					
		2.05				425±10*					
		2.24				412±10*					
		2.43				425±25*					
Krick et al [162]	1970	0.1-1.8		78±8	171±17		65±6				
		0.7-1.3								160±50	
Brown et al [182]	1971	14.8	269±40			182±27					
Clifford et al. [185]	1971	Fast			170±8	460±30					
Benedict et al. [186]	1971	14.8	190±30			230±40					
Conant et al. [183]	1971	thermal		67±3(k)	157±7(k)		66±6(k)				
Moscati et al [221]	1962	Photo-fission	270±80			360±80					
Nikotin et al [222]	1966	Photo-fission	380±60		96±13	310±40	36±6				

(a) For a complete summary of delayed-neutron measurements up to 1956 see Keepin [155, 157]

(b) Highly degraded fission spectrum of the Experimental Breeder Reactor (ANL).

(c) Slightly degraded fission spectrum (Godiva critical assembly).

(d) Near-Fission spectrum with average energy of about 1 MeV (Zephyr reactor).

(e) The reported absolute yields are deduced from the published relative yields, and are based on a ^{235}U fast fission yield of 0.0165 delayed neutrons per fission [32].

(f) Published absolute values.

(g) Absolute yields deduced from the published relative yields taking $\bar{\nu}_d(^{235}U) = 0.0165$ n/fission [32].

(h) The reported absolute yields are deduced from the published relative yields, and are based on a ^{235}U thermal fission yield of 0.0158 n/fission [32].

(i) Deduced from the delayed neutron yield per incident source neutron by multiplying by the fission cross section at 14.9 MeV. Assigned errors do not include uncertainty in fission cross sections.

(k) The reported absolute yields are deduced from the measured delayed fractions by using the standard total $\bar{\nu}$ values of table 4.

(*) Numerical values read from published graphs.

([illegible]) Measurements were made relative to thermal ^{235}U fission for the first 5 groups. Data converted to

Table 18

Delayed neutron yields per fission [163]

En (MeV)	^{233}U (n/f)	En (MeV)	^{235}U (n/f)	En (MeV)	^{238}U (n/f)	En (MeV)	^{239}Pu (n/f)
0.1	0.00769	0.1	0.0173	4.0	0.049	0.1	0.00647
0.2	0.00769	0.2	0.0169	4.25	0.049	0.2	0.00643
0.3	0.00764	0.3	0.0174	4.5	0.048	0.3	0.00639
0.4	0.00775	0.4	0.0173	4.75	0.049	0.4	0.00649
0.5	0.00768	0.5	0.0169	5.15	0.046	0.5	0.00656
0.6	0.00779	0.6	0.0167	5.35	0.046	0.6	0.00664
0.7	0.00779	0.7	0.0167	5.50	0.0435	0.7	0.00667
0.8	0.00794	0.8	0.0169	5.75	0.043	0.8	0.00665
0.9	0.00794	0.9	0.0171	6.0	0.042	0.9	0.00652
1.0	0.00783	1.0	0.0167	6.3	0.041	1.0	0.00651
1.1	0.00794	1.1	0.0171	6.5	0.040	1.1	0.00657
1.2	0.00794	1.2	0.0175	6.7	0.0386	1.2	0.00654
1.3	0.00778	1.3	0.0179	6.9	0.0380	1.3	0.00658
1.4	0.00800	1.4	0.0178			1.4	0.00666
1.5	0.00800	1.5	0.0167			1.5	0.00666
1.6	0.00794	1.6	0.0175			1.6	0.00655
1.7	0.00773	1.7	0.0171			1.7	0.00647
1.8	0.00794	1.8	0.0168			1.8	0.00651
4.0	0.0084	4.0	0.0168				
4.5	0.0077	4.4	0.0160				
5.1	0.0073	4.8	0.0166				
5.35	0.0068	5.1	0.0150				
5.6	0.0058	5.5	0.0140				
6.1	0.0052	5.8	0.0127				
6.6	0.0053	6.1	0.0141				
		6.4	0.0117				
		6.7	0.0123				

TABLE 19

Average delayed-neutron yields

Target nucleus	Neutron yield ($n/10^4$ fission)				
	Thermal fission	Fast (1) fission	14-15 MeV fission	Photo- (2) fission	Spontaneous fission
^{232}Th		515±14	311 ±19	340±50	
^{231}Pa			60±15		
^{233}U	66±2	72±3	44±3		
^{235}U	158±5	166±3	95±6	96±13	
^{238}U		430±10	278±18	320±36	
^{239}Pu	61±2	65±2	43±3	36±6	
^{240}Pu		88±6	57±5		
^{241}Pu	154±15		84±8		
^{242}Pu		160±50			
^{252}Cf					86±10

(1) Average values for $0.1 < E_n < 4 - 5$ MeV

(2) For a maximum bremsstrahlung energy of 15 MeV

TABLE 20

$\bar{\nu}$ values and spin assignments for the resonances of ^{239}Pu

Weinstein et al [190]			Weston et al [189]			Ryabov et al [195]			
En (eV)	$\bar{\nu}$	J	En (eV)	$\bar{\nu}$	J	En	$\bar{\nu}_1/\langle\bar{\nu}\rangle^{(1)}$	$\bar{\nu}$	J
0.012	2.878 ± 0.08 (1)		14.3	2.868 ± 0.011	1	7.93	1.0120 ± 0.0075	2.907 ± 0.021	1
0.015	2.885 ± 0.008(1)		14.7	2.908 ± 0.007	1	10.97	1.0250 ± 0.0075	2.945 ± 0.021	1
0.018	2.863 ± 0.006(1)		15.5	2.884 ± 0.012	0	11.91	1.0100 ± 0.0075	2.901 ± 0.021	1
0.022	2.876 ± 0.005(1)		17.6	2.893 ± 0.0095	1	14.36	1.0125 ± 0.0075	2.909 ± 0.021	1
0.027	2.873 ± 0.005(1)		22.2	2.895 ± 0.0079	1	14.75	1.0200 ± 0.0075	2.930 ± 0.021	1
0.034	2.876 ± 0.004(1)		23.9	2.919 ± 0.0514	1	15.47	0.9575 ± 0.010	2.751 ± 0.029	0
0.046	2.869 ± 0.004(1)		26.2	2.867 ± 0.0120	1	17.69	1.0060 ± 0.010	2.890 ± 0.029	1
0.063	2.866 ± 0.003(1)		32.3	2.897 ± 0.0271	0	22.28	1.0150 ± 0.010	2.916 ± 0.029	1
0.092	2.862 ± 0.003(1)		41.4	2.853 ± 0.0147	1	26.37	0.9635 ± 0.010	2.768 ± 0.029	0
0.148	2.862 ± 0.003(1)		44.5	2.805 ± 0.0203	1	32.4	0.9250 ± 0.030	2.657 ± 0.086	0
0.298	2.845 ± 0.002(1)		47.6	2.877 ± 0.0129	0	41.64	0.9965 ± 0.010	2.863 ± 0.029	1
0.70	2.862 ± 0.006(1)		50.2	2.866 ± 0.0124	1	44.64	1.0350 ± 0.008	2.973 ± 0.023	1
0.298	2.853 ± 0.010	1	52.6	2.844 ± 0.0133	(0)#	47.92	0.9825 ± 0.010	2.823 ± 0.029	0
7.85	2.852 ± 0.014	1	55.8	2.848 ± 0.0217	(1)	50.18	1.0250 ± 0.013	2.945 ± 0.037	1
10.95	2.852 ± 0.013	1	57.6	2.895 ± 0.0072	0	52.9	1.0300 ± 0.020	2.959 ± 0.057	1
11.9	2.813 ± 0.021	1	59.4	2.884 ± 0.0086	1	57.8	1.0075 ± 0.012	2.894 ± 0.034	0
14.3	2.821 ± 0.023	1	63.4	2.912 ± 0.0203	(0)+	58.6	0.9625 ± 0.0075	2.765 ± 0.021	0
14.7	2.850 ± 0.019	1	65.9	2.889 ± 0.0065	1	66.2	1.0400 ± 0.0175	2.988 ± 0.050	1
15.5	2.933 ± 0.030	0	74.3	2.830 ± 0.0199	1	75.6	1.0100 ± 0.0050	2.902 ± 0.114	1
17.7	2.864 ± 0.021	1	75.2	2.877 ± 0.0056	1	85.7	0.9610 ± 0.008	2.761 ± 0.023	0
22.3	2.875 ± 0.013	1	82.0	2.869 ± 0.0047	0				
23.9	2.866 ± 0.052	1	85.6	2.866 ± 0.0061	1				
26.2	2.846 ± 0.019	1	90.9	2.845 ± 0.0147	(0)#				
32.3	2.932 ± 0.046	0	97.0	2.907 ± 0.0083	0				
41.7	2.869 ± 0.027	1	103.0	2.903 ± 0.031	1*				
44.6	2.829 ± 0.036	1	105.4	2.842 ± 0.031	1*				
47.8	2.926 ± 0.032	0	106.8	2.868 ± 0.014	1*				
52.5	2.934 ± 0.036	(0)+	110.4	2.896 ± 0.060	0*				
62.0	2.966 ± 0.041	0	116.1	2.871 ± 0.014	0*				
74.9	2.887 ± 0.017	1	118.9	2.854 ± 0.010	1*				
81.	2.948 ± 0.036	0	121.0	2.846 ± 0.024	0*				
90.	2.956 ± 0.047	0	123.4	2.898 ± 0.040	(0)*				
			131.9	2.872 ± 0.009	0*				
			136.8	2.899 ± 0.018	0*				
			143.2	2.830 ± 0.015	1*				
			146.3	2.870 ± 0.021	1*				
			148.0	2.918 ± 0.035	0*				
			157.0	2.900 ± 0.011	0*				
			164.4	2.821 ± 0.021	1*				
			166.9	2.863 ± 0.018	1*				
			170.5	2.932 ± 0.035	0*				
			175.8	2.876 ± 0.041	1*				
			178.8	2.915 ± 0.059	(1)*				
			185.1	2.882 ± 0.017	0*				
			190.3	2.956 ± 0.057	(0)*				
			195.1	2.878 ± 0.006	0*				

(1) Numerical values read from published graphs

(+) Parentheses indicate uncertain assignments

(#) According to [194] resonances at 52.6 and 90.9 eV should have spin 1+

(*) Spin assignments taken by us from [194]

Table 21

Recommended values of $\bar{\nu}_p$ and $\bar{\nu}_t$ for ^{232}Th.

En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$	En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$
1.390	2.272 ± 0.039	2.323	4.000	2.457 ± 0.013	2.508
1.400	2.260 ± 0.036	2.311	4.250	2.495 ± 0.013	2.546
1.425	2.231 ± 0.030	2.282	4.500	2.532 ± 0.013	2.583
1.450	2.205 ± 0.025	2.256	4.750	2.570 ± 0.014	2.620
1.475	2.181 ± 0.022	2.232	5.000	2.608 ± 0.014	2.658
1.500	2.160 ± 0.019	2.211	5.250	2.646 ± 0.015	2.695
1.550	2.126 ± 0.018	2.177	5.500	2.684 ± 0.015	2.732
1.600	2.102 ± 0.016	2.153	5.750	2.722 ± 0.016	2.769
1.650	2.101 ± 0.015	2.152	6.000	2.759 ± 0.016	2.806
1.700	2.109 ± 0.015	2.160	6.250	2.797 ± 0.017	2.843
1.750	2.116 ± 0.015	2.167	6.500	2.835 ± 0.017	2.890
1.800	2.124 ± 0.014	2.175	6.750	2.873 ± 0.018	2.916
1.850	2.131 ± 0.014	2.182	7.000	2.911 ± 0.019	2.953
1.900	2.139 ± 0.014	2.190	7.250	2.948 ± 0.019	2.988
1.950	2.147 ± 0.014	2.198	7.500	2.986 ± 0.020	3.025
2.000	2.154 ± 0.014	2.205	7.750	3.024 ± 0.021	3.062
2.200	2.185 ± 0.014	2.236	8.000	3.062 ± 0.021	3.098
2.400	2.215 ± 0.014	2.266	8.500	3.138 ± 0.023	3.172
2.600	2.245 ± 0.013	2.296	9.000	3.213 ± 0.025	3.245
2.800	2.275 ± 0.013	2.326	10.000	3.364 ± 0.028	3.395
3.000	2.306 ± 0.013	2.357	11.000	3.516 ± 0.031	3.547
3.200	2.336 ± 0.013	2.387	12.000	3.667 ± 0.035	3.698
3.400	2.366 ± 0.013	2.417	13.000	3.818 ± 0.038	3.849
3.600	2.396 ± 0.013	2.447	14.000	3.970 ± 0.041	4.001
3.800	2.427 ± 0.013	2.478	15.000	4.121 ± 0.045	4.152

TABLE 22

Recommended values of $\bar{\nu}_p$ and $\bar{\nu}_t$ for ^{233}U

En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$	En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$
Thermal	2.4800±0.0069*	2.4866*	0.525	2.4946±0.0057	2.5018
0.010	2.4775±0.0069	2.4847	0.550	2.4972±0.0055	2.5044
0.020	2.4770±0.0067	2.4842	0.575	2.4999±0.0054	2.5071
0.030	2.4765±0.0064	2.4837	0.600	2.5027±0.0053	2.5099
0.040	2.4761±0.0063	2.4833	0.625	2.5056±0.0052	2.5128
0.050	2.4757±0.0061	2.4829	0.650	2.5086±0.0052	2.5158
0.060	2.4753±0.0060	2.4825	0.675	2.5117±0.0052	2.5189
0.070	2.4750±0.0059	2.4822	0.700	2.5148±0.0052	2.5220
0.080	2.4747±0.0059	2.4819	0.725	2.5180±0.0053	2.5252
0.090	2.4745±0.0059	2.4817	0.750	2.5213±0.0055	2.5285
0.100	2.4742±0.0058	2.4814	0.775	2.5247±0.0057	2.5319
0.120	2.4740±0.0059	2.4812	0.800	2.5281±0.0060	2.5353
0.140	2.4739±0.0060	2.4811	0.825	2.5315±0.0061	2.5387
0.160	2.4738±0.0061	2.4810	0.850	2.5350±0.0062	2.5422
0.180	2.4739±0.0062	2.4811	0.875	2.5385±0.0061	2.5457
0.200	2.4742±0 0063	2.4814	0.900	2.5420±0.0060	2.5492
0.220	2.4746±0.0065	2.4818	0.925	2.5453±0.0058	2.5525
0.240	2.4751±0.0066	2.4823	0.950	2.5484±0.0055	2.5556
0.260	2.4758±0.0066	2.4830	0.975	2.5516±0.0052	2.5588
0.280	2.4766±0.0067	2.4838	1.000	2.5548±0.0050	2.5620
0.300	2.4775±0.0067	2.4847	1.025	2.5580±0.0048	2.5652
0.320	2.4785±0.0067	2.4857	1.050	2.5611±0.0046	2.5683
0.340	2.4796±0.0067	2.4868	1.075	2.5643±0.0045	2.5715
0.360	2.4808±0.0066	2.4880	1.100	2.5675±0.0045	2.5747
0.380	2.4821±0.0065	2.4893	1.125	2.5707±0.0045	2.5779
0.400	2.4836±0.0064	2.4908	1.150	2.5739±0.0045	2.5811
0.420	2.4851±0.0063	2.4923	1.175	2.5770±0.0045	2.5842
0.440	2.4867±0.0062	2.4939	1.200	2.5802±0.0045	2.5874
0.460	2.4884±0.0060	2.4956	1.225	2.5834±0.0045	2.5906
0.480	2.4903±0.0059	2.4975	1.250	2.5866±0.0045	2.5938
0.500	2.4921±0.0058	2.4993	1.275	2.5898±0.0045	2.5970

* From Hanna et al. [1]

TABLE 22 (continued)

En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$	En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$
1.300	2.5929 ± 0.0045	2.6001	3.300	2.8472 ± 0.0058	2.8544
1.325	2.5961 ± 0.0045	2.6033	3.400	2.8599 ± 0.0053	2.8671
1.350	2.5993 ± 0.0045	2.6065	3.500	2.8727 ± 0.0054	2.8799
1.375	2.6024 ± 0.0045	2.6096	3.600	2.8854 ± 0.0055	2.8926
1.400	2.6056 ± 0.0045	2.6128	3.700	2.8981 ± 0.0056	2.9053
1.425	2.6088 ± 0.0045	2.6160	3.800	2.9108 ± 0.0057	2.9180
1.450	2.6120 ± 0.0044	2.6192	3.900	2.9235 ± 0.0058	2.9307
1.475	2.6152 ± 0.0044	2.6224	4.000	2.9362 ± 0.0059	2.9434
1.500	2.6183 ± 0.0044	2.6255	4.250	2.9680 ± 0.0062	2.9752
1.550	2.6247 ± 0.0044	2.6319	4.500	2.9998 ± 0.0065	3.0070
1.600	2.6311 ± 0.0044	2.6383	4.750	3.0316 ± 0.0068	3.0388
1.650	2.6374 ± 0.0045	2.6446	5.000	3.0634 ± 0.0072	3.0706
1.700	2.6438 ± 0.0045	2.6510	5.250	3.0952 ± 0.0074	3.1022
1.750	2.6502 ± 0.0045	2.6574	5.500	3.1269 ± 0.0077	3.1334
1.800	2.6565 ± 0.0045	2.6637	5.750	3.1587 ± 0.0080	3.1648
1.850	2.6629 ± 0.0045	2.6701	6.000	3.1905 ± 0.0084	3.1962
1.900	2.6692 ± 0.0045	2.6764	6.250	3.2223 ± 0.0087	3.2277
1.950	2.6756 ± 0.0045	2.6828	6.500	3.2541 ± 0.0090	3.2593
2.000	2.6819 ± 0.0045	2.6891	6.750	3.2859 ± 0.0094	3.2909
2.100	2.6947 ± 0.0045	2.7019	7.000	3.3177 ± 0.0097	3.3225
2.200	2.7074 ± 0.0046	2.7146	7.250	3.3495 ± 0.0101	3.3542
2.300	2.7201 ± 0.0046	2.7273	7.500	3.3812 ± 0.0105	3.3858
2.400	2.7328 ± 0.0046	2.7400	7.750	3.4130 ± 0.0108	3.4175
2.500	2.7455 ± 0.0047	2.7527	8.000	3.4448 ± 0.0112	3.4493
2.600	2.7582 ± 0.0048	2.7654	9.000	3.5720 ± 0.0126	3.5764
2.700	2.7709 ± 0.0048	2.7781	10.000	3.6991 ± 0.0141	3.7035
2.800	2.7837 ± 0.0049	2.7909	11.000	3.8263 ± 0.0156	3.8307
2.900	2.7964 ± 0.0049	2.8036	12.000	3.9534 ± 0.0142	3.9578
3.000	2.8091 ± 0.0030	2.8163	13.000	4.0805 ± 0.0187	4.0849
3.100	2.8218 ± 0.0031	2.8290	14.000	4.2077 ± 0.0203	4.2121
3.200	2.8345 ± 0.0052	2.8417	15.000	4.3348 ± 0.0218	4.3392

Table 23

Recommended values of $\bar{\nu}_p$ and $\bar{\nu}_t$ for ^{235}U

En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_f$	En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$
Thermal	2.4071±0.0066*	2.4229*	0.525	2.4630±0.0025	2.4796
0.010	2.4060±0.0052	2.4226	0.550	2.4639±0.0026	2.4805
0.020	2.4065±0.0046	2.4231	0.575	2.4650±0.0026	2.4816
0.030	2.4074±0.0043	2.4240	0.600	2.4665±0.0027	2.4831
0.040	2.4086±0.0044	2.4252	0.625	2.4683±0.0028	2.4849
0.050	2.4101±0.0045	2.4267	0.650	2.4705±0.0029	2.4871
0.060	2.4118±0.0047	2.4284	0.675	2.4731±0.0029	2.4897
0.070	2.4137±0.0049	2.4303	0.700	2.4760±0.0030	2.4926
0.080	2.4158±0.0050	2.4324	0.725	2.4794±0.0030	2.4960
0.090	2.4179±0.0051	2.4345	0.750	2.4830±0.0031	2.4996
0.100	2.4201±0.0052	2.4367	0.775	2.4869±0.0031	2.5035
0.120	2.4247±0.0052	2.4413	0.800	2.4911±0.0032	2.5077
0.140	2.4293±0.0050	2.4459	0.825	2.4956±0.0032	2.5122
0.160	2.4338±0.0048	2.4504	0.850	2.5001±0.0033	2.5167
0.180	2.4380±0.0045	2.4546	0.875	2.5048±0.0034	2.5214
0.200	2.4419±0.0042	2.4585	0.900	2.5095±0.0035	2.5261
0.220	2.4454±0.0039	2.4620	0.925	2.5143±0.0037	2.5309
0.240	2.4485±0.0037	2.4651	0.950	2.5189±0.0038	2.5355
0.260	2.4513±0.0035	2.4679	0.975	2.5235±0.0040	2.5401
0.280	2.4536±0.0034	2.4702	1.000	2.5279±0.0041	2.5445
0.300	2.4555±0.0033	2.4721	1.025	2.5321±0.0042	2.5487
0.320	2.4570±0.0032	2.4736	1.050	2.5361±0.0043	2.5527
0.340	2.4583±0.0031	2.4749	1.075	2.5398±0.0044	2.5564
0.360	2.4592±0.0030	2.4758	1.100	2.5432±0.0045	2.5598
0.380	2.4600±0.0029	2.4766	1.125	2.5447±0.0045	2.5613
0.400	2.4605±0.0028	2.4771	1.150	2.5490±0.0046	2.5656
0.420	2.4609±0.0027	2.4775	1.175	2.5515±0.0046	2.5681
0.440	2.4613±0.0026	2.4779	1.200	2.5536±0.0046	2.5702
0.460	2.4616±0.0026	2.4782	1.225	2.5554±0.0047	2.5720
0.480	2.4619±0.0025	2.4785	1.250	2.5570±0.0047	2.5736
0.500	2.4623±0.0025	2.4799	1.275	2.5583±0.0047	2.5749

* From Hanna et al. [1]

Table 23 (continued)

En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$	En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$
1.300	2.5593±0.0048	2.5759	3.300	2.8030±0.0081	2.8196
1.325	2.5603±0.0049	2.5769	3.400	2.8156±0.0081	2.8322
1.350	2.5610±0.0050	2.5776	3.500	2.8283±0.0081	2.8449
1.375	2.5617±0.0051	2.5783	3.600	2.8412±0.0080	2.8578
1.400	2.5624±0.0052	2.5790	3.700	2.8542±0.0081	2.8708
1.425	2.5631±0.0054	2.5797	3.800	2.8675±0.0081	2.8841
1.450	2.5639±0.0055	2.5805	3.900	2.8810±0.0082	2.8976
1.475	2.5648±0.0057	2.5814	4.000	2.8947±0.0084	2.9113
1.500	2.5659±0.0059	2.5825	4.250	2.9301±0.0089	2.9467
1.550	2.5688±0.0063	2.5854	4.500	2.9672±0.0096	2.9838
1.600	2.5728±0.0068	2.5894	4.750	3.0062±0.0102	3.0228
1.650	2.5782±0.0074	2.5948	5.000	3.0470±0.0108	3.0630
1.700	2.5850±0.0080	2.6016	5.250	3.0896±0.0111	3.1051
1.750	2.5931±0.0084	2.6097	5.500	3.1339±0.0112	3.1489
1.800	2.6020±0.0086	2.6186	5.750	3.1796±0.0111	3.1937
1.850	2.6115±0.0086	2.6281	6.000	3.2266±0.0107	3.2401
1.900	2.6209±0.0086	2.6375	6.250	3.2744±0.0103	3.2873
1.950	2.6298±0.0085	2.6464	6.500	3.3227±0.0100	3.3349
2.000	2.6378±0.0089	2.6544	6.750	3.3710±0.0099	3.3827
2.100	2.6521±0.0078	2.6687	7.000	3.4188±0.0100	3.4300
2.200	2.6655±0.0072	2.6821	7.250	3.4653±0.0102	3.4761
2.300	2.6786±0.0068	2.6951	7.500	3.5099±0.0106	3.5204
2.400	2.6914±0.0069	2.7080	7.750	3.5445±0.0099	3.5547
2.500	2.7041±0.0071	2.7207	8.000	3.5763±0.0082	3.5863
2.600	2.7166±0.0074	2.7332	9.000	3.7118±0.0063	3.7214
2.700	2.7290±0.0077	2.7456	10.000	3.8473±0.0051	3.8568
2.800	2.7413±0.0079	2.7579	11.000	3.9828±0.0046	3.9923
2.900	2.7536±0.0080	2.7702	12.000	4.1183±0.0053	4.1278
3.000	2.7659±0.0081	2.7825	13.000	4.2538±0.0067	4.2633
3.100	2.7782±0.0082	2.7948	14.000	4.3892±0.0088	4.3987
3.200	2.7906±0.0082	2.8072	15.000	4.5247±0.0104	4.5342

TABLE 24

Recommended values of $\bar{\nu}_p$ and $\bar{\nu}_t$ for ^{238}U

En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$	En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$
1.350	2.5327 ± 0.0174	2.5757	3.500	2.8023 ± 0.0100	2.8453
1.375	2.5345 ± 0.0168	2.5775	3.600	2.8182 ± 0.0098	2.8612
1.400	2.5363 ± 0.0162	2.5803	3.700	2.8342 ± 0.0097	2.8772
1.425	2.5382 ± 0.0157	2.5812	3.800	2.8504 ± 0.0096	2.8934
1.450	2.5401 ± 0.0151	2.5831	3.900	2.8667 ± 0.0095	2.9097
1.475	2.5421 ± 0.0147	2.5851	4.000	2.8830 ± 0.0094	2.9260
1.500	2.5441 ± 0.0142	2.5871	4.250	2.9241 ± 0.0093	2.9671
1.550	2.5482 ± 0.0134	2.5912	4.500	2.9654 ± 0.0094	3.0084
1.600	2.5525 ± 0.0126	2.5955	4.750	3.0067 ± 0.0096	3.0497
1.650	2.5570 ± 0.0120	2.6000	5.000	3.0479 ± 0.0098	3.0904
1.700	2.5616 ± 0.0114	2.6046	5.250	3.0890 ± 0.0102	3.1310
1.750	2.5664 ± 0.0110	2.6094	5.500	3.1297 ± 0.0104	3.1707
1.800	2.5713 ± 0.0106	2.6143	5.750	3.1700 ± 0.0106	3.2100
1.850	2.5764 ± 0.0103	2.6194	6.000	3.2099 ± 0.0107	3.2489
1.900	2.5816 ± 0.0101	2.6246	6.250	3.2494 ± 0.0106	3.2869
1.950	2.5870 ± 0.0100	2.6300	6.500	3.2884 ± 0.0105	3.3244
2.000	2.5925 ± 0.0099	2.6355	6.750	3.3270 ± 0.0102	3.3620
2.100	2.6039 ± 0.0098	2.6469	7.000	3.3652 ± 0.0099	3.3982
2.200	2.6158 ± 0.0099	2.6588	7.250	3.4030 ± 0.0096	3.4350
2.300	2.6282 ± 0.0100	2.6712	7.500	3.4404 ± 0.0092	3.4714
2.400	2.6410 ± 0.0102	2.6840	7.750	3.4775 ± 0.0089	3.5075
2.500	2.6542 ± 0.0103	2.6972	8.000	3.5144 ± 0.0086	3.5439
2.600	2.6677 ± 0.0104	2.7107	8.500	3.5877 ± 0.0085	3.6162
2.700	2.6816 ± 0.0105	2.7246	9.000	3.6608 ± 0.0086	3.6886
2.800	2.6958 ± 0.0106	2.7388	9.500	3.7341 ± 0.0089	3.7619
2.900	2.7104 ± 0.0106	2.7534	10.000	3.8083 ± 0.0092	3.8361
3.000	2.7251 ± 0.0105	2.7681	11.000	3.9597 ± 0.0092	3.9875
3.100	2.7402 ± 0.0105	2.7832	12.000	4.1149 ± 0.0103	4.1427
3.200	2.7554 ± 0.0104	2.7984	13.000	4.2688 ± 0.0126	4.2966
3.300	2.7708 ± 0.0103	2.8138	14.000	4.4097 ± 0.0125	4.4375
3.400	2.7865 ± 0.0101	2.8295	15.000	4.5172 ± 0.0282	4.5450

Table 25

Recommended values of $\bar{\nu}_p$ and $\bar{\nu}_t$ for ^{239}Pu

En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$	En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$
Thermal	2.8738+0.0090(*)	2.8799(*)	0.525	2.9317±0.0028	2.9382
0.010	2.8710±0.0066	2.8775	0.550	2.9350±0.0028	2.9415
0.020	2.8720±0.0065	2.8885	0.575	2.9384±0.0028	2.9449
0.030	2.8730±0.0063	2.8895	0.600	2.9418±0.0028	2.9483
0.040	2.8740±0.0061	2.8805	0.625	2.9452±0.0028	2.9517
0.050	2.8750±0.0060	2.8815	0.650	2.9487±0.0028	2.9552
0.060	2.8760±0.0058	2.8825	0.675	2.9521±0.0028	2.9586
0.070	2.8771±0.0056	2.8836	0.700	2.9556±0.0028	2.9621
0.080	2.8781±0.0055	2.8846	0.725	2.9591±0.0029	2.9656
0.090	2.8792±0.0053	2.8857	0.750	2.9627±0.0029	2.9392
0.100	2.8802±0.0052	2.8867	0.775	2.9663±0.0029	2.9728
0.120	2.8824±0.0050	2.8989	0.800	2.9698±0.0029	2.9763
0.140	2.8846±0.0047	2.8911	0.825	2.9734±0.0029	2.9799
0.160	2.8868±0.0045	2.8923	0.850	2.9771±0.0029	2.9836
0.180	2.8890±0.0042	2.8955	0.875	2.9807±0.0029	2.9872
0.200	2.8913±0.0040	2.8978	0.900	2.9844±0.0030	2.9909
0.220	2.8936±0.0039	2.9891	0.925	2.9880±0.0030	2.9945
0.240	2.8959±0.0038	2.9024	0.950	2.9917±0.0030	2.9882
0.260	2.8982±0.0037	2.9047	0.975	2.9954±0.0030	3.0019
0.280	2.9006±0.0036	2.9071	1.000	2.9991±0.0031	3.0056
0.300	2.9030±0.0035	2.9095	1.025	3.0029±0.0031	3.0094
0.320	2.9055±0.0034	2.9120	1.050	3.0066±0.0031	3.0131
0.340	2.9079±0.0033	2.9144	1.075	3.0103±0.0032	3.0168
0.360	2.9104±0.0032	2.9169	1.100	3.0141±0.0032	3.0206
0.380	2.9129±0.0031	2.9194	1.125	3.0179±0.0032	3.0244
0.400	2.9154±0.0030	2.9219	1.150	3.0217±0.0033	3.0282
0.420	2.9180±0.0030	2.9245	1.175	3.0255±0.0033	3.0320
0.440	2.9205±0.0029	2.9270	1.200	3.0293±0.0034	3.0358
0.460	2.9231±0.0029	2.9296	1.225	3.0331±0.0034	3.0396
0.480	2.9257±0.0028	2.9322	1.250	3.0369±0.0035	3.0434
0.500	2.9284±0.0028	2.9349	1.275	3.0407±0.0035	3.0472

Table 25 (continued)

En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$	En (MeV)	$\bar{\nu}_p$	$\bar{\nu}_t$
1.300	3.0445±0.0036	3.0510	3.300	3.3440±0.0065	3.3505
1.325	3.0484±0.0037	3.0549	3.400	3.3582±0.0065	3.3647
1.350	3.0522±0.0037	3.0587	3.500	3.3723±0.0066	3.3788
1.375	3.0560±0.0038	3.0625	3.600	3.3864±0.0066	3.3929
1.400	3.0599±0.0039	3.0664	3.700	3.4005±0.0067	3.4070
1.425	3.0637±0.0040	3.0702	3.800	3.4146±0.0068	3.4211
1.450	3.0676±0.0040	3.0741	3.900	3.4297±0.0069	3.4362
1.475	3.0714±0.0041	3.0779	4.000	3.4450±0.0066	3.4615
1.500	3.0753±0.0042	3.0818	4.250	3.4834±0.0064	3.4899
1.550	3.0830±0.0044	3.0895	4.500	3.5220±0.0062	3.5285
1.600	3.0908±0.0045	3.0973	4.750	3.5607±0.0060	3.5672
1.650	3.0985±0.0047	3.1050	5.000	3.5995±0.0056	3.6060
1.700	3.1062±0.0047	3.1127	5.250	3.6384±0.0053	3.6448
1.750	3.1139±0.0048	3.1204	5.500	3.6773±0.0050	3.6846
1.800	3.1216±0.0050	3.1281	5.750	3.7163±0.0048	3.7225
1.850	3.1293±0.0051	3.1358	6.000	3.7553±0.0048	3.7614
1.900	3.1370±0.0052	3.1435	6.250	3.7944±0.0048	3.8004
1.950	3.1447±0.0054	3.1512	6.500	3.8334±0.0048	3.8384
2.000	3.1524±0.0056	3.1689	6.750	3.8724±0.0048	3.8780
2.100	3.1676±0.0058	3.1741	7.000	3.9113±0.0048	3.9167
2.200	3.1828±0.0060	3.1893	7.250	3.9502±0.0048	3.9556
2.300	3.1979±0.0062	3.2044	7.500	3.9890±0.0048	3.9942
2.400	3.2130±0.0063	3.2195	7.750	4.0277±0.0049	4.0327
2.500	3.2279±0.0064	3.2344	8.000	4.0663±0.0050	4.0710
2.600	3.2427±0.0065	3.2492	9.000	4.2193±0.0054	4.2238
2.700	3.2574±0.0065	3.2639	10.000	4.3690±0.0056	4.3733
2.800	3.2721±0.0065	3.2786	11.000	4.5143±0.0057	4.5186
2.900	3.2866±0.0065	3.2931	12.000	4.6542±0.0058	4.6585
3.000	3.3011±0.0065	3.3076	13.000	4.7874±0.0070	4.7917
3.100	3.3154±0.0065	3.3219	14.000	4.9129±0.0101	4.9172
3.200	3.3297±0.0065	3.3362	15.000	5.0295±0.0140	5.0338

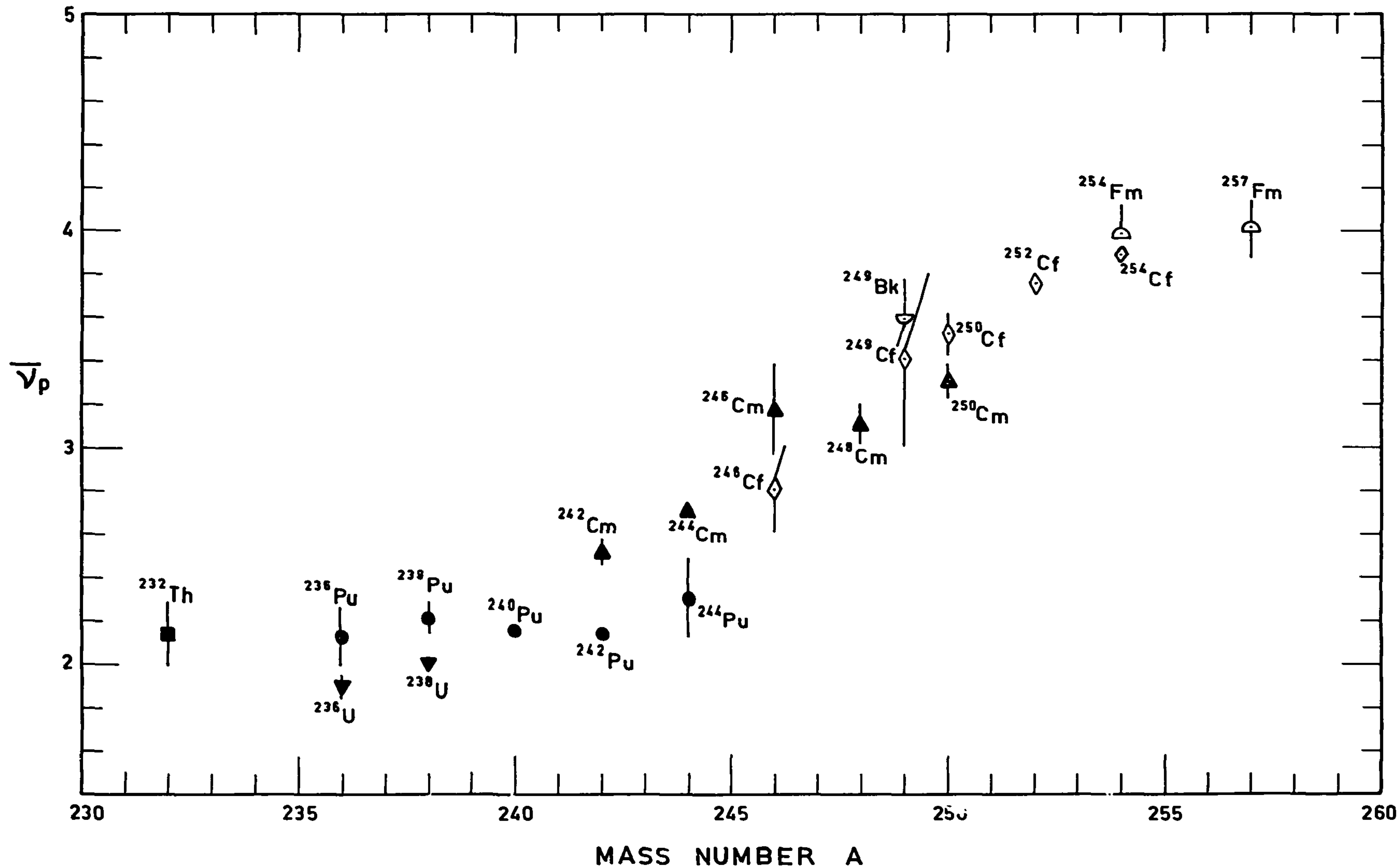

Fig. 1. DEPENDENCE OF PROMPT $\overline{\nu}_p$ FOR SPONTANEOUS FISSION ON THE MASS NUMBER A

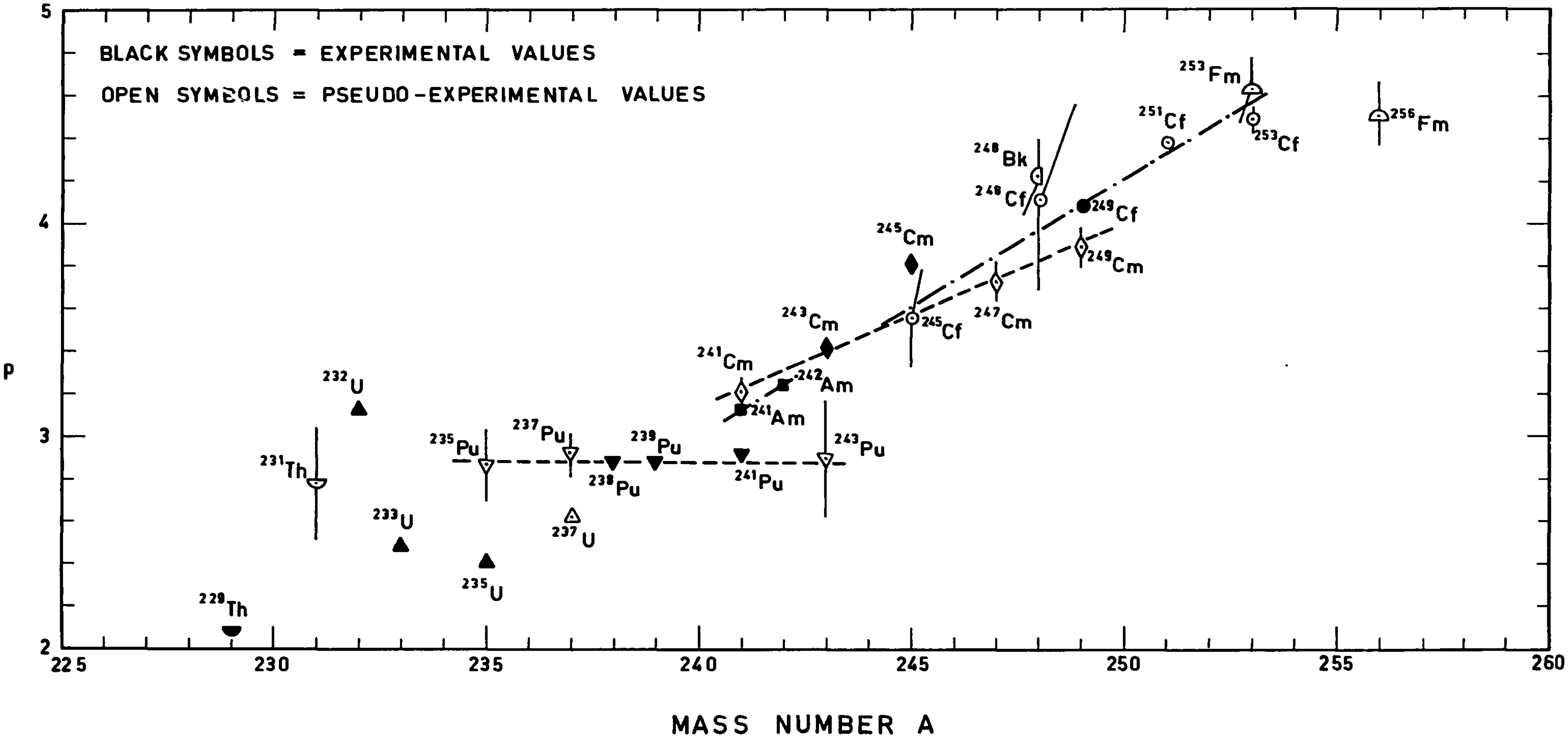

Fig. 2. DEPENDENCE OF $\overline{\nu}_p$ FOR THERMAL FISSION ON THE MASS NUMBER A

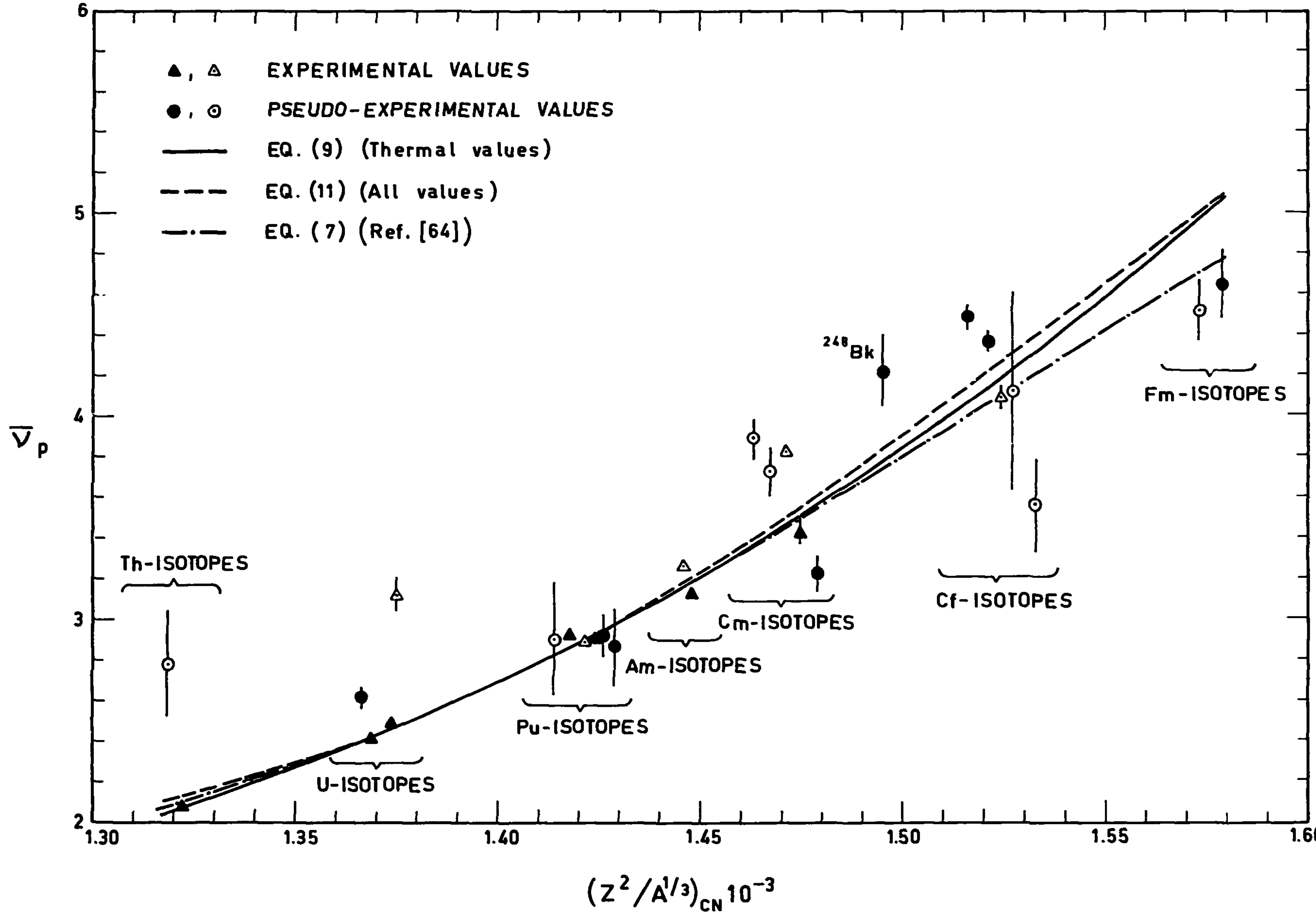

Fig. 3. DEPENDENCE OF THERMAL $\overline{\nu}_p$ ON THE PARAMETER $(Z^2/A^{1/3})_{CN}$

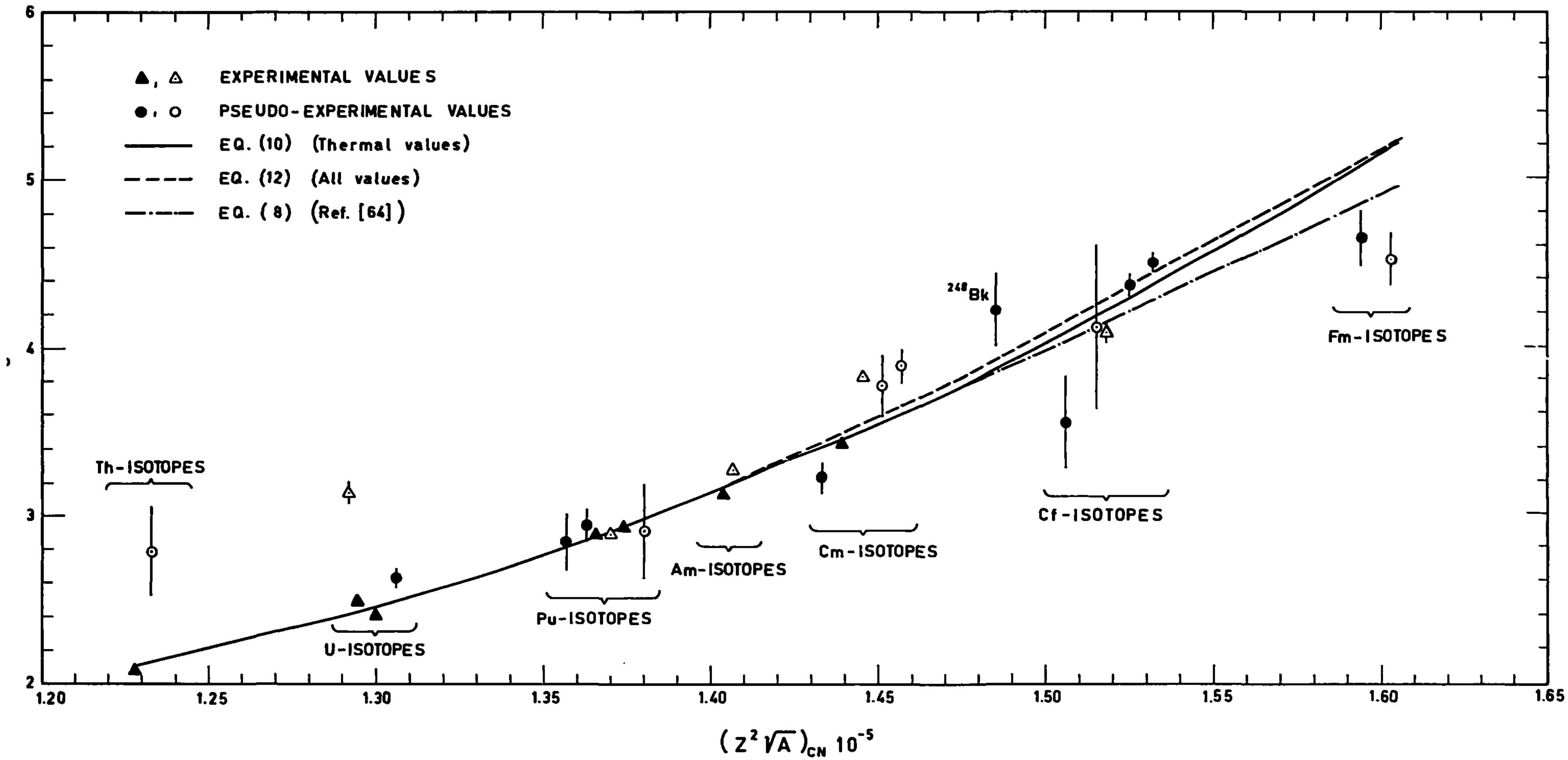

Fig. 4. DEPENDENCE OF THERMAL $\overline{\nu}_p$ ON THE PARAMETER $(Z^2\sqrt{A})_{CN}$

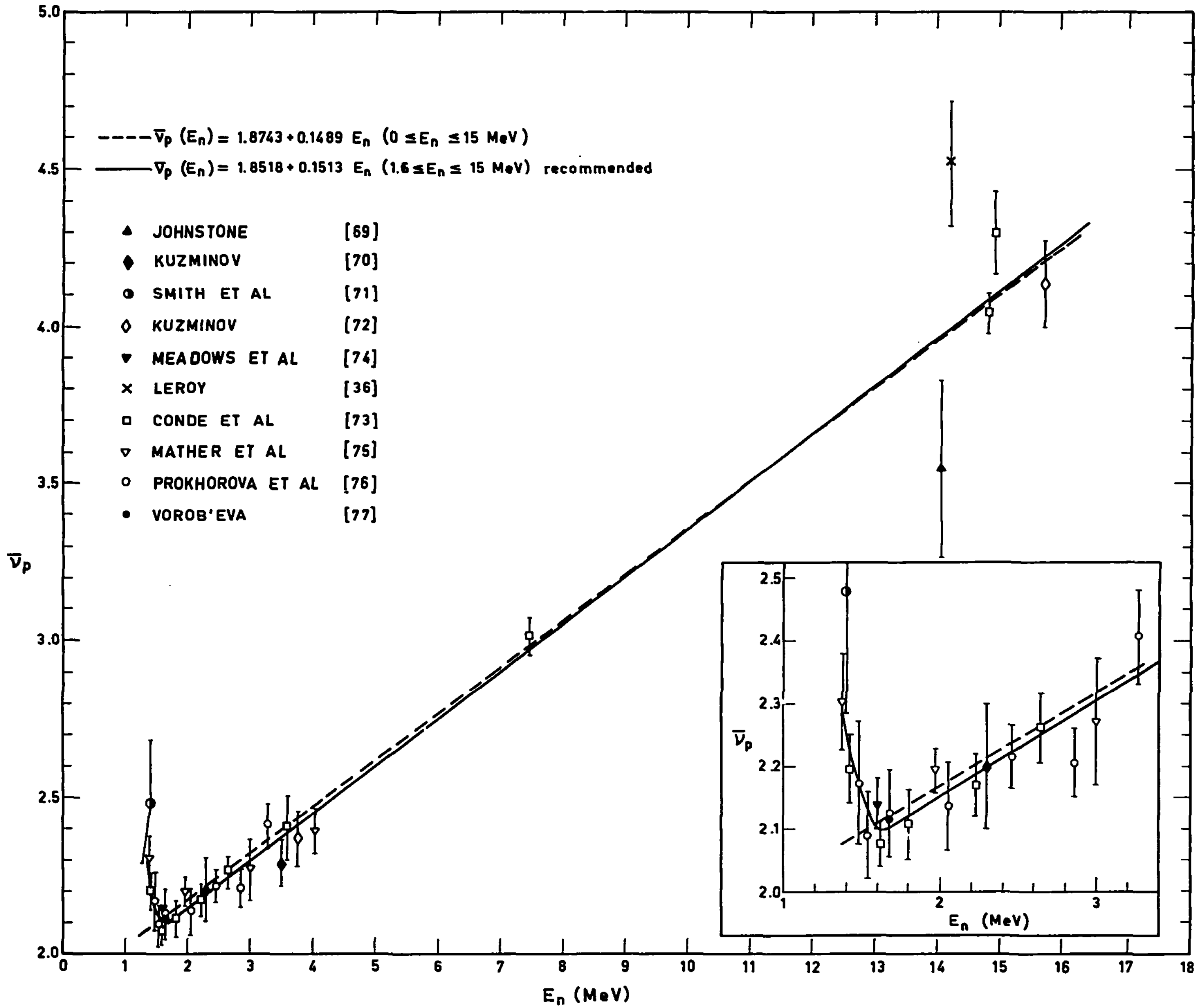

Fig.5. ENERGY DEPENDENCE OF $\overline{\nu}_p$ FOR ^{232}Th BETWEEN 0 AND 15 MeV

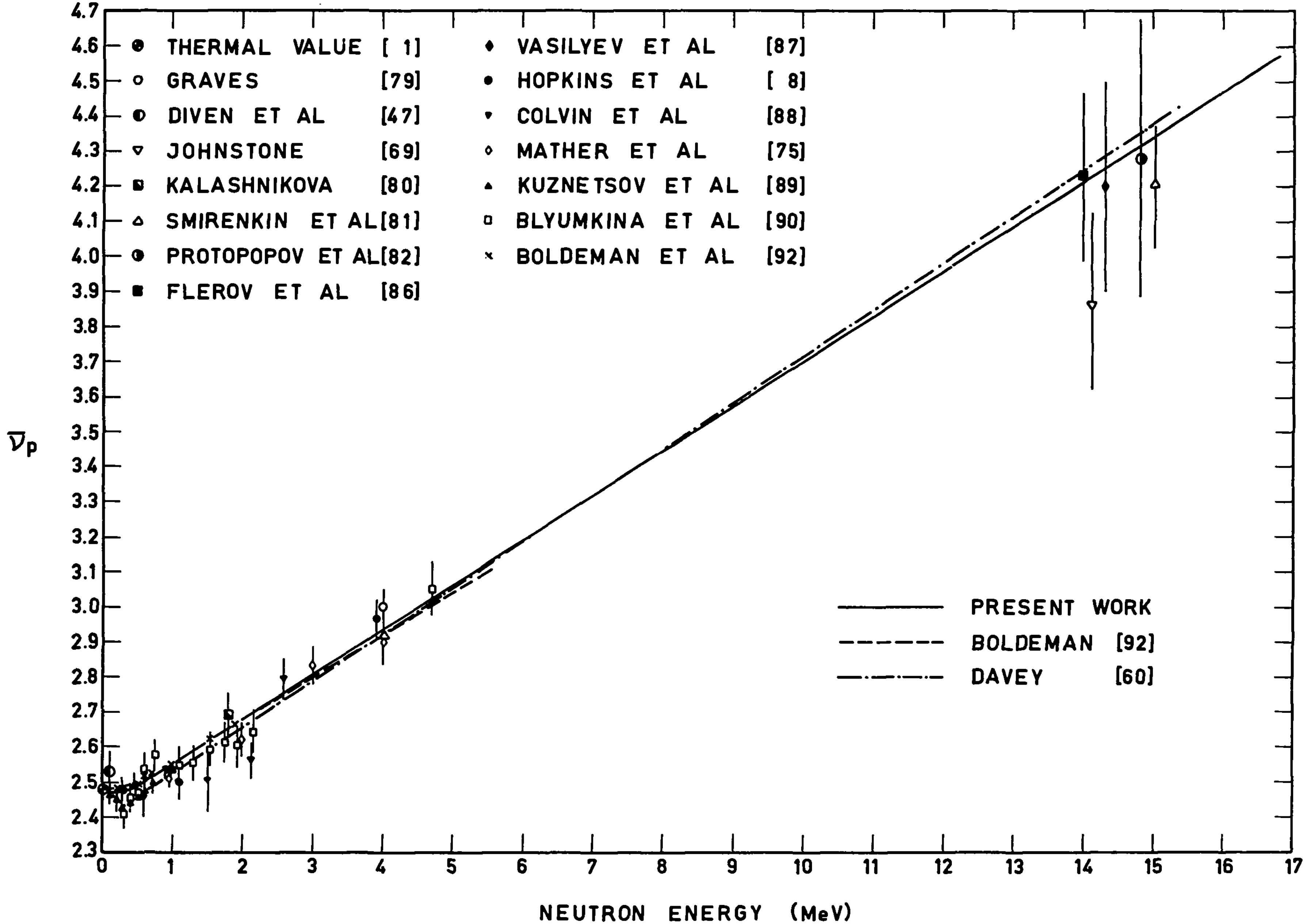

Fig. 6. ENERGY DEPENDENCE OF $\bar{\nu}_p$ FOR ^{233}U BETWEEN 0 AND 15 MeV

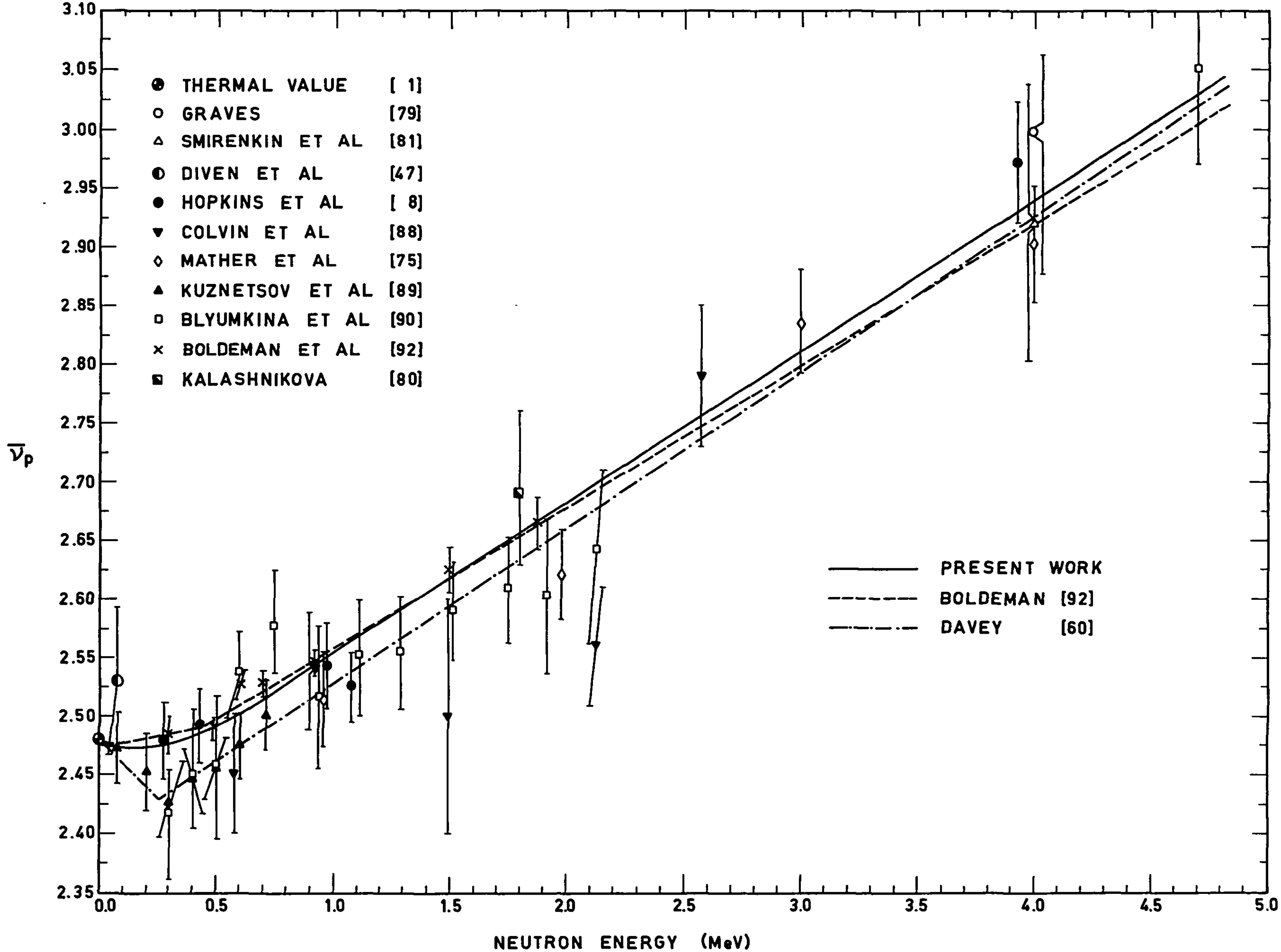

Fig. 7. ENERGY DEPENDENCE OF $\overline{\nu}_p$ FOR ^{233}U BELOW 5 MeV

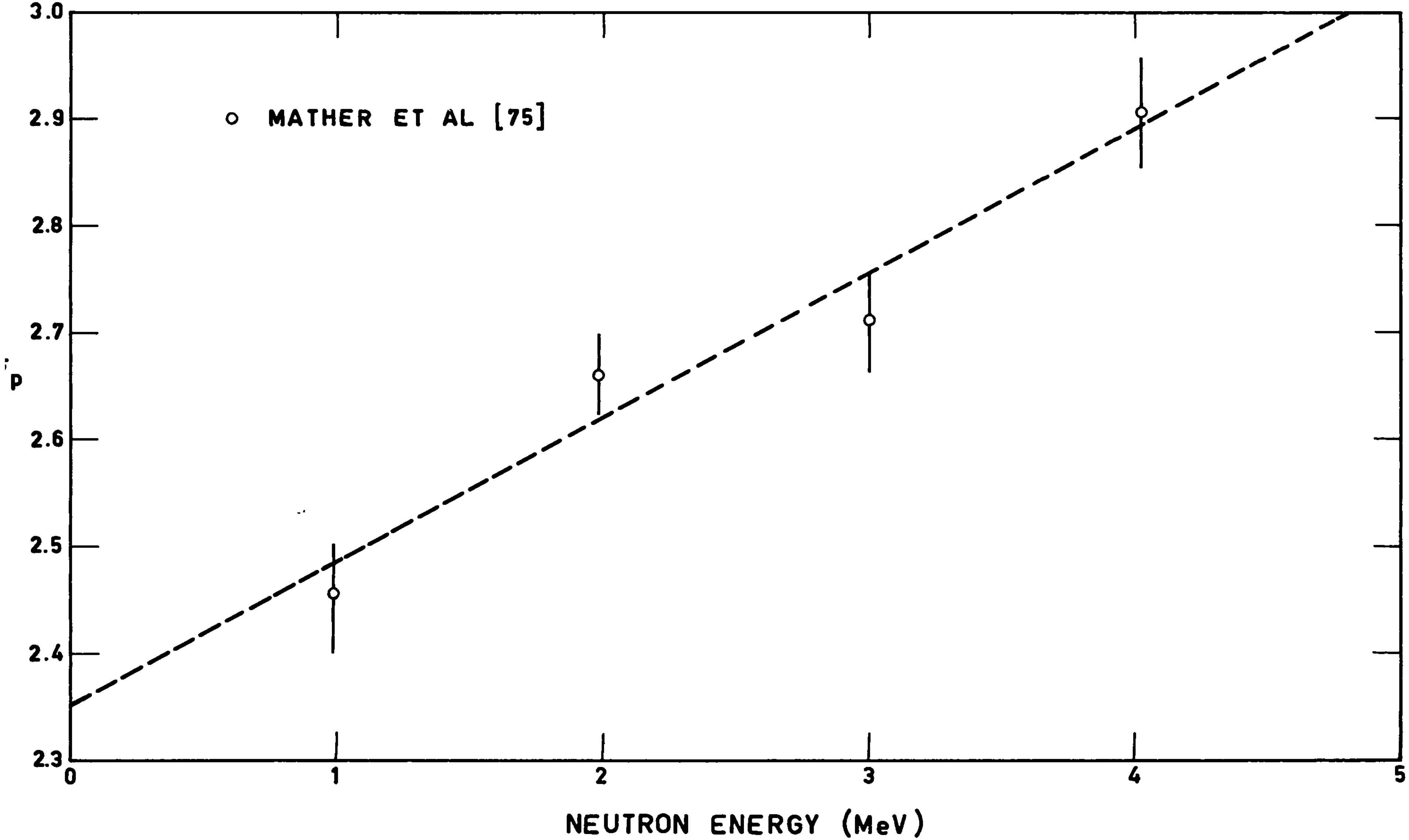

Fig. 8. ENERGY DEPENDENCE OF $\bar{\nu}_p$ FOR ^{234}U BELOW 5 MeV

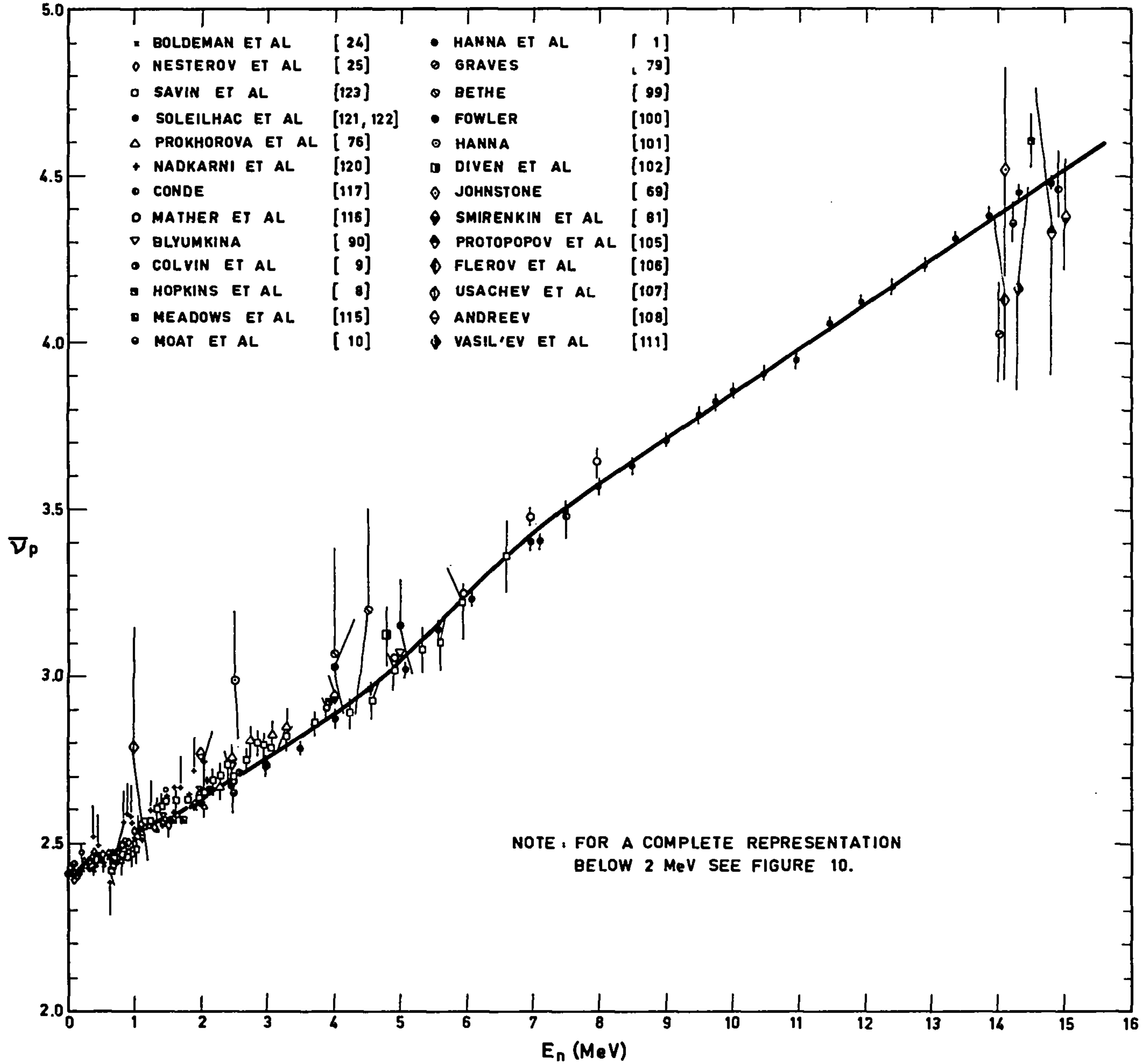

Fig. 9. ENERGY DEPENDENCE OF $\overline{\nu}_p$ FOR ^{235}U BETWEEN 0 AND 15 MeV

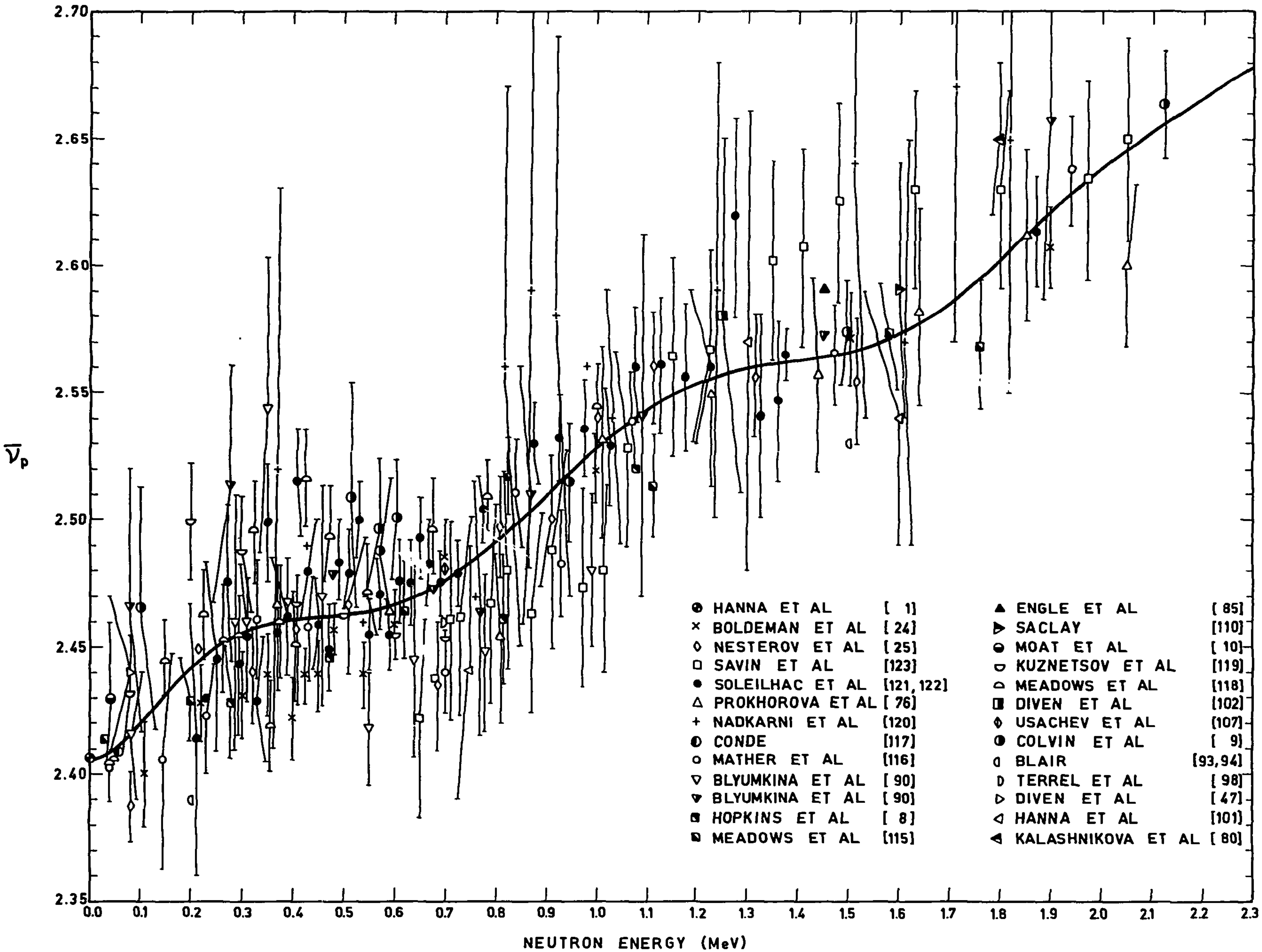

Fig. 10. ENERGY DEPENDENCE OF $\overline{\nu}_p$ FOR ^{235}U BELOW 2 MeV

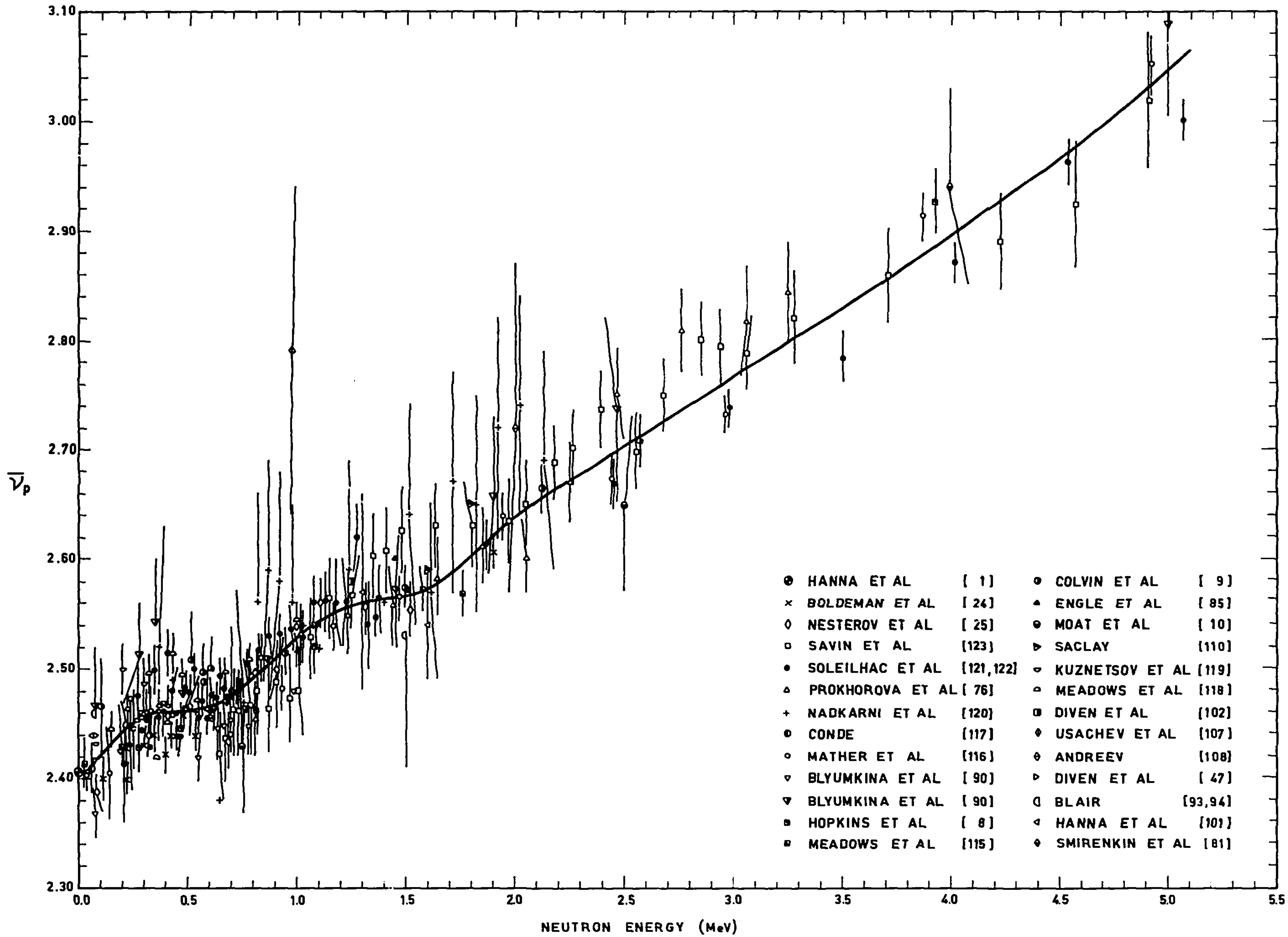

Fig. 11. ENERGY DEPENDENCE OF $\overline{\nu}_p$ FOR ^{235}U BELOW 5 MeV

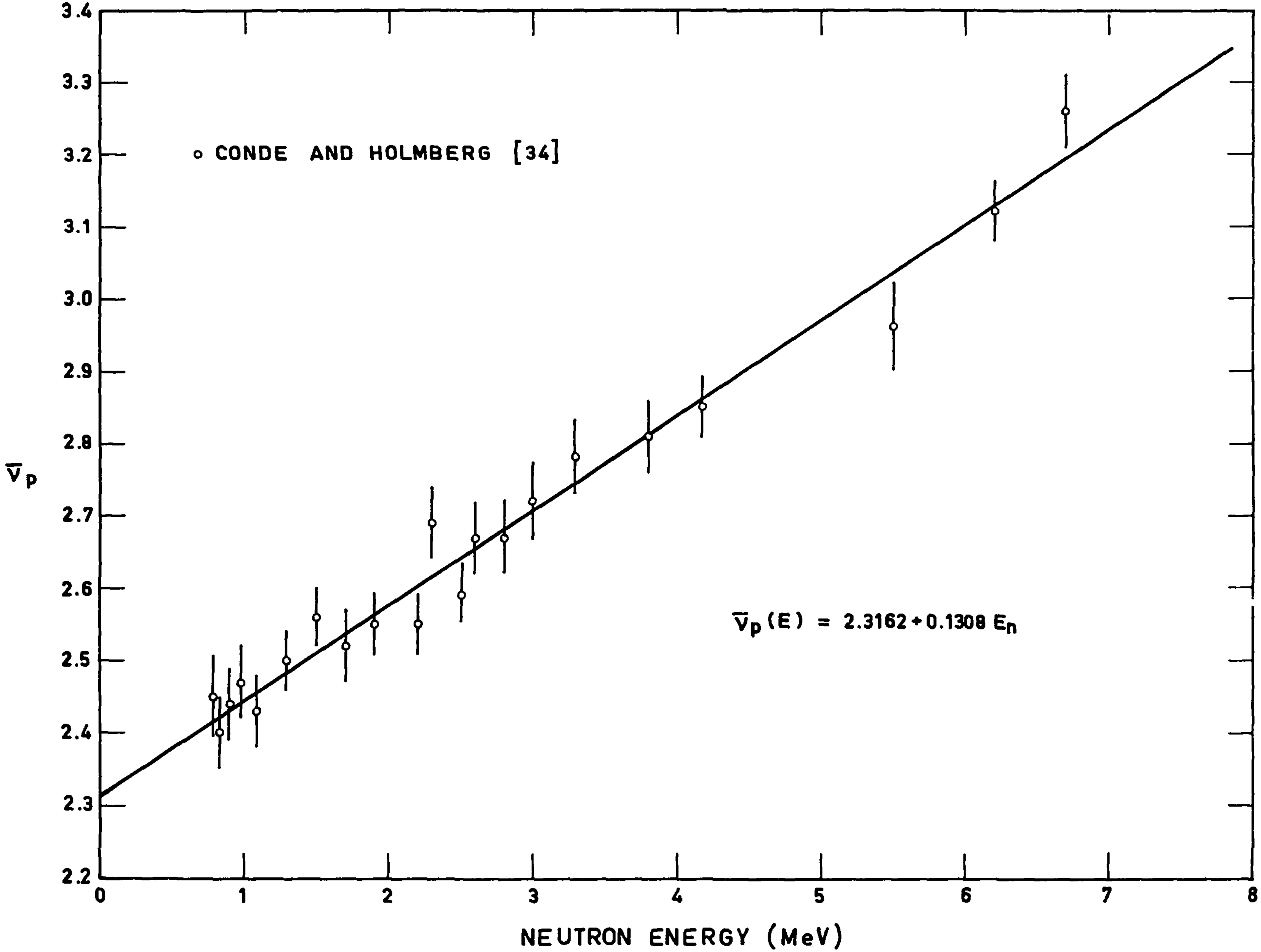

Fig. 12. ENERGY DEPENDENCE OF $\overline{\nu}_p$ FOR ^{236}U BELOW 7 MeV

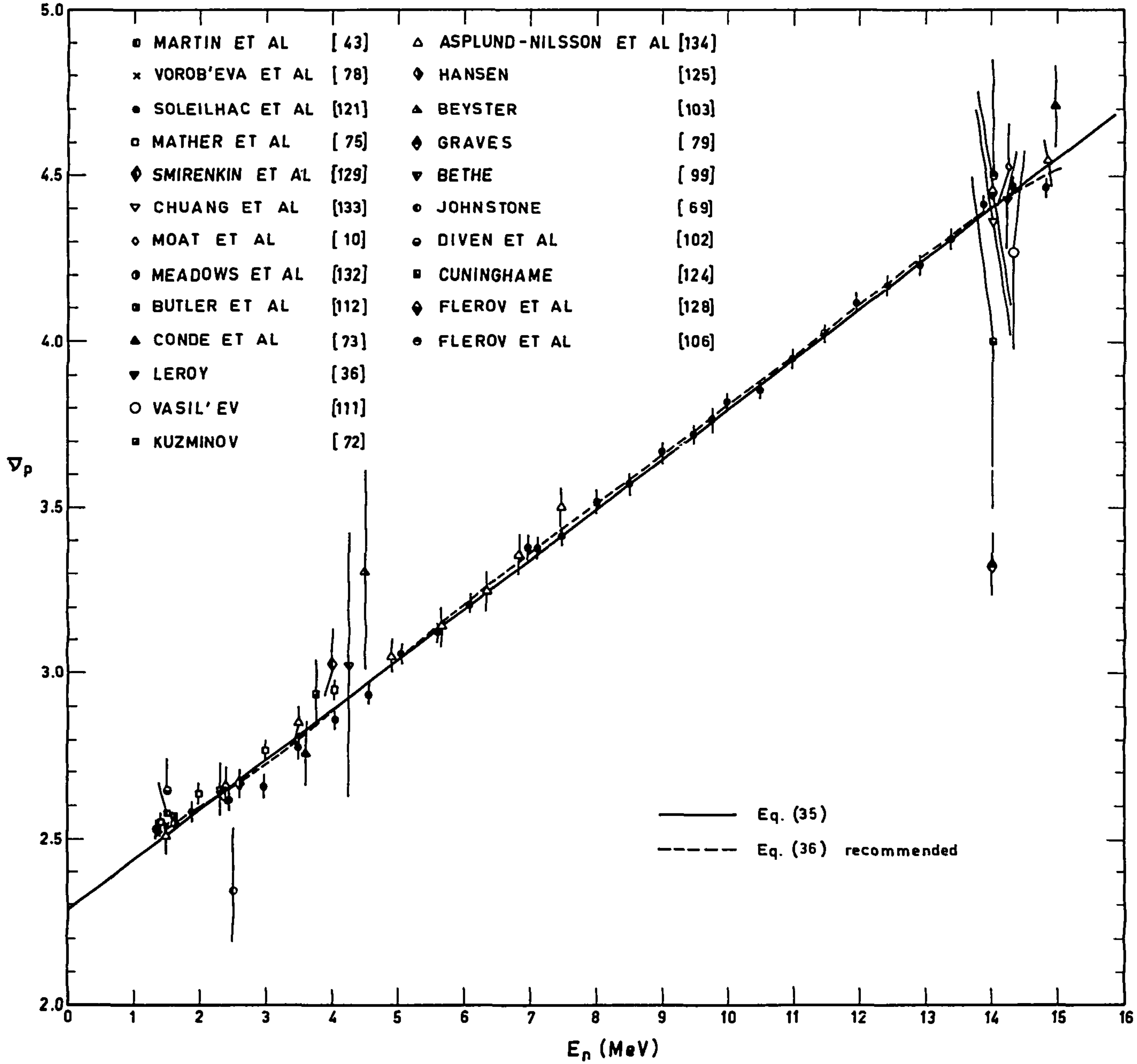

Fig. 13. ENERGY DEPENDENCE OF $\bar{\nu}_p$ FOR ^{238}U BETWEEN 0 AND 15 MeV

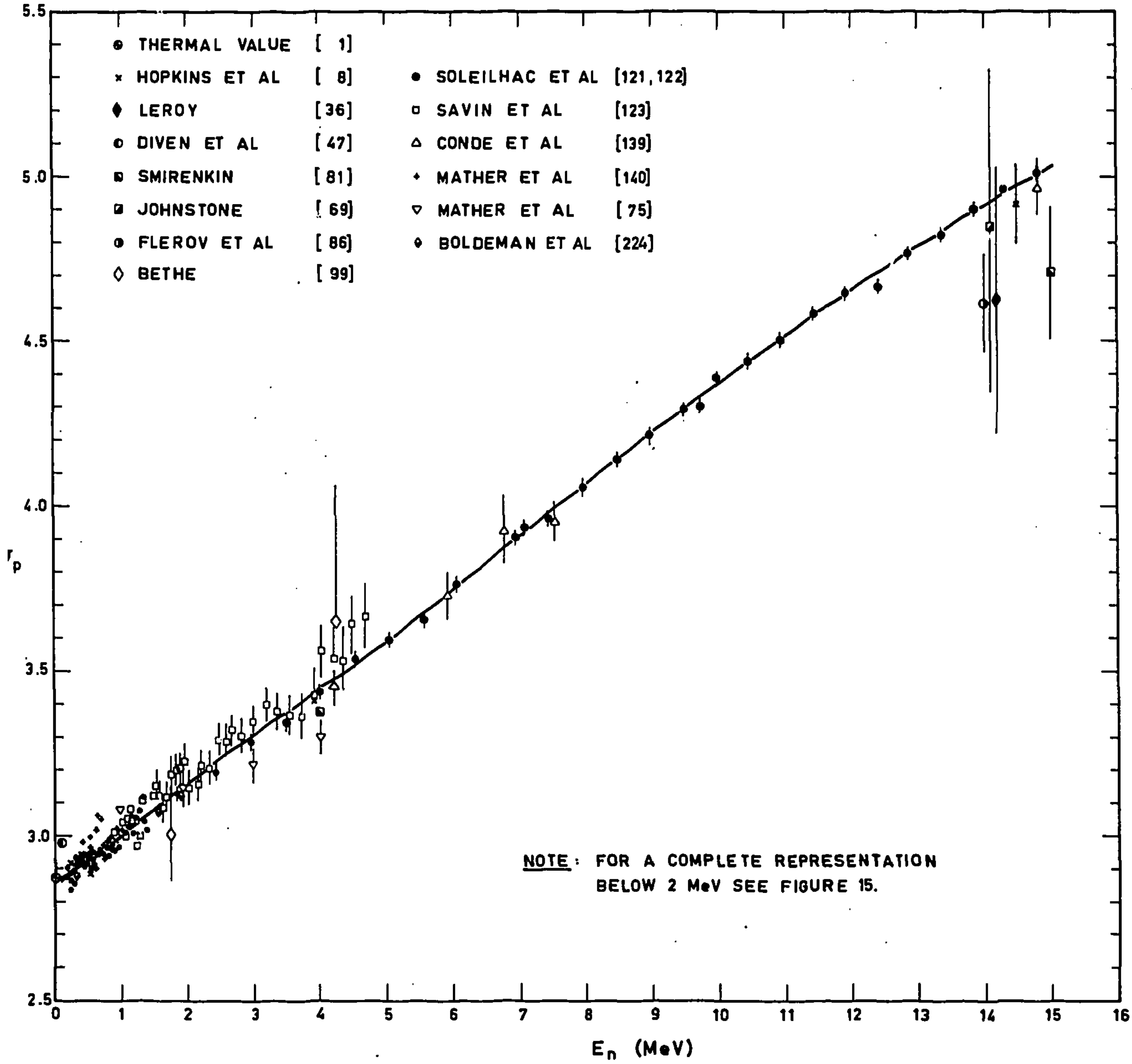

Fig. 14. ENERGY DEPENDENCE OF $\overline{\nu}_p$ FOR ^{239}Pu BETWEEN 0 AND 15 MeV

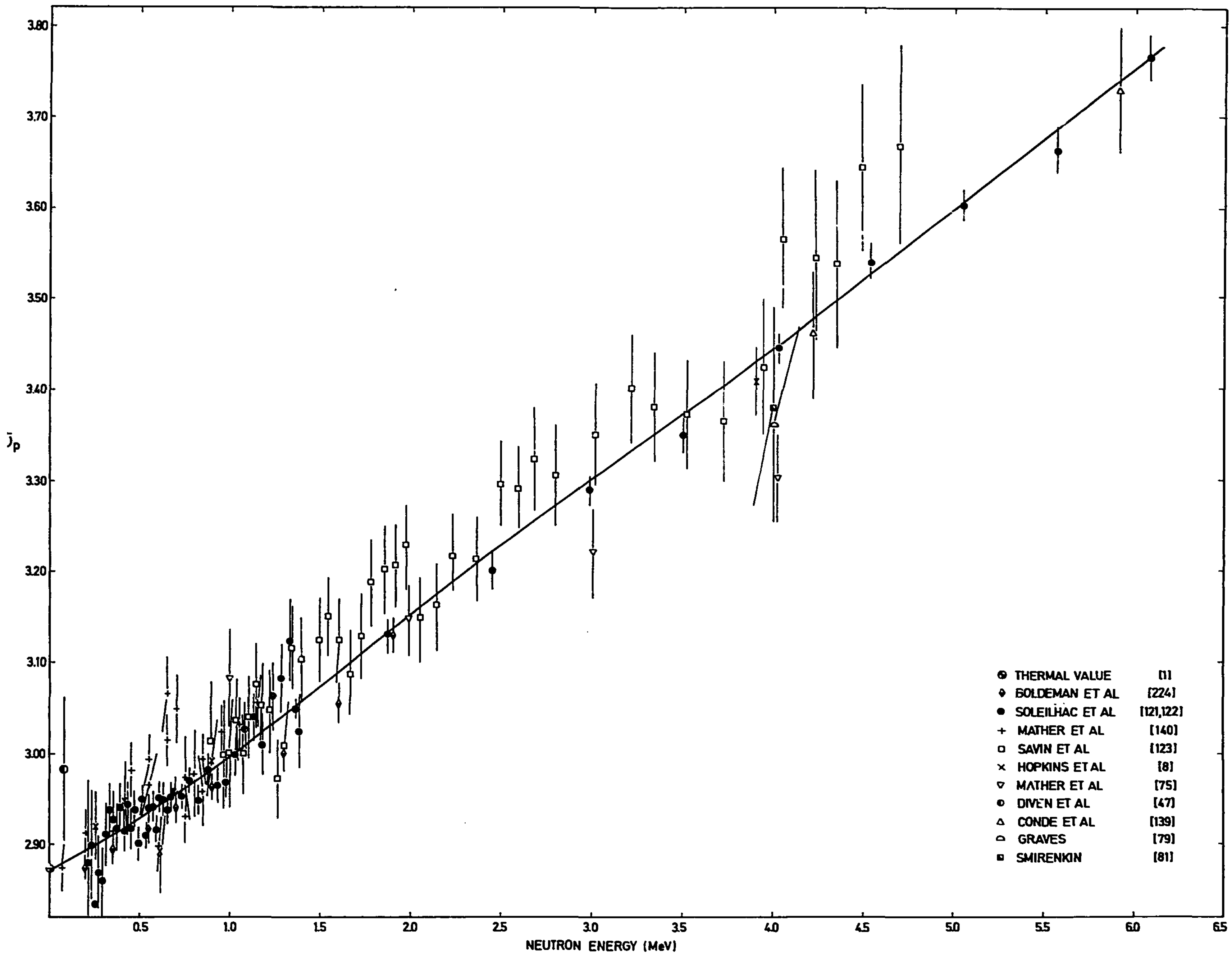

Fig.15. ENERGY DEPENDENCE OF $\bar{\nu}_p$ FOR ^{239}Pu BELOW 6 MeV

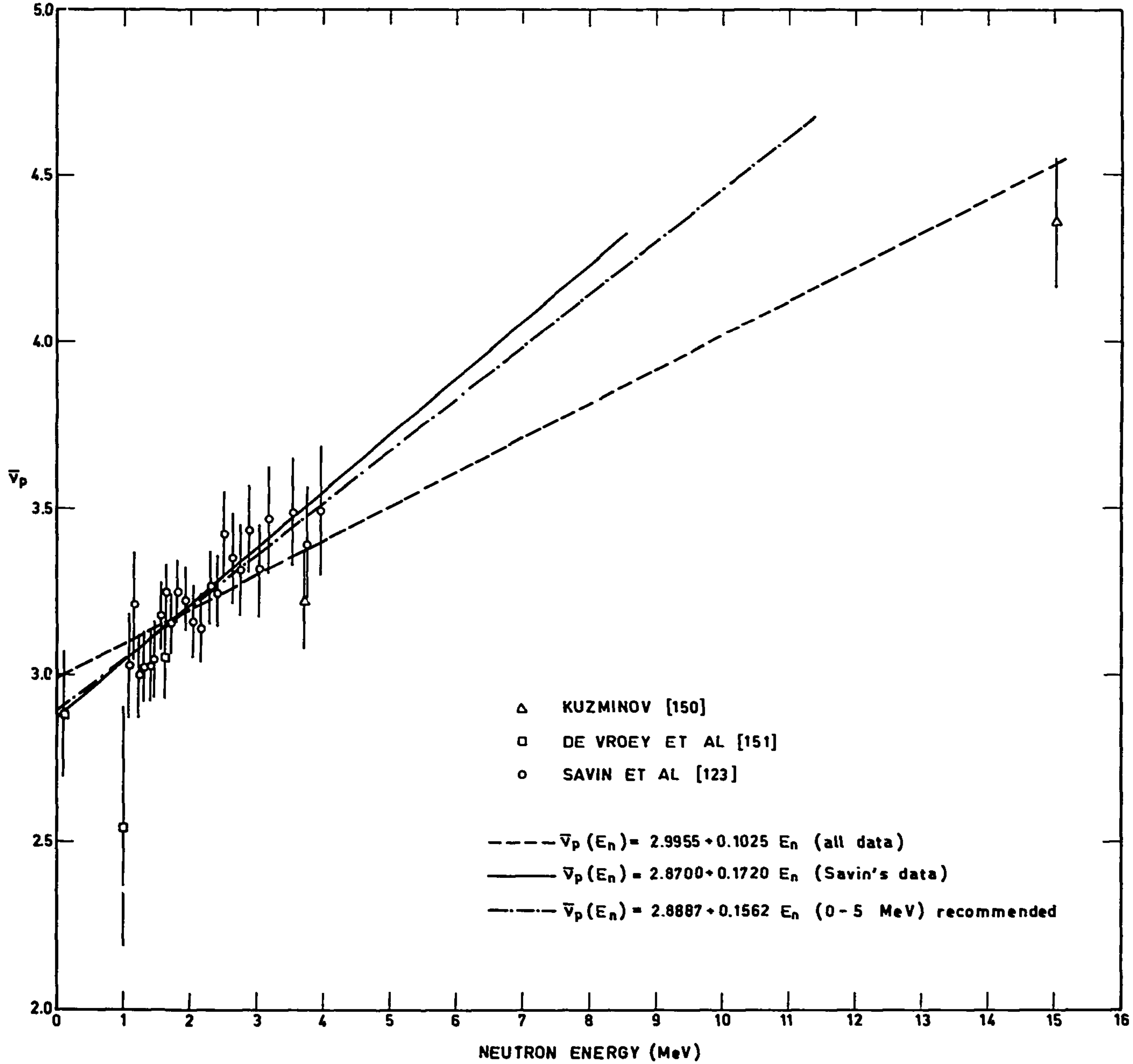

Fig. 16. ENERGY DEPENDENCE OF $\overline{\nu}_p$ FOR ^{240}Pu BETWEEN 0 AND 15 MeV

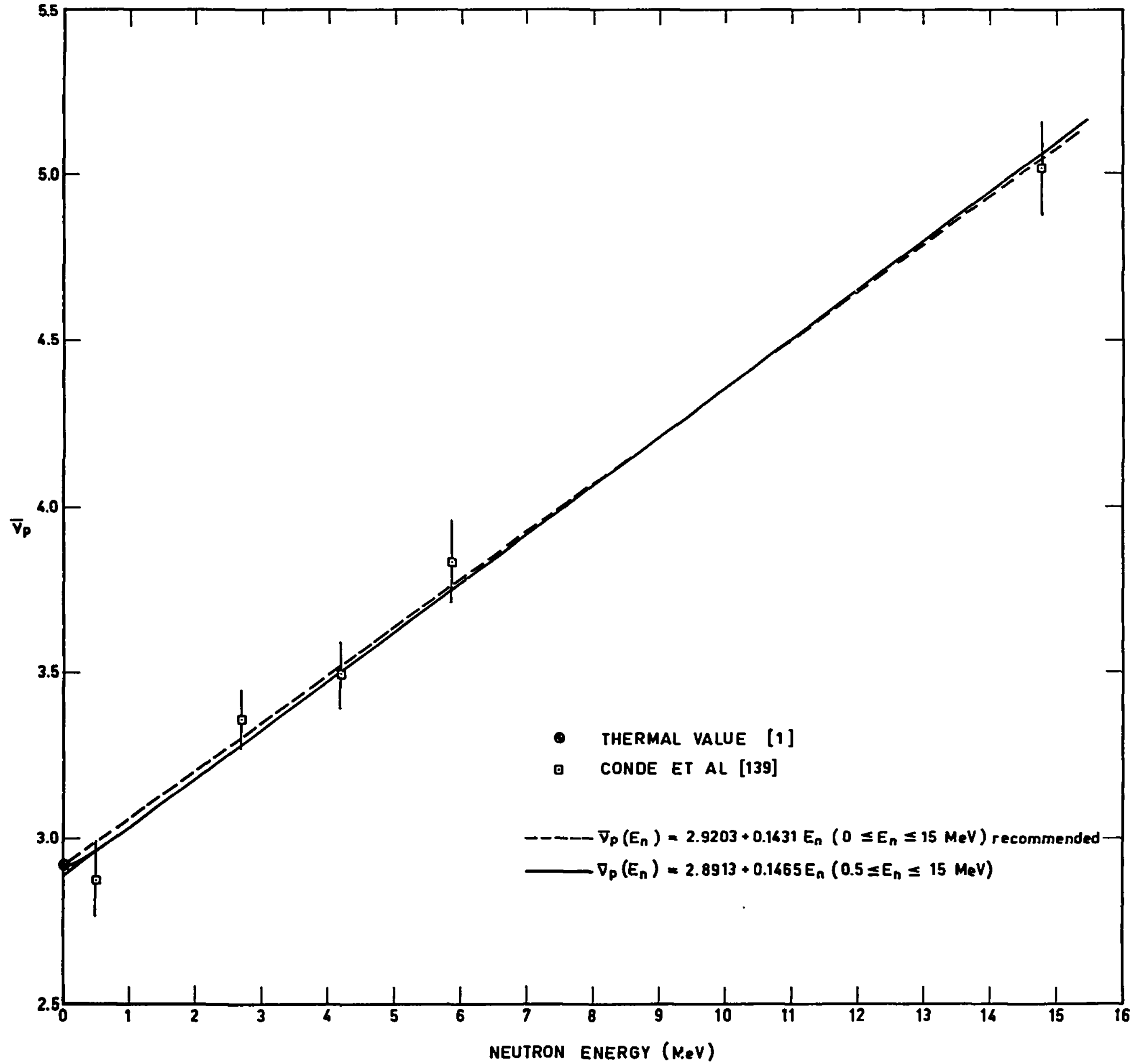

Fig. 17. ENERGY DEPENDENCE OF $\overline{\nu}_p$ FOR ^{241}Pu BETWEEN 0 AND 15 MeV

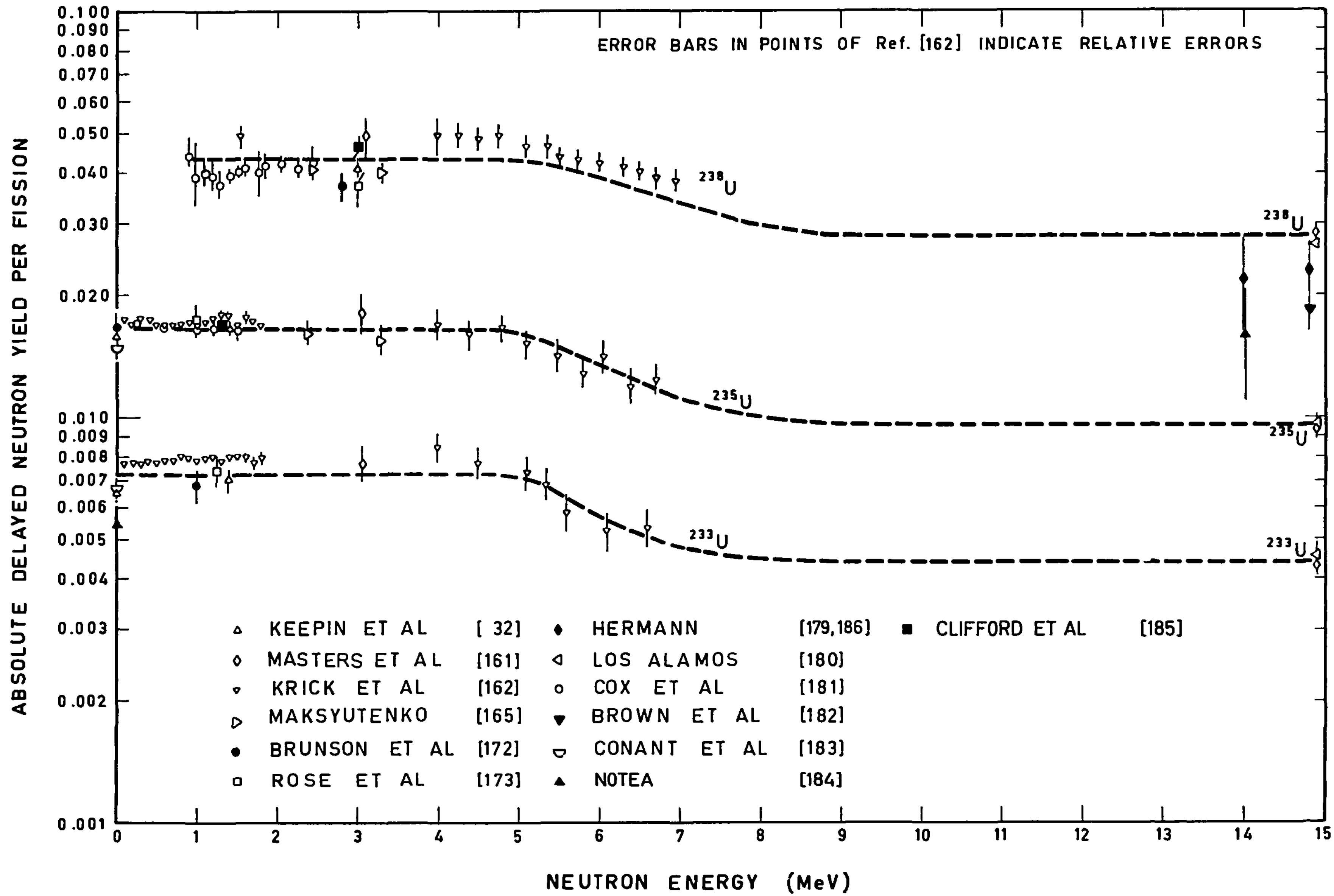

Fig. 18. ABSOLUTE DELAYED NEUTRON YIELD PER FISSION AS A FUNCTION OF NEUTRON ENERGY FOR THE URANIUM ISOTOPES

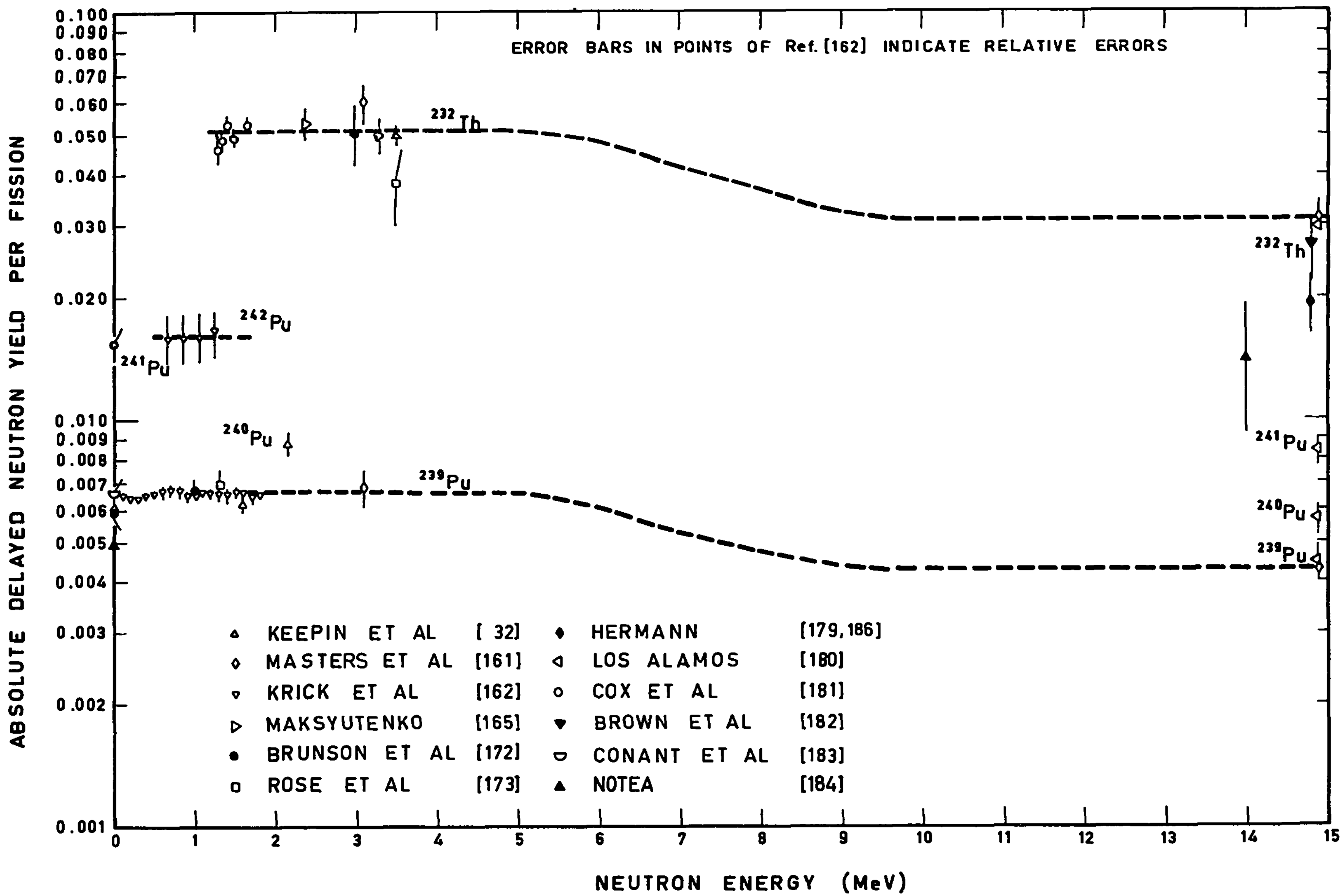

Fig. 19. ABSOLUTE DELAYED NEUTRON YIELD PER FISSION AS A FUNCTION OF NEUTRON ENERGY FOR ^{232}Th AND THE PLUTONIUM ISOTOPES

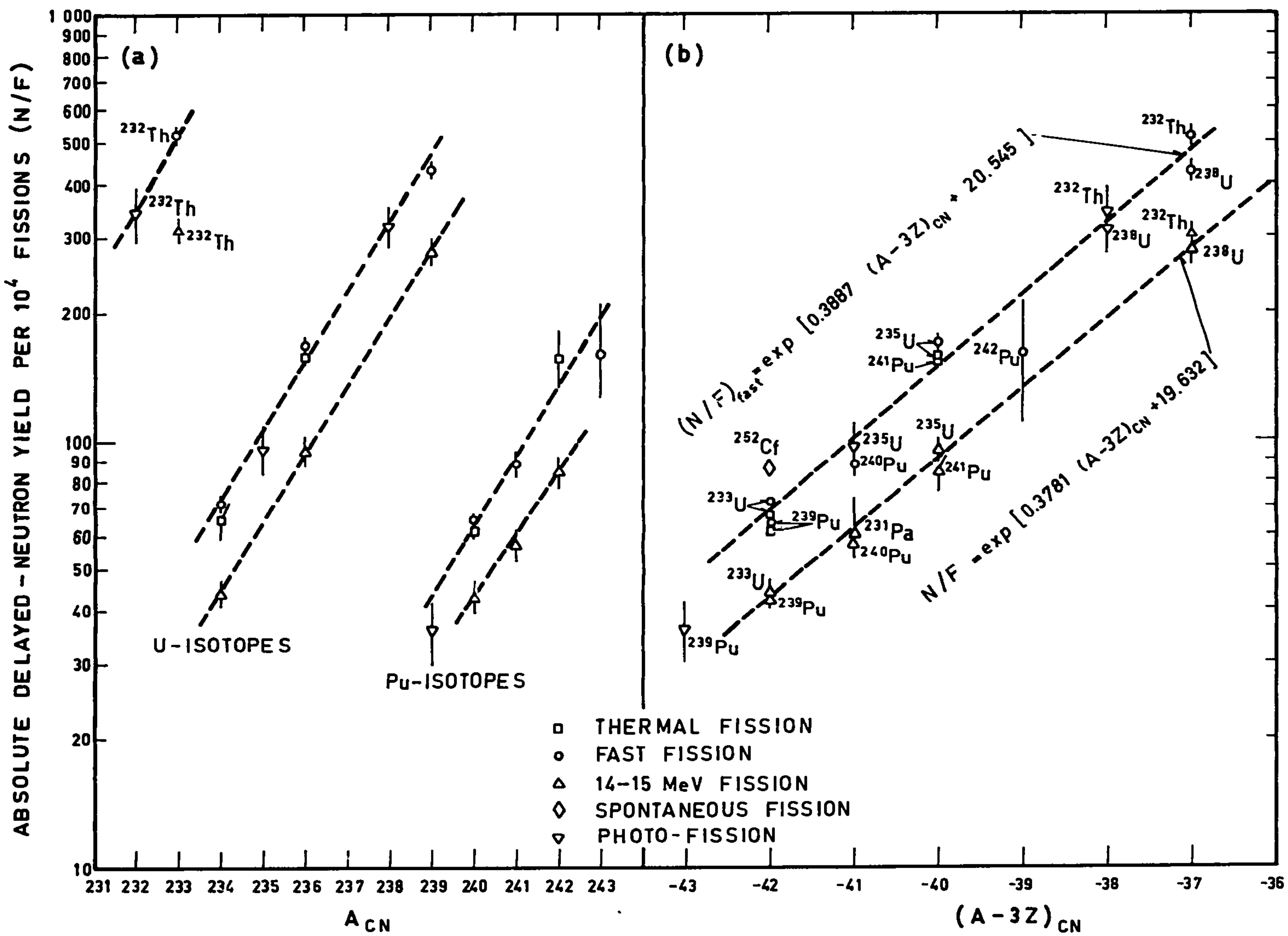

Fig. 20. SYSTEMATICS OF TOTAL DELAYED-NEUTRON YIELDS

(a) AS A FUNCTION OF THE MASS NUMBER A_{CN}

(b) AS A FUNCTION OF THE PARAMETER $(A-3Z)_{CN}$

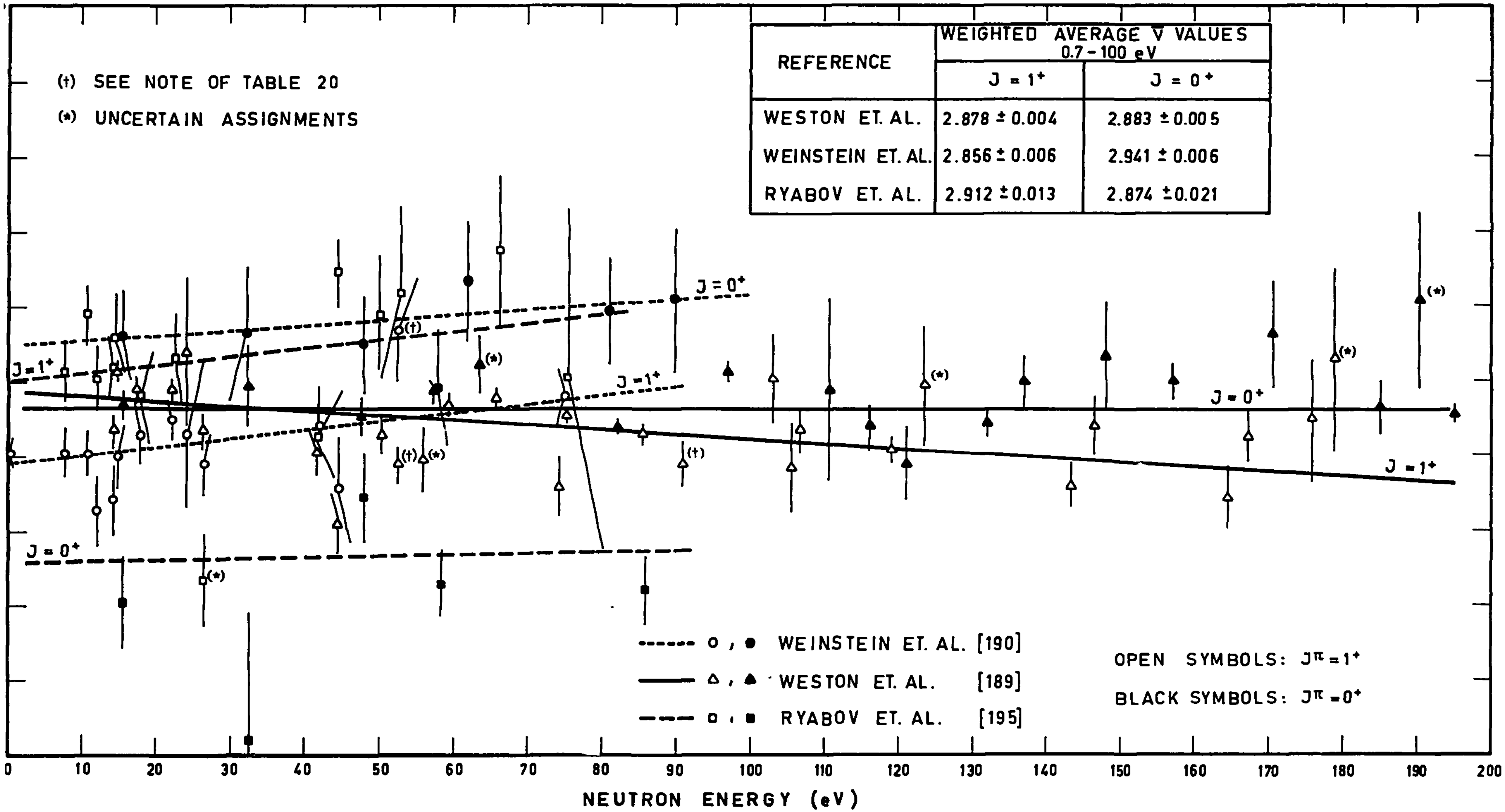

Fig. 21. ENERGY AND SPIN DEPENDENCE OF $\bar{\nu}$ FOR ^{239}Pu IN THE RESONANCE ENERGY REGION

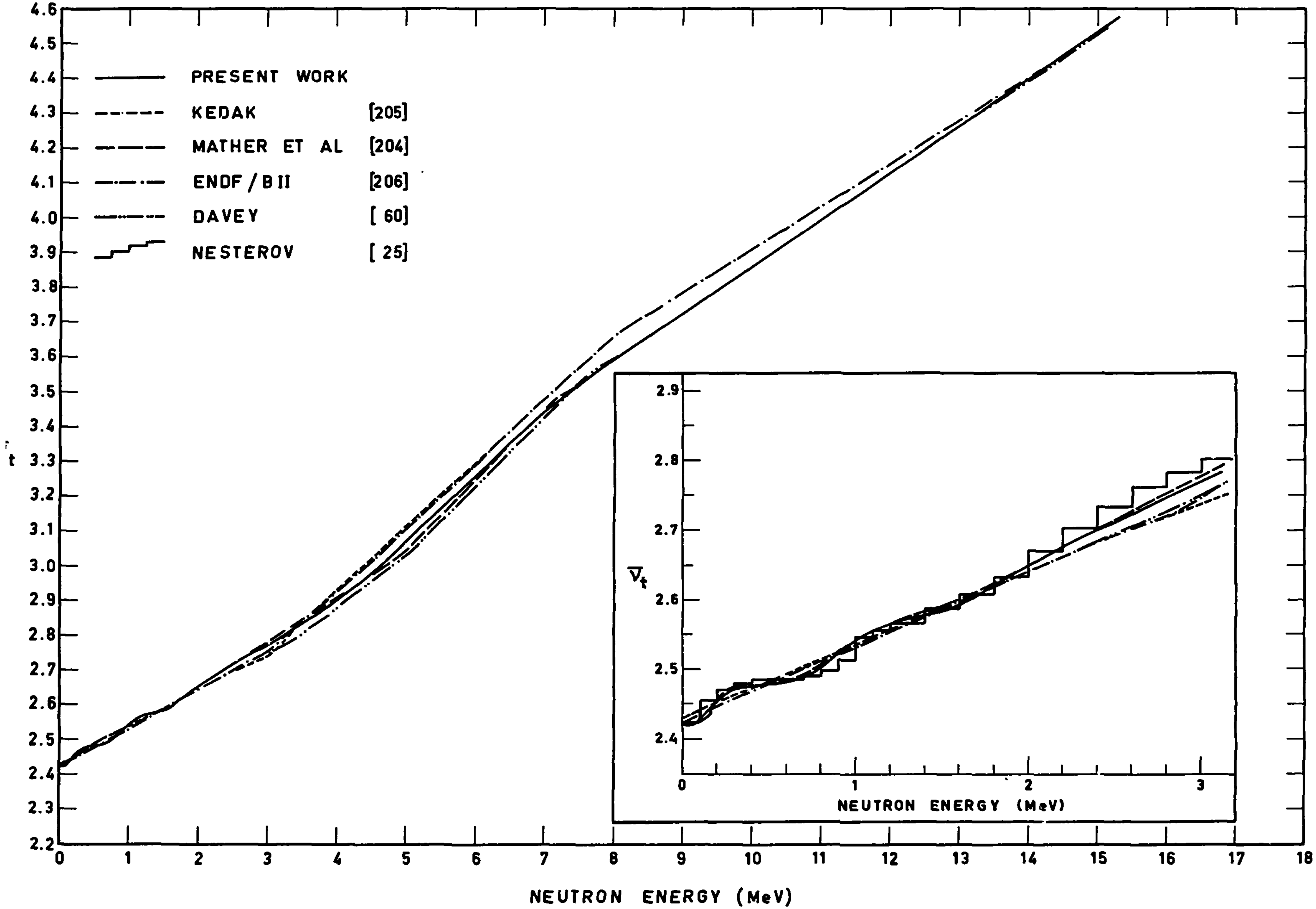

Fig. 22. EVALUATED DATA FOR ^{235}U BETWEEN THERMAL AND 15 MeV

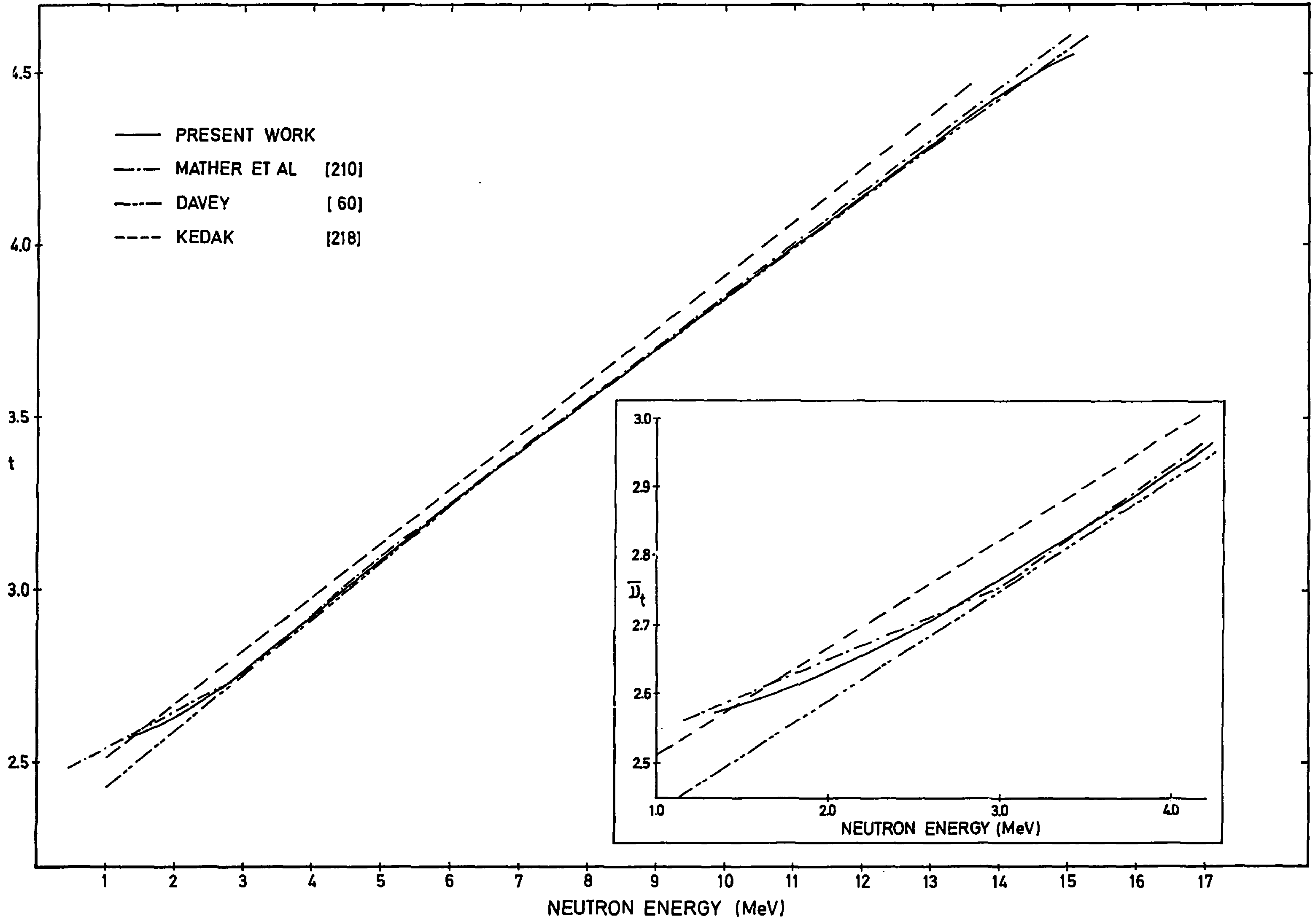

Fig.23. EVALUATED DATA FOR ^{238}U BELOW 15 MeV

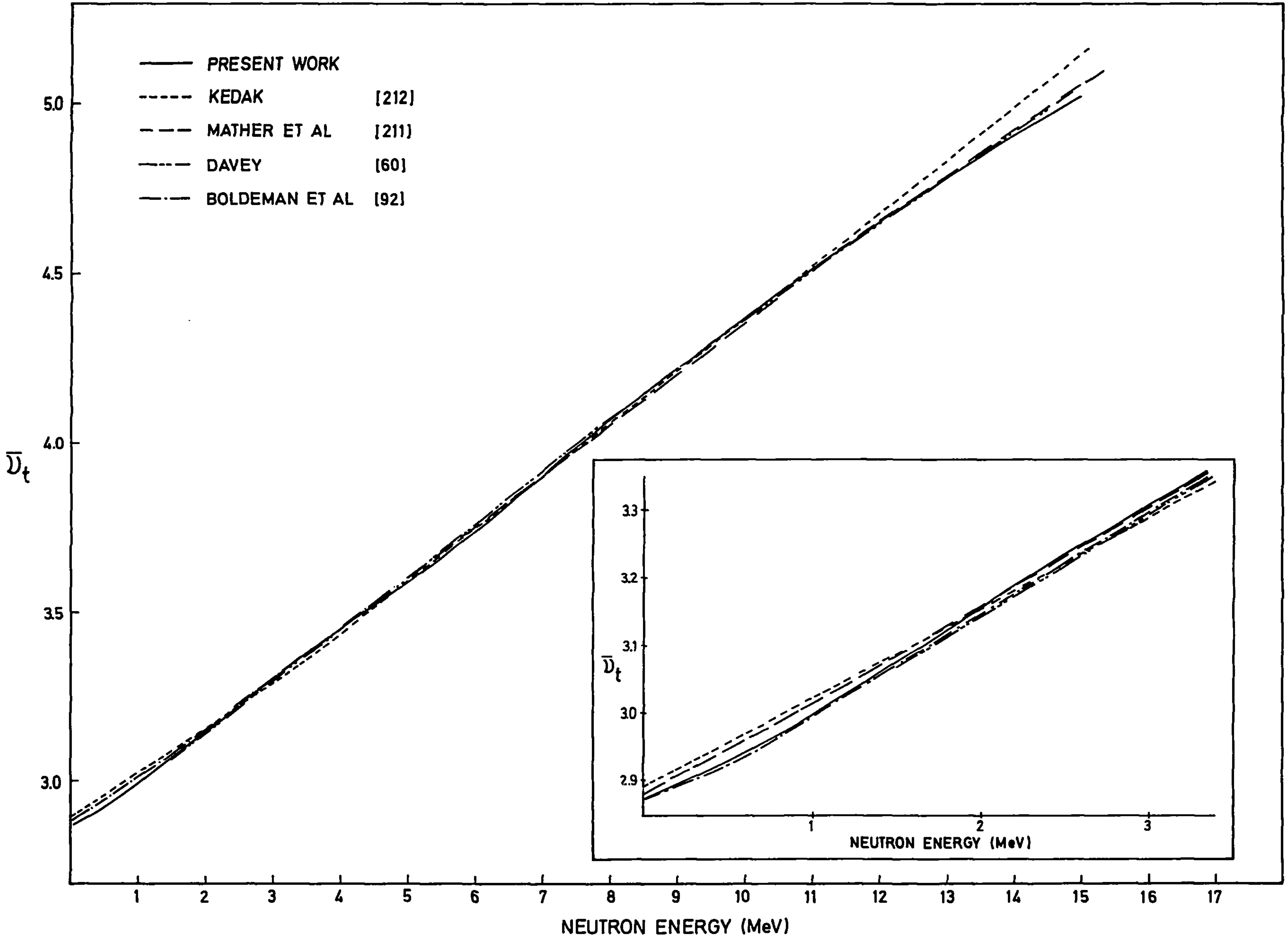

Fig. 24. EVALUATED DATA FOR ^{239}Pu BETWEEN THERMAL AND 15 MeV