Final Report of Subgroup 7

Nuclear Data Standards

An International Evaluation of the Neutron Cross Section Standards

---

Coordinator: A .D. Carlson

Members of Subgroup 7 : S. A. Badikov,[1] A. D. Carlson,[2] Z. Chen,[3] E. V. Gai,[1] G. M. Hale,[4] F.-J. Hambsch,[5] H. M. Hofmann,[6] T. Kawano,[7] N. M. Larson,[8] S.Y. Oh,[9] V. G. Pronyaev,[10] D. L. Smith,[11] S. Tagesen,[12] and H. Vonach[12]

SUMMARY: Work is reported on the results of an international evaluation of the neutron cross section standards. The evaluations include the H(n,n), ^{6}Li(n,t), ^{10}B(n,α), ^{10}B(n,$\alpha_1\gamma$), ^{197}Au(n,γ), ^{235}U(n,f), and ^{238}U(n,f) standard reactions. In addition evaluations were produced for the non-standard ^{238}U(n,γ) and ^{239}Pu(n,f) reactions. This evaluation was performed to include new experiments on the standards that have been made since the ENDF/B-VI standards evaluation was completed and to improve the evaluation process. Evaluations were not done for the ^{3}He(n,p) and C(n,n) standards. These standards will be carried over from ENDF/B-VI. The interest in standards above 20 MeV led to the extension of the ^{235}U(n,f) and ^{238}U(n,f) cross sections to 200 MeV. The ^{239}Pu(n,f) cross section was also extended to 200 MeV. The general trend observed for the evaluations is an increase in the cross sections for most of the reactions from fractions of a percent to several percent compared with the ENDF/B-VI results.

Introduction

The standards are the basis for the neutron reaction cross section libraries. Significant improvements have been made in the standard cross section database since the last complete evaluation of the neutron cross section standards, almost 20 years ago. It is important to re-evaluate these cross sections taking into account new experimental data and improved evaluation

---

[1]Institute of Physics & Power Engineering, Obninsk, Russia.
[2]National Institute of Standards and Technology, Gaithersburg, MD, USA, 20899.
[3]Tsinghua University, Beijing, China.
[4]Los Alamos National Laboratory, Los Alamos, NM, USA.
[5]Institute for Reference Materials and Measurements, Geel, Belgium.
[6]Erlangen-Nürnberg University, Erlangen, Germany.
[7]Los Alamos National Laboratory, Los Alamos, NM, USA, formerly at Kyushu U., Kasuga, Japan.
[8]Oak Ridge National Laboratory , Oak Ridge, TN, USA.
[9]Korea Atomic Energy Research Institute , Yuseong, Daejeon, Republic of Korea.
[10]Institute of Physics & Power Engineering, Obninsk, Russia, formerly at the IAEA, Vienna, Austria.
[11]Argonne National Laboratory, Argonne, IL, USA.
[12]Vienna University, Vienna, Austria.

techniques. In response to requests for improvements in the standards, the Cross Section Evaluation Working Group (CSEWG) formed a Task Force, the Working Party on International Evaluation Cooperation of the Nuclear Energy Agency Nuclear Science Committee formed a Subgroup and the International Atomic Energy Agency (IAEA) formed a Coordinated Research Project (CRP). These groups have worked cooperatively to improve the evaluation process. The emphasis has been on the H(n,n), $^{10}B(n,\alpha)$, and fission standards. Table 1 shows the standards and the energies where they are considered standards. Extended energy ranges compared with the ENDF/B-VI results were obtained for the cross sections for $^{235}U(n,f)$ and $^{238}U(n,f)$ from 20 MeV to 200 MeV; and for $^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$ from 250 keV to 1 MeV. Work is continuing on the extension of the H(n,n) standard to 200 MeV.

