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EVALUATION OF THE FAST NEUTRON CROSS SECTIONS OF 56FE INCLUDING COMPLETE COVARIANCE INFORMATION

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EVALUATION
OF THE FAST NEUTRON CROSS SECTIONS OF ^{56}Fe
INCLUDING COMPLETE COVARIANCE INFORMATION

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Abstract

A new evaluation of all important neutron cross sections of ^{56}Fe was performed in the neutron energy range 0.85 - 20 MeV, that is for the whole energy range above the resonance region. The evaluation combines the results of nuclear model calculations and the complete existing experimental data base in order to obtain the most accurate description of the cross sections possible within our present knowledge. The evaluation was performed in the following way: The cross sections from the EFF-2 file (results of model calculations) and their estimated covariances are used as prior information which is successively improved by adding experimental data and applying Bayes' theorem to obtain the posterior information. For this process the code GLUCS was used. As the results we obtained evaluated cross sections and their covariances for a chosen set of 12 independent cross sections. On the average the uncertainties of these cross sections are smaller by a factor of 2 to 3 than the uncertainties in the recent evaluated files ENDF/B-VI and EFF-2. There are considerable correlations between the uncertainties for different cross - section types. This is a natural consequence of the existence of accurate experimental data on "redundant" cross sections which enter as constraints into the described least - squares analysis. Our results confirm that the uncertainties for ENDF/B-VI and EFF-2, though derived by rather qualitative methods, are essentially correct.

1. Introduction

For materials important in fusion and fission technology, e. g. iron, consistent and complete high-quality evaluations (*Cheng 91*) are needed. Although usually a large number of accurate cross - section measurements exist for such materials, the demand for completeness makes it necessary to use cross sections from model calculations at least for these reactions for which measurements cover only a part of the required energy range. This guarantees completeness and internal consistency of the evaluations, however at the expense of a considerable loss of accuracy compared to an "ideal evaluation" which makes full use of all existing experimental and theoretical information. The reason for this shortcoming are the inherent deficiencies of our present nuclear reaction models which do not allow us to calculate cross sections to better than 5 - 10% even after optimum adjustment of all relevant parameters (*Vonach 88, Kawano 91*). Thus for such cross sections and energy ranges where measurements accurate to a few percent are available, cross sections from model calculations definitely have much larger uncertainties than the weighted average of the experimental values. Thus, in order to obtain a complete evaluation of the highest possible accuracy it is necessary to use model calculations not as a final result but as a starting point and to improve them by a "fine-adjustment" based on all existing experimental data.

The purpose of this work is to present a procedure appropriate to carry out such evaluations in a quantitative way by application of Bayes' theorem and to demonstrate the improvements obtainable in this way for one nucleus of special interest: ^{56}Fe, the main isotope of iron.

This nucleus was chosen for the following reasons:

1) Iron will be the most important shielding material for the next-generation fusion reactors ITER or NET and therefore its neutron cross - sections are needed with a very high accuracy. Although several new evaluations for ^{56}Fe became available recently, their uncertainties are still considerably larger than required for fusion reactor design (*Dänner 90*).

2) Because of its technical importance the reaction cross - sections of iron and especially of ^{56}Fe were studied in many rather accurate experiments. Thus, for this material adding experimental information to the results of model calculations can be expected to result in a large reduction of the uncertainties.

3) For ^{56}Fe we already have two recent evaluations (*Nordborg 91, Dunford 91*) based mainly on model calculations which include covariance information. By performing a new evaluation with reduced uncertainties it will be possible to check the rather qualitative uncertainty estimates of the existing evaluations.

4) The neutron cross - sections of ^{56}Fe and their covariances are studied by an international working group (subgroup 2 of the International Working Group on Evaluation Cooperation) which should especially compare the results of different approaches to estimate cross - section uncertainties.

2. General evaluation procedure

The general principle of this evaluation is rather simple; it is shown schematically in Fig. 1. As the starting point we use the EFF-2 evaluation (*Uhl 91*) and its covariances (*Vonach 91*) with some modifications as discussed later in section 3; this constitutes our prior knowledge of the neutron cross - sections of ^{56}Fe. For each type of cross section this prior is represented by a cross - section vector and its covariance matrix. Then Bayes' theorem is used to add successively the experimental data for the various ^{56}Fe cross sections to the respective prior. This is done in the following way: If the data are described by a vector R with the covariance matrix V, application of Bayes' theorem results in the following relations for the improved cross sections T' and the covariances M'

$$T' = T + M G^{+} (G M G^{+} + V)^{-1} (R - R_T) \quad (1)$$
$$M' = M - M G^{+} (G M G^{+} + V)^{-1} G M, \quad (2)$$

where R_T presents the prior value interpolated at the point where R is given, G is the sensitivity matrix of the new experimental data relative to the prior data with the matrix elements $g_{ij} = \delta R_i/\delta T_j$, and the upscript (+) means transpose and (-1) inverse operation. One of the most important conditions for obtaining these formulae is an absence of correlations between the data vectors T and R. This condition is fulfilled as T was derived from nuclear model calculations and R are results of measurements.

From this procedure (depicted at the left side of Figure 1) we get a set of improved cross sections with much reduced uncertainties compared to the prior EFF - 2 values. Cross sections for which no experimental data exist (e. g. $\sigma_{n,np}$, $\sigma_{n,n\ cont.}$) remain unchanged at this step. Due to the independent adjustment of the individual cross sections the internal consistency (e. g. between σ_{non} and the sum of all partial cross sections) gets lost to some degree. Therefore in a final step (see right side of Figure 1) this consistency, that is the physical relation between the different cross sections, is restored by a least - squares adjustment which also further improves the overall accuracy of the evaluation. For this purpose a set of independent cross sections (see Figure 1) is selected as the new prior whereas the remaining redundant cross sections (which can be expressed as linear functions of the basic cross sections) are used as "data" for application of the equations 1 and 2.

Thus the evaluation proceeds in the following steps:

1) Establishment of the prior data for all cross sections of interest.
2) Establishment of the experimental data base.
3) Calculation of the improved cross sections T' and covariances M' for all important cross sections for which data are available.
4) Restoring of the internal consistency of the evaluation by a constrained least - squares adjustment of the results obtained at step 3. This leads to a final result of the evaluation in form of a cross - section vector T' containing a complete set of independent cross sections and one large covariance matrix M' which can be

subdivided into covariance matrices for the individual cross sections and covariance matrices between different cross - section types.

3. Establishment of the prior information for all cross sections of interest

We decided to use the EFF - 2 evaluation as the basis for the prior (T, M) in this evaluation because it provides a complete description of the ^{56}Fe cross sections, has sufficiently detailed covariance information and is essentially uncorrelated with the experimental data to be added. In detail, however, some modifications especially concerning the covariances M had to be made. Therefore, in the following a brief description of the priors actually used is given:

A: Cross sections

1) For the cross sections σ_{el}, σ_{non}, σ_{inel}, $\sigma_{n,p}$, $\sigma_{n,np}$, $\sigma_{n,2n}$ and $\sigma_{n,\alpha}$ the cross sections from EFF - 2 were used as prior values without any changes.

2) The total cross section of iron is covered by accurate measurements over the whole energy range of this evaluation (0.85 - 20 MeV). Therefore this cross section was evaluated entirely from the experimental data without any prior from model calculations.

3) In EFF - 2 inelastic neutron scattering cross - sections are given separately for 33 discrete levels and to the continuum. In this evaluation we considered separately inelastic scattering to the first three levels, to three groups of resolved levels covering the levels 4 - 32, and to the continuum (see section 5.3.). Values for these partial cross sections were obtained from EFF - 2 either directly or by summing over all levels in the selected groups.

B: Covariances

1) Uncertainties (standard deviations):

Relative uncertainties as a function of neutron energy were taken from the EFF - 2 covariance estimates (*Vonach 91*) for σ_{non}, σ_{el}, σ_{inel}, $\sigma_{n,p}$, $\sigma_{n,\alpha}$, $\sigma_{n,np}$, $\sigma_{n,2n}$ and $\sigma_{n,n\ cont}$ (see Figs. 47 and 48 of *Vonach 91*). For inelastic scattering to discrete levels EFF - 2 gives only covariances for the sum of all discrete cross sections, therefore uncertainties for $\sigma_{n,n1}$, $\sigma_{n,n2}$, $\sigma_{n,n3}$ and the cross sections for the selected groups of discrete levels were estimated from the differences of these cross sections between the evaluations EFF - 2, ENDF/B -VI, JENDL-3 and BROND using the procedures developed in *Vonach 91*.

2) Energy grid of the covariance matrices:

In EFF - 2 the energy range of the evaluation (0.85 - 20 MeV) had been divided into intervals for the representation of the covariance matrices resulting in energy intervals of 0.5 MeV and 1 MeV within which cross sections are fully correlated. In the lower energy range of our evaluation these intervals appeared too large for a detailed description of the excitation function. Therefore a finer energy grid (40 intervals) was adopted for this evaluation. Energy bins of 0.2 MeV were chosen in the energy range 0.85 - 3.0 MeV, 0.5 MeV in the energy range 3.0 - 15.0 MeV and 1.0 MeV above 15 MeV (see for example Table 2). This structure of the covariance matrices was used for all cross sections. For the best description of each individual reaction it would have been desirable to adjust the group structure of the covariance matrix to the shape of the respective excitation function. The need for the final joint least - squares adjustment of all cross sections, however, made it necessary to use a common energy - group structure for all covariance matrices.

3) For EFF - 2 a Gaussian type of correlations with a constant width (FWHM) of 4 MeV, independent of neutron energy, was assumed for all cross sections in order to describe the (positive) correlations between the cross - section uncertainties at different neutron energies E_1 and E_2 (see discussion on page 6 in *Vonach 91*). Again especially in the low energy range this correlation width appeared to be too large resulting in very "stiff" excitation functions which cannot be easily adjusted to experimental data of a slightly different shape of the excitation function. Thus as a somewhat more realistic approximation in this evaluation we used a Gaussian - type correlation function with variable width (the FWHM increasing linearly from 1 at 1 MeV to 4 at 20 MeV) for generating the off - diagonal elements of the covariances of our priors. Correlation coefficients between cross - section uncertainties at the energies E_1 and E_2 were calculated according to the relation

$$\mathrm{cov}\,(\sigma_1\,\sigma_2) = \mathrm{sqrt}[\mathrm{Var}(\sigma_1)\,\mathrm{Var}(\sigma_2)] * \exp[-((E_1 - E_2)^2/\Gamma_{12}{}^2) * \ln 2]. \qquad (3)$$

4. Establishment of the experimental data base including construction of covariance matrices for all data sets

We used the experimental data compiled in EXFOR (*Lemmel 86, McLane 88*) and supplemented them by very recent ones which were mostly obtained directly from the authors. In addition to measurements on ^{56}Fe we also used measurements on natural iron for such cross sections for which either the difference between ^{56}Fe and ^{nat}Fe is known to be small or for which an accurate conversion from ^{nat}Fe to ^{56}Fe is possible using the cross sections for the minor isotopes. Additionally, in order to widen our data base also some more complex cross sections like the γ - production cross section for the first 2^+ level were included in our data base if good measurements existed and accurate conversion procedures to basic cross sections, e.g. σ_{non}, could be developed. Differential elastic and inelastic scattering cross sections measured over a sufficient angular range were used to derive the total elastic and inelastic scattering cross sections by means of fits with Legendre polynomials in those cases where the integrations had not been performed by the authors.

All data sets were critically reviewed; obviously wrong data were rejected. The accepted data were renormalized if necessary with regard to the standard cross sections or decay data used. In some cases renormalizations were also applied if comparisons of a data set with other data consistently indicated the need for such renormalizations.

For the construction of the covariance matrices of the experimental data sets it is necessary to have detailed information on all uncertainty components of the measurements and the correlation of each component within the data set. As this information is not given for most of the experiments various appoximations had to be used.

For σ_{tot}, σ_{non}, σ_{el} and all inelastic cross sections, where the uncertainty information is rather incomplete in many cases, the following procedure was adopted:

We assumed that the covariance matrix of total uncertainties can be split into three matrices of partial uncertainties:

1) a covariance matrix of partial uncertainties describing short-energy-range (SER) correlation properties such as statistical uncertainties due to a finite number of counts per channel;

2) a covariance matrix of partial uncertainties connected with properties that give rise to medium-energy-range (MER) correlations, such as uncertainties due to the correction for the dead time and to the determination of the detector efficiency, the effect/background separation, multiple scattering and scattering at the collimator, the spectrometer resolution function and neutron source properties;

3) a covariance matrix of partial uncertainties connected with properties which induce large-energy-range (LER) correlations, such as systematical uncertainties due to any normalization of the cross sections in order to get absolute values, to the determination of the number of nuclei in a sample, to geometrical sizes and distances and to sample self-absorption properties for the non-resonance energy region.

The magnitudes of the described three components were chosen according to the uncertainty information given by the authors; in the assessment of the medium-energy-range correlations also the deviations between the different data sets were taken into account as discussed more extensively in section 5.1.

For the (n,2n), (n,p) and (n,α) cross sections where on average the existing uncertainty information is somewhat more detailed, the covariance matrices were constructed more rigorously by adding up the contributions from each uncertainty component using an estimated degree of correlation for each component. Obviously missing uncertainty components were estimated and also added in some cases as explained in the sections on these reactions.

All steps for deriving the experimental data base according to the procedures outlined here are described comprehensively in section 5, where the evaluation of the different types of cross sections is treated in detail. The cross - section values and their covariances derived in this way cannot be given in this report, they are, however, available on request at our institute.

5. Evaluation of the cross sections for individual reactions

5.1. The total cross section

We started with the evaluation of the total cross section for which the number of data points is maximal. Because most of the high-energy neutron data were obtained for natural iron containing 91.7% of ^{56}Fe and since the isotopical dependence of the total cross section for the non-resonance region is rather weak, we used the data for natural iron for the evaluation of the ^{56}Fe total cross section.

All high resolution data for the total cross section from the EXFOR data base were averaged with a constant averaging function f(E,E') = 1.0 in a 40 - group structure for the energy region 0.85 MeV $\leqslant$ E $\leqslant$ 20 MeV. Data were intercompared and evidently discrepant data were discarded as well as in many cases those in the first and the last group for a given data set. As a rule the authors of the different papers specify only the statistical component of the uncertainty. Due to the averaging process within each group the statistical uncertainties cancel to a certain extent and the group-average diagonal elements of the SER correlation matrix can approximately be evaluated as:

$$\varepsilon^{k}_{SER} = 1 / SQRT(\sum_{i} 1/(\varepsilon_{i}^{k})^{2}) \qquad (4)$$

where ε_i^k is the statistical standard deviation for the i-th energy point in the k-th group and summing is carried out over all energy points in the respective group. The cancellation of the statistical uncertainties may be substantial. We consider, for example, the EXFOR entry 10006, *Schwartz 74*. The statistical uncertainty for the energy range 0.85 MeV < E < 1.0 MeV is about 3 - 4%; the averaging procedure reduces it to an ε_{SER} = 0.23%. The SER vector of the deviations is given in the fifth column of Table 1 and the diagonal elements of the correlation matrix will be just 1 along the main diagonal and 0 for non-diagonal elements.

The LER correlation matrix is also simple as each element of this matrix is equal to 1. Some authors state the contribution of the systematical uncertainty to amount to about 1%; we used this value for all data sets except for the data from EXFOR entry 20010, *Cierjacks 68*: for them a systematical uncertainty of 1.5% was taken because these data deviate by about 1.5% from the general average practically in the entire energy region. All elements of column 6, the vector of the systematic standard deviations, are equal to 1% (or 1.5% for the data from *Cierjacks 68*).

MER variances and covariances were obtained in the following manner: A general average <<tot(k)>> for 16 averaged data sets <tot(j,k)> (where k is a group number and j is a data set number) was obtained considering that a pseudo-statistical ensemble of measurement conditions is realized for these sets. The list of data sets which were included in obtaining this general average is given in Part I of Table 1. The absolute deviations for each data set then were obtained as

$$\varepsilon^{k,j}_{MER} = | <<tot(k)>> - <tot(j,k)> | / <<tot(k)>> \qquad (5)$$

and squares of these values averaged over 2 MeV intervals were treated as the diagonal elements for a MER correlation matrix. In order to determine the non-diagonal elements of this matrix, we used the hypothesis that the propagation of these correlations has a Gaussian shape and calculated correlation coefficients (normalized to 1) as:

$$<\varepsilon^{k,j}_{MER}\,\varepsilon^{l,j}_{MER}>/(<\varepsilon^{k,j}_{MER}><\varepsilon^{l,j}_{MER}>) = \exp[-((E_k-E_l)^2/\Gamma_j^2)\,.\,\ln(2)] = f(E_k,E_l) \quad (7)$$

Γ_j = 2 MeV was usually taken because the scale for major changes in the shape of LER data was similar. Then a MER covariance matrix may be obtained in a simple way.

The complete covariance matrix is constructed from the partial SER, MER and LER matrices by summing the corresponding elements. Results for EXFOR entry 10006, *Schwartz 74*, are shown as an example in Table 2 with the variances given in column 4, and a low-triangle matrix, which is a correlation matrix normalised to 100%, is displayed in line ordering. A non-regular behaviour of the correlation coefficients is due to their normalisation with an explicit form for the non-diagonal elements (the index j is omitted):

$$CORR(k,l)=((\varepsilon_{LER})^2 + \varepsilon^k_{MER} * \varepsilon^l_{MER} * f(E_k,E_l))/$$
$$\mathrm{sqrt}[((\varepsilon_{LER})^2 + (\varepsilon^k_{MER})^2 + (\varepsilon^k_{SER})^2) * ((\varepsilon_{LER})^2 + (\varepsilon^l_{MER})^2 + (\varepsilon^l_{SER})^2)] * 100\% \quad (6)$$

At the next step the GLUCS code was used to obtain the evaluated average cross sections and their covariances. Due to a big (up to 30%) well-known discrepancy between the optical model predictions of the total cross section (taken as EFF-2 evaluated cross section) for energies below 4 MeV and the existing experimental data, we did not use the EFF-2 evaluation of the total cross section as a prior data set. In its place the averaged cross sections from the experiment *Cierjacks 68* with covariances were taken as initial prior data as this experiment covers the entire energy range considered in this evaluation. Then step by step 23 experimental data sets (comprising cross sections and covariances) were added applying Bayes' theorem by means of the code GLUCS (*Hetric 80*). From the papers *Bratenahl 58* (containing 5 data points) and *McCallum 60* (comprising 11 data points) only the data in the 14 - MeV energy region were used for the present evaluation. The correlations between different experimental data sets were considered to be negligible. Beside the data listed in Part I of Table 1 also the data from measurements at a single energy are given in Part II. The SER and MER standard deviations presented in Table 1 state the highest values for these components in cases where they are energy - dependent. The χ^2 values given for each data set depend to a certain extent on the sequence in which the data are included in the Bayesian procedure. The general χ^2 for the entire data base represents a more objective characteristic of the consistency of the data. The χ^2 values were usually between 1.0 - 1.5 for experimental data sets covering a large energy range, less than 1.0 for measurements at a single energy and between 2.0 and 4.0 for some intermediate cases. But due to this stepwise procedure these values can be different if we change the sequence of successive inclusion of data. The last two groups

(18 to 19 MeV and 19 to 20 MeV) were collapsed into one group (18 to 20 MeV) in the process of generating the evaluated correlation matrix.

The overall χ^2 value per degree of freedom, considering all experimental data sets, was about 1.7 after the first run. This result indicated that the consistency among the different data sets was not satisfactory and/or the experimental uncertainties had been underestimated. Therefore an iteration procedure had to be applied: at the next step we had to increase the assigned LER and MER components of the covariances for those experimental data sets for which the χ^2 value per degree of freedom was higher than 1 and then repeat the whole procedure. In order to avoid this we increased the standard deviation values by a factor 1.5, which is equivalent to some extent (if the SER part of the covariances is small) just to increasing the covariances for all experimental data sets by a factor of 2.25. The high accuracy of the group-averaged evaluated data obtained then (for a number of energy groups the standard deviations were as low as 0.5%) in reality reflects a rather high consistency of the experimental data base for the iron neutron total cross section.

5.2. The nonelastic cross section

The nonelastic cross section for fast neutron energies (E > 4 MeV in ^{56}Fe) constitutes a substantial part of the total cross section and, as a rule, is measured with a higher accuracy than the elastic scattering cross section. For low energies there are many experimental data which can be reduced to nonelastic cross sections. The following features of the nonelastic cross section of ^{56}Fe for energies between 0.85 MeV and 20 MeV were taken into account for the evaluation:

- as the capture cross section is less than a few mb in this energy region and the effective thresholds of the (n,p) and (n,α) reactions are higher than 5 MeV, the total inelastic cross section for 0.85 < E < 5 MeV is with a high accuracy (< 0.1%) equal to the nonelastic one;

- due to the specific nuclear structure properties of the ^{56}Fe nucleus observed in many experiments with γ-ray transition measurements, the production of the 0.847 MeV γ-rays (transition between the first excited 2^+ level and the ground state) is equal to 0.93 - 1.00 times the total inelastic scattering cross section with an energy dependence that can be evaluated from known decay schemes and experimental data on partial γ-ray production;

- most of the high - energy nonelastic cross sections obtained in sphere transmission measurements and presented in the EXFOR data base as total nonelastic cross sections are in reality the partial nonelastic cross sections without inclusion of the inelastic scattering cross section for the first (2^+) excited level.

A complete EXFOR data base relevant for the nonelastic cross section in ^{56}Fe or ^{nat}Fe consists of more than 400 data sets (sub-entries). This extensive data base includes:

a) The results of high - resolution experiments (up to ΔE = 2 - 3 keV) of γ - ray production cross sections for separate γ - transitions: These data are either measured at separate angles or represent angle - integrated results covering a large energy region.

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Many data for the 847 keV transition from the first excited state are measured for an angle of 125° and can be transformed with reliable accuracy into an angle - integrated value by simply multiplying them with a factor 4π. For neutron energies below 2 MeV, however, the nonisotropic contribution described by a 4^{th} order Legendre polynomial coefficient is non - zero and strongly energy - dependent (see data from *Smith 76*). This was accounted for when the angle - integrated γ - production cross sections were obtained from data measured at a single angle.

We converted the γ - ray production cross section for the 847 keV line into the total inelastic cross section relying on data for the γ - transition scheme given in the Nuclear Data Sheets (Vol 51, no. 1, p. 44 (1987)) (*Huo 87*) as well as on the ENDF/B-VI data file for ^{56}Fe (*Rose 91, Ed.*) for the excitation of levels below 4.6 MeV in inelastic scattering and on the results of accurate γ - yield measurements (*Armitage 69, Lachkar 74, Shi 82*).

The energy dependence of the coefficient $R = \sigma_{total\ inelastic}/\sigma_{847\ keV}$, with which the 847 keV - γ - production cross - section has to be multiplied in order to get the total inelastic cross section, is shown in Fig. 2. The inelastic cross section is equal to the nonelastic one in the energy region 0.85 MeV to 5 MeV. All high - resolution data covering a large energy range were averaged applying the same method as described for the total cross section; besides, the same group structure was used.

b) The results from direct measurements of the nonelastic cross sections by means of the sphere transmission method: Usually the experimenters claim a high accuracy for these absolute measurements. Since many of them obtained only partial cross sections (see *Vonach 91* for explanantion), the missing partial cross sections were added in order to obtain the total nonelastic cross section.

c) The results for the excitation of single levels or their sum measured via neutron detection by the time - of - flight method: As a rule these data are measured with low resolution. The cross section for total inelastic scattering may be obtained by summing over all partial cross sections. Apparently some of these data are affected by the problem of separating the contributions from inelastic scattering to the neutron spectrum from those, which are produced by elastic scattering. This difficulty arises when the spectrometer resolution function is not well known.

d) The results obtained via integration of the spectra of inelastically scattered neutrons measured by means of the time - of - flight method: The results of these measurements, too, in many cases are impaired by the above - mentioned difficulty in separating the contributions from elastic scattering processes.

e) Inelastic scattering cross sections obtained as the difference between the well - known total cross section and the measured cross section for elastic scattering. (The total cross section in general is known with an accuracy of about 1 %): In most cases this procedure can be used for neutrons with an energy above a few MeV, where the nonelastic cross section exceeds the elastic one. We did not use these derived data in order to avoid a double counting as the data for elastic scattering were accounted for at the last step of the evaluation.

As a result only 46 data sets (see Table 3) were chosen for the evaluation of the nonelastic cross section and its covariances. The prior values were taken from the EFF-2 cross section and covariance files. For creating MER correlations for the experimental data the same method was employed as described above for the total cross section. In the energy region up to 4 MeV the results of nine measurements covering a large energy range were used for creating general group - averaged nonelastic cross sections, between 4 and 20 MeV the respective data from the EFF - 2 evaluation served for this purpose. The general group - averaged cross sections were used for the construction of the MER covariances applying the same approach as described for the total cross section. The SER and LER components of the covariances were obtained from the information on uncertainty analysis given by the authors of the respective papers. Typical values for the assigned LER standard deviations amounted to 8 - 15% (as compared to about 1 % for the total cross section), the uncertainty components correlated over a short energy range amounted to between 1 and 10% and the MER uncertainty contributions ranged from 8 to 20%.

The last six data sets listed in Table 3 present the results for nonelastic cross sections measured by means of the sphere transmission method. We corrected these data taking into account the special features of the measurements mentioned above in b).

In the 14 MeV region (i.e. from 13.5 - 14.8 MeV) the data from the individual experiments have already been evaluated before at the IRK; the result presented as *Vonach 91* in Table 3 is included as one data point in the present evaluation. Therefore, the single experimental data and data sets in that energy range are no longer listed in Table 3.

The overall χ^2 was equal to 1.1 and was obtained in a second run after some adjustment of the correlation matrix for a few shape-type experimental data which were inconsistent with the prior data. (Usually χ^2 for these data is much higher than 1 due to a different shape as compared with the prior data). The adjustment was made by reducing the range (Γ parameter) of the MER correlations and the ratio of LER to SER standard deviation values (both lead to a reduction of the correlations between the data at different energy points for a given experimental data set).

The evaluated central values and covariances for the nonelastic cross section were considered as redundant and included in the further evaluation process as pseudo-experimental data when consistency conditions between total and partial cross sections were imposed.

5.3. The cross sections for inelastic scattering

The ^{56}Fe scheme of discrete levels is known without noticable gaps up to 4.51 MeV, the energy of the excitation of the low-lying octupole vibrational level. The number of levels given in different evaluated data files and in the Nuclear Data Sheets (*Huo 87*) is different: 25 in the ENDF/B-VI file, 27 in the Nuclear Data Sheets from the observed γ - transitions and 33 in the EFF-2 file. We used the level scheme and neutron inelastic scattering cross sections for the excitation of these levels as given in the EFF-2 evaluated data file as prior values. Only one correction was carried out: the low-lying 3.070 MeV level (MT = 56, EFF-2) was excluded because it was not observed in any measurement of γ -transitions; its presence and competition in statistical model calculations, however, leads to a substantial decrease of the inelastic scattering cross section for other levels.

The existing experimental information on the excitation functions for the separate levels and groups of levels gives a chance to improve the cross sections and related covariances if the Bayesian procedure is applied to the following levels and groups of levels (with MT reaction numbers from the EFF-2 file):

1. MT = 51, E_{lev} = 0.847 MeV
2. MT = 52, E_{lev} = 2.085 MeV
3. MT = 53, E_{lev} = 2.658 MeV
4. MT = 54 - 58, E_{lev} = 2.942 - 3.123 MeV (but without MT = 56, E_{lev} = 3.070 MeV, as explained above)
5. MT = 59 - 65, E_{lev} = 3.370 - 3.607 MeV
6. MT = 66 - 83, E_{lev} = 3.748 - 4.510 MeV
7. MT = 91, E_{lev} = 4.52 MeV, continuum of levels.

For this purpose the inelastic scattering cross sections for the excitation of separate levels were summed up regarding the groups given above. When necessary, the experimental data were treated similarly, but in many cases, due to the finite experimental resolution, the authors gave measured values for these levels and groups of levels.

With an accuracy of a few mb (which corresponds to the value of the (n,γ) cross section) the inelastic scattering cross section for the excitation of the first level in ^{56}Fe (E_{lev} = 0.846 MeV, I^{π} = 2^{+}) coincides with the nonelastic cross section below an energy of 2.08 MeV, the threshold for the inelastic scattering with excitation of the second excited level. To preclude a double counting of the same data for the Bayesian procedure, only the experimental data for neutron energies higher than 2.08 MeV were taken into account when the excitation function for inelastic scattering to the first excited level was evaluated. The experimental data sets included in the present evaluation are listed in Table 4. As the starting point the EFF-2 evaluated cross sections for inelastic scattering to the discrete levels and to the continuum together with the corresponding covariances were chosen as the prior information. The overall χ^2 (0.35) per degree of freedom proves that the experimental data are very consistent. Such a consistency, however, was obtained only after reducing the MER correlation width for the experimental covariances from the usual value of 2.0 MeV to 0.2 MeV for some shape-type measurements, what is practically equivalent to converting them into separate - point measurements. The angular differential data from the works *Mellema 86* and *Tsukada 65* were integrated using the code GPOLFIT (*Pavlik 90*).