The $^{238}U(n,f)$ cross section, which is an NEANDC/INDC standard, was accepted as an ENDF standard at the Fall 2004 CSEWG meeting. However 2 MeV was recommended as the lower bound for use of this cross section as a standard. The use of this cross section from threshold to 2 MeV is discouraged as a standard due to the very rapid change of this cross section in that energy range and the very small cross section in the threshold energy region. The present evaluation of this cross section does extend down to 1 MeV so it can be used at the lower energies that are needed for applications.

TABLE 1- The Neutron Cross Section Standards

Reaction	Standards Energy Range
H(n,n)	1 keV to 20 MeV
$^{3}He(n,p)$	0.0253 eV to 50 keV
$^{6}Li(n,t)$	0.0253 eV to 1 MeV
$^{10}B(n,\alpha)$	0.0253 eV to 1 MeV
$^{10}B(n,\alpha_1\gamma)$	0.0253 eV to 1 MeV
C(n,n)	0.0253 eV to 1.8 MeV
$Au(n,\gamma)$	0.0253 eV, 0.2 MeV to 2.5 MeV
$^{235}U(n,f)$	0.0253 eV, 0.15 to 200 MeV
$^{238}U(n,f)$	2 MeV to 200 MeV

Evaluation Objectives

The largest contribution to the evaluation process has been made by the IAEA CRP. The CRP has included membership from Austria, Belgium, China, Germany, Japan, the Republic of Korea, Russia and the USA. The main objectives of the evaluation are the following: Improve the methodology for determination of the covariance matrix used in cross section evaluations; Upgrade the computer codes using this methodology; Study the reasons for uncertainty reduction in R-matrix and model independent fits; Evaluate cross sections and covariance matrices for the light elements, H(n,n), $^{3}He(n,p)$, $^{6}Li(n,t)$, $^{10}B(n,\alpha_1\gamma)$, and $^{10}B(n,\alpha)$; Establish the methodology and computer codes for combining the light element with the heavy element evaluations leading to a final evaluation of the neutron cross section standards. The evaluation work includes improvements to the experimental data in the standards database and methods for handling discrepant data; R-matrix evaluation of the hydrogen scattering cross section and conversion of measurements relative to the hydrogen cross section to the new standard; studies of the effect of

Peelle's Pertinent Puzzle (PPP) and its effect on the standards; evaluation work on microscopic calculations leading to independent determinations of R-matrix poles; studies of the small uncertainties resulting from evaluations; smoothing procedures; and finally, results provided for use in the cross section libraries of evaluation projects.

The evaluation efforts [1] have led to many results. Extensive documentation [2] of the work done on the evaluation is being prepared. The present report is a summary of that document.

Database Studies

The status of the standards database [3] was reported on recently. For each experiment in the database, the documentation was investigated for possible corrections that may need to be made and for errors or missing information. This investigative procedure in many cases led to estimates of the uncertainties and correlations within an experiment and correlations with other experiments. This information was used to obtain covariance matrices for the measurements that were used in the evaluation process. The database included both shape and absolute cross section measurements and their ratios. It also included data involving the ^{238}U(n,γ) and ^{239}Pu(n,f) cross sections. There are many very accurate measurements of these cross sections. The use of these additional data improves the database as a result of ratio measurements of those cross sections to the traditional standards. Measurements of the ^{235}U and ^{239}Pu fission cross sections in the ^{252}Cf spontaneous fission neutron spectrum were also included in the database. These data can be obtained with high accuracy and are only weakly dependent on the uncertainties in the ^{252}Cf spontaneous neutron fission spectrum. These data can have an important effect on the normalization of the evaluated cross sections. Also scattering and total cross section data have been included for ^{6}Li and ^{10}B since they provide information on the standard cross sections. Charged-particle data were also included since they can be used in R-matrix analyses to provide improved cross sections for the light element standards. No evaluation of the C(n,n) cross section was made because very little new data have been obtained subsequent to the ENDF/B-VI evaluation; what was obtained is in good agreement with that evaluation.

Significant improvements were obtained for the thermal constants used in the evaluation. This was largely due to the very accurate coherent scattering measurements for ^{235}U obtained by Arif [4] that were used to provide a more accurate scattering cross section; and an improved analysis of the Gwin [5] ν bar uncertainties.

A large database of measurements, a significant portion of which were assembled by Poenitz [6] for the ENDF/B-VI standards evaluation, was used for the evaluation. In addition to the data sets introduced after the ENDF/B-VI evaluation and before the initiation of this evaluation, more than 30 data sets have been added to the standards database. Work has been done to understand the experiments and possible problems with them that may cause discrepancies to exist. During the ENDF/B-VI evaluation process, unusual results [7] were observed with the code GMA [8] when correlated discrepant data were used. To remove problems associated with these discrepancies, data greater than three standard deviations away from the output results were down weighted in the ENDF/B-VI GMA evaluation. This had the effect of making χ^2 per degree of freedom essentially one. For the R-matrix code EDA [9] that was also used in the ENDF/B-VI standards evaluation, its output covariances were modified by the χ^2 per degree of freedom value of the fit. This procedure is equivalent to increasing the uncertainty of all the experimental data in the fit, not just the outliers. This procedure was also used for the present evaluation. It would be better if the sources of the discrepancies could be found, then the evaluation could be done with consistent data sets. This is a very difficult task since there are thousands of data points. To reduce the effect of discrepant data on the GMA analysis and the RAC [10] R-matrix evaluation for the database of neutron experiments used in the present international evaluation, deviations of experimental measurements from the output of the evaluation were compared with the uncertainties on the data. The outliers were defined as those for which the difference from the evaluated output value was above two standard deviations for a single point or above one standard deviation for a few sequential points. The uncertainty of outliers was increased by adding an additional component to the covariance matrix of the uncertainty of each outlying data set. The length of correlation for this additional medium energy range correlation component was evaluated from an analysis of the energy dependence of the discrepancy. This results in a much better χ^2 per degree of freedom and larger uncertainty in the evaluated results. The change in the cross section from this procedure is small.

Hydrogen Evaluation

The hydrogen scattering cross section below 20 MeV neutron energy has been evaluated at LANL using the R-matrix code EDA. Calculations of the angular distribution using these R-matrix parameters are in much better agreement with recent measurements [11] than the ENDF/B-VI evaluation. Comparisons of the new hydrogen evaluation with other evaluations are shown in Fig. 1. With the availability of the new hydrogen standard, all data in the database relative to hydrogen cross sections were converted so they are relative to the new standard. After this conversion process was completed, a hydrogen re-evaluation was recommended as a result of preliminary data testing due to concerns about the thermal capture cross section. The re-evaluation resulted in small changes in the hydrogen standard cross section. The conversion process was not re-done but uncertainties on the converted data were increased to account for the changes in the hydrogen cross section.

The database contained measurements relative to several different versions of total cross sections. Also a number of experiments were in the database that used different laboratory angles, and different versions of the differential cross section. The effect of the change in the hydrogen standard cross section causes, for example, a change as large as 0.5% for the evaluated ^{235}U(n,f) cross section. There are plans to extend the hydrogen evaluation to 200 MeV neutron energy.

Peelle's Pertinent Puzzle (PPP)

Problems associated with PPP were observed early in the evaluation process [12]. A test run using a model independent least squares code fitting the logarithm of the cross section produced higher cross sections than a run fitting the cross section. There were discrepant data in the test run. The problem appears to be largely a result of using discrepant data but it also is caused by the existence of data correlations. This is the maxi-PPP vs mini-PPP effect. The EDA R-matrix analysis uses only statistical uncertainties for the cross sections, but also includes a procedure for fitting normalizations that takes into account the normalization uncertainties; this procedure does not suffer the PPP problem, as it is equivalent to the Propagated-Uncertainty-Method [13]. Analyses using the RAC R-matrix code (Tsinghua University) that includes medium range

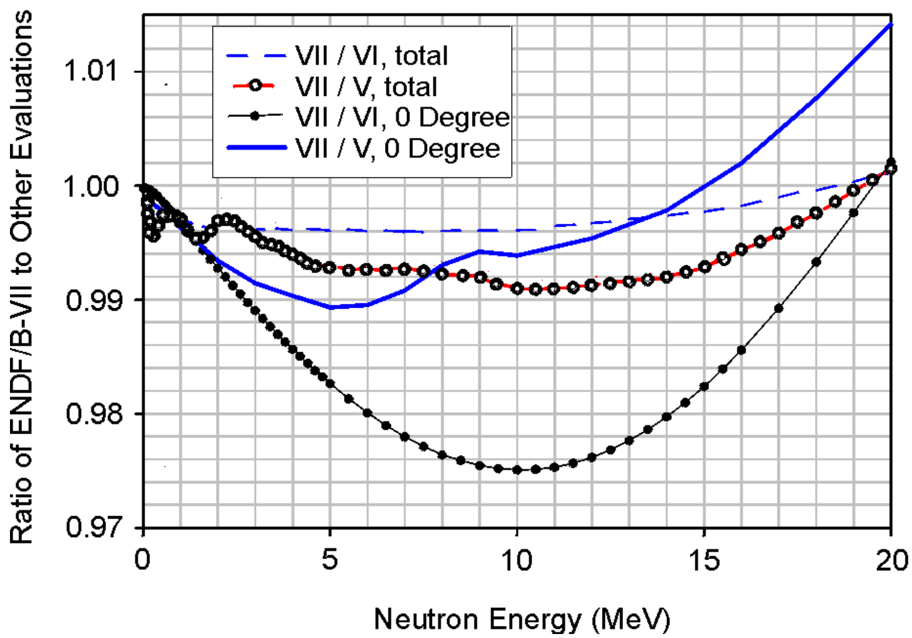

FIG. 1- *Comparison of the present hydrogen evaluation to other evaluations. The ENDF/B-VI and ENDF/B-V total cross section are compared with the present results. Also the laboratory zero degree differential cross sections for the ENDF/B-VI and ENDF/B-V evaluations are compared with the results of this evaluation.*

correlations do suffer this problem to some degree. A number of methods for reducing PPP have been employed such as using percent uncertainties, using a logarithmic transformation or the Box-Cox transformation. The GMA code was modified by adding the Chiba-Smith [14] option to handle PPP problems. This option, called GMAP, renormalizes the experimental absolute errors on the assumption that it is the fractional error that actually reflects the accuracy the experimenter has provided. This approach appears to have reduced the effect of PPP significantly. Comparisons using the Chiba-Smith, Box-Cox and logarithmic transformation are in good agreement for a number of test cases. An important outcome of this work is the observation that special care should be exercised to reduce the effect of discrepant data and PPP to improve the quality of any nuclear data evaluation.

Theoretical Model Calculations

Theoretical calculations have been made to help describe some of the light-nuclei standard cross sections. Since there are relatively few nucleons involved for the ^{4}He compound nucleus, it was possible to use the Refined Resonating Group Model (RRGM) to obtain information about the ^{3}He(n,p) cross section. This model allows realistic nuclear interactions to be used, however it required very large computer resources. Using effective NN potentials allowed heavier nuclei to be studied such as the A=7 case which provided information on the ^{6}Li(n,t) standard. Using effective potentials allowed the calculations to be done with a standard personal computer. The work on these two standards progressed well. The calculations produced results that are rather close to those given by R-matrix analyses. Transforming the RRGM results to R-matrix poles provided guidance for initial values in the R-matrix analyses. This work led to improved values of the parameters and more realistic uncertainties in the cross sections. There were cases where the information on the poles allowed limitations in experimental data sets to be recognized.

The small uncertainty problem

The small uncertainties obtained in the ENDF/B-VI evaluation process [7] were of great concern. An important task for the present effort was to try to understand in detail how standard error propagation in model independent or R-matrix analyses