The same procedure was applied for the other levels and groups of levels. The experiments considered for the present evaluation are listed in the Tables 5 to 8. The χ^2 values per degree of freedom obtained were equal to 1.3 for the MT = 52 level, 0.95 for the MT = 53 level, 0.65 for the group of the levels 4 - 7 (MT = 54 - 58 without MT = 56), and 0.73 for the group of the levels 8 - 14 (MT = 59 - 65). The higher χ^2 values for MT =

52 and MT = 53 result partially from the fact that we used as a prior the evaluated excitation functions from the EFF-2 library with the underestimated values of the respective cross section due to the presence of the fictitious level at 3.07 MeV.

As most of the data on total inelastic scattering were already accounted for in the evaluation of the nonelastic cross section and the corresponding covariances, we considered inelastic scattering cross section data only for neutron energies above 12 MeV, where the difference between the nonelastic and inelastic cross sections becomes substantial. For the 14 - MeV energy region (13.5 - 14.8 MeV) an evaluation performed previously at the IRK (*Vonach 91*) resulted in a cross - section value of high accuracy at 14.0 MeV, which was included in the present evaluation as a single data point replacing all experimental data in that energy range. The remaining data are the 847 keV γ-ray production cross-section measurements given in the works *Dickens 91*, *Voss 71* and *Corcalciuc 78*, which can be reduced to the total inelastic scattering cross section as shown before (see Fig. 2). By doing this we found that the data given in *Dickens 91* and *Voss 71* are not consistent with the evaluated value at 14.0 MeV, being too low by about 10% and 40% respectively. The reason for this discrepancy is unclear, but probably it is a problem of neutron flux measurement and/or background separation when the spectrometer resolution function is not explicitly known. To avoid further complications with accounting for these discrepant data we treated the data from *Dickens 91* as shape cross-section measurements by renormalizing them to the 14 MeV data point and by increasing the long-energy-range component of the uncertainty for this data set to such values that the original data may be considered to be consistent ($\chi^2 \approx 1$). The data from the work *Voss 71* were discarded because of a big discrepancy with other experimental data and with the prior data.

These measured total inelastic scattering cross section data were considered as redundant data, which were included in the evaluation process at the last stage when consistency conditions between total and partial cross sections were imposed. Finally, all partial inelastic scattering cross sections for the individual levels inside the groups were renormalized in such a way that the ratios between them as predicted by model calculations for the EFF-2 evaluated data file were preserved.

5.4. The cross section for elastic scattering

Elastic scattering cross sections for ^{56}Fe are generally known with less accuracy than the total and nonelastic cross sections. Due to the relation $\sigma_{tot} = \sigma_{el} + \sigma_{non}$, the elastic cross section and covariances can be obtained from the total and nonelastic cross sections and their covariances (NC type subsection in MF = 33) on the one hand, and, on the other hand, the existing experimental information on elastic cross sections and covariances serves to improve our knowledge of the total and nonelastic cross section and their respective covariances.

In order to include the existing experimental information on the elastic scattering cross sections and covariances into the evaluation we proceeded as follows: As a first step the evaluation of the elastic scattering cross section and covariances was performed independently from the data on the total and nonelastic cross sections. For this purpose the elastic scattering cross section and the covariance matrix from the EFF-2 file including only elastic scattering cross section correlations between different energies were taken as prior information. The covariances were obtained by a purely mathematical procedure converting a NC-type into a NI-type subsection. Then the Bayesian method was used to account for all experimental cross section data on elastic scattering existing in the EXFOR data base. The experimental data base for elastic scattering comprises 34 data sets as given in Table 10. Some of the integral cross sections were obtained by integrating angular - differential data via a polynomial fit carried out by means of the code GPOLFIT (*Pavlik 90*). The results of 20 experiments (*Walt 54* to *Olsson 87*, listed in Table 9) providing cross - section data at a single energy were combined into one uncorrelated data set. This was possible since these works exhibited no obvious correlations among each other. The covariance matrices for the cross - section data for elastic scattering were prepared as described for the total cross section. By intercomparison with the elastic scattering cross section obtained as the difference between the evaluated total and nonelastic data and the corresponding uncertainties we found a serious discrepancy between these two independent evaluations of the elastic scattering cross section in the energy region from 4 to 8 MeV. The apparent reason is an underestimation of the integral elastic scattering cross sections by 5 - 15% in practically all direct measurements for this energy region.

Although we mentioned to have taken the ^{56}Fe elastic scattering cross section from the EFF-2 library as a prior, this is true only for neutron energies above 4 MeV. For lower energies, due to the problems with a spherical model description of the total and elastic scattering cross sections (this approach was used for the EFF-2 evaluation for ^{56}Fe) we chose as a prior a group-averaged cross section obtained as the difference between the new evaluated total and nonelastic cross sections with their respective covariance matrices as described above. The covariances for practically all experimental data on elastic scattering in the energy region between 4 and 8 MeV were revised by increasing the total errors to 15% and decreasing the correlations between different energy points. Thus the χ^2 value for the 34 chosen data sets was close to 1.

5.5. The (n,p) reaction cross section

For this dosimetry reaction there exists a considerable number of experimental cross section data in the energy range from the effective threshold up to 20 MeV, which were measured predominantly by means of the activation method. The experimental data base was established relying on an EXFOR retrieval and including a very recent precision measurement which covered the energy region 9.1 - 14.6 MeV (*Mannhart 92*). In the 14 - 15 MeV energy region a slightly different method was adopted: We relied upon the result of a careful and well - documented evaluation carried out by Ryves (*Ryves 89*) at 14.7 MeV instead of repeating his work. The shape of the ^{56}Fe(n,p)^{56}Mn excitation function in this energy region had been measured very accurately in a work by Vonach et al. (*Vonach*

68). Therefore, we combined this shape measurement with the above - mentioned evaluated absolute cross section at 14.7 MeV taking into account the correlations thus established.

The data given in the literature were carefully reviewed in order to discard obsolete or obviously wrong results. Two experiments (*Jönsson 69* and *Mostafa 76*) were excluded for the following reasons:

Jönsson 69: In this work, due to the irradiation geometry used, the energies of the incident neutrons covered a wide range (14.7 MeV - 15.5 MeV) and the mean energy is not well - defined. This, however, is essential as in that energy region the cross section is strongly energy - dependent.

Mostafa 76: The measured shape of the $^{56}Fe(n,p)^{56}Mn$ excitation function markedly differs from the shape given in a number of other reliable works.

The published experimental values were renormalized to the most recent reference cross sections taken from the IRDF-90 (*Kocherov 90*) ($^{27}Al(n,\alpha)^{24}Na$), ENDF/B-VI ($^{238}U(n,f)$) and an evaluation of dosimetry cross sections in the 14 - 15 MeV region performed by Ryves (*Ryves 89*) ($^{65}Cu(n,2n)^{64}Cu$, $^{56}Fe(n,p)^{56}Mn$). For the experiment *Santry 64* the $^{32}S(n,p)^{32}P$ reference cross sections as given by the authors were retained since they were based to a great extent on their own measurements. An uncertainty of ± 5% was assigned to them. At 14.5 MeV the $^{32}S(n,p)^{32}P$ cross section which they used for normalization of their data in the energy range 13.58 - 20.3 MeV (226 mb) agrees very well with the evaluated cross section recommended in *Ryves 89* at this energy (225.9 mb). Thus, in that higher-energy region the uncertainty given for the evaluated reference value at 14.7 MeV added in quadrature to the uncertainty for the slope of the $^{32}S(n,p)^{32}P$ excitation function was taken. In a number of experiments, namely *Liskien 65*, *Liskien 66*, *Ryves 78* and *Kudo 87* above a neutron energy of 15 MeV) the n-p scattering cross section had been chosen as a reference. For the data published in these works no renormalization for the standard cross section was necessary. Since the decay data for ^{56}Mn are well-known for many years, no adjustment of the results was needed in this regard. As a common reference we used the data quoted by Tuli (*Tuli 87*) and by Lorenz (*Lorenz 87*) in the *Handbook on Nuclear Activation Data* (*Okamoto 87, Ed.*).

Obviously missing uncertainty components for the results given in a number of papers were supplemented according to our best estimate adding them in quadrature to the quoted uncertainties on a 1 σ - level. For the reference cross sections the most recent uncertainty values were taken.

Most authors irradiated iron foils or powder of natural isotopic composition which contains 2.15% ^{57}Fe and measured the ^{56}Mn production cross section. In order to extract the true $^{56}Fe(n,p)^{56}Mn$ cross section, the contribution from the $^{57}Fe[(n,np) + (n,d)]^{56}Mn$ reaction had to be taken into account above an energy of 15 MeV, where it gains increasing importance due to the opposite slopes of the excitation functions of the (n,p) and the (n,np) reactions. To this purpose we used the calculations given by Kudo et al. (*Kudo 87*); the required correction factors were read from Fig. 4 in their work.

Table 10 presents the experimental data base, i.e. the works accepted for this evaluation, and gives an overview of the corrections applied to the original data.

Correlation matrices were constructed for every single paper containing measurements at more than one energy. A detailed documentation on the contributions of random and systematic uncertainties to the total uncertainty was provided in some papers, e.g. *Vonach 68*, *Ryves 78*, *Kudo 87*, thus permitting to establish the off - diagonal elements of the covariance matrix, or the authors directly informed us on the level of correlations in their work (e.g. *Mannhart 92*). But mostly a rough estimate of the total systematic uncertainties is supplied in the original publications, which led to a reasonable estimate of the correlations; for a few papers no uncertainty analysis at all was given, therefore we had to rely on a judgement based on the overall experimental conditions for the respective work in order to estimate the impact of correlated uncertainty compents. Correlations between different experiments had been established especially when the measured cross section values were based on the same reference cross sections. In general, due to much more prominent contributions to the total uncertainty from other sources these inter-correlations proved to be rather small, that means that the corresponding off-diagonal elements of the composed correlation matrix were < 5%. Where they played a more prominent role, e.g. in the works *Vonach 68* - *Ryves 89* (evaluation) (41 %), *Liskien 65* - *Ryves 78* - *Kudo 87* (7 - 24 %), they were accounted for and the correlated experimental values were processed as one data set in the evaluation. The decay data of ^{56}Mn are known with a high accuracy so that the correlations caused thereby were negligible.

For the evaluation we started from the data contained in the EFF-2 file. A group structure like that used for the above mentioned reactions was used for these data, yet the different interpolation laws proposed in EFF-2 in different energy regions were retained as far as possible. The high long-energy-range correlations given for the EFF-2 prior data, however, conflicted with the relatively high correlations present in a number of experiments which, too, covered a large energy region; this was especially true for the more accurate measurements, as soon as a slight deviation of the shape of both the respective prior excitation function and the new experimental data set occurred. In order to amend this situation a "white-sheet-prior" was taken where the off-diagonal elements of the covariance matrix were practically set to zero.

Another difficulty was posed by the work *Smith 75*; the χ^2 value of > 6.5 was caused by a deviation in the shape in the 8.5 - 10 MeV region and by small - scale structure in their data. Since the interpolation rule between adjacent energy point requires a smooth behaviour of the excitation function, these deviations had to be accounted for by increasing the quoted uncertainties by a factor of 2 near the threshold and in those energy regions where structure was present in their data (in the energy regions 4.80 - 5.0 MeV and 5.60 - 6.0 MeV). The difference in energy between neighbouring data points in these regions is $\leqslant$ 100 keV, whereas the energy resolution is quoted to be ≈ 140 keV. Since the results given in *Smith 75* appear to be too low by ≈ 10% in the energy range 8.50 - 10 MeV - a fact that was observed also for other cross sections measured in the same work, e.g. ^{58}Ni(n,p)^{58}Co (see *Smith 91*) -, the total uncertainty in this energy region was increased to ± 10% decreasing the corresponding correlations accordingly.

The general χ^2 value per degree of freedom is 1.47, indicating an only moderate consistency of the experimental data. Nevertheless, an obvious improvement of the recommended cross sections for this important reference reaction could be attained by the application of Bayes' theorem in this stepwise evaluation. The $^{56}Fe(n,p)^{56}Mn$ cross section entered the last step in this evaluation procedure as an independent cross section when consistency conditions were imposed.

5.6. The (n,2n) reaction cross section

For this reaction, too, the prior values of the cross section were taken from the EFF - 2 file; its covariances were supplied by the above mentioned expert evaluation.

In order to be able to utilize a broader experimental data base we also took into account the measured (n,2n) cross section data on natural iron, to which we applied a correction for the contributions from the minor Fe isotopes. Besides a number of point-wise cross section measurements in the 14 MeV region three data sets covering a larger energy range (*Fréhaut 80a* (for ^{nat}Fe), *Fréhaut 80b* (for ^{56}Fe) and *Auchampaugh 80* (for ^{nat}Fe)) are available from the literature or from EXFOR. The results given in Fréhaut's works were renormalized by a factor of 1.077 according to the reasons discussed in detail by Vonach et al. (*Vonach 90*).

Corrections for the contributions from minor isotopes, especially from ^{57}Fe and ^{54}Fe, were carried out in the following way: Both the $^{57}Fe(n,2n)^{56}Fe$ and the $^{54}Fe(n,2n)^{53}Fe$ excitation functions were obtained as the unweighted average of the cross sections recommended in the ENDF/B-VI and the BROND-2 (*Manokhin 88*) evaluations; the differences between the respective values were regarded as the uncertainties to be assigned to these averages. The contribution from the $^{58}Fe(n,2n)^{57}Fe$ reaction was assumed to be negligible due to the low isotopic abundance of ^{58}Fe (0.29%). In the case of the Fréhaut data only the contribution from the reaction $^{57}Fe(n,2n)^{56}Fe$ had to be accounted for.

For the papers *Fréhaut 80a,b* and *Auchampaugh 80* a detailed account of the systematic and hence correlated uncertainties was lacking. Therefore we had to rely on a summary statement in their reports and therefrom to estimate the values for the correlated portion of the total uncertainties. The additional correlation introduced by the correction for the minor isotopes was also considered. The data sets *Fréhaut 80a and 80b* are correlated to a relatively large extent due to the fact that the authors used the same experimental method in both investigations; these correlation, too, was properly taken into account and the results of both experiments were treated as a single data set in the sequential evaluation.

The results published in the paper *Auchampaugh 80* were stated to be preliminary ones. Until now no final publication was issued. The authors indicated that the cross section value at 21 MeV should be augmented by 5 - 10%, remain unchanged at 18 MeV and be reduced by 3 - 5% at 14.7 MeV to account for additional corrections due to efficiency changes with the incident neutron energy. In a private communication Veeser confirmed these values (*Veeser 92*) and suggested to supply them with uncertainties as large as the corrections. At the intermediate energies we used linear interpolation. Finally, the uncertainty given for the 17 MeV data point was doubled for physical reasons, since the (n,2n) excitation function in that energy range is expected to increase smoothly. The data point at 21 MeV from *Auchampaugh 80* was not included in our evaluation, since the highest energy contained in the prior EFF - 2 file is 20.375 MeV.

The cross section data at a single energy in the 14 MeV region are either measured for highly enriched ^{56}Fe targets (*Wenusch 62, Qaim 76, Greenwood 88*) or derived from results from natural iron (*Ashby 58*); in the latter case the contributions from minor isotopes were again corrected for. Moreover, Ashby's data were renormalized by a factor of 0.815 according to the reasons explained in *Vonach 90*. The result given in *Wenusch 62* was renormalized to the actual recommended $^{27}Al(n,\alpha)^{24}Na$ reference cross section (*Wagner et al., 1990*).

The data from three papers were discarded for the following reasons:

Prokopets 80: The energy of the single data point (20.6 MeV) exceeded the energy range within which the prior EFF - 2 file contains data.

Kozyr' 78: The cross section given by these authors at 14.6 MeV does not result from a direct measurement but rather is derived from secondary neutron emission spectra.

Corcalciuc 77: In this experiment partial (n,2n) cross sections were measured via the γ-rays emitted in the deexcitation of excited ^{55}Fe levels. The cross-section value for the direct population of the ground state can be obtained only by model calculations. The authors did not carry out or document explicitly such calculations.

Table 11 shows a summary of the experimental data base used for this evaluation and the corrections applied to the published results. The χ^2 values for the single experimental works ranged from 1.50 to < 0.1; the general χ^2 was 1.06, indicating a satisfactory consistency of the input data. The evaluated cross section and covariance matrix was used as one of the basic data sets when consistency conditions between partial and total cross sections were taken into account.

5.7. The (n,α) reaction cross section

In the case of the $^{56}Fe(n,\alpha)^{53}Cr$ reaction again the excitation function as contained in the EFF - 2 evaluated data file together with the corresponding covariances obtained by expert evaluation was chosen to be the prior data set. The standard deviations for these recommended cross sections are rather large, ranging from 80% (from above the threshold energy to 11 MeV) to 20% (in the 14 - 15 MeV region).

Experimental data for this reaction are scanty, especially outside the 14 MeV energy region. Since the reaction product ^{53}Cr is a stable nuclide, the (n,α) cross section for ^{56}Fe cannot be measured by activation. In fact, all experimental data published in the literature represent cross sections for α - emission or total He production either on natural iron or on enriched ^{56}Fe targets. Besides a small number of works reporting measurements at a single neutron energy in the 14 MeV region hitherto only two further investigations (*Paulsen 81* and *Saraf 91*) were carried out studying the energy dependence of the α - emission cross section in the 4.89 - 9.97 MeV and 8.0 - 11.0 MeV energy ranges, respectively. At these energies the measured cross sections essentially represent the (n,α) reaction only, since the contribution from (n,nα) processes is either nonexistent or negligible in comparison to the uncertainties stated for the experimental results. Paulsen et al. (*Paulsen 81*) measured double - differential α - emission cross sections on natural iron employing a specially constructed reaction chamber. Results are also given for the angle - integrated total α - emission cross sections and their random uncertainties; in addition, a systematic uncertainty of 6.4% is stated. The contribution from the ^{54}Fe(n,α)^{51}Cr reaction was corrected for in order to extract the isotopic ^{56}Fe(n,α) cross section. To this aim the results of a recent precision measurement of the ^{54}Fe(n,α)^{51}Cr excitation function carried out by Meadows et al. (*Meadows 91*) were relied upon. The contributions from the other minor Fe isotopes, ^{57}Fe and ^{58}Fe, were considered to be negligible due to their low abundance. The angle - integrated results of a very recent experiment on α - emission for ^{56}Fe reported by Saraf et al. (*Saraf 91*) are discrepant to Paulsen's data in the common energy region. Since, however, the cross sections given for the ^{54}Fe(n,α) reaction in Saraf's work agree within the uncertainty limits with those obtained in *Meadows 92* by the activation method, there was no hint indicating which of both data sets is to be regarded erroneous and both were included into the evaluation. However, we increased the total uncertainties of the cross sections in both works by a factor 1.5 in order to arrive at a more consistent input data base. The correlation matrices for both data sets were constructed using the information on systematic uncertainties as supplied in the respective papers. For the experiment *Paulsen 81* the impact of the correction for the contribution from the ^{54}Fe(n,α)^{51}Cr reaction was taken into account.

In the 14 MeV region the total α - production cross sections from the literature were used. The result reported in *Wattecamps 83* for natural iron was corrected for the contribution from the minor Fe isotopes using Kneff's data (*Kneff 86*) on He production for the individual Fe isotopes at 14.8 MeV. In view of the rather big uncertainty given by Wattecamps for his data the relatively small energy dependence of this correction in the 14.1 to 14.8 MeV region was neglected. From the total α - production cross sections the (n,nα) reaction cross section as derived from theoretical estimates (1.10 $\pm$ 0.57 mb, see *Pavlik 91*) was subtracted in each case. This procedure does not introduce a large error since at $\approx$ 14 MeV this cross section constitutes only a small fraction of the total α - emission cross section. The data published by Dolya et al. (*Dolya 75*) were excluded as his measurement is known to systematically overestimate the α - production cross section (see also the comment in *Vonach 91*). Table 12 presents a summary of the experimental data base used for this evaluation and the corrections applied to the published results. The general χ^2 in the case of the (n,α) cross section amounts to 0.90. The individually evaluated cross section was used as a new prior data set for the final evaluation of all ^{56}Fe cross sections considered in this work.

6. Consistent joint evaluation of all cross sections

As the last step of the evaluation consistency between all cross sections was restored by means of the following procedure: The improved individual basic cross sections (see section 5) were used as a new prior and the values of the redundant cross sections (σ_{el}, σ_{non}, σ_{inel}, $\sigma_{p\text{-}prod}$) were added as "data" using again the code GLUCS based on the equations 1 and 2 (see section 2). The posterior derived in this way not only fulfills strictly the consistency relations (equations 8 - 11) but is also considerably improved in quality as many of the redundant cross sections (e.g. σ_{non} and σ_{inel}) are known rather accurately and this accuracy is in part transferred to the basic cross sections by means of the applied constrained least - squares fit. In detail the following consistency conditions between different reaction cross sections were introduced:

$$\sigma_{p\text{-}prod} = \sigma_{n,p} + \sigma_{n,np} \tag{8}$$

$$\sigma_{inel} = \sigma_{n,n1} + \sigma_{n,n2} + \sigma_{n,n3} + \sigma_{n,n4\text{-}n7} + \sigma_{n,n8\text{-}n14} + \sigma_{n,n15\text{-}n32} + \sigma_{n,n\ cont} \tag{9}$$

$$\sigma_{non}^{*} = \sigma_{n,2n} + \sigma_{n,\alpha} + \sigma_{n,p} + \sigma_{n,np} + \sigma_{n,n1} + \sigma_{n,n2} + \sigma_{n,n3} + \sigma_{n,n4\text{-}n7} + \sigma_{n,n8\text{-}n14} + \sigma_{n15\text{-}n32} + \sigma_{n,n\ cont} \tag{10}$$

$$\sigma_{el} = \sigma^{*}_{tot} - \sigma_{n,2n} - \sigma_{n,\alpha} - \sigma_{n,p} - \sigma_{n,np} - \sigma_{n,n1} - \sigma_{n,n2} - \sigma_{n,n3} - \sigma_{n,n4\text{-}n7} - \sigma_{n,n8\text{-}n14} - \sigma_{n,n15\text{-}n32} - \sigma_{n,n\ cont} \tag{11}$$

where the right side presents the basic cross sections evaluated as described in section 5, which are considered now as new prior data, and the left side presents the redundant cross sections. They are either new experimental data, e.g. for proton production, or pseudo-experimental data as, e.g., for the nonelastic cross section. The experimental data base for the elastic and inelastic scattering cross sections was presented above; for proton production there exist only two measurements hitherto (*Grimes 79* and *Saraf 91*), which are listed in Table 13. σ_{tot}^{*} and σ_{non}^{*} are the total and nonelastic cross sections evaluated above, from which a part representing the sum of so-called minor cross sections for the energy range considered, such as the (n,γ), (n,d), (n,t), (n,^{3}He) and (n,nα) reaction cross sections, were subtracted.[1)] Since the EFF-2 file was incomplete with respect to some of these reaction cross sections, we took these data from the ENDF/B-VI file. Then all relevant data were processed by the GLUCS code in one run.

In order to cope with this task, the original GLUCS code was revised by one of us (S.T.) in two aspects: First of all, it is now possible to introduce new experimental data for the sum and the difference or for any linear combinations of prior reaction cross sections.

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1) This was done in order to keep the size of the prior data vector in reasonable limits. No experimental data exist for these small cross sections and because of their very small absolute values no information about them can be obtained from the consistency relations. Furthermore, their uncertainties can be neglected compared to the uncertainties of σ_{tot} and σ_{non}; thus it is permitted to use the uncertainties derived for σ_{tot} and σ_{non} also for σ_{tot}^{*} and σ_{non}^{*}.

Secondly, thanks to a new option, a much simpler format for the correlation matrix can by used in those cases where no correlations exist between two or more subsets of one data set, as was the case for our prior, where no correlations existed between the cross sections for different reactions.

Because of the conditions (8) - (11) and the consideration of all 12 non-redundant cross sections as one coupled set (see also Fig. 1), the resulting correlation matrix now includes parts which describe correlations between different energy intervals of different cross sections. We have to decide whether these correlations are important or not. If the level of correlations between two experiments is low, we may leave out the corresponding rectangular correlation matrix from file MF = 33, in order to greatly simplify the presentation of the information on the covariances.

To demonstrate the level of correlations which appear as a consequence of imposing the consistency conditions, the highest values of the correlation coefficients within the correlation matrices between any two basic cross sections are shown in Table 14. Although the coefficients contained in the rectangular matrices describing the correlations between different energy groups of two reactions in general are small, we may point out that the level of correlations between some types of cross sections is rather high. This information has to be kept in the evaluated data files. An example of such a matrix describing the correlations between different energy groups of the total and the inelastic scattering cross sections with excitation of the first level is shown in Table 15. Evidently the matrix is unsymmetric: $c(\sigma_1(E_1),\sigma_2(E_2)) \neq c(\sigma_1(E_2),\sigma_2(E_1))$. That means that new measurements of the total cross section in the 14 MeV energy range may influence the values for the inelastic scattering cross section with excitation of the first level near its threshold, but not vice - versa.

7. Results of the evaluation

The main result of this evaluation is a complete but non-redundant set of cross sections (σ_{tot}, $\sigma_{n,n1}$, $\sigma_{n,n2}$, $\sigma_{n,n3}$, $\sigma_{n,n4-n7}$, $\sigma_{n,n8-n14}$, $\sigma_{n,n15-n32}$, $\sigma_{n,ncont}$, $\sigma_{n,p}$, $\sigma_{n,np}$, $\sigma_{n,\alpha}$, $\sigma_{n,2n}$) and their covariances in the fast neutron energy range 0.85 - 20 MeV in a 40-group structure. In addition, cross sections and covariances for σ_{el}, σ_{non} and σ_{inel} were obtained by expressing these cross sections as linear functions of the basic cross sections (see equations 8 - 11). In the Tables 16 - 22 the final results of this evaluation, i.e., the group-averaged cross sections and their uncertainties, are listed. These results are also presented in the Figures 3 - 16. For convenience two figures are shown for each reaction in order to facilitate the comparison: the first figure (labeled a)) displays the adjusted experimental data base together with the cross sections from the EFF - 2 file and its uncertainty limits taken usually as the prior data; the second figure (labeled b)) compares the prior EFF - 2 cross sections and the corresponding uncertainties (now shown as the symbol O) with the resulting excitation function from the present evaluation. For some of our basic cross sections ($\sigma_{n,n15-n32}$, $\sigma_{n,ncont}$, $\sigma_{n,np}$) no experimental data are published in the literature. Therefore, only one figure is given showing the prior data and the final evaluated result. In these cases the improvement is entirely due to the experimental data on the redundant cross sections introduced at the last step of the evaluation. From these figures the progress achieved in this evaluation is immediately obvious.

1) The largest improvement in the evaluated cross sections was attained in the energy region below 3 MeV. At these low energies the theoretical description of the cross section by means of the optical model becomes rather poor so that rather large uncertainties are to be assigned to any calculated cross sections (*Vonach 91*) and experimental data are more accurate.

2) For all cross sections above 3 MeV our new evaluated cross sections eventually agree with the prior EFF - 2 values; the new uncertainty limits confirm at the same time the validity of the uncertainty estimates for the cross sections from the EFF - 2 file, which were derived from the dispersion of recent evaluations. In the case of the (n,p) cross section, however, one exception should be mentioned with regard to the 14.5 - 16.5 MeV energy region where the experimental data governed the outcome of the present evaluation. There the new cross - section values are lower than those recommended in the EFF - 2 evaluation and the high level of accuracy obtained for the presently evaluated cross sections results in a slight disagreement between the prior and the final data sets. In all other energy regions such differences are smaller than the combined uncertainty limits.

3) The most important improvement of our new evaluation is certainly the considerable reduction of the uncertainties for the cross sections in energy ranges where accurate measurements exist. For the most important cross sections σ_{tot} and σ_{non} the uncertainties are reduced by about a factor of three to six over the whole energy range up to 14 MeV. Eventually our evaluation procedure is an evaluation of experimental data in the energy regions where such data were measured with a high accuracy, joined smoothly to the theory - based EFF - 2 evaluation in those regions where data are lacking.

One might question the rather small uncertainties resulting from our evaluation because of possible correlations between our prior data and the added data sets. This objection, however, is not valid because the statistical weight of the priors becomes negligible if the added data are much more accurate than the prior ones, and just this situation exists in these parts of our evaluation where the uncertainties are very low.

Of course, as is the case with any evaluation of experimental data, the uncertainties of our results could be too small because of unrealistically low uncertainty estimates given for the data or because of neglecting correlations between different data sets. As discussed in the previous chapters we accounted for such effects by increasing the uncertainty components as estimated by the authors in all cases which appeared doubtful to us. Correlations between different data sets were checked and generally found to be small. Finally our uncertainty estimates are confirmed by the fact that in all evaluations of individual cross sections and in the final joint evaluation χ^2 values of about unity were obtained. According to our judgement which is also based on our previous experience with evaluations of experimental data (*Pavlik 88, Wagner 90, Vonach 91*) the final uncertainties of the present evaluation are realistic effective standard deviations at the 1 σ confidence level.

In addition, a comparison with the reaction cross sections as recommended in the ENDF/B-VI evaluation is presented in the Figures 17- 27. In general both evaluations agree within their combined uncertainty limits. On the average it appears that the uncertainties in ENDF/B-VI have been estimated somewhat too pessimistic.

As a result of the final step of the present evaluation due to taking into account the consistency conditions (8) - (11) and new data the total cross section was decreased at the average by 0.5% and the nonelastic cross section was increased by $\approx$ 1% in comparison with the results at the first step of our evaluation. The same level of adjustment is characteristic for the (n,p), (n,2n) and (n,α) reaction cross sections and for those partial cross sections for inelastic scattering which had rather low uncertainties as a result of the first step in this evaluation, i.e. the independent evaluation of each individual cross section. To a greater extent the applied procedure at the final step of the evaluation influenced the results for the cross sections and covariances for the (n,np) reaction and for inelastic scattering with excitation of the third group of levels (15 - 32, corresponding to MT = 65 to 82) and of continuum states, since the prior uncertainties for these cross sections were rather high.

8. Discussion of this approach

A few interesting phenomena which are characteristic for data with correlations between different energy points and look strange when we forget about the existence of these correlations should be discussed because they may substantially influence the results of the evaluation. Unexpected phenomena may appear when the theoretically evaluated data with expert-evaluated covariance matrices having rather large correlations over a wide energy range are used as prior data for including by the Bayesian procedure:

1) highly accurate values at separate energy points;

2) highly correlated data covering a large energy region (shape type data).

In the first case a "preserving-the-value" phenomenon is observed when a prior correlation matrix containing only positive elements is converted into a posterior matrix which also contains negative values for the elements describing correlations between energy points on different sides of this highly accurate measured (or evaluated) data point. As a result, any new values which cause an increase of the posterior data, e.g., at the higher-energy side may simultaneously lead to a decrease of the posterior data at the lower-energy side - viewed from the accurate data point in question - , while the cross-section value for this point is preserved.

In the second case a "preserving-the-shape" phenomenon is observed when new highly correlated shape-type data, which are, e.g., definitely higher than the prior data and exhibit a different shape with respect to the sign of the second derivative, are introduced. This leads to posterior cross-section values which are lower than the prior data. The reason for this result which at first sight seems strange, is an attempt to combine the highly correlated data exhibiting a different shape with the prior data which are also highly correlated. As a rule, the χ^2 value in such a case is very large proving thus that the prior evaluation and the new data are inconsistent. In order to overcome this problem we have either to recognize that the shape of the long-energy-range correlations of the prior evaluation is wrong or to reduce the level of correlations between the energy groups of the experimental data considering them practically as a set of uncorrelated measurements at single energy points.

9. Creation of the final cross - section and covariance file in the ENDF/B-6 format

For most of the excitation functions the results of the GLUCS evaluation procedure have been formatted immediately to ENDF-6 specifications. For the total cross section and the inelastic scattering cross sections to the first three excited levels, however, a special procedure has been used for the following reason:

The energy group structure chosen in the GLUCS evaluation is appropriate to describe existing covariances. The (low) variances derived in our evaluation are, consequently, the result of the according group - averaging procedure and hence valid for the group - averaged cross sections only. Description of deep penetration experiments in bulk iron samples with neutrons in the energy range of 0.85 to 5 MeV, however, will be much improved, if the fine structure in the cross section, known from high - resolution measurements, is used in the calculations. For this situation the ENDF-6 specifications provide the possibility to "reintroduce" known uncertainty information on a much finer energy grid by means of a LB = 8 subsubsection in file 33. Therefore our file 33 contains in a LB = 5 subsubsection the results of the group - averaged GLUCS evaluation, the variances reduced by a statistical component given in a LB = 8 subsubsection. When the covariance matrix is transformed to a finer energy grid, this uncorrelated component will scale up to the original statistical uncertainty of the high - resolution data and thus create a correct covariance matrix.

Therefore, in constructing the final evaluated data file, the group - averaged cross sections for the total cross section and for the inelastic scattering cross section with excitation of the first three levels were replaced by the results of high - resolution measurements normalized within each energy group to the respective evaluated group - averaged cross section. The results of the high resolution measurements carried out by Larson *(Larson 89)* were used for the total cross section and those performed by Voss et al. (*Voss 71*) for the partial inelastic scattering cross sections. As a consequence the redundant cross sections, i.e., the cross sections for elastic scattering, the nonelastic and the total inelastic cross section, also exhibit fine - structure.

10. Conclusions

The results obtained in the present work show that the application of Bayes' theorem for updating theoretically evaluated cross sections, taken as prior data, by experimental data can result in a much improved evaluation. Essentially in all energy regions where accurate data exist, the evaluations are dominated by these data with a corresponding reduction of the uncertainties, while at the same time the basic advantages of theory - based evaluations, - completeness and consistency - remain fully conserved. In our case of ^{56}Fe a reduction of a factor 2 - 3 has been obtained for the cross - section uncertainties over extended energy ranges. It is to be expected that similar improvements can be obtained for all materials for which accurate experimental data are available, which mostly are also materials of high importance for applications as other structural materials.

Furthermore our results confirm the validity of the recent evaluations EFF - 2 and ENDF/B-VI within their stated uncertainties. Thus it appears that a rather qualitative and rough method for generating covariances as used in these evaluations is quite reliable.

For the cross sections which are most important for the calculation of neutron deep - penetration effects, the obtained evaluated group-averaged cross sections and covariances in a simple manner can be converted into a point-wise form having fine structure. As a result of this work a new ^{56}Fe file (MF = 3 + 33) based on theoretical model calculations and a complete experimental data base is now available.

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Table 1: Experimental data base for the total cross section

Part I. Large energy range measurements

EXFOR Entry	First Author and Year	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
11121	*Wells 63*	1	0.85-1.00		3.8 (total)		1.0
21044	*Manero 64*	11	8.50-14.0	1	1	1	0.4
11467	*Albergotti 66*	4	12.5-14.5	0.5	1	1	0.8
11522	*Galloway 66*	25	3.50-17.0	0.5	1	2	1.3
12144	*Smith 66*	3	0.85-1.40	0.5	1	0	4.4
20482	*Cabe 67*	2	0.85-1.20	0.5	1	2	14.6
11497	*Carlson 67*	6	4.50-7.50	0.5	1	1	0.3
20010	*Cierjacks 68*	40	0.85-20.0	0.5	1.5	3	used as prior data
11584	*Ferguson 68*	3	1.80-2.40	1	1	3	2.3
30241	*Hussain 69*	4	1.20-2.0	0.5	1	0.5	13.5
10011	*Carlson 70*	23	0.85-9.0	0.5	1	2	1.5
10047	*Foster 71*	27	2.20-14.5	0.5	1	1.5	1.2
10377	*Perey 72*	40	0.85-20.0	0.5	1	3	1.5
20450	*Pattenden 73*	2	0.85-1.20	0.5	1	3	0.4
10006	*Schwartz 74*	35	0.85-15.0	1	1	2	1.1
-	*Larson 89*	7	0.85-2.2	0	1	2	3.7

ENDF/B-VI file for ^{56}Fe (ORNL unpublished results)

Part II. Measurements at a single energy

EXFOR Entry	First Author and Year	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
11056	*Coon 52*	1	14.1		2(total)		0.2
40709	*Khaletskij 57*	1	14.8		2(total)		0.0
11155	*Bratenahl 58*	1	14.5		2(total)		0.0
21122	*McCallum 60*	1	14.3		3(total)		0.8
11108	*Peterson 60*	1	17.3		2.1(total)		3.8
12681	*Western 65*	1	14.6		2(total)		0.7
30113	*Angeli 70*	1	14.5		2(total)		0.3
21947	*James 75*	1	0.93		3.0(total)		0.9

Table 2: Group - averaged total cross sections, standard deviations and correlation matrix generated for the experimental data from the paper *Schwartz 74*.

Energy - group number	Central value of energy group (MeV)	Group - averaged cross section (barn)	Standard deviation (in %)
1	9.25	2.2556	1.55
2	1.10	2.3927	1.50
3	1.30	2.7675	1.41
4	1.50	2.9036	1.32
5	1.70	2.7930	1.26
6	1.90	2.9781	1.24
7	2.10	3.1715	1.15
8	2.30	3.1105	1.11
9	2.50	3.6526	1.08
10	2.70	3.3514	1.06
11	2.90	3.3059	1.04
12	3.25	3.4386	1.02
13	3.75	3.5105	1.02
14	4.25	3.6549	1.03
15	4.75	3.6779	1.05
16	5.25	3.6904	1.08
17	5.75	3.6773	1.07
18	6.25	3.6423	1.10
19	6.75	3.5763	1.15
20	7.25	3.5241	1.16
21	7.75	3.4633	1.11
22	8.25	3.3496	1.13
23	8.75	3.2361	1.12
24	9.25	3.1969	1.14
25	9.75	3.1110	1.17
26	10.25	3.0599	1.22
27	10.75	2.9969	1.29
28	11.25	2.8874	1.33
29	11.75	2.8721	1.44
30	12.25	2.7721	1.51
31	12.75	2.7385	1.85
32	13.25	2.6935	1.93
33	13.75	2.6477	2.06
34	14.25	2.5979	2.13
35	14.75	2.5113	2.28

Table 2 (continued): Group - averaged total cross sections, standard deviations and correlation matrix generated for the experimental data from the paper *Schwartz 74*.

Correlation matrix (correlations are given in %)

GROUP NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	ENERGY GROUP [MeV] to [MeV]
1	100																																			0.85 - 1.00
2	98	100																																		1.00 - 1.20
3	96	98	100																																	1.20 - 1.40
4	92	95	97	100																																1.40 - 1.60
5	88	92	95	98	100																															1.60 - 1.80
6	83	87	92	96	98	100																														1.80 - 2.00
7	78	82	88	92	95	97	100																													2.00 - 2.20
8	73	78	83	88	92	94	97	100																												2.20 - 2.40
9	69	73	78	84	88	90	94	95	100																											2.40 - 2.60
10	67	70	75	81	85	87	92	94	95	100																										2.60 - 2.80
11	65	67	72	78	81	83	89	92	93	94	100																									2.80 - 3.00
12	64	66	71	76	80	81	88	91	93	95	95	100																								3.25 - 3.50
13	63	65	69	74	77	79	85	88	91	92	94	96	100																							3.50 - 4.00
14	62	64	69	74	77	79	85	88	91	92	94	95	95	100																						4.00 - 4.50
15	61	63	67	72	76	77	84	87	89	91	93	94	93	94	100																					4.50 - 5.00
16	59	61	65	70	73	75	81	84	86	88	90	91	90	91	93	100																				5.00 - 5.50
17	60	62	66	71	73	75	81	84	86	88	90	91	91	91	92	92	100																			5.50 - 6.00
18	58	60	64	69	71	73	79	82	84	86	87	89	89	88	89	90	91	100																		6.00 - 6.50
19	55	57	61	65	68	69	75	78	80	82	83	85	85	84	84	85	87	90	100																	6.50 - 7.00
20	55	57	61	65	68	69	75	77	79	81	83	84	84	83	83	82	84	87	89	100																7.00 - 7.50
21	57	59	63	68	70	72	78	81	83	85	86	88	88	87	86	84	85	85	85	87	100															7.50 - 8.00
22	57	59	62	67	69	71	77	79	82	83	85	86	86	85	84	82	83	82	81	83	86	100														8.00 - 8.50
23	57	59	63	67	70	71	77	80	82	84	86	87	87	86	85	82	83	81	78	78	81	81	100													8.50 - 9.00
24	56	58	62	66	69	70	76	79	81	83	84	86	86	85	83	81	81	79	76	75	79	78	78	100												9.00 - 9.50
25	55	57	60	65	67	69	74	77	79	81	82	84	84	83	82	79	80	78	74	74	77	76	76	75	100											9.50 - 10.00
26	52	54	58	62	64	66	71	74	76	77	79	80	80	79	78	76	76	74	71	70	73	73	73	72	70	100										10.00 - 10.50
27	49	51	54	58	61	62	67	69	71	73	74	75	75	75	73	71	72	70	67	66	69	68	69	67	66	63	100									10.50 - 11.00
28	48	49	53	56	59	60	65	67	69	70	72	73	73	72	71	69	69	68	64	64	67	66	67	65	64	62	58	100								11.00 - 11.50
29	44	46	49	52	54	56	60	62	64	65	67	68	68	67	66	64	64	63	60	59	62	61	62	61	59	57	54	54	100							11.50 - 12.00
30	42	44	46	50	52	53	57	59	61	62	63	65	64	64	63	61	61	60	57	57	59	58	59	58	56	54	51	52	51	100						12.00 - 12.50
31	34	36	38	41	42	43	47	48	50	51	52	53	53	52	51	50	50	49	46	46	48	47	48	47	46	44	42	43	43	48	100					12.50 - 13.00
32	33	34	36	39	40	41	45	46	48	49	49	50	50	50	49	48	48	47	44	44	46	45	46	45	44	42	40	40	40	44	49	100				13.00 - 13.50
33	31	32	34	36	38	39	42	43	45	46	46	47	47	47	46	45	45	44	42	41	43	43	43	42	41	39	37	37	36	38	41	46	100			13.50 - 14.00
34	30	31	33	35	37	37	40	42	43	44	45	46	45	45	44	43	43	42	40	40	42	41	41	41	40	38	36	35	33	34	34	39	41	100		14.00 - 14.50
35	28	29	31	33	34	35	38	39	40	41	42	43	42	42	41	40	40	39	38	37	39	38	39	38	37	35	33	32	30	30	27	30	32	34	100	14.50 - 15.00

Table 3: Experimental data base for the nonelastic cross-section

EXFOR Entry	First Author and Year	Type of Exper.	Correct. Applied	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
21379	*Beghian 55*	847 keV b)		1	2.5		25(tot.)		0.1
11396	*Cranberg 56*	a)	2-nd lev. contr.add.	2	2.2-2.5	5	8	6	0.8
11218	*Day 56*	847 keV b)	γ-ray ang. distr.	1	2.6		8(tot.)		0.1
11316	*Muehlhause 56*	0.847 keV b)		1	1.7		10(tot.)		3.1
20286	*Hosoe 59*	847 keV b)		1	1.1		6(tot.)		2.3
11233	*Day 60*	847 keV b)		1	2.6		6(tot.)		0.8
11489	*Boring 61*	847 keV b)		1	2.9		9(tot.)		2.9
40652	*Kardashev 62*	847 keV b)		10	1.0-3.5	5	7	21	2.1
20962	*Montague 62*	847 keV b)	γ-ray ang. distr.	11	1.0-3.5	10	20	12	0.2
11495	*Thompson 63*	a)	1-st lev. contr. add.	1	7.0		9(tot.)		0.3
11702	*Vanpatter 64*	847 keV b)	γ-ray ang. distr.	8	1.0-3.5	7	7	24	1.3

Table 3: (continued) Experimental data base for the nonelastic cross-section

EXFOR Entry	First Author and Year	Type of Exper.	Correct. Applied	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
40035	*Broder 65*	847 keV b)	γ-ray ang. distr., R. new standard	1	6.9		10(tot.)		0.3
21097	*Gilboy 65*	a)		6	1.4-2.6	6	14	7	0.7
11704	*Benjamin 66*	847 keV b)	R[1)]	4	0.9-3.1	5	19	27	4.4
20379	*Jacquot 66*	a)	2-nd lev. contr. add.	5	1.3-2.3	6	6	8	1.2
12144	*Smith 66*	a)		2	1.0-1.4	2	5	7	1.6
11276	*Rogers 67*	a)		1	2.3		9(tot.)		0.5
20905	*Towle 67*	a)		1	7.0		5(tot.)		1.2
13048	*Barrows 68*	a) sum of levels		1	2.9		10(tot.)		2.3
10025	*Drake 70*	847 keV b)	R, (n,p) contr.	5	4.0-7.7	5	10	8	0.2
20008	*Tomita 70*	847 kev b)	γ-ray ang. distr., R	4	1.4-2.2	10	10	4	0.6
10219	*Hoot 71*	847 keV b)	γ-ray ang. dist., R, (n,p) contr.	14	0.9-7.3	10	10	30	0.6
10529	*Perey 71*	847 keV b)	γ-ray ang. distr.	7	0.8-2.2	2	10	18	2.5
10146	*Rogers 71*	847 keV b)		10	0.9-1.8	8	8	18	1.6

Table 3: (continued) Experimental data base for the nonelastic cross-section

EXFOR Entry	First Author and Year	Type of Exper.	Correct. Applied	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
20371	*Voss 71*	847 keV b)	γ-ray ang. distr., R	12	0.8-3.5	1	9	30	3.3
40213	*Konobeevskij 73*	847 keV b)	γ-ray ang. distr., new standard	2	0.8-1.2	1	10	5	0.4
20474	*Lachkar 74*	all γ-rays from (n,n'γ)		8	4.8-8.8	7	8	10	0.4
20788	*Almen-Ramström 75*	a)		2	2.0-2.3	6	10	8	0.0
40531	*Korzh 75*	a)		4	1.5-3.0	6	6	5	0.2
10519	*Nardini 75*	847 keV b)		10	1.0-3.0	5	10	11	0.6
10754	*Williams 75*	847 keV b)	R	1	4.2		14(tot)		0.1
10580	*Chapman 76*	847 keV b)	γ-ray ang. distr., R. (n,p) contr.	19	1.2-11.	4	10	6	0.9
40346	*Savin 76*	847 keV b)	γ-ray ang. distr.,R	12	1.0-4.0	3	6	26	1.6
10613	*Smith 76*	847 keV b)		4	1.6-2.4	5	8	11	0.6
10682	*Kinney 77*	847 keV b)	γ-ray ang. distr.	6	0.8-2.0	5	7	18	0.2
10886	*Smith 80*	a)		4	1.6-2.4	2	10	16	1.4

Table 3: (continued) Experimental data base for the nonelastic cross-section

EXFOR Entry	First Author and Year	Type of Exper.	Correct. Applied	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
30589	*Salama 81*	847 keV b)		1	2.0		15(tot)		0.5
10958	*El-Kadi 82*	a)		4	8.0-14.	4	5	8	0.4
13500	*Dickens 91*	847 keV b)	γ-ray ang. distr., R. (n,p), (n,α) contrib.	15	0.8-11.	5	6	19	0.3
	Vonach 91	Evaluation		1	14.0		1(tot.)		0.8
11216	*Beyster 55*	sphere transm.		2	4.0-4.5	3	3	0	1.1
11217	*Taylor 55*	sphere transm.	(n,n_1) contr.	4	3.5-13.	3	3	0	
11215	*Walt 55*	sphere transm.		1	4.1		13(tot.)		
40645	*Degtjarev 61*	sphere transm.	(n,n_1) and (n,n_2) contr.	3	15.-20.	3	3	0	0.8
11705	*Beghian 63*	sphere transm.		3	1.0-1.5	8	8	0	
40694	*Degtjarev 65*	sphere transm.	(n,n_1), (n,n_2) and (n,n_3) contr.	2	8.1-20.	3	3	0	0.5

a) neutron detection b) γ-ray production 1) $R = \sigma_{total\ inel.} / \sigma_{847\ keV}$ (see section 5.2)

Table 4: Data base for the (n,n') cross sections for excitation of the first 2^+ level (MT=51).

EXFOR Entry	First Author and Year	Type of Exper.	Correct. Applied	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
11396	*Cranberg 56*	a)		2	2.2-2.5	5	10	20	0.1
40652	*Kardashev 62*	b)		7	2.0-3.9	10	10	23	0.3
21097	*Gilboy 65*	a)		6	2.2-4.0	4	10	13	0.8
20040	*Antolkovic 66*	a)		1	4.6		10(total)		0.8
11276	*Rogers 67*	a)		1	2.3		10(total)		0.1
13048	*Barrows 68*	a)		1	2.9		15(total)		1.1
11708	*Kinney 68*	a)		6	4.6-7.6	10	10	20	0.3
20304	*Tsukada 69*	a)		3	2.0-3.3	3	10	0	0.4
10111	*Kinney 70*	a)		7	4.6-8.6	8	10	15	0.6
10037	*Boschung 71*	a)		2	5.0-5.9	6	10	30	0.2
10384	*Velkley 74*	a)		1	9.0		10(total)		0.0
20788	*Almen-Ramström 75*	a)		8	2.0-4.5	15	10	10	0.4
40531	*Korzh 75*	a)		3	2.0-3.0	6	10	14	0.5
10519	*Nardini 75*	b)		7	2.0-4.0	10	10	15	0.2
30463	*Schweitzer 78*	a)		1	3.4		18(total)		0.3
10886	*Smith 80*	a)		7	2.0-4.0	10	0	15	0.2
30589	*Salama 81*	a)		6	2.0-4.0	15	10	13	0.4
12873	*Mellema 86*	a)		1	11.		8(total)		0.0
22128	*Olsson 90*	a)	reduced to 19.4 MeV	1	21.6		10(total)		0.6
	Vonach 91	evaluation		1	14.		6(total)		0.1

a) neutron detection
b) γ-ray detection

Table 5: Data base for the (n,n') cross section for excitation of the second (4^+) level (MT=52).

EXFOR Entry	First Author and Year	Type of Exper.	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
40652	*Kardashev 62*	b)	6	2.2-4.0	10	10	20	1.0
20962	*Montague 62*	b)	6	2.0-3.5	5	10	19	1.1
21097	*Gilboy 65*	a)	4	2.6-4.0	6	5	10	4.1
11720	*Tucker 65*	b)	2	2.0-2.4	15	25	6	2.4
20040	*Antolkovic 66*	a)	1	4.6		10(total)		0.9
13048	*Barrows 68*	a)	1	2.9		10(total)		3.3
20304	*Tsukada 69*	a)	2	2.7-3.3	4	5	10	1.7
10111	*Kinney 70*	a)	8	4.2-8.6	8	5	9	0.6
10037	*Boschung 71*	a)	2	5.1-5.9	10	5	5	2.0
20371	*Voss 71*	b)	6	2.0-3.5	5	10	17	0.4
20788	*Almen-Ramström 75*	a)	3	3.0-4.5	9	5	15	0.4
40531	*Korzh 75*	a)	1	3.0		10(total)		3.9
10519	*Nardini 75*	b)	7	2.0-4.0	5	10	8	0.4
10886	*Smith 80*	a)	3	2.8-4.0	10	10	14	2.3
12873	*Mellema 86*	a)	1	11.		5(total)		0.3

a) neutron detection
b) γ-ray detection

Table 6: Data base for the (n,n') cross section for excitation of the third level (2^+) (MT=53).

EXFOR Entry	First Author and Year	Type of Exper.	Correct. Applied	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
40652	*Kardashev 62*	b)		4	2.7-4.0	10	10	24	0.8
20962	*Montague 62*	b)	corr. for contrib. from other levels	2	3.5-4.5	5	15	19	0.1
21097	*Gilboy 65*	a)		1	4.0		10(total)		1.5
20040	*Antolkovic 66*	a)		1	4.6		10(total)		2.2
20304	*Tsukada 69*	a)		1	3.3		10(total)		0.7
10111	*Kinney 70*	a)		8	4.2-8.6	5	10	17	0.3
10037	*Boschung 71*	a)		2	5.0-5.9	5	15	20	1.0
20371	*Voss 71*	b)		4	2.6-4.0	5	15	17	3.4
20474	*Lachkar 74*	b)		1	4.8		35(total)		0.3
20788	*Almen-Ramström 75*	a)		2	3.5-4.5	10	10	7	1.2
10519	*Nardini 75*	b)		3	2.6-3.5	5	10	21	0.5
12873	*Mellema 86*	a)		1	11.		10(total)		0.1

a) neutron detection
b) γ-ray detection

Table 7: Data base for the (n,n') cross section for excitation of the group of levels 4-7 (MT=54 - 58).

EXFOR Entry	First Author and Year	Type of Exper.	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
21097	*Gilboy 65*	a)	1	4.0		7(total)		2.6
20040	*Antolkovic 66*	a)	1	4.6		30(total)		0.6
11708	*Kinney 68*	a)	4	4.6-6.5	10	10	0	1.8
10111	*Kinney 70*	a)	6	5.0-8.6	11	11	0	0.4
10037	*Boschung 71*	a)	2	5.1-5.9	4	10	17	1.1
20788	*Almen-Ramström 75*	a)	3	4.0-4.5	9	9	0	0.3
12690	*Williams 75*	b)	1	4.2		15(total)		0.0
12873	*Mellema 86*	a)	1	11.		8(total)		0.0

a) neutron detection
b) γ-ray detection

Table 8: Data base for the (n,n') cross section for excitation of the group of levels 8-14 (MT=59 - 65).

EXFOR Entry	First Author and Year	Type of Exper.	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
11708	*Kinney 68*	a)	5	5.0-7.6	11	11	0	0.9
10111	*Kinney 70*	a)	6	5.0-7.6	14	14	0	0.6
10037	*Boschung 71*	a)	2	5.1-5.9	10	10	0	0.9
12690	*Williams 75*	b)	1	4.2		15(total)		1.3
12873	*Mellema 86*	a)	1	11.		10(total)		0.1
22025	*Yabuta 86*	a)	2	14.-18.	14	14	0	0.4

a) neutron detection
b) γ-ray detection

Table 9: Experimental data base for the evaluation of the elastic scattering cross section

EXFOR Entry	First Author and Year	Correct. Applied	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %	χ^2
11637	*Walt 54*		1	1.0		(10,total)		1.0
11220	*Beyster 56*		1	7.0		(5,total)		1.0
40367	*Popov 57*		1	2.9		(10,total)		1.0
11717	*Landon 58*		1	2.2		(10,total)		1.0
40706	*Kazakova 65*		1	2.0		(10,total)		1.0
11511	*Becker 66*		1	3.2		(5,total)		1.0
11276	*Rogers 67*		1	2.3		(18,total)		1.0
20162	*Holmqvist 71*		1	6.0		(10,total)		1.0
10332	*Cox 72*		1	0.9		(10,total)		1.0
40075	*Morozov 72*		1	1.8		(5,total)		1.0
20855	*Corcalciuc 74*		1	7.0		(10,total)		1.0
10384	*Velkley 74*		1	9.0		(5,total)		1.0
10578	*Brandenberger 75*		1	1.5		(5,total)		1.0
10633	*Ferrer 77*		1	11.0		(5,total)		1.0
30463	*Schweitzer 78*		1	3.4		(19,total)		1.0
21664	*Begum 79*		1	16.1		(11,total)		1.0
20761	*Galloway 79*		1	2.9		(10,total)		1.0
30633	*Begum 81*		1	2.9		(5,total)		1.0
12862	*Mellema 83*		1	11.0		(5,total)		1.0
22048	*Olsson 87*	reduced to 19.4 MeV	1	19.4		(5,total)		1.0
11341	*Bostrom 59*		3	3.7-4.7	7	6	0	0.1
21097	*Gilboy 65*		4	1.0-4.0	8	6	0	0.7
12144	*Smith 66*		2	1.2-1.6	2	8	0	0.0
11708	*Kinney 68*		7	4.6-7.6	10	0	0	0.8
20019	*Holmqvist 69*		5	3.0-8.0	8	6	0	0.4
10111	*Kinney 70*		10	4.6-8.6	10	0	0	1.0
20008	*Tomita 70*		4	1.4-2.2	4	3	0	1.8
20020	*Holmqvist 70*		5	1.8-2.8	8	6	0	0.5
10037	*Boschung 71*		2	5.0-5.6	8	6	0	1.3
10571	*Kinney 76*		9	0.8-2.6	7	5	0	0.4
40532	*Korzh 77*		4	1.5-2.1	8	6	0	0.8
10886	*Smith 80*		9	1.6-4.0	2	8	7	2.1
10958	*El-Kadi 82*		4	8.0-14.	8	6	0	0.3
	Vonach 91	evaluation at 14.0 MeV	1	14.		2.6(total)		0.5

Table 10: Experimental data base for the evaluation of the $^{56}Fe(n,p)^{56}Mn$ reaction cross section

EXFOR Entry No.	First Author and Year	Energy range (MeV)	No. of data points used for our evaluation	Comments	Corrections applied	Uncertainties (%) Statist. (uncorrel.)	Uncertainties (%) Systematic (correl.)	χ^2 per degree of freedom
11715	*Terrell 58*	3.43-17.89	16	1)	σ_{ref}*)	5.5(Min.)	5.4 (E_d+ =2 MeV)	
					2)	6.9(Min.)	7.3 (Ed+ =4.98 MeV)	1.98
					3)	0.9-2.9	1.7 (T(d,n))	
21339	*Bormann 62*	13.2-19.6	5	correlations estimated	σ_{ref}*),3)	5.2-7.6	2.7	2.27
11696	*Cross 63*	13.78	1	-	σ_{ref}*)	10(total)		0.71
11701	*Santry 64*	4.57-20.3	43	-	3)	3.8-9.8	4.2 (T(p,n)+D(d,n))	0.91
						3.1-5.8	3.3 (T(d,n)-react.)	
21372	*Hemingway 66*	13.5	1	absolute meas.	-	4.40(total)		4.0
20387	*Liskien 66*	6.06-8.20	17	γγ-coincidence meas.	-	3.3-5.6	3.8	1.47
10417	*Grundl 67*	3.95-10.0	8	4)	-	4-90	2	1.30
20890	*Cuzzocrea 68*	13.70-13.975	8	correlations estimated	σ_{ref}*)	5.3-5.9	4.2	0.27
20815	*Vonach 68*	13.6-14.6	6	shape-measur.	5)	0.75	0.75	0.39°)
-	*Ryves 89*	14.7	1	evaluation	-	0.46(total)		

Table 10: (continued) Experimental data base for the evaluation of the $^{56}Fe(n,p)^{56}Mn$ reaction cross section

EXFOR No.	First Author and Year	Energy range (MeV)	No. of data points	Comments	Corrections applied	Uncertainties (%) Statist.	Systematic	χ^2
10238	*Smith 75*	3.979-9.945	29	$\sigma(Fe(n,p))/\sigma_{238U(n,f)}$ given	(see text) σ_{ref}*)	4 -9.5+)	3	3.53
30483	*Li-Chi-Chou 78*	12.79-18.26	20	absolute meas.	3)	1.5-3.3	2.5	0.27
20772	*Ryves 78*	15.30-18.95	5	-	3)	0.34-1.55	1.9	
21923	*Kudo 87*	15.21-19.87	5	-	-	0.6-5.2	2.1	1.57°)
20377	*Liskien 65*	12.60-19.58	23	-	3)	2.2-4.1	5.0	
40485	*Nemilov 79*	7.7-9.3	3	correlations estimated	-	4.6-8.5	6	0.64
30590	*Raics 80*	6.78-10.50	8	$\sigma(Fe(n,p))/\sigma_{238U(n,f)}$ given	σ_{ref}*)	2.05-6.15	3.2	2.23
30644	*Viennot 82*	13.77-13.93	2	correlations estimated	-	4	5	1.73
30562	*Ngoc 84*	13.55-13.77	2	correlations estimated	-	6.1-6.6	6	1.54
22089	*Ikeda 88*	13.33-13.75	3	-	σ_{ref}*)	3.3	2.6	0.46
-	*Mannhart 92*	9.098-13.810	10	-	-	1.7-4	2.8	0.29

1) different levels of correlations for the different source reactions used
2) corr. for angular distributions
3) corr. for $^{57}Fe(n,np)^{56}Mn$ contribution
4) shape measurement normalized to preliminary eval. excit. function
5) normalized to eval. σ (Ryves)
+) above the near-threshold region
*) σ_{ref}: Renormalization of the results according to recent standard reference cross section values
°) treated as one correlated data set

Table 11: Experimental data base for the evaluation of the cross section for the $^{56}Fe(n,2n)^{55}Fe$ reaction.

EXFOR Entry No.	First Author and Year	Energy range (MeV)	No. of data points	Comments	Corrections applied	Uncertainties (%) Statistical (uncorrel.)	Uncertainties (%) Systematic (correl.)	χ^2 per degree of freedom
11097	*Ashby 58*	14.1	1	neutron detection ^{nat}Fe	1) normalization by a factor 0.815	7.8(total)		0.03
20091	*Wenusch 62*	14.8	1	activ., enriched ^{56}Fe	recent reference cross section	20.5 (total)		0.74
20721	*Qaim 76*	14.7	1	activ., enriched ^{56}Fe	-	9.1 (total)		1.17
12936	*Auchampaugh 80*	14.7-20.0	6	neutron detection, ^{nat}Fe	2)	4.3-9.5	4	0.31
20416.044	*Fréhaut 80A*	11.88-14.76	7	neutron det. ^{nat}Fe	renormalization	2.7-17	6.2	1.50 3)
20416.003	*Fréhaut 80B*	11.88-14.76	7	neutron detection enriched ^{56}Fe	by a factor 1.077	2.6-9.6	5.1	
13132	*Greenwood 88*	14.8	1	activ., enriched ^{56}Fe	-	7.7 (total)		0.72

1) correct. for minor Fe isotopes
2) correct. for minor Fe isotopes; correc. for energy-dependent efficiency of the detector (see text)
3) because of strong correlations the results of both experiments were processed as one single data set.

Table 12: Experimental data base for the evaluation of the cross section for the $^{56}Fe(n,\alpha)^{53}Cr$ reaction.

EXFOR Entry No.	First Author and Year	Energy range (MeV)	No. of data points	Comments	Corrections applied	Uncertainties (%) Statistical (uncorrel.)	Systematic (correl.)	χ^2 per degree of freedom
10827	Grimes 79	14.8	1	enriched ^{56}Fe α-emission	+)	17.6 (total)		0.00
21658	Paulsen 81	4.89-9.97	11	^{nat}Fe, α-emission	for contribution from the reaction $^{54}Fe(n,\alpha)^{51}Cr$	7.4-18	6.4	0.79
21873	Wattecamps 83	14.1	1	^{nat}Fe α-emission	for contributions from minor Fe isotopes and +)	21.8 (total)		0.01
21920	Fischer 84	14.1	1	enriched ^{56}Fe α-emission	+)	4.85 (total)		0.42
10933	Kneff 86	14.8	1	enriched ^{56}Fe He-production	+)	6.8 (total)		0.63
-	Saraf 91	8.0-11.0	3	enriched ^{56}Fe α-emission	-	14.1-26.3	6.2	2.14

+) correct. for contribution from the $(n,n\alpha)$-reaction

Table 13: Experimental data base for the proton production cross section (MT=103 + 28)

EXFOR Entry	First Author and Year	Nr.of data points	Energy Range (MeV)	SER %	LER %	MER %
10827	*Grimes 79*	1	14.8		13,0(total)	
-	*Saraf 91*	2	9.5-11.0	8.0	8.0	0

Table 14: "Blocked" full covariance matrix for ^{56}Fe reactions. Numbers indicate maximum correlation within each block in %.

MT#	1	103	28	51	52	53	851	852	853	91	16	107	
1													
103	0												
28	4	1											
51	12	0	0										
52	1	0	0	20									
53	2	0	0	38	6								
851	4	0	0	47	13	28							851=54 to 58
852	3	0	0	28	19	12	29						852=59 to 65
853	4	0	2	22	12	16	24	54					853=66 to 83
91	10	5	33	45	8	12	21	16	92				
16	2	0	85	0	0	0	0	0	1	37			
107	1	0	27	0	0	0	0	0	0	17	9		

Table 15: Final thinned correlation matrix of rectangular block 10 - 9.

SET 9 SET10	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	-4	-10	-1	-2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	-11	-27	-5	-5	-1	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	-4	-10	-1	-2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	-12	-13	-77	-30	-23	-3	3	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	12	-4	-29	-87	-60	-38	-12	1	4	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	15	2	-22	-59	-90	-75	-49	-19	-2	3	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	4	4	-3	-36	-73	-91	-78	-51	-23	-5	1	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	2	3	-11	-48	-78	-92	-81	-54	-27	-9	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	2	4	1	-18	-49	-79	-91	-80	-56	-31	-13	-3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
11	0	1	3	4	5	-1	-21	-50	-77	-88	-78	-57	-33	-16	-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	2	4	4	5	4	-3	-22	-49	-73	-82	-74	-55	-34	-17	-7	-1	0	0	0	0	0	0	0	0	0	0	0	0
13	0	3	4	3	3	4	2	-6	-25	-50	-70	-78	-72	-55	-35	-19	-8	-2	0	0	0	0	0	0	0	0	0	0	0
14	0	2	3	3	2	3	3	0	-8	-25	-46	-64	-71	-65	-51	-33	-19	-9	-3	0	0	0	0	0	0	0	0	0	0
15	0	2	2	2	2	2	3	2	-1	-11	-28	-48	-64	-71	-66	-52	-35	-20	-10	-4	-1	0	0	0	0	1	1	0	0
16	0	1	2	2	1	1	2	2	1	-2	-13	-28	-47	-62	-68	-63	-50	-34	-20	-10	-4	-1	0	1	1	1	1	1	1
17	0	1	1	1	1	1	1	1	1	0	-4	-14	-28	-45	-58	-63	-58	-47	-32	-19	-9	-4	0	0	1	1	1	1	1
18	0	0	1	1	1	1	1	1	1	0	0	-5	-14	-27	-42	-53	-57	-53	-43	-30	-18	-9	-4	0	1	1	1	1	1
19	0	1	1	1	0	0	0	0	1	0	0	-1	-6	-14	-26	-39	-50	-54	-50	-41	-29	-18	-9	-2	0	1	1	1	1
20	0	0	1	0	0	0	0	0	0	0	0	0	-2	-6	-15	-27	-39	-49	-53	-50	-41	-30	-19	-7	0	1	1	1	1
21	0	0	1	0	0	0	0	0	0	0	0	0	0	-2	-7	-16	-28	-42	-52	-56	-53	-43	-32	-15	-3	0	1	1	1
22	0	0	1	0	0	0	0	0	0	0	0	0	0	0	-3	-9	-19	-32	-46	-57	-61	-57	-48	-29	-9	-1	0	1	1
23	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	-4	-10	-21	-35	-49	-60	-64	-60	-44	-19	-4	0	1	1
24	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	-4	-11	-21	-34	-47	-57	-61	-53	-29	-9	0	1	1
25	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	-2	-6	-13	-23	-34	-43	-49	-39	-19	-5	0	0
26	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	-2	-5	-11	-19	-31	-39	-32	-17	-5	-5
27	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	-3	-8	-20	-39	-48	-39	-20	-20
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4	-12	-24	-29	-23	-23
29	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	-7	-24	-46	-57	-57
30	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	-7	-24	-46	-57	-57

Table 16: Present evaluation: cross sections and uncertainties

incid.Energy [MeV]	total [barns]	elastic scattering [barns]
0.925	2.2926 +- 0.0140	2.0850 +- 0.0146
1.100	2.4316 +- 0.0132	2.0086 +- 0.0143
1.300	2.7978 +- 0.0139	2.3195 +- 0.0147
1.500	2.9312 +- 0.0145	2.2740 +- 0.0159
1.700	2.8138 +- 0.0139	2.1488 +- 0.0158
1.900	2.9880 +- 0.0153	2.2313 +- 0.0174
2.100	3.1851 +- 0.0157	2.3012 +- 0.0183
2.300	3.1001 +- 0.0148	2.1862 +- 0.0181
2.500	3.6335 +- 0.0167	2.6386 +- 0.0193
2.700	3.3292 +- 0.0150	2.3591 +- 0.0184
2.900	3.2882 +- 0.0143	2.2605 +- 0.0177
3.250	3.4102 +- 0.0144	2.3107 +- 0.0189
3.750	3.4788 +- 0.0145	2.2288 +- 0.0205
4.250	3.6206 +- 0.0156	2.2833 +- 0.0228
4.750	3.6449 +- 0.0163	2.2389 +- 0.0250
5.250	3.6455 +- 0.0175	2.1740 +- 0.0274
5.750	3.6387 +- 0.0179	2.1423 +- 0.0288
6.250	3.5868 +- 0.0178	2.1108 +- 0.0292
6.750	3.5404 +- 0.0169	2.0619 +- 0.0283
7.250	3.4776 +- 0.0173	1.9874 +- 0.0272
7.750	3.4177 +- 0.0163	1.9730 +- 0.0260
8.250	3.3241 +- 0.0171	1.8980 +- 0.0266
8.750	3.2240 +- 0.0160	1.8181 +- 0.0269
9.250	3.1701 +- 0.0155	1.7605 +- 0.0277
9.750	3.1001 +- 0.0154	1.6913 +- 0.0283
10.250	3.0275 +- 0.0161	1.6094 +- 0.0284
10.750	2.9590 +- 0.0176	1.5265 +- 0.0286
11.250	2.8925 +- 0.0187	1.4567 +- 0.0297
11.750	2.8294 +- 0.0188	1.3849 +- 0.0312
12.250	2.7514 +- 0.0174	1.3084 +- 0.0307
12.750	2.6838 +- 0.0158	1.2469 +- 0.0285
13.250	2.6341 +- 0.0145	1.2001 +- 0.0244
13.750	2.5875 +- 0.0138	1.1558 +- 0.0194
14.250	2.5415 +- 0.0157	1.1111 +- 0.0178
14.750	2.4734 +- 0.0207	1.0601 +- 0.0236
15.500	2.4166 +- 0.0189	1.0239 +- 0.0244
16.500	2.2584 +- 0.0162	0.9434 +- 0.0272
17.500	2.2405 +- 0.0346	0.9513 +- 0.0444
18.500	2.1953 +- 0.0240	0.9488 +- 0.0368
19.500	2.1666 +- 0.0221	0.9434 +- 0.0400

Table 17: Present evaluation: cross sections and uncertainties

incid.Energy [MeV]	nonelastic [barns]	(n,a) [milibarns]
0.925	0.2080 +- 0.0041	
1.100	0.4220 +- 0.0058	
1.300	0.4760 +- 0.0066	
1.500	0.6560 +- 0.0086	
1.700	0.6630 +- 0.0090	
1.900	0.7550 +- 0.0102	
2.100	0.8820 +- 0.0117	
2.300	0.9120 +- 0.0119	
2.500	0.9910 +- 0.0123	
2.700	0.9680 +- 0.0121	
2.900	1.0240 +- 0.0120	
3.250	1.0960 +- 0.0138	0.0000 +- 0.0000
3.750	1.2440 +- 0.0158	0.0068 +- 0.0056
4.250	1.3320 +- 0.0179	0.0332 +- 0.0264
4.750	1.3990 +- 0.0203	0.1092 +- 0.0685
5.250	1.4670 +- 0.0227	0.3564 +- 0.1231
5.750	1.4900 +- 0.0244	1.110 +- 0.244
6.250	1.4700 +- 0.0251	2.804 +- 0.532
6.750	1.4710 +- 0.0246	4.888 +- 0.816
7.250	1.4590 +- 0.0229	6.564 +- 0.986
7.750	1.4330 +- 0.0217	7.994 +- 1.212
8.250	1.4170 +- 0.0217	10.158 +- 1.640
8.750	1.4050 +- 0.0228	13.322 +- 2.061
9.250	1.3997 +- 0.0243	16.863 +- 2.302
9.750	1.4020 +- 0.0252	20.485 +- 2.634
10.250	1.4014 +- 0.0252	24.677 +- 3.521
10.750	1.4280 +- 0.0253	28.838 +- 5.985
11.250	1.4320 +- 0.0262	31.760 +- 7.058
11.750	1.4380 +- 0.0271	32.661 +- 8.093
12.250	1.4410 +- 0.0269	36.867 +- 7.492
12.750	1.4370 +- 0.0251	39.016 +- 7.154
13.250	1.4350 +- 0.0211	39.826 +- 6.773
13.750	1.4320 +- 0.0157	41.539 +- 4.409
14.250	1.4290 +- 0.0111	42.578 +- 2.217
14.750	1.4220 +- 0.0119	44.570 +- 2.144
15.500	1.3930 +- 0.0158	47.418 +- 7.151
16.500	1.3530 +- 0.0221	44.728 +-11.068
17.500	1.3180 +- 0.0285	40.155 +-14.790
18.500	1.2940 +- 0.0287	34.289 +-15.597
19.500	1.2810 +- 0.0290	28.500 +-14.752
20.375		23.133 +-11.974

Table 18: Present evaluation: cross sections and uncertainties

inel. scattering	- first level	- second level
incid.Energy [MeV]	[milibarns]	[milibarns]
.862	0.00	
.925	207.57 +- 5.0	
1.100	420.83 +- 6.1	
1.300	475.47 +- 6.4	
1.500	653.90 +- 08.9	
1.700	661.92 +- 08.9	
1.900	753.48 +- 10.2	
2.100	876.67 +- 11.9	
2.1226		0.00
2.30	888.38 +- 11.8	22.74 +- 1.25
2.50	941.68 +- 12.7	47.16 +- 2.02
2.70	864.99 +- 12.3	78.43 +- 2.75
2.90	778.73 +- 12.6	109.97 +- 3.46
3.25	629.87 +- 12.5	123.49 +- 4.59
3.75	437.44 +- 13.1	131.55 +- 7.07
4.25	320.78 +- 13.7	126.85 +- 6.64
4.75	245.25 +- 11.5	101.76 +- 5.97
5.25	211.69 +- 13.1	78.73 +- 5.59
5.75	185.43 +- 16.8	64.23 +- 4.91
6.25	161.08 +- 16.0	52.05 +- 4.20
6.75	157.88 +- 15.9	37.29 +- 3.64
7.25	126.46 +- 13.6	25.46 +- 2.85
7.75	108.34 +- 13.4	18.50 +- 2.20
8.25	108.30 +- 13.3	15.32 +- 1.68
8.75	106.53 +- 15.4	13.81 +- 1.71
9.25	95.31 +- 9.0	12.50 +- 2.46
9.75	96.23 +- 14.1	10.92 +- 2.65
10.25	90.16 +- 4.5	9.27 +- 2.00
10.75	85.08 +- 5.0	8.19 +- 1.02
11.25	79.57 +- 4.1	6.84 +- 0.97
11.75	75.83 +- 4.3	6.38 +- 1.87
12.25	73.55 +- 6.0	5.76 +- 2.48
12.75	72.43 +- 7.2	5.24 +- 2.72
13.25	71.92 +- 7.0	4.81 +- 2.73
13.75	71.31 +- 5.6	4.44 +- 2.62
14.25	71.73 +- 4.0	4.12 +- 2.47
14.75	71.28 +- 4.0	3.97 +- 2.40
15.50	67.35 +- 5.3	3.48 +- 2.12
16.50	68.81 +- 7.7	3.18 +- 1.94
17.50	68.19 +- 8.6	3.12 +- 1.91
18.50	66.77 +- 7.3	3.03 +- 1.85
19.50	65.16 +- 6.4	2.96 +- 1.81

Table 19: Present evaluation: cross sections and uncertainties

incid.Energy [MeV]	inel. scattering - third level [milibarns]	- group of levels 4-7 [milibarns]
2.7059	0.00 +- 0.00	
2.90	136.20 +- 7.58	
2.9951		0.00
3.25	165.62 +- 8.05	194.97 +- 9.38
3.75	159.77 +- 8.34	299.82 +- 11.17
4.25	133.23 +- 7.96	288.34 +- 9.64
4.75	108.52 +- 8.04	249.43 +- 10.84
5.25	78.49 +- 6.96	202.71 +- 8.14
5.75	61.55 +- 6.17	170.69 +- 5.41
6.25	48.64 +- 5.68	133.36 +- 3.75
6.75	37.19 +- 4.77	88.91 +- 3.31
7.25	27.90 +- 3.83	57.74 +- 1.41
7.75	22.07 +- 3.05	43.26 +- 0.98
8.25	18.94 +- 2.67	38.36 +- 1.21
8.75	16.68 +- 2.76	35.33 +- 1.03
9.25	14.46 +- 3.32	31.00 +- 2.90
9.75	11.97 +- 3.32	25.81 +- 3.85
10.25	9.68 +- 2.45	20.48 +- 3.23
10.75	8.11 +- 1.14	16.54 +- 1.73
11.25	6.94 +- 1.13	14.13 +- 1.73
11.75	6.15 +- 2.39	12.56 +- 3.42
12.25	5.57 +- 3.32	11.61 +- 4.77
12.75	5.12 +- 3.82	11.03 +- 5.56
13.25	4.72 +- 3.96	10.55 +- 5.89
13.75	4.35 +- 3.90	10.03 +- 5.93
14.25	4.03 +- 3.67	9.51 +- 5.85
14.75	3.85 +- 3.53	9.04 +- 5.57
15.50	3.42 +- 3.17	8.08 +- 5.00
16.50	3.09 +- 2.89	7.35 +- 4.58
17.50	2.82 +- 2.64	6.75 +- 4.22
18.50	2.80 +- 2.61	6.66 +- 4.15
19.50	2.71 +- 2.53	6.48 +- 4.04

Table 20: Present evaluation: cross sections and uncertainties

inel. scatt. incid.Energy [MeV]	- group of levels 8-14 [milibarns]	- group of levels 15-32 [milibarns]
3.4308	0.00	
3.75	206.47 +- 16.60	
3.8156		0.00
4.25	323.12 +- 19.63	136.01 +- 18.53
4.75	323.56 +- 23.80	328.91 +- 32.57
5.25	296.34 +- 23.08	379.20 +- 57.24
5.75	231.57 +- 17.87	368.26 +- 75.43
6.25	172.41 +- 11.96	328.70 +- 79.04
6.75	118.20 +- 10.62	267.26 +- 80.78
7.25	78.19 +- 6.23	212.47 +- 76.19
7.75	57.03 +- 5.10	168.87 +- 63.98
8.25	45.14 +- 7.04	133.42 +- 54.09
8.75	37.96 +- 8.26	105.65 +- 46.00
9.25	32.59 +- 9.10	86.05 +- 39.75
9.75	27.99 +- 8.58	72.36 +- 34.73
10.25	24.87 +- 6.36	62.48 +- 30.57
10.75	20.72 +- 2.80	55.18 +- 27.21
11.25	18.63 +- 2.73	49.56 +- 24.56
11.75	16.03 +- 5.01	45.19 +- 22.54
12.25	14.09 +- 6.21	41.57 +- 20.92
12.75	12.25 +- 5.94	38.66 +- 19.66
13.25	10.68 +- 4.48	36.37 +- 18.69
13.75	9.51 +- 2.48	34.54 +- 17.92
14.25	9.09 +- 1.89	33.03 +- 17.28
14.75	8.92 +- 3.27	31.64 +- 16.68
15.50	9.16 +- 4.50	29.13 +- 15.55
16.50	9.76 +- 3.66	26.60 +- 14.41
17.50	9.65 +- 1.82	24.79 +- 13.49
18.50	9.45 +- 2.97	23.55 +- 12.68
19.50	9.21 +- 2.90	23.37 +- 12.35
20.00		23.56 +- 12.44

Table 21: Present evaluation: cross sections and uncertainties

incid.Energy [MeV]	(n,p) [milibarns]	inel. scattering to continuum [barns]
3.75	0.0000 +- 0.000	
4.25	0.0363 +- 0.0022	
4.6178		0.00
4.6956		0.0152 +- 0.0045
4.75	0.549 +- 0.015	0.0386 +- 0.0110
4.7945		0.0448 +- 0.0130
5.25	2.01 +- 0.06	0.2053 +- 0.0496
5.75	8.06 +- 0.20	0.3868 +- 0.0712
6.25	17.41 +- 0.41	0.5611 +- 0.0760
6.75	27.12 +- 0.53	0.7353 +- 0.0797
7.25	31.96 +- 0.72	0.8876 +- 0.0755
7.75	42.42 +- 0.89	0.9653 +- 0.0649
8.25	46.14 +- 0.98	1.0019 +- 0.0563
8.75	57.95 +- 1.61	1.0166 +- 0.0504
9.25	62.87 +- 2.12	1.0477 +- 0.0453
9.75	67.49 +- 2.17	1.0646 +- 0.0433
10.25	75.72 +- 2.23	1.0914 +- 0.0384
10.75	81.37 +- 2.14	1.1179 +- 0.0363
11.25	91.36 +- 2.44	1.1301 +- 0.0355
11.75	95.46 +- 2.31	1.1149 +- 0.0357
12.25	106.22 +- 2.08	1.0509 +- 0.0353
12.75	114.71 +- 1.63	0.9392 +- 0.0337
13.25	116.55 +- 1.37	0.8185 +- 0.0311
13.75	115.48 +- 0.81	0.7121 +- 0.0278
14.25	113.60 +- 0.99	0.6276 +- 0.0257
14.75	107.55 +- 0.47	0.5591 +- 0.0261
15.50	94.18 +- 0.94	0.4354 +- 0.0291
16.50	78.41 +- 0.69	0.2961 +- 0.0326
17.50	64.83 +- 0.76	0.2301 +- 0.0247
18.50	56.31 +- 0.84	0.1966 +- 0.0337
19.50	49.21 +- 0.81	0.1543 +- 0.0193
20.00		0.1481 +- 0.0185
20.375	42.23 +- 0.69	

Table 22: Present evaluation: cross sections and uncertainties

(n,2n)

incid.Energy [MeV]	[milibarns]
11.399	0.00 +- 0.00
11.513	2.91 +- 0.23
12.250	81.08 +- 3.63
12.750	175.17 +- 6.68
13.250	282.46 +- 10.39
13.750	373.09 +- 12.75
14.250	437.14 +- 13.53
14.750	483.76 +- 14.46
15.500	556.15 +- 23.85
16.500	636.96 +- 37.25
17.500	677.10 +- 37.06
18.500	692.11 +- 38.12
19.500	697.80 +- 40.25
20.370	698.58 +- 40.29

(n,np)

incid.Energy [MeV]	[milibarns]
11.00	0.00 +- 0.00
11.49	0.00 +- 0.00
11.50	0.40 +- 0.19
12.00	3.56 +- 1.62
12.50	11.93 +- 5.11
13.00	24.86 +- 8.53
13.50	42.45 +- 10.80
14.00	62.65 +- 11.39
14.50	87.06 +- 14.00
15.00	122.80 +- 22.42
16.00	151.37 +- 34.84
17.00	151.28 +- 42.26
18.00	149.42 +- 44.44
19.00	172.24 +- 44.22
20.00	176.56 +- 45.32

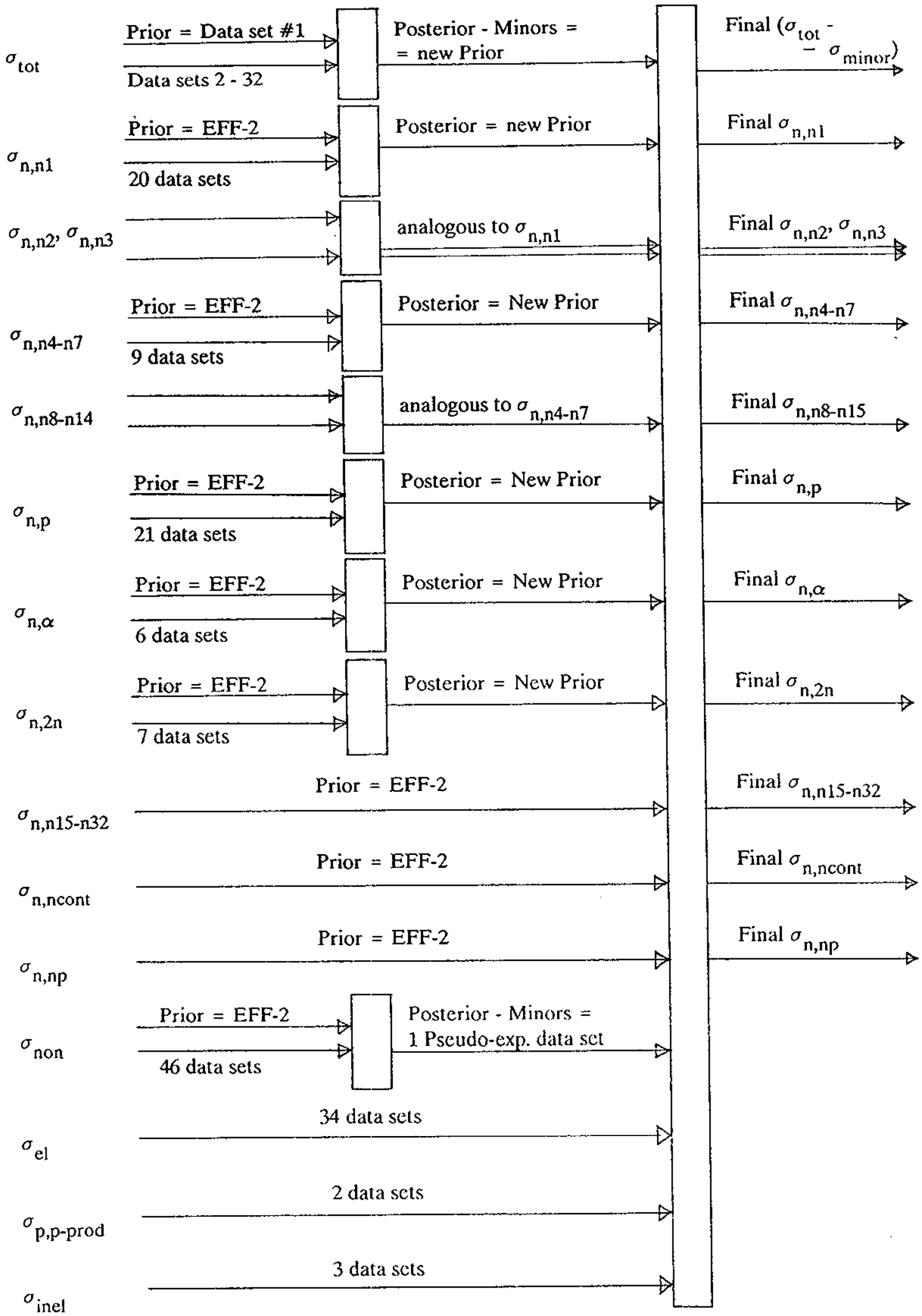


Fig.1: Data processing chart. GLUCS running is shown by the vertical boxes. As the final output we get 12 independent evaluated cross sections and a large covariance matrix including co-variances between the basic reaction cross sections. The cross section for total proton production, the nonelastic, the total inelastic and the elastic scattering cross sections are considered as redundant. "Minors" represents the sum of the (n,γ) -, (n,d) -, (n,t) -, $(n,^3He)$ - and $(n,n\alpha)$ - reaction cross sections.

18990061

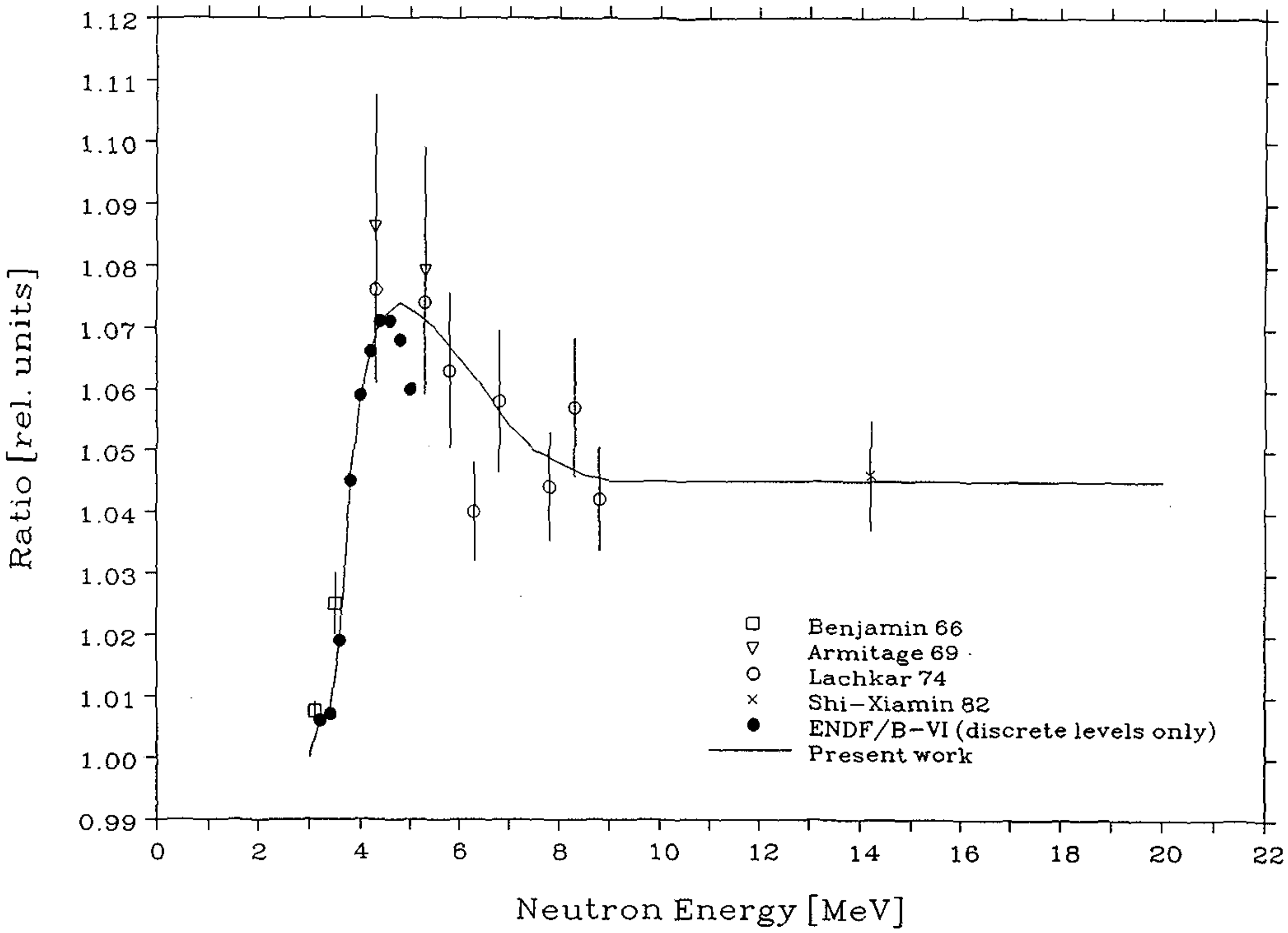


Figure 2: Ratio of the total inelastic scattering cross section to the cross section for production of the 0.847 MeV γ - ray obtained from available experimental and evaluated data. The solid line is drawn as an eye guide and represents the values used in the present work.

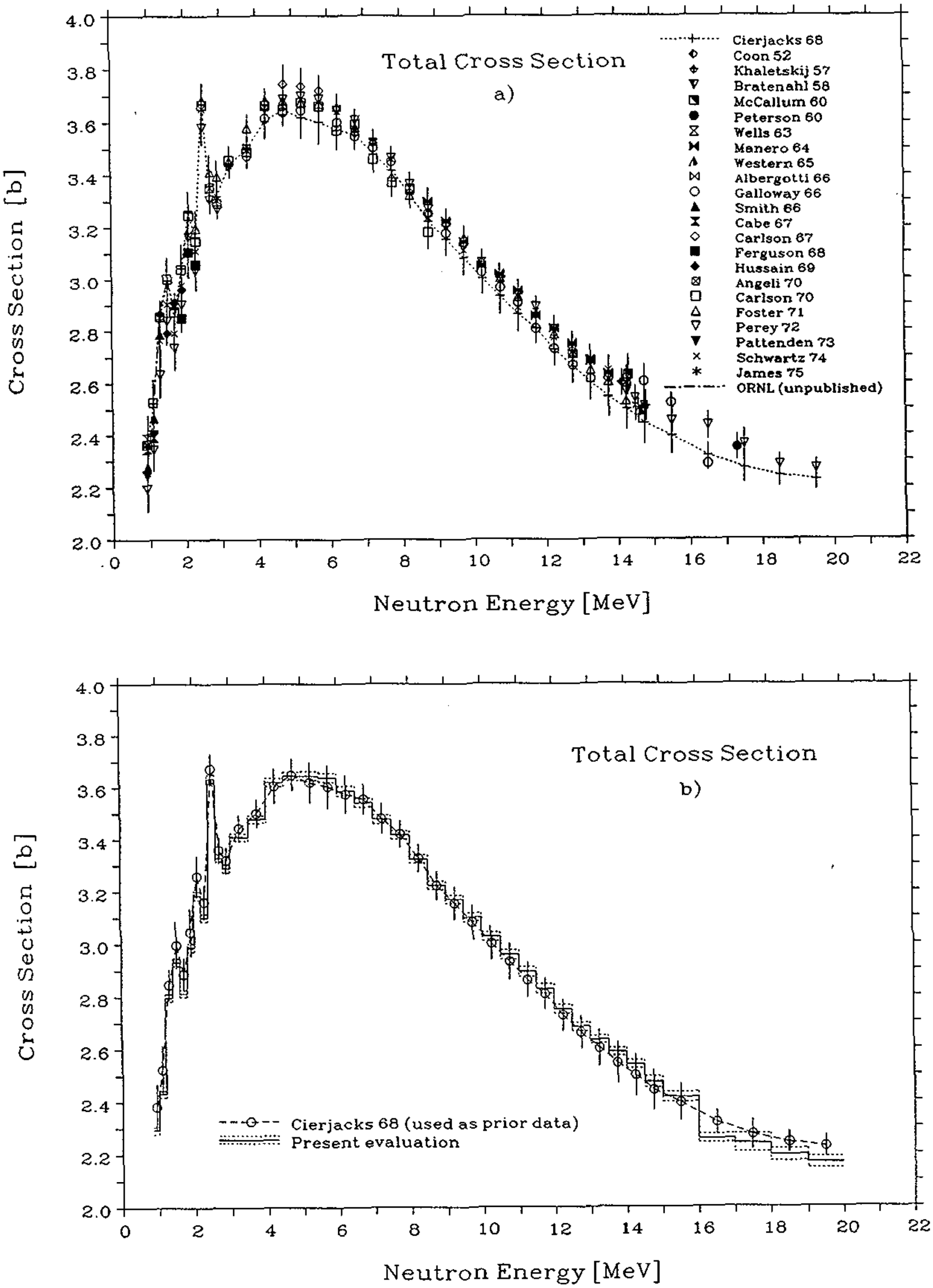
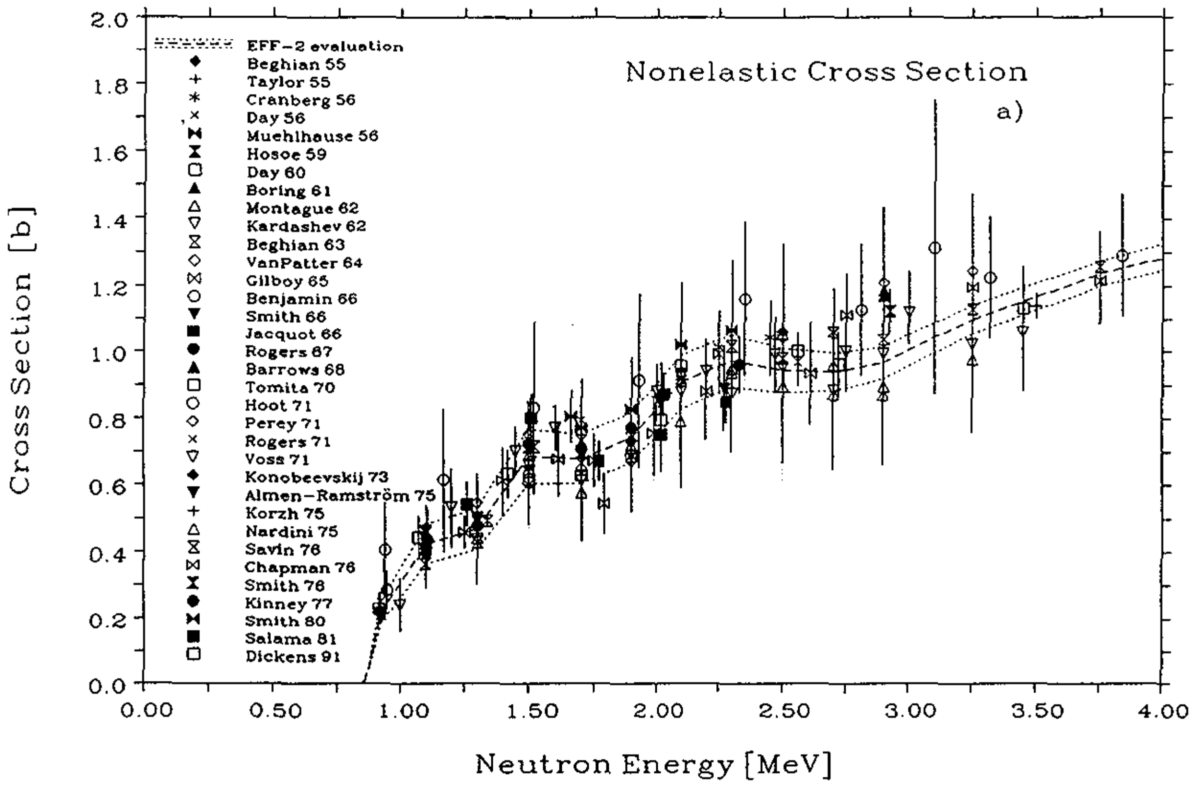


Figure 3: The total cross section of ^{56}Fe:

a) The experimental data base used for the present evaluation. The excitation function as measured by Cierjacks et al. (*Cierjacks 68*) was taken as the prior data set.

b) Comparison of the prior data with the group - averaged cross sections obtained as the final result of the present evaluation.



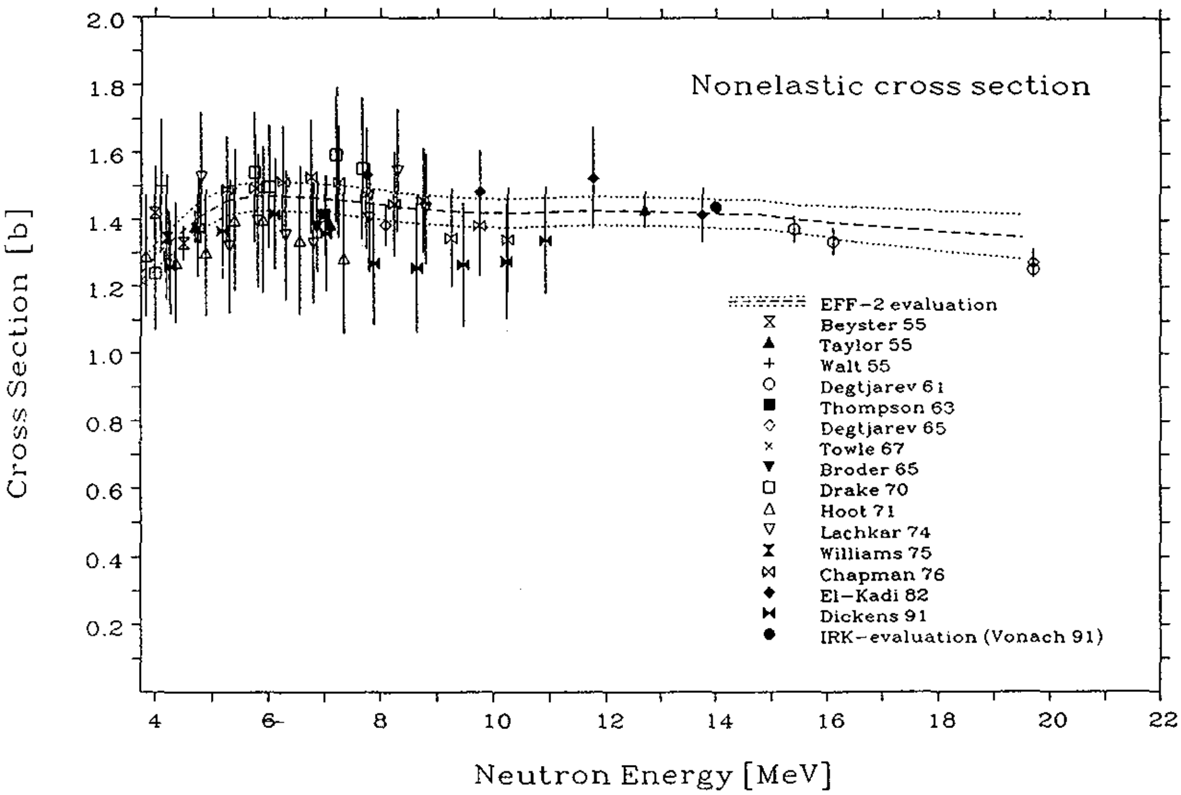


Figure 4 a: The nonelastic cross section of ^{56}Fe:
The adjusted experimental data base used for the present evaluation as compared with the excitation function recommended in the EFF-2 evaluation (prior data). For improved legibility the data are displayed separately for the 0 - 4 MeV and the 4 - 20 MeV regions.

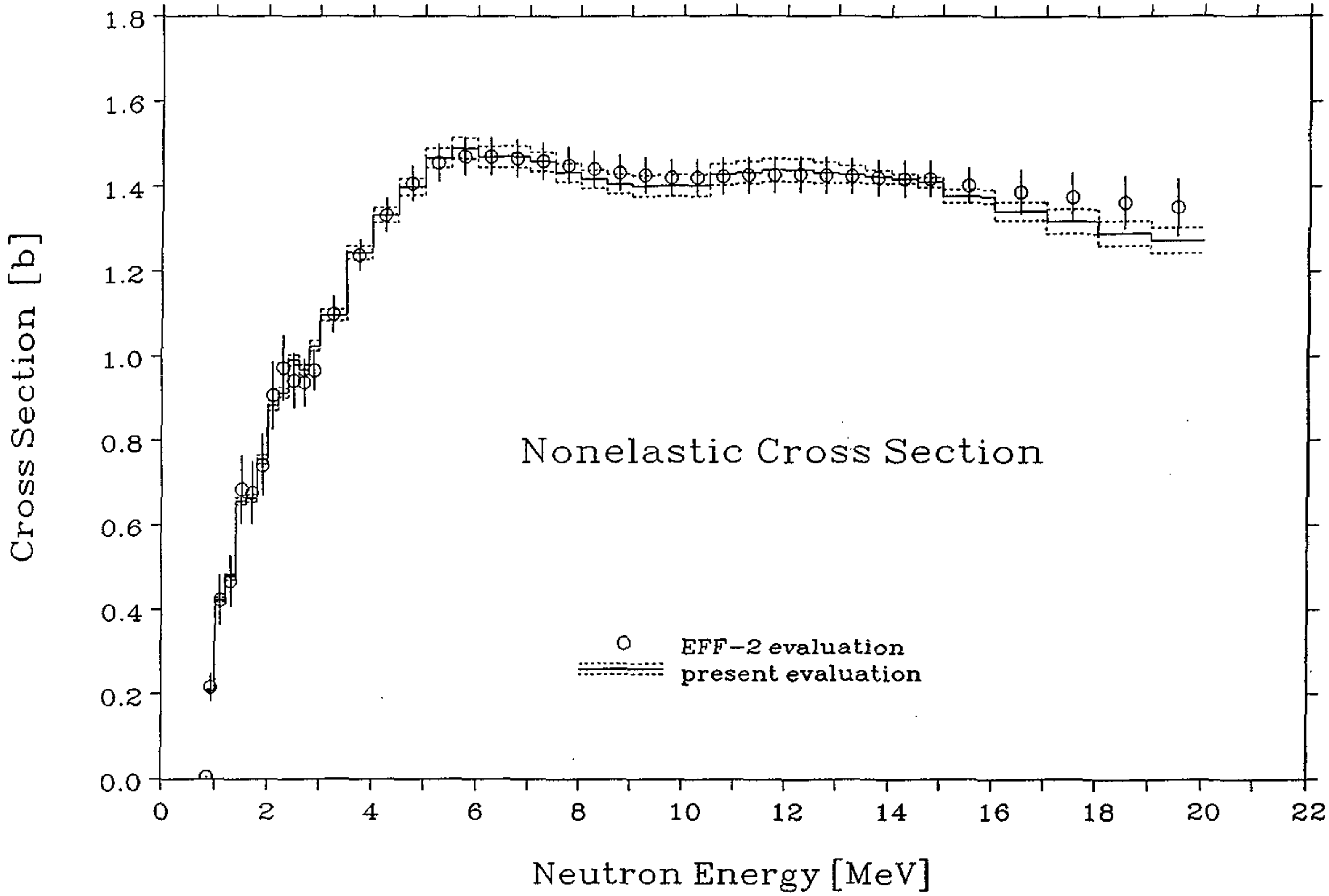
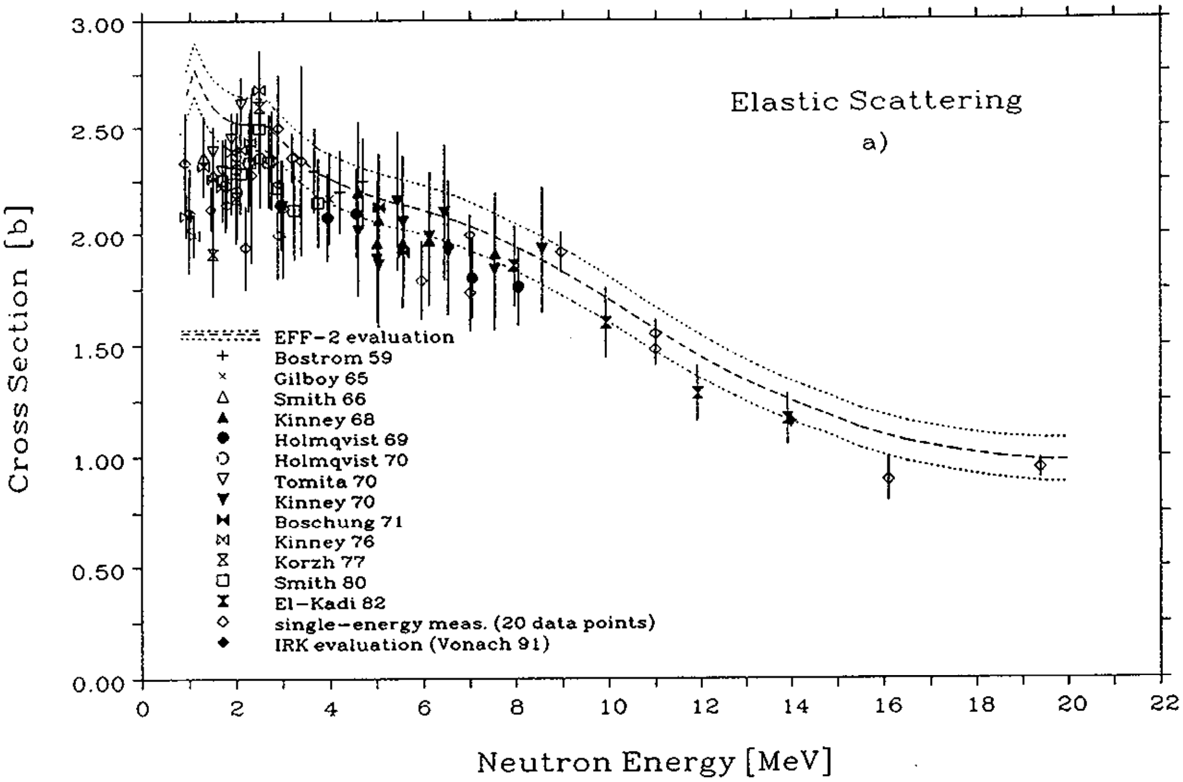


Figure 4 b: The nonelastic cross section: Comparison of the EFF-2 evaluation (prior data) with the group-averaged cross sections obtained as the final result of the present evaluation.



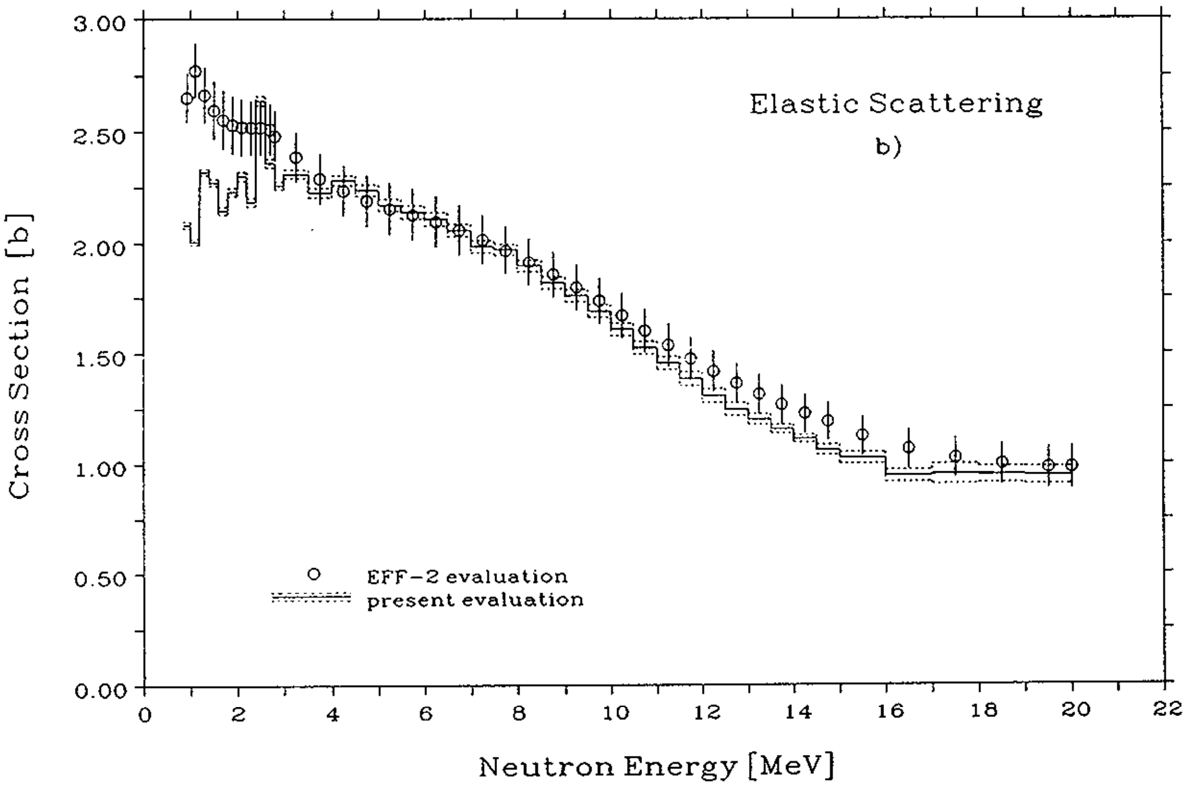


Figure 5: The cross section for elastic neutron scattering:
a) The experimental data base used for the present evaluation as compared with the evaluated cross section from EFF-2 (prior data).
b) Comparison of the EFF-2 evaluation with the group - averaged cross sections obtained as the final result of the present evaluation.

18990066

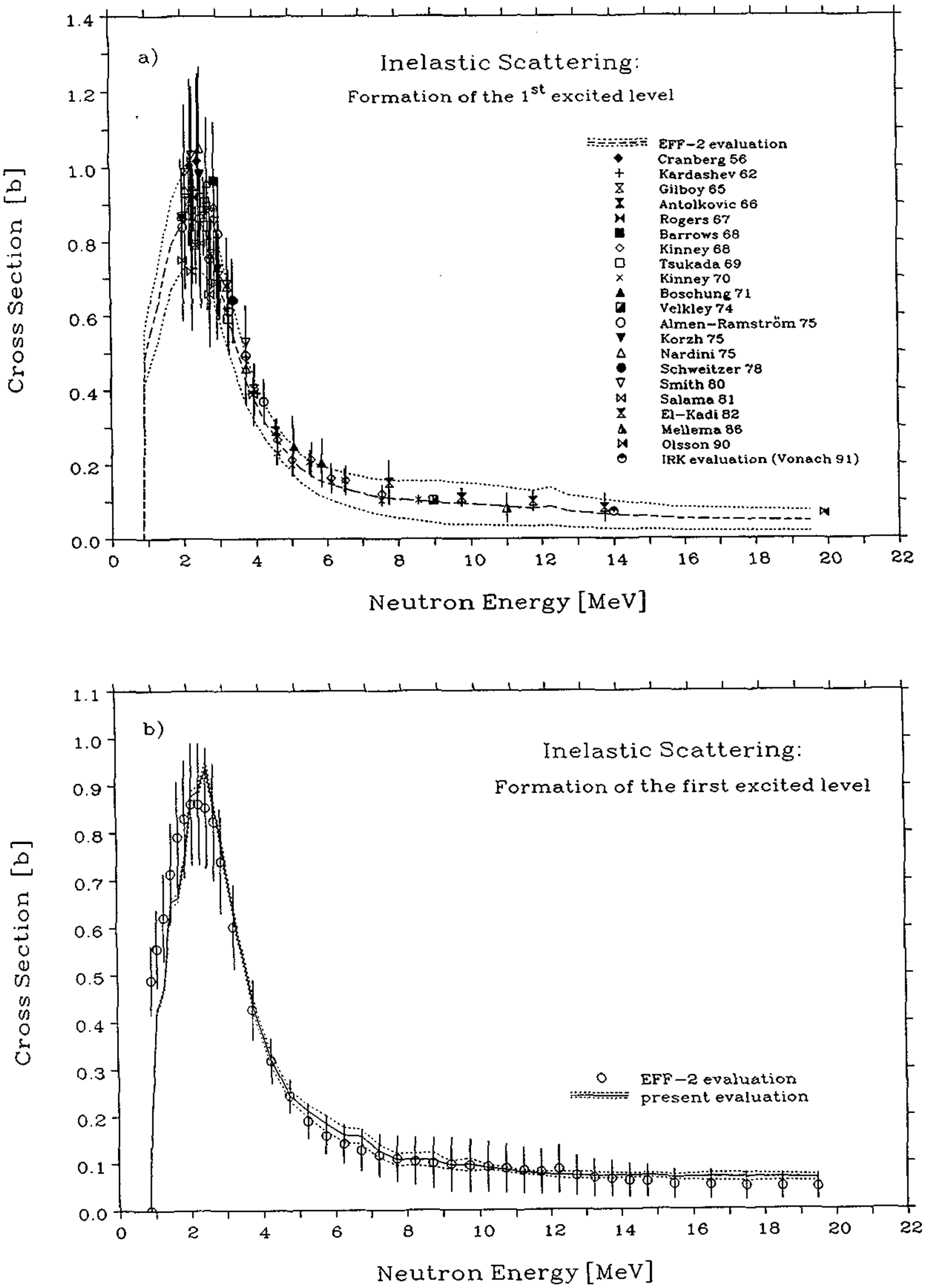


Figure 6: The cross section for the formation of the first excited ^{56}Fe level (E_{lev} = 0.847 MeV) by inelastic neutron scattering:
a) The evaluated cross section from EFF-2 used as prior data and experimental data providing additional information.
b) Comparison of the EFF-2 evaluation with the final results of the present evaluation.

18990067

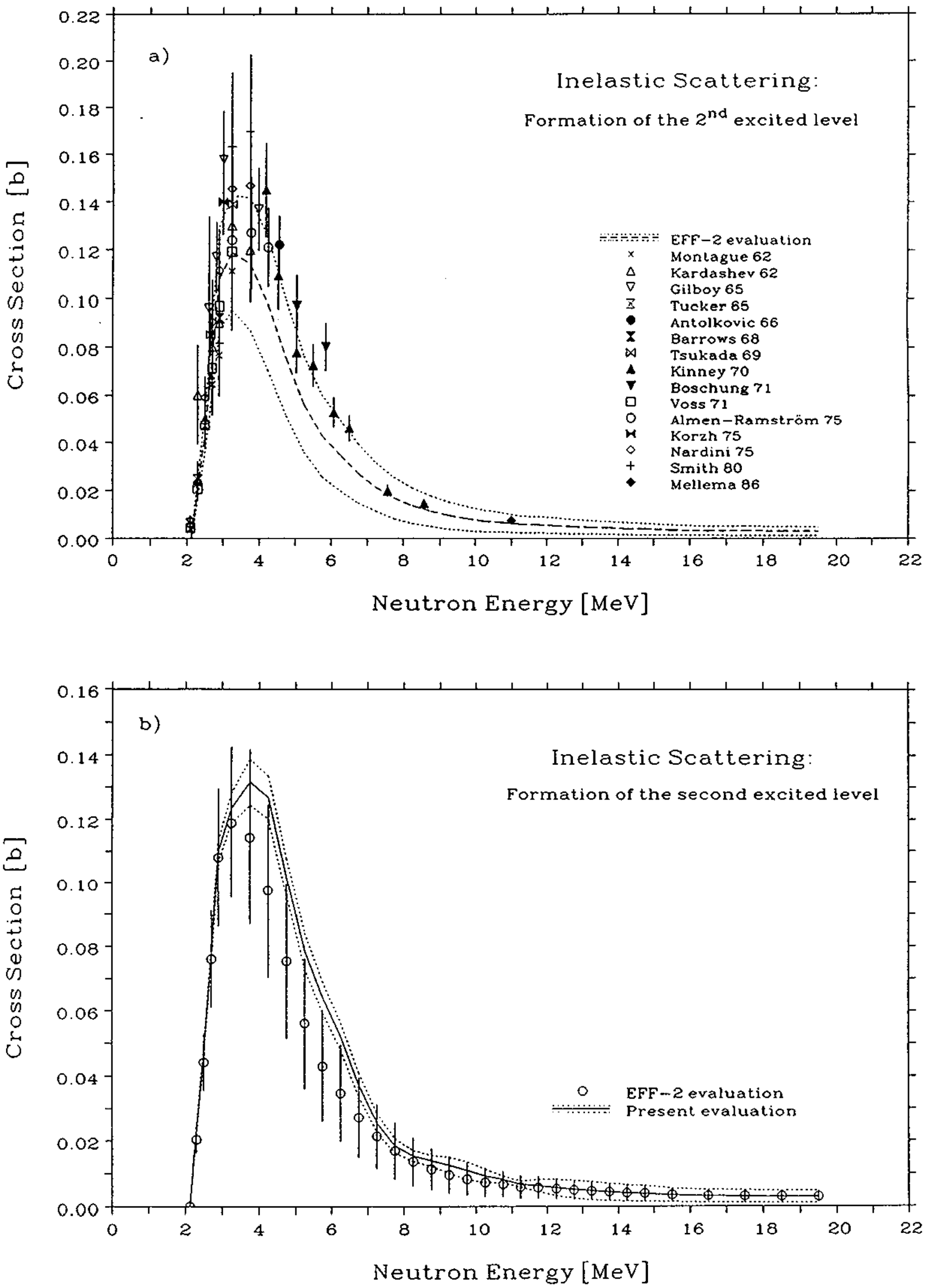


Figure 7: The cross section for the formation of the second excited ^{56}Fe level (E_{lev} = 2.085 MeV) by inelastic neutron scattering:
a) The evaluated cross section from EFF-2 used as prior data and experimental data providing additional information.
b) Comparison of the EFF-2 evaluation with the final results of the present evaluation.

18990068

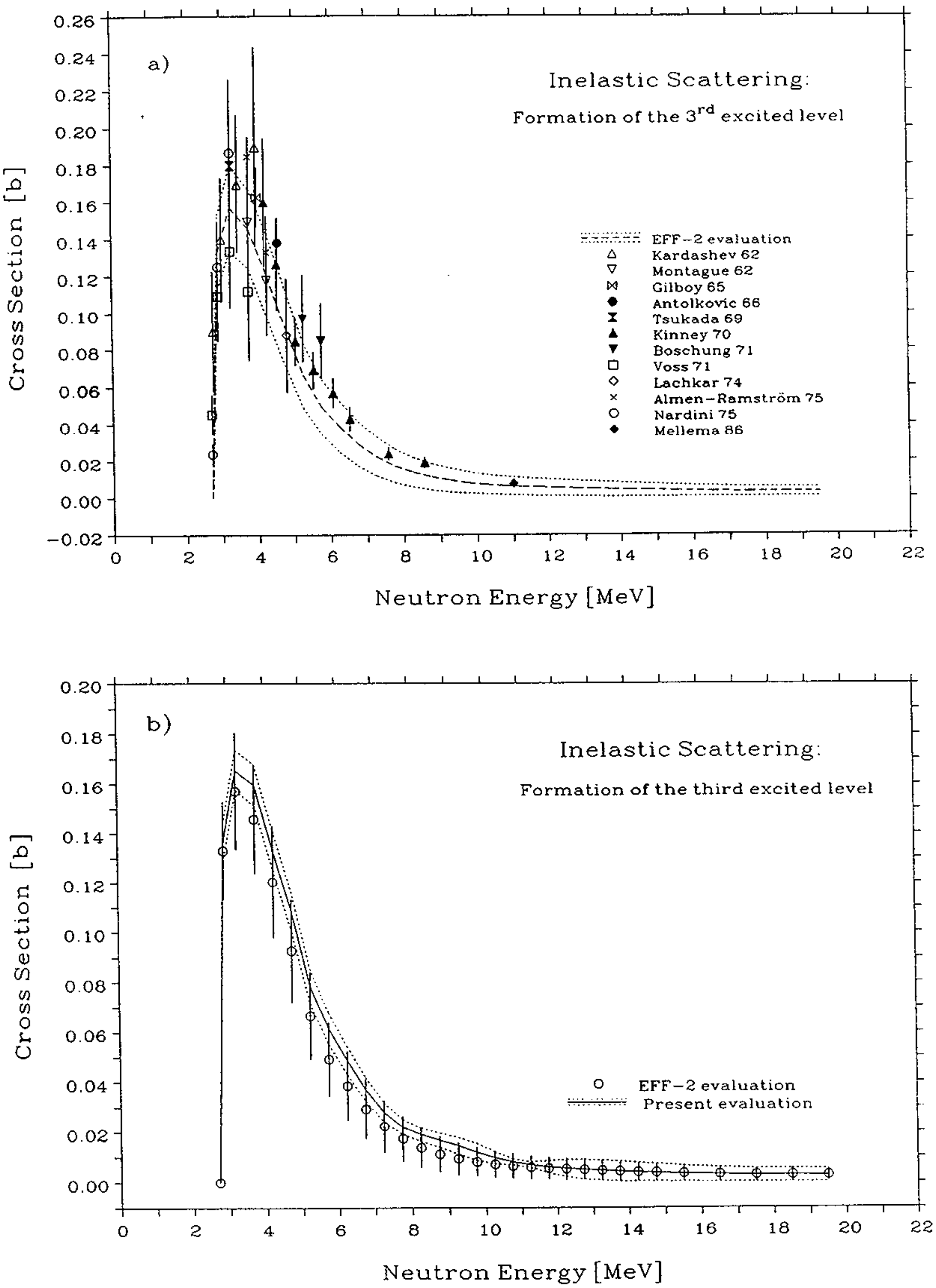
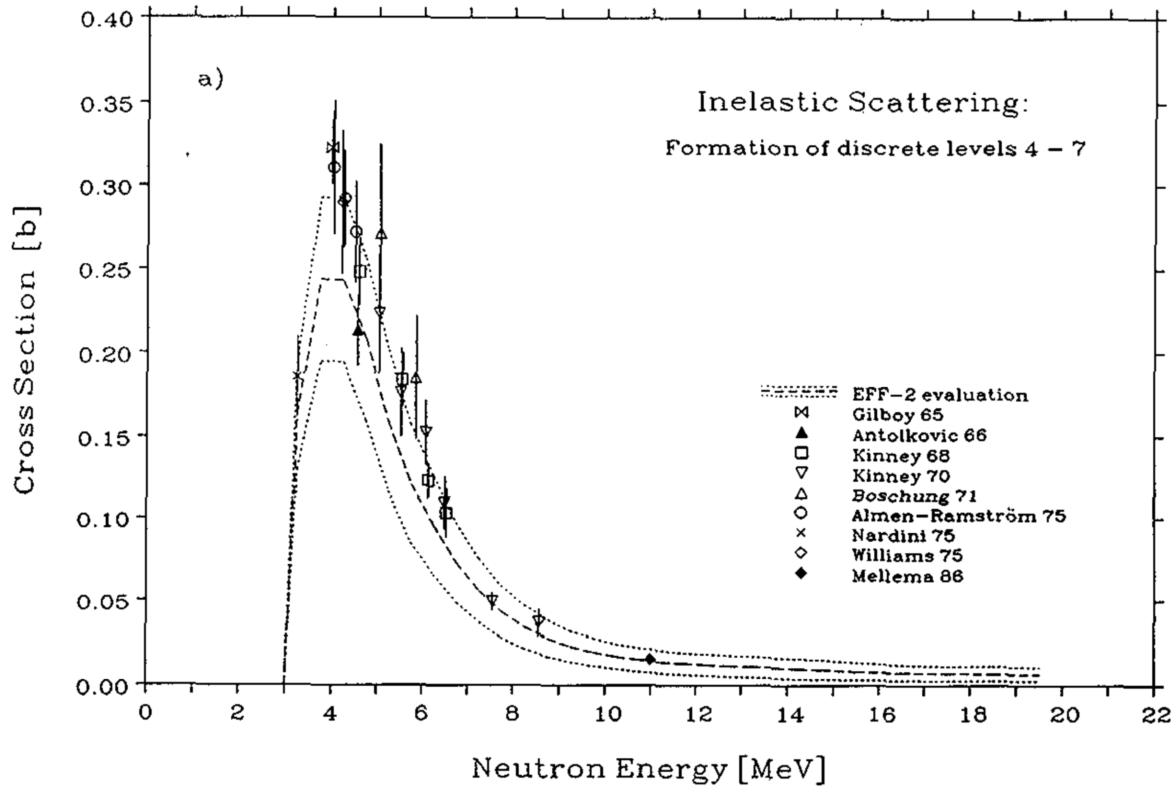


Figure 8: The cross section for the formation of the third excited ^{56}Fe level (E_{lev} = 2.658 MeV) by inelastic neutron scattering:
a) The evaluated cross section from EFF-2 used as prior data and experimental data providing additional information.
b) Comparison of the EFF-2 evaluation with the final results of the present evaluation.

18990069



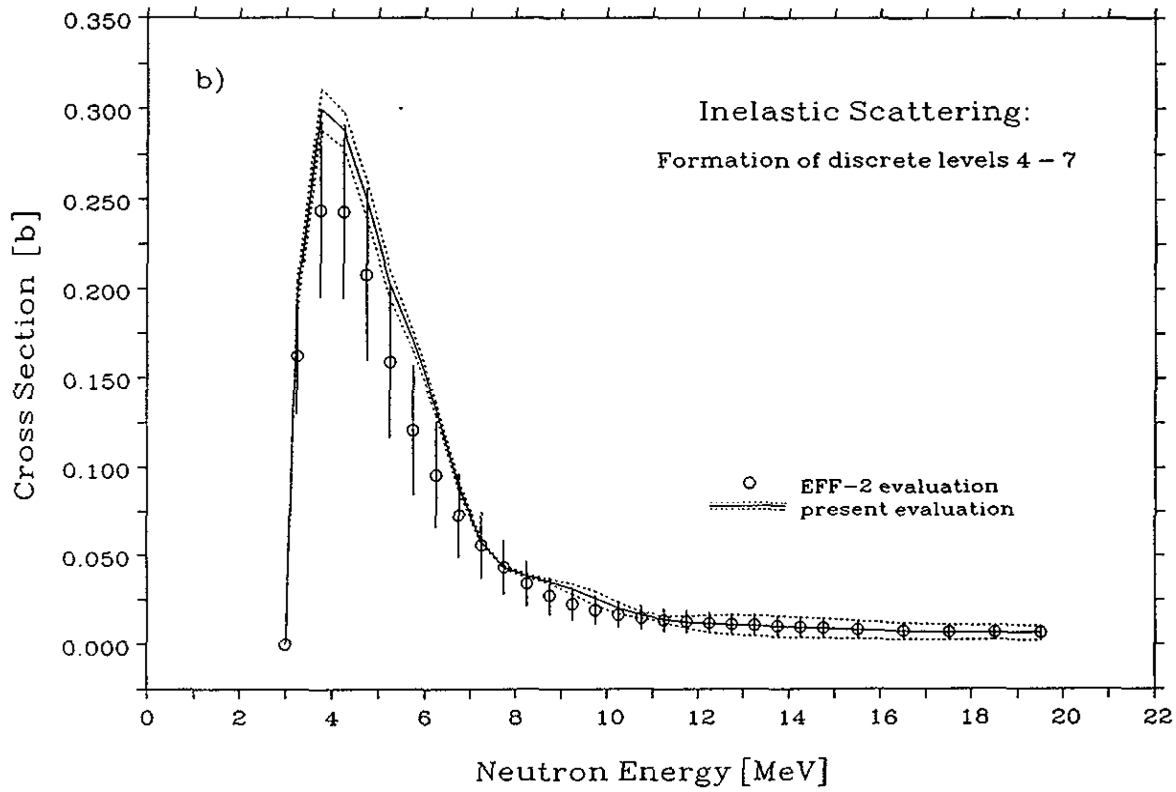


Figure 9: The excitation function for the formation of the discrete levels 4 - 7 (E_{lev} = 2.942 - 3.123 MeV) by *inelastic neutron scattering:*
a) The evaluated cross section from EFF-2 used as prior data and experimental data providing additional information.
b) Comparison of the EFF-2 evaluation with the final results of the present evaluation.

18990070

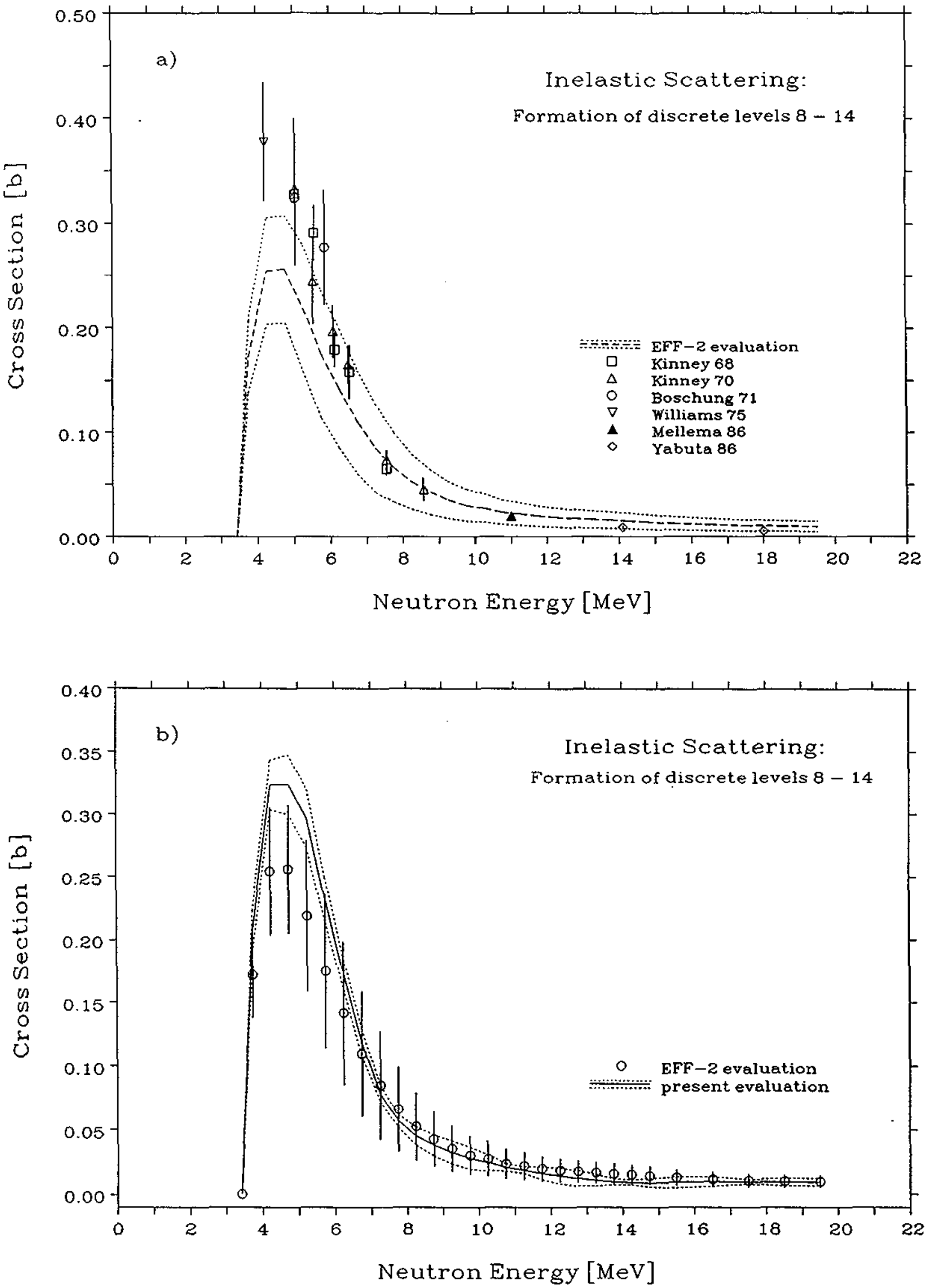


Figure 10: The excitation function for the formation of the discrete levels 8 - 14 (E_{lev} = 3.370 - 3.607 MeV) by inelastic neutron scattering:
a) The evaluated cross section from EFF-2 used as prior data and experimental data providing additional information.
b) Comparison of the EFF-2 evaluation with the final results of the present evaluation.

18990071

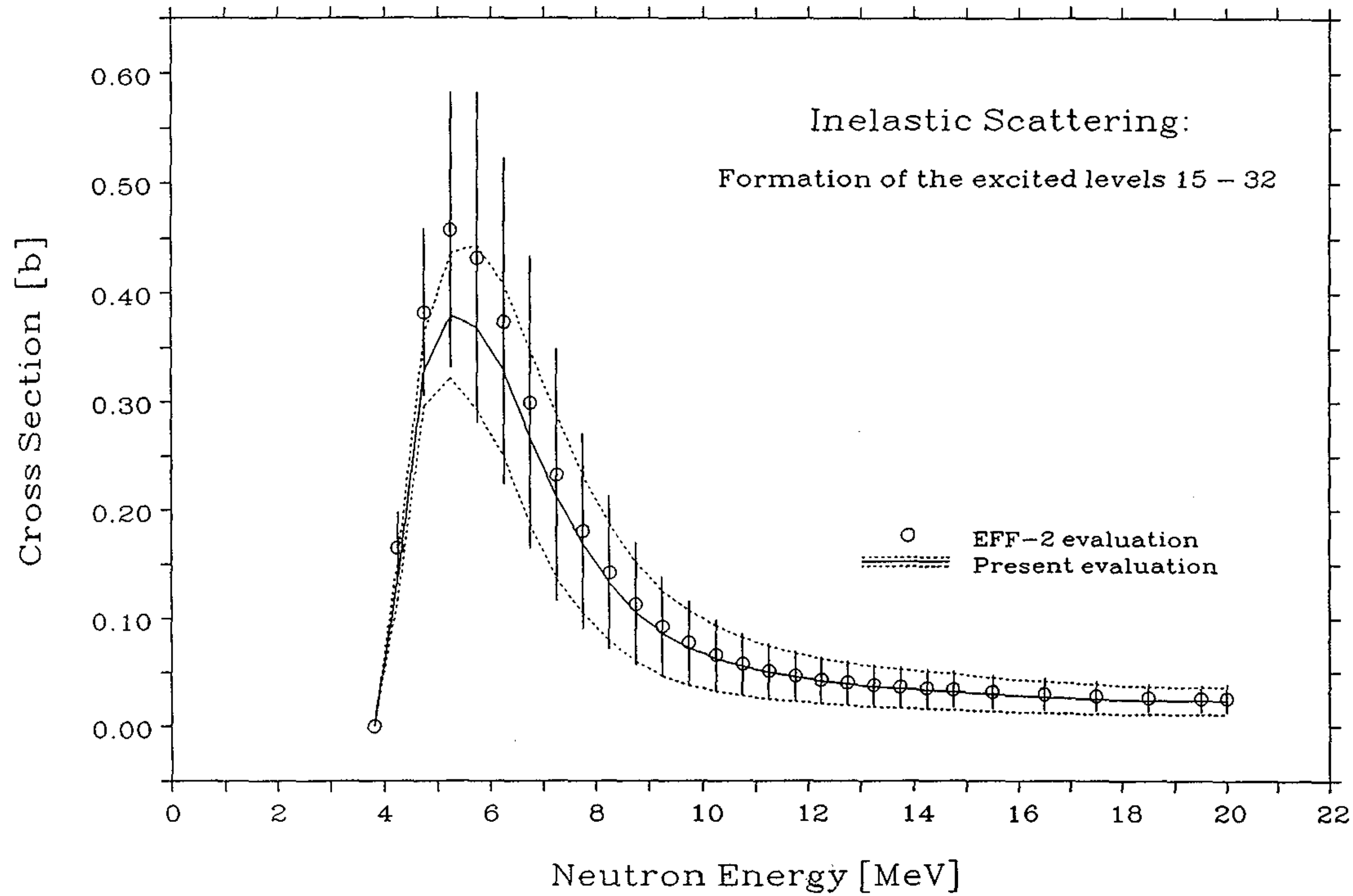


Figure 11: The excitation function for the formation of the discrete levels 15 - 32 (E_{lev} = 3.748 - 4.510 MeV) by inelastic neutron scattering: Comparison of the evaluated cross sections from EFF-2 with the final result of the present evaluation.

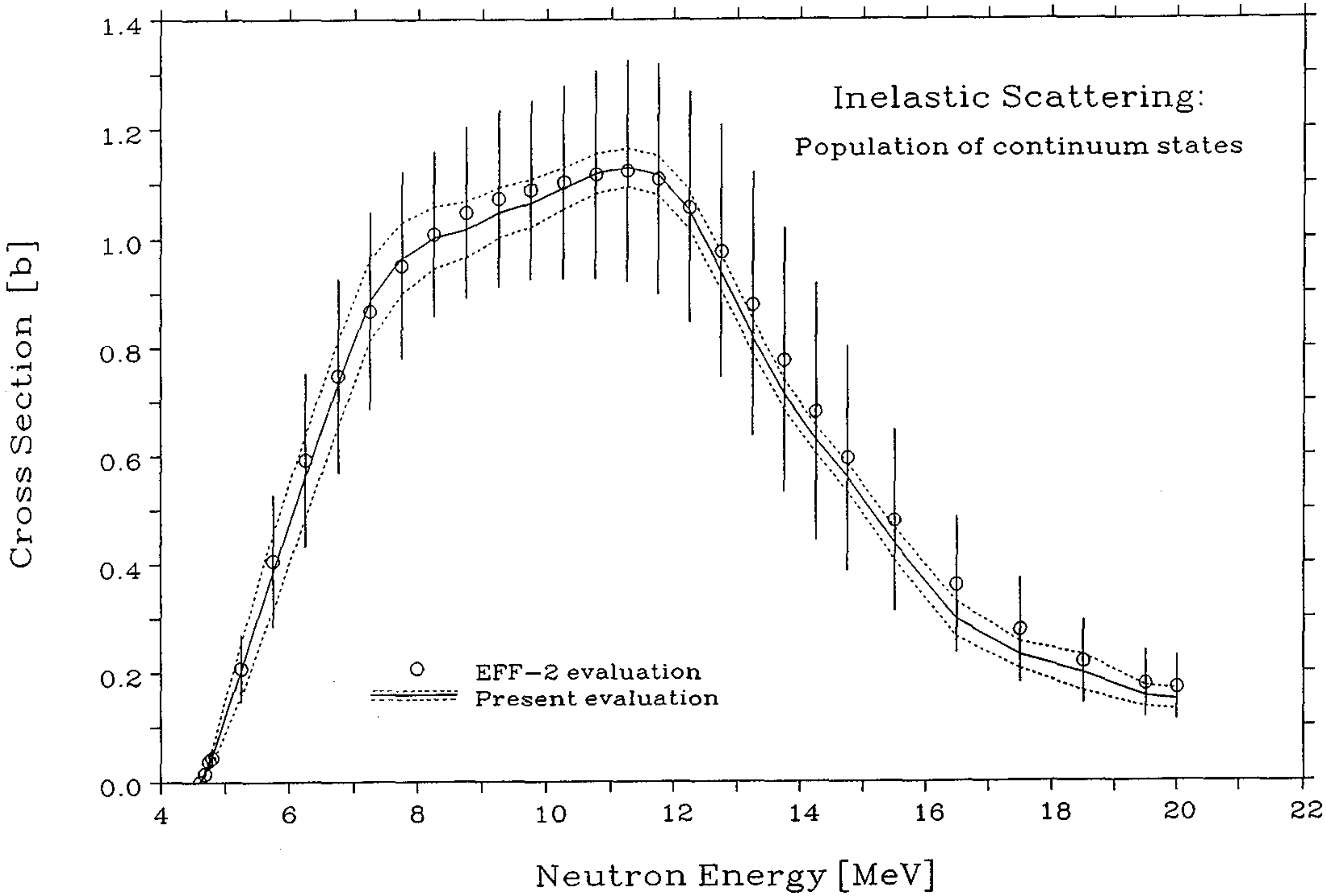


Figure 12: The excitation function for the population of continuum states in ^{56}Fe by inelastic neutron scattering: Comparison between the EFF-2 evaluation and the final results of the present evaluation.

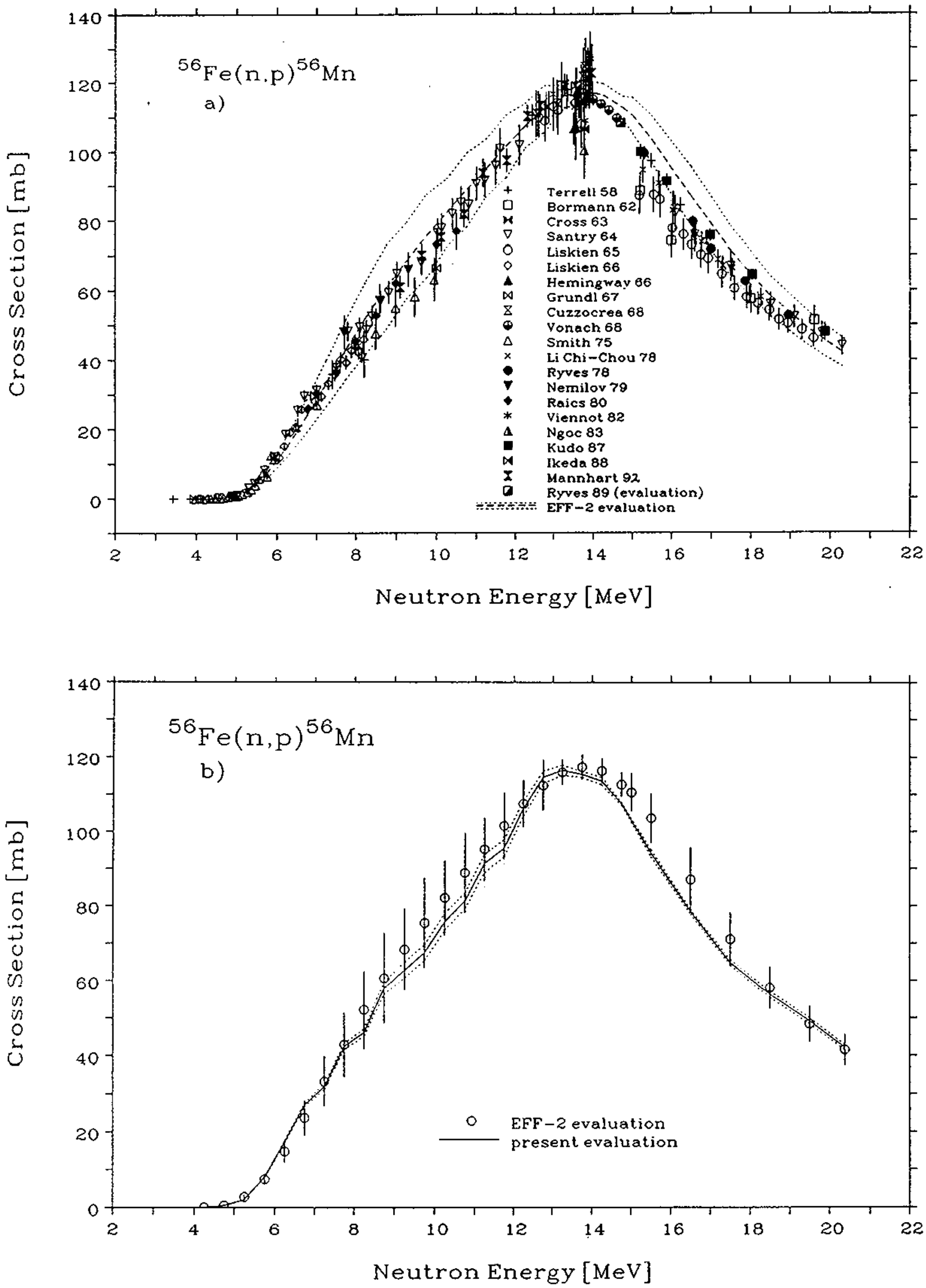
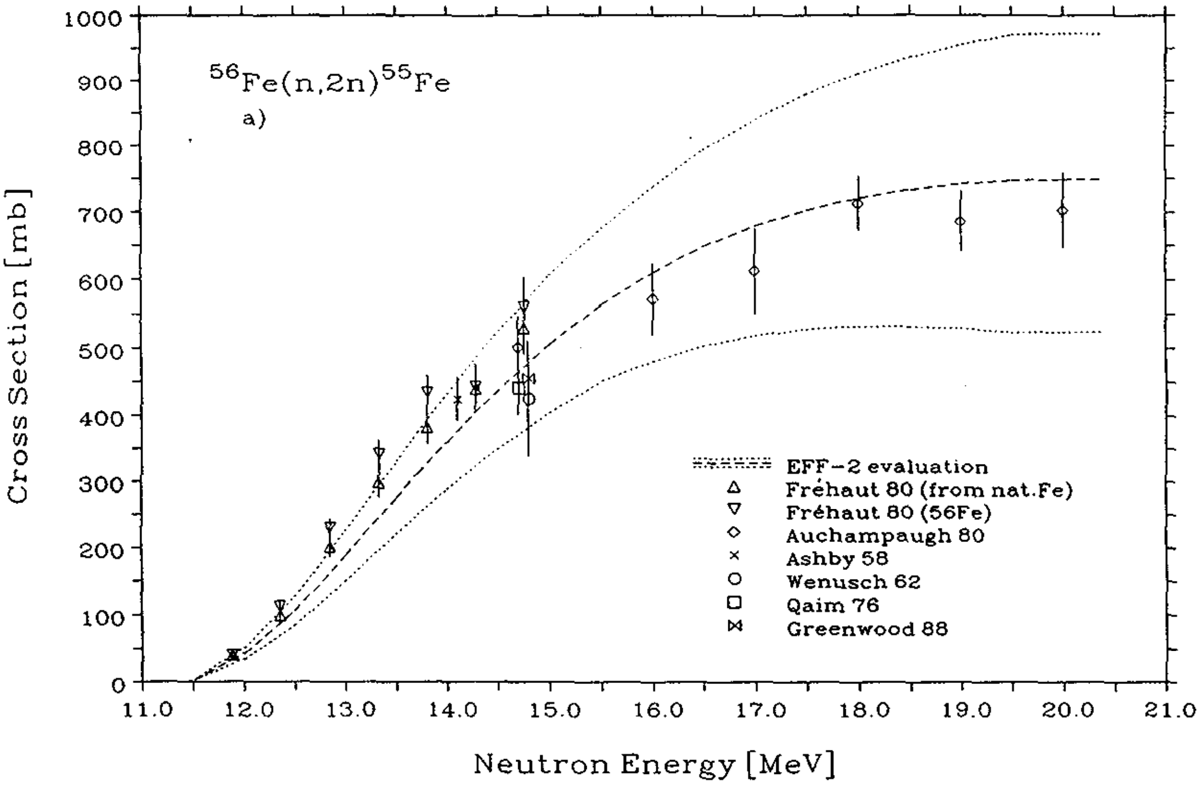


Figure 13: The excitation function for the $^{56}Fe(n,p)^{56}Mn$ reaction:
a) The evaluated cross sections from EFF-2 taken as prior data and renormalized experimental data providing additional information.
b) Comparison of the EFF-2 evaluation with the final results of the present evaluation.



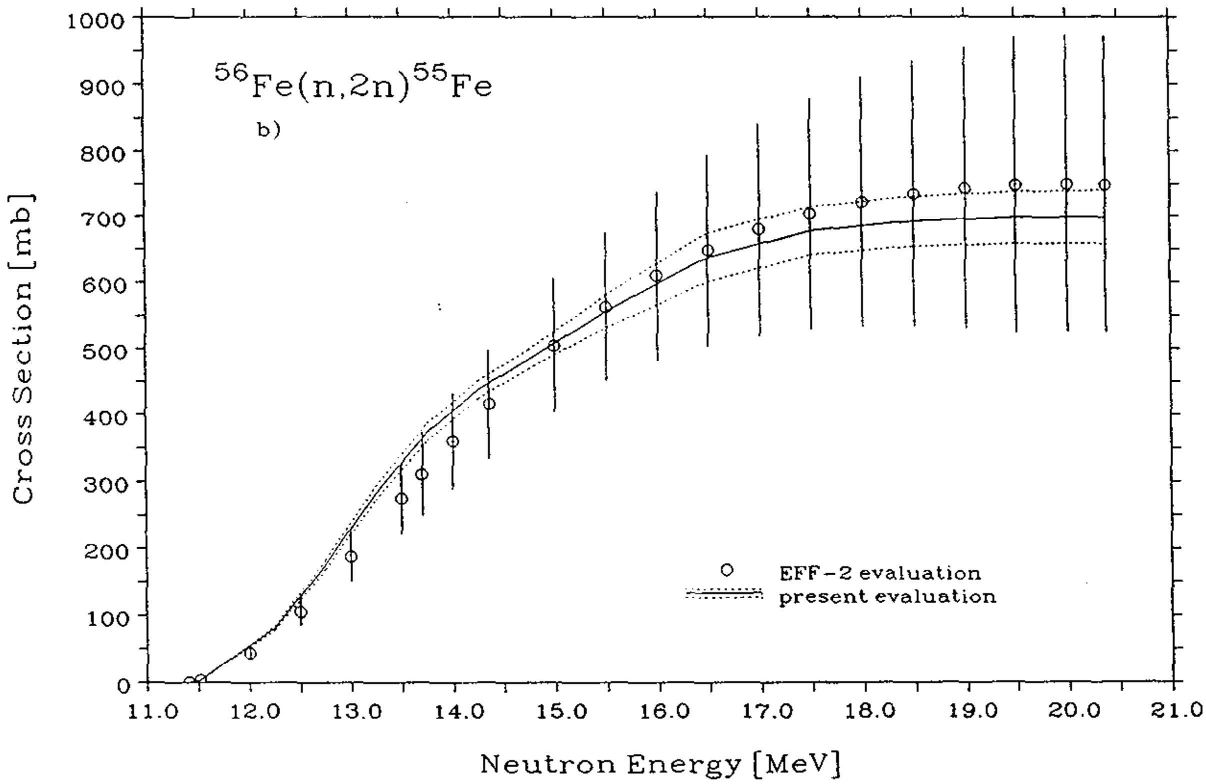
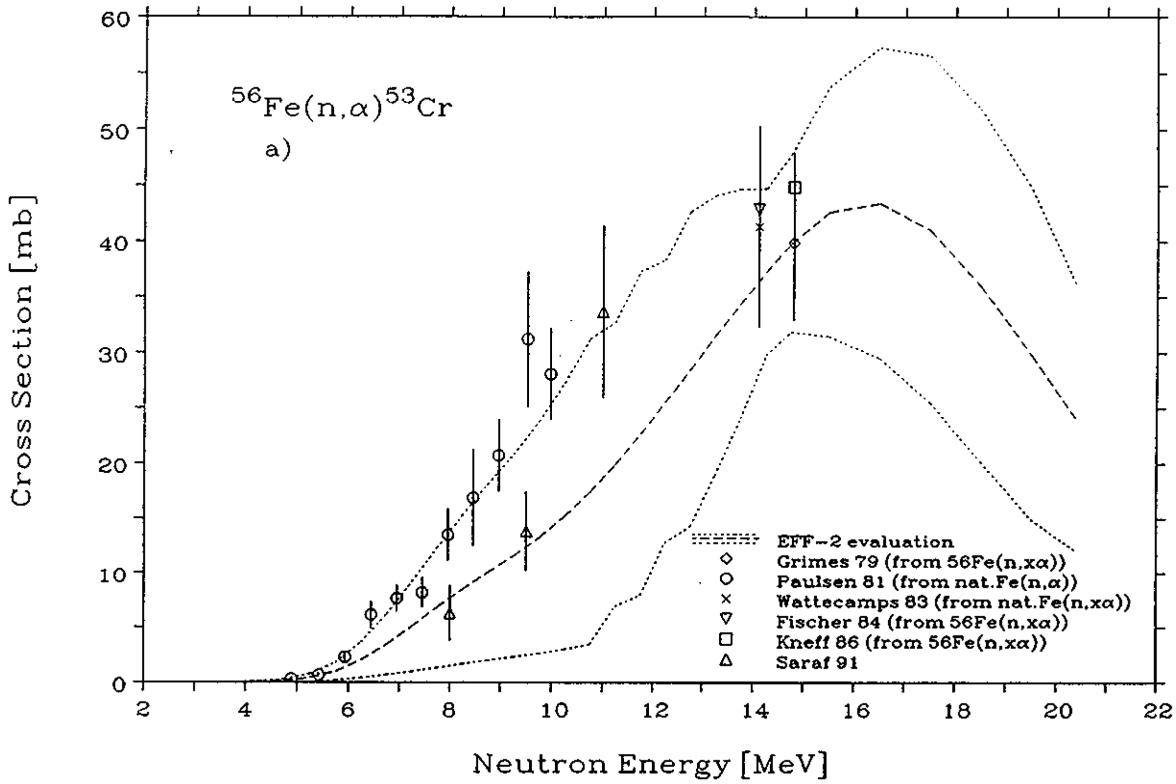


Figure 14: The excitation function for the ^{56}Fe(n,2n)^{55}Fe reaction:
a) The evaluated cross section from EFF-2 taken as prior data and the renormalized experimental data providing additional information.
b) Comparison of the EFF-2 evaluation with the final results of the present evaluation.

18990075



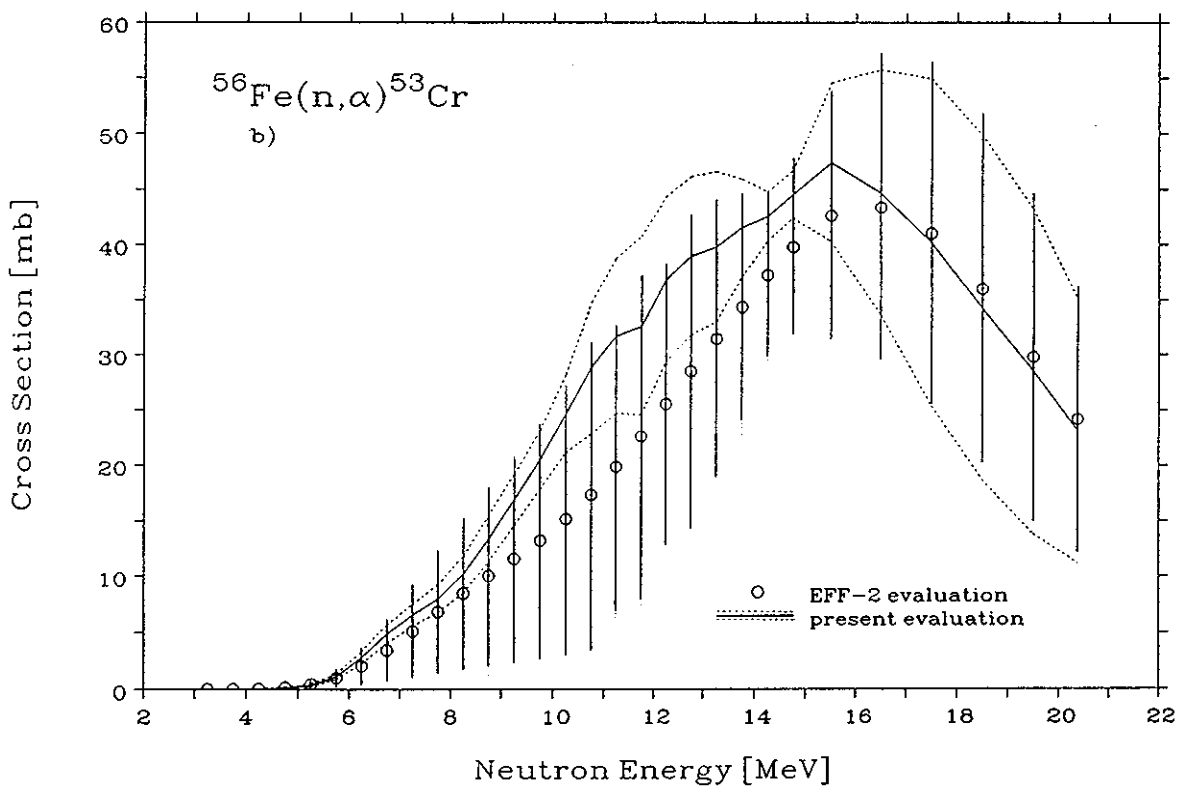


Figure 15: The excitation function for the $^{56}Fe(n,\alpha)^{53}Cr$ reaction:
a) The evaluated cross section from EFF-2 taken as prior data and experimental data providing additional information.
b) Comparison of the EFF-2 evaluation with the final results of the present evaluation.

18990076

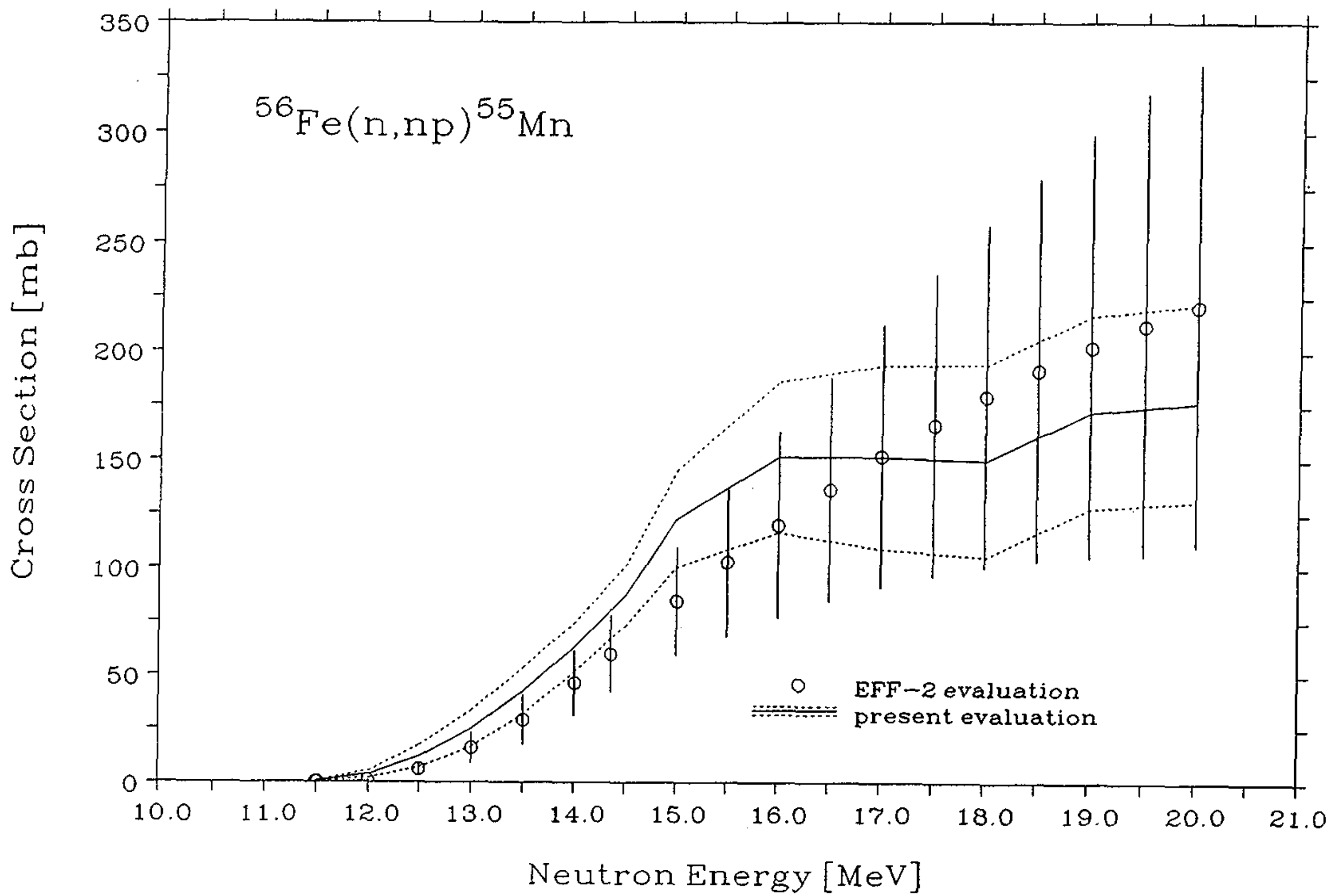


Figure 16: The excitation function for the $^{56}Fe(n,np)^{55}Mn$ reaction: Comparison between the EFF-2 evaluation used as prior data and the result of the present evaluation.

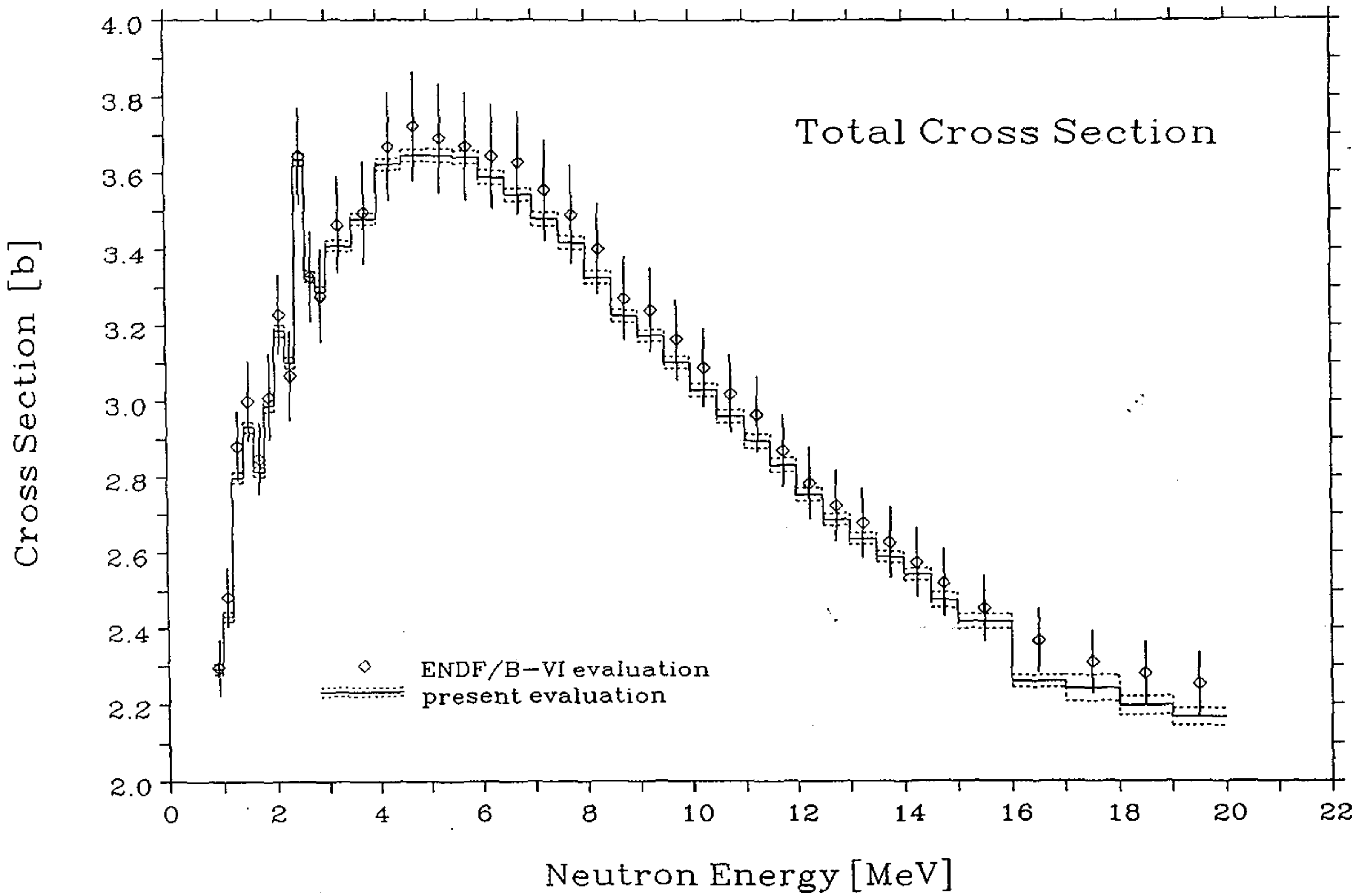


Figure 17: The total cross section of ^{56}Fe: Comparison of the group - averaged cross sections from the ENDF/B-VI evaluation and those obtained in the present evaluation.

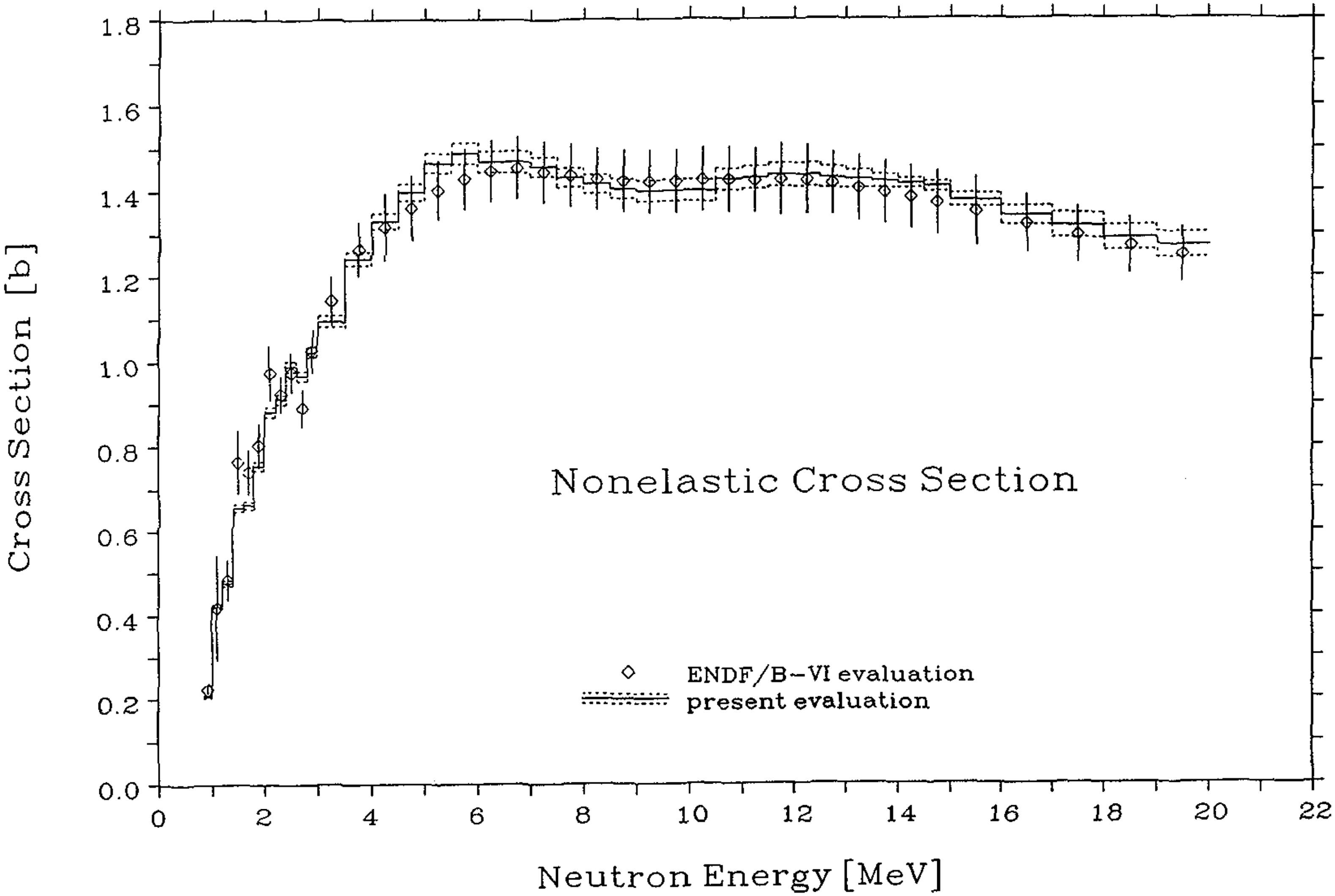


Figure 18: The nonelastic cross section of ^{56}Fe: Comparison of the group - averaged cross sections from the ENDF/B-VI evaluation and those obtained in the present evaluation.

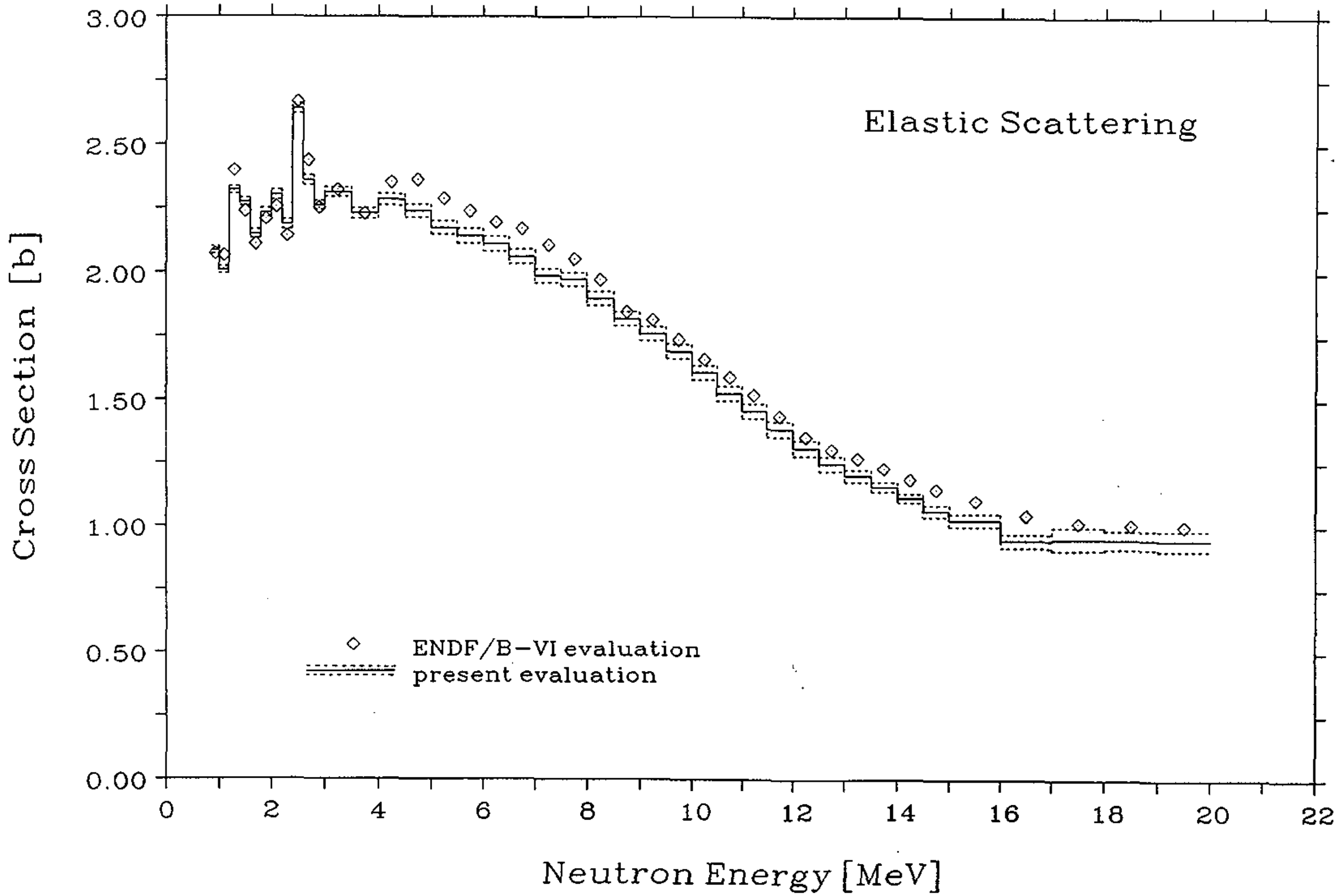


Figure 19: The cross section for elastic scattering: Comparison of the group - averaged cross sections from the ENDF/B-VI evaluation and those obtained in the present evaluation. The differences between the results of both evaluations are smaller than the uncertainties of the ENDF/B-VI data.

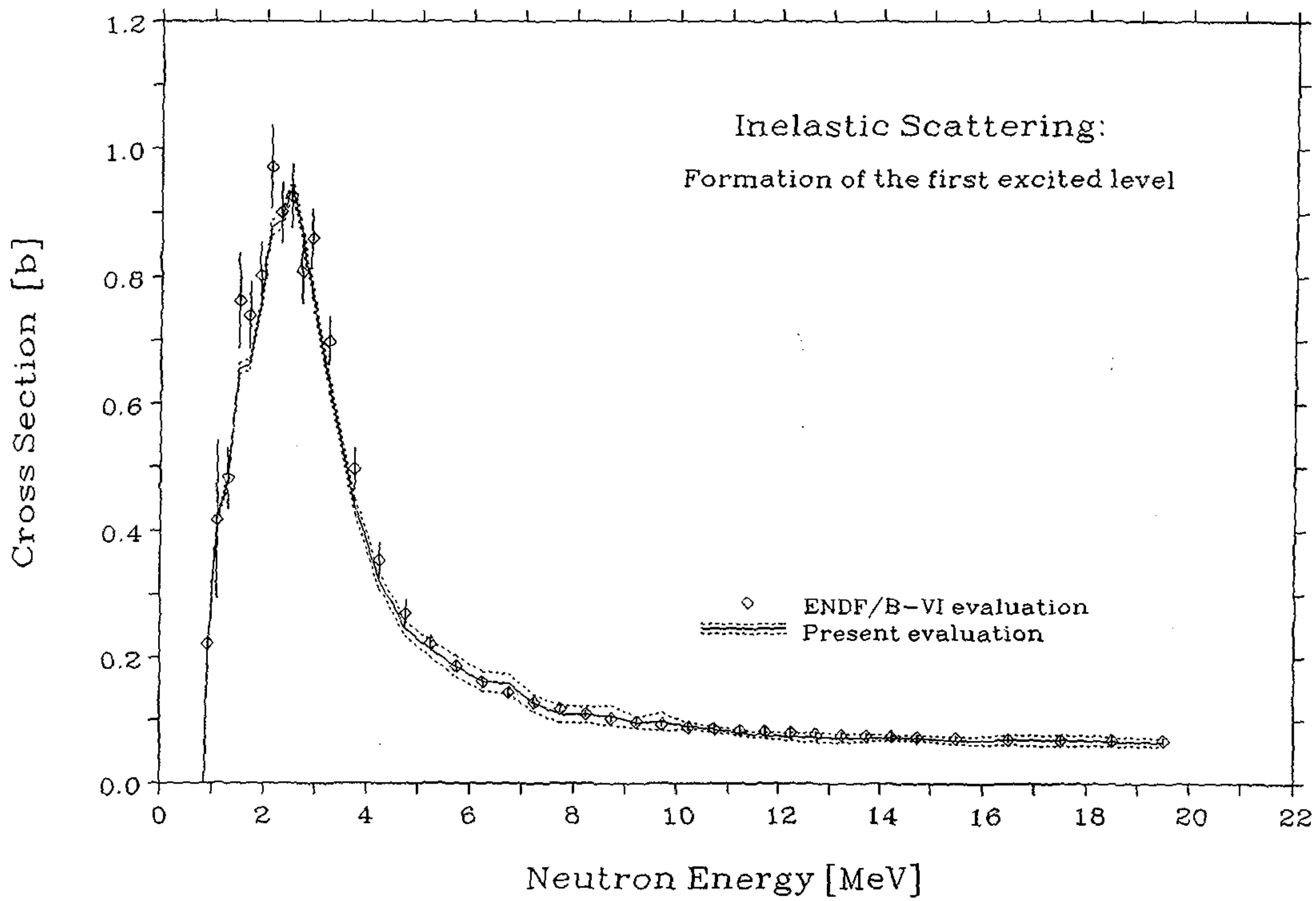


Figure 20: The cross section for the formation of the first excited ^{56}Fe level by inelastic neutron scattering: Comparison of the group - averaged cross sections from the ENDF/B-VI evaluation and those resulting from the present evaluation.

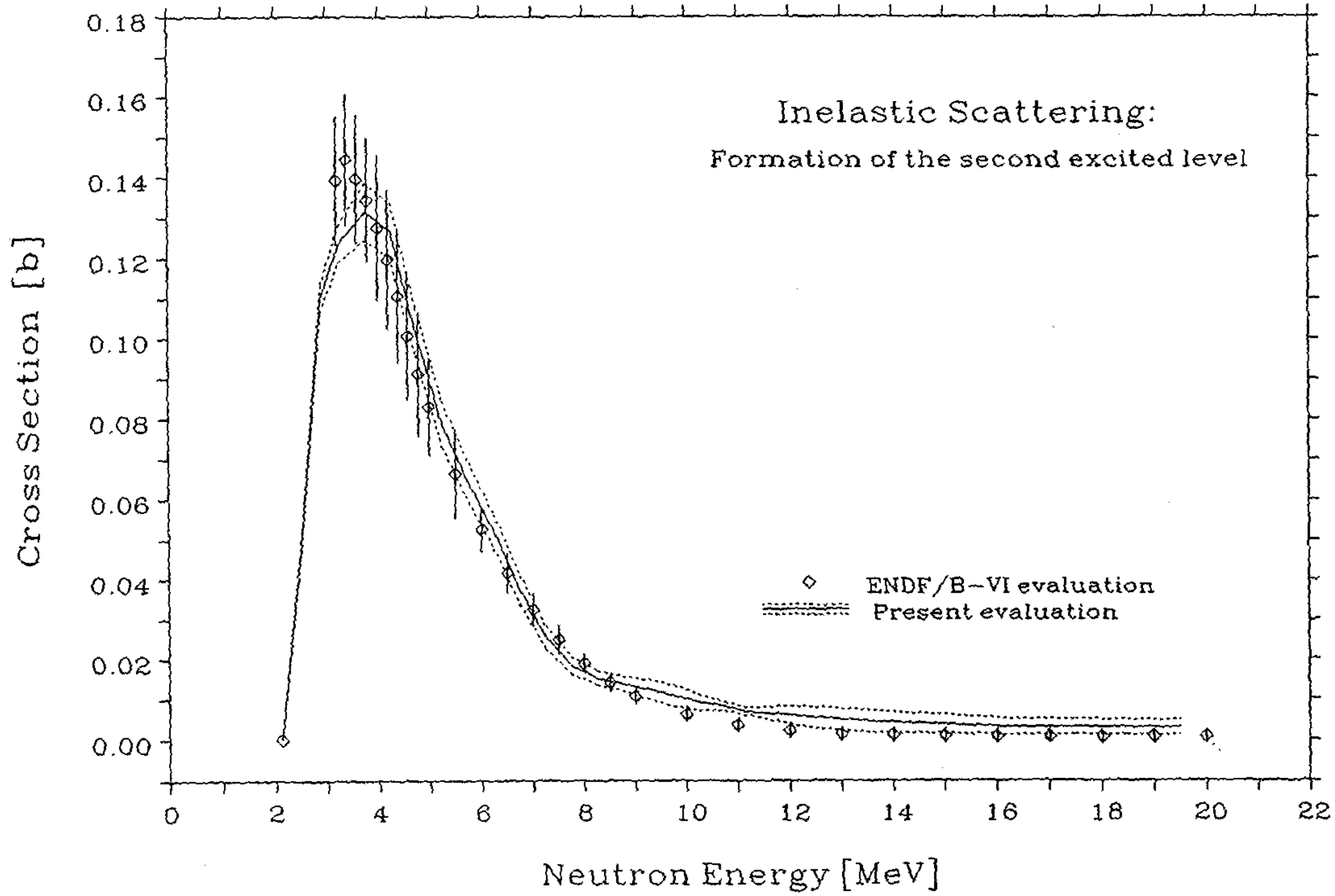


Figure 21: The cross section for the formation of the second excited ^{56}Fe level by inelastic neutron scattering: Comparison of the cross sections recommended in the ENDF/B-VI evaluation and the group - averaged values resulting from the present evaluation.

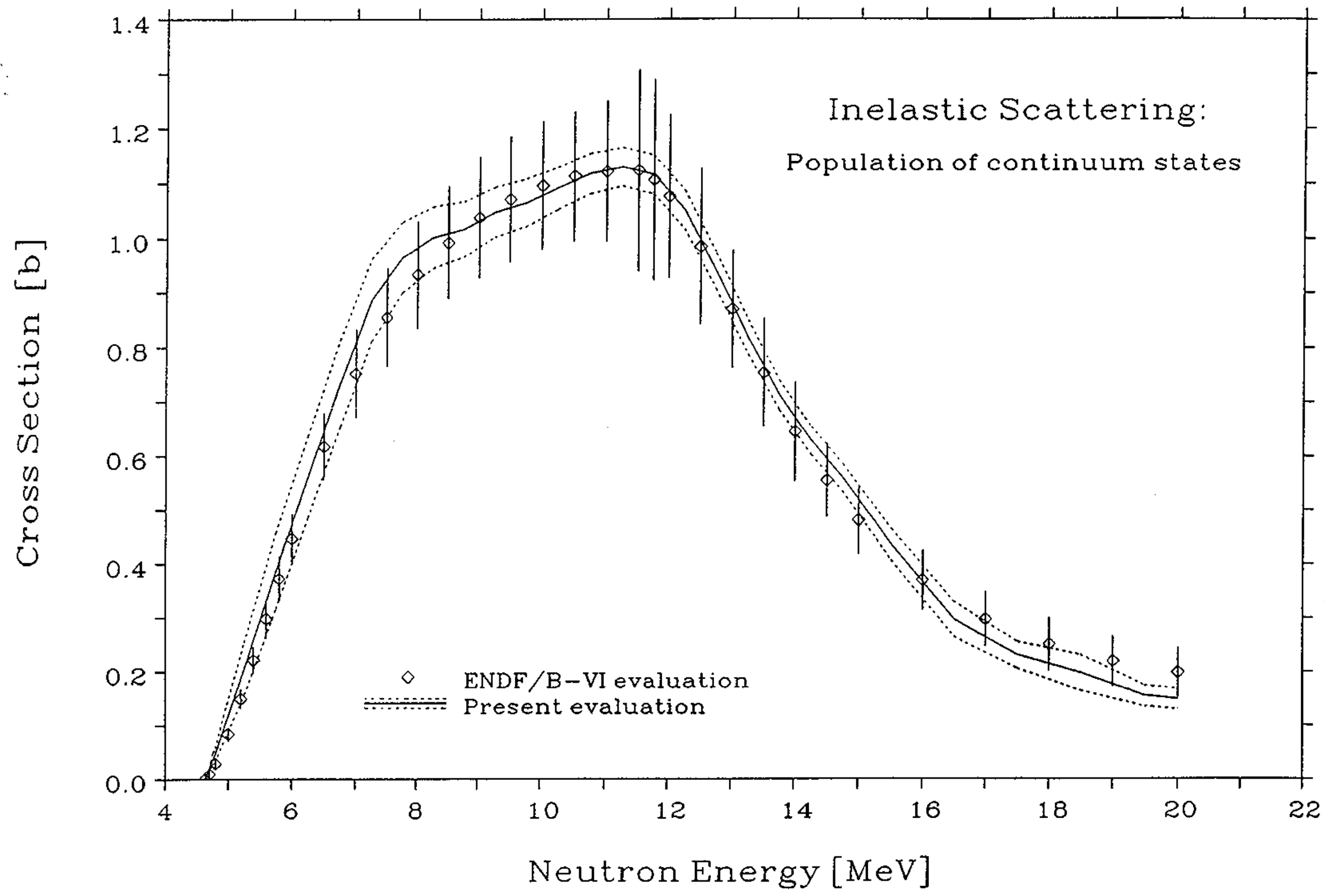


Figure 23: The excitation function for the population of continuum states in ^{56}Fe by inelastic neutron scattering: Comparison of the cross sections recommended in the ENDF/B-VI evaluation and the results obtained in the present evaluation.

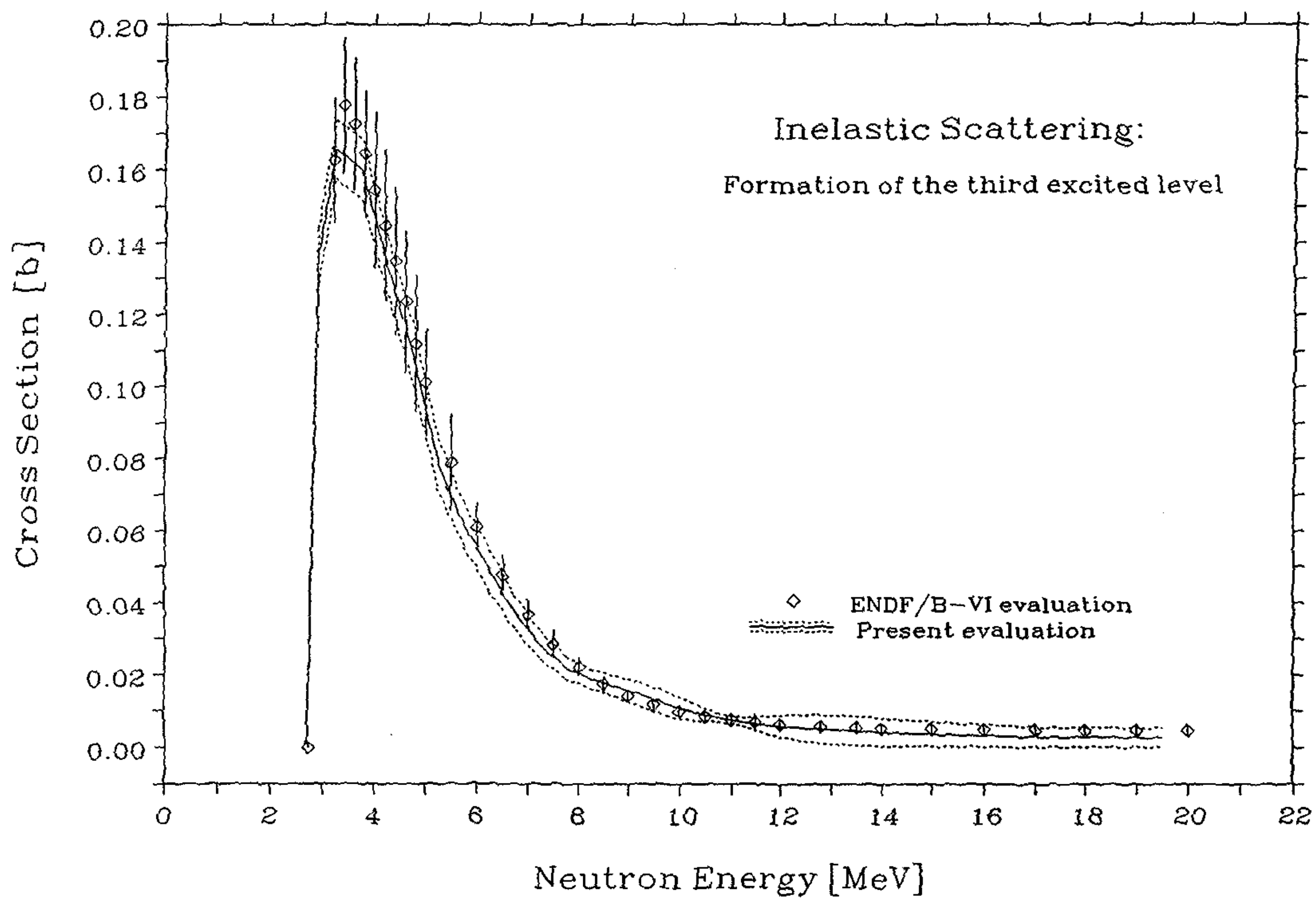


Figure 22: The cross section for the formation of the third excited ^{56}Fe level by inelastic neutron scattering: Comparison of the cross sections recommended in the ENDF/B-VI evaluation and the group - averaged values resulting from the present evaluation.

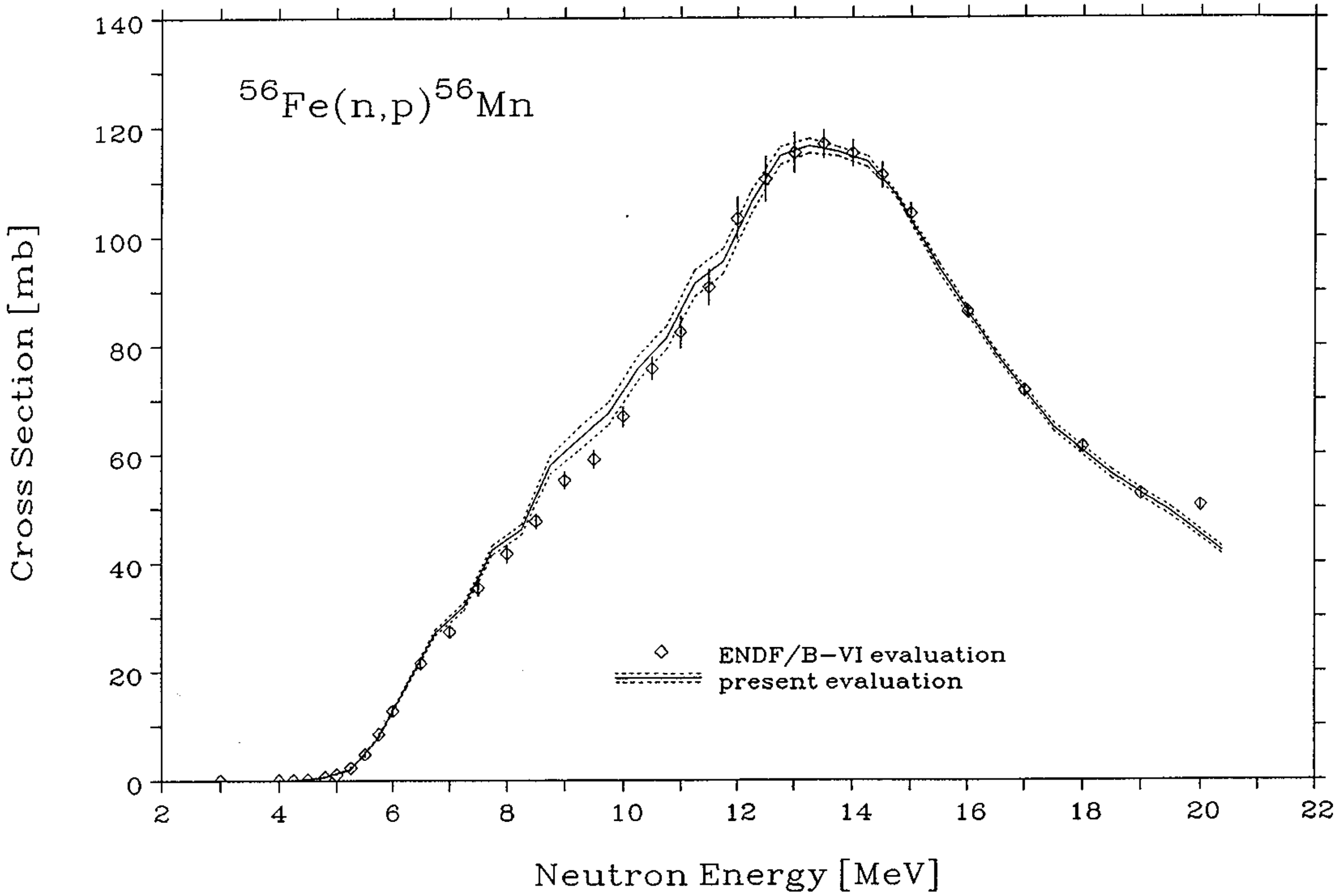


Figure 24: The excitation function for the $^{56}Fe(n,p)^{56}Mn$ reaction: Comparison of the cross sections recommended in the ENDF/B-VI evaluation and the results obtained in the present evaluation.

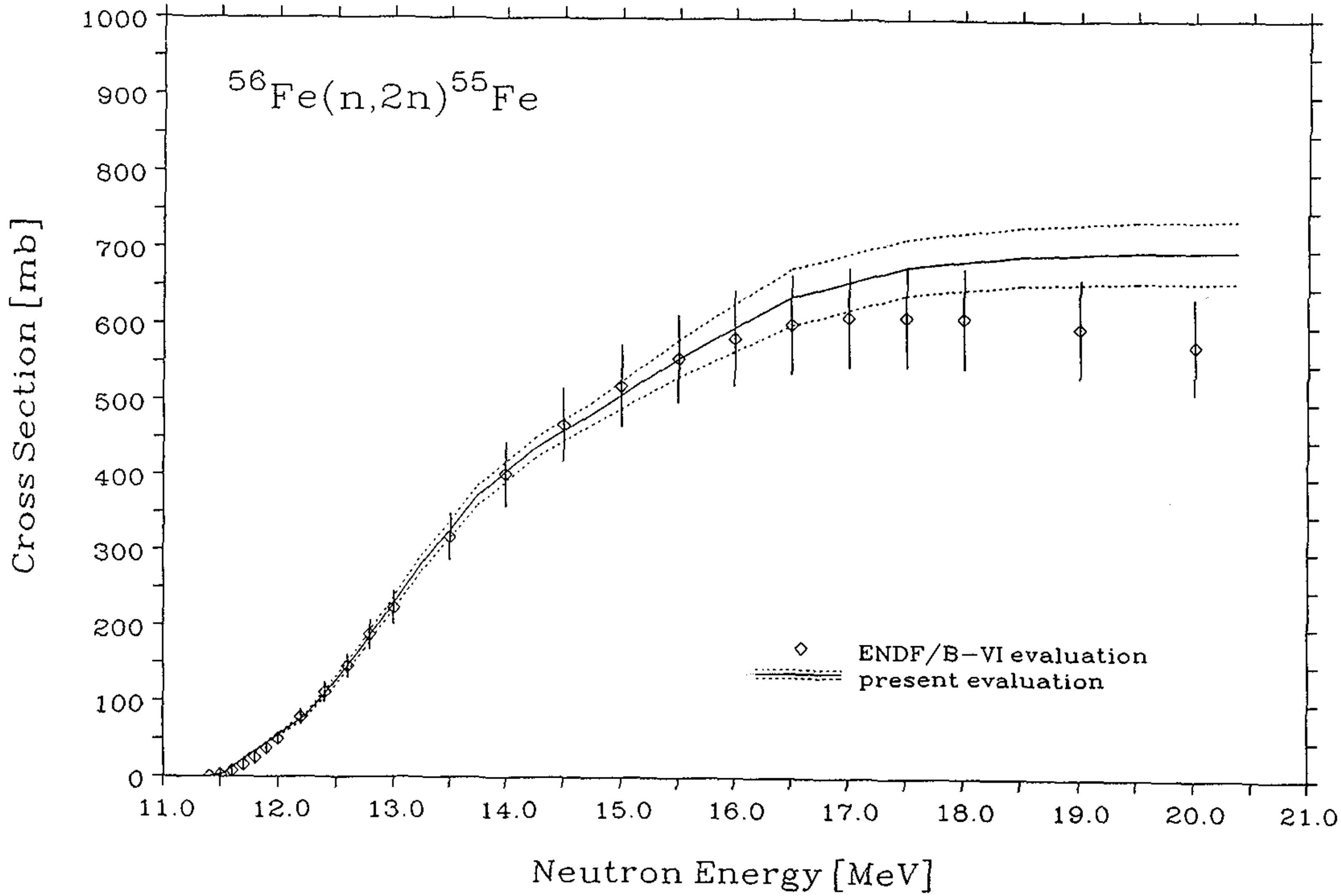


Figure 25: The excitation function for the ^{56}Fe(n,2n)^{55}Fe reaction: Comparison of the cross sections recommended in the ENDF/B-VI evaluation and the results obtained in the present evaluation.

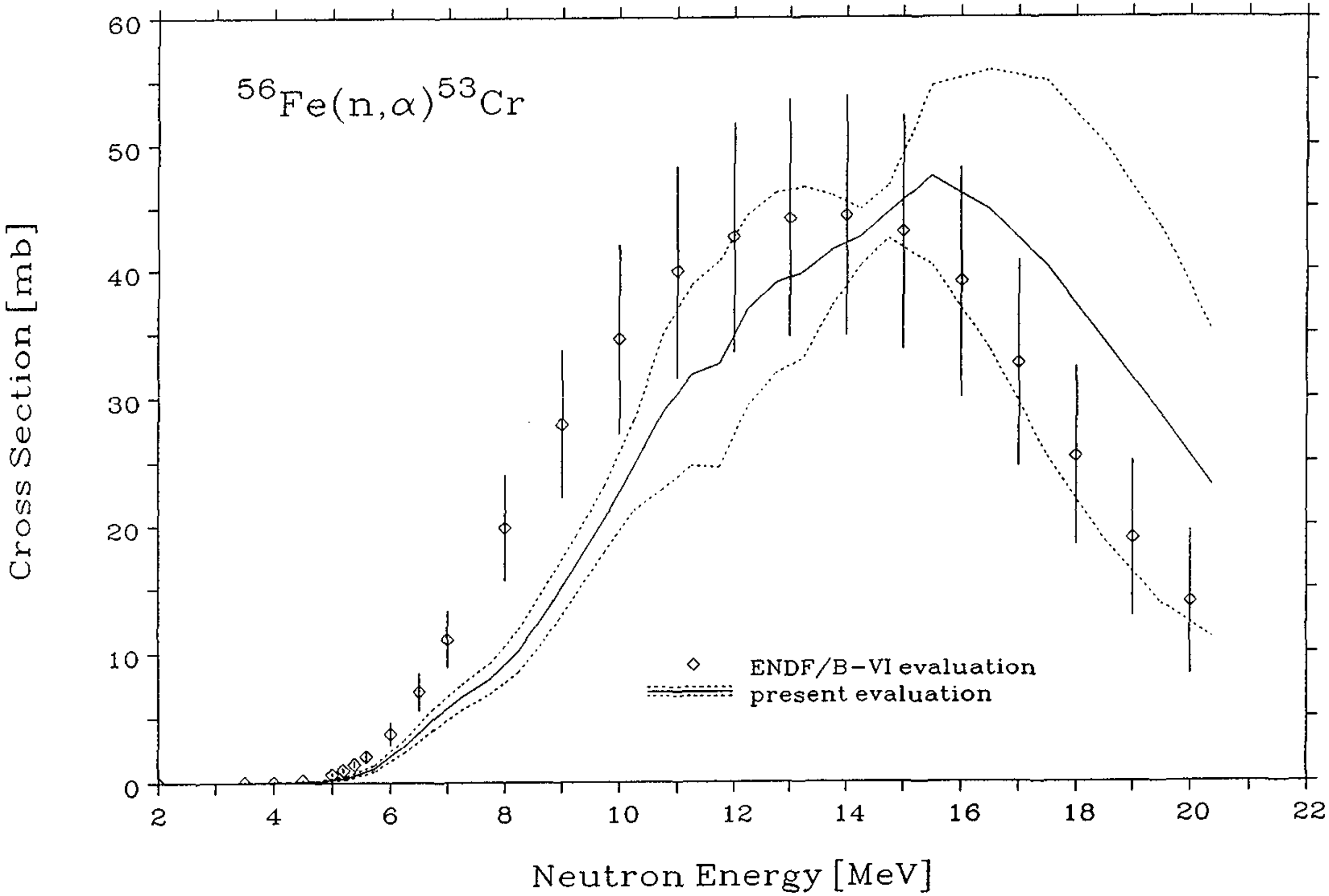


Figure 26: The excitation function for the $^{56}Fe(n,\alpha)^{53}Cr$ reaction: Comparison of the cross sections recommended in the ENDF/B-VI evaluation and the results obtained in the present evaluation.

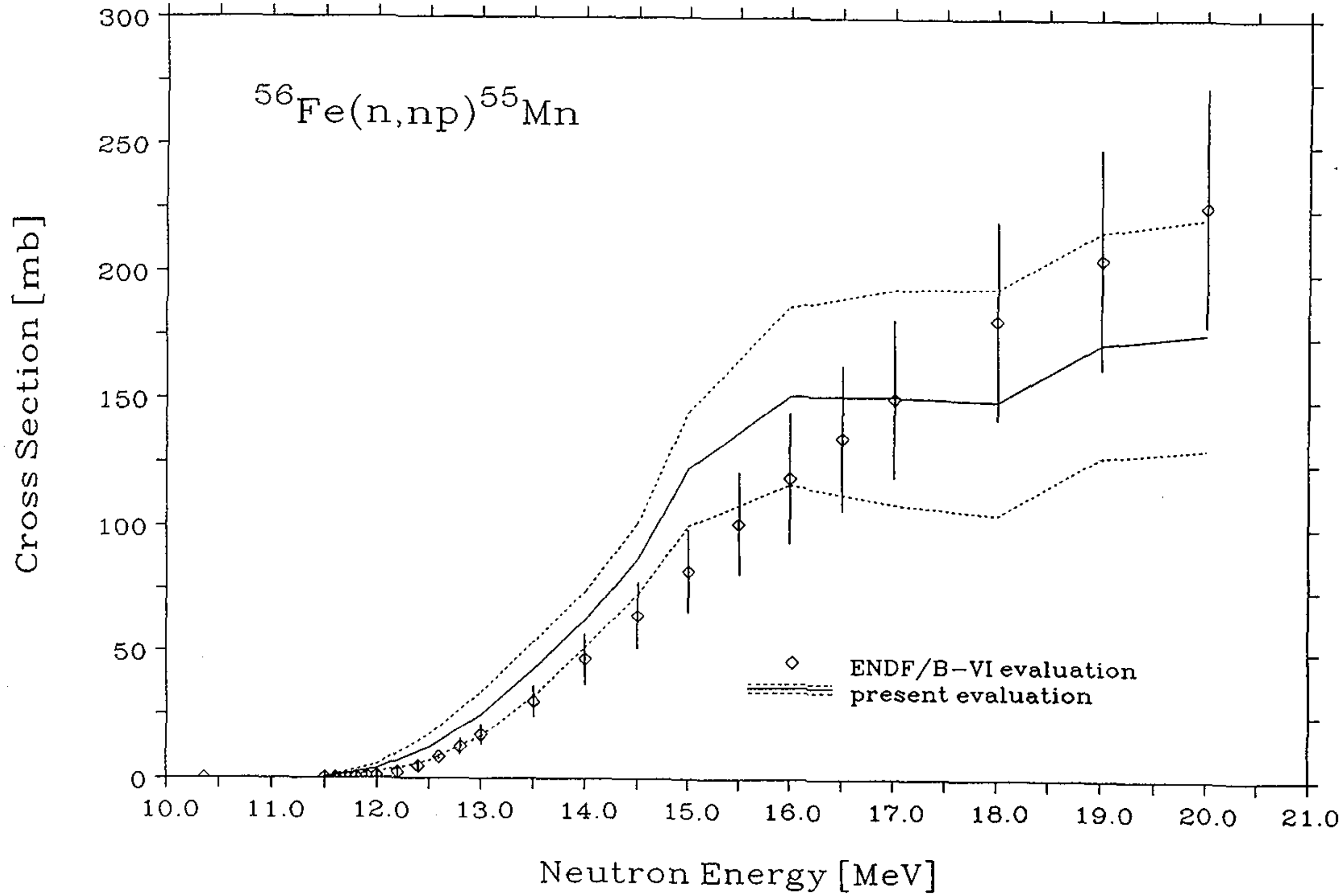


Figure 27: The excitation function for the $^{56}Fe(n,np)^{55}Mn$ reaction: Comparison of the cross sections recommended in the ENDF/B-VI evaluation and the results obtained in the present evaluation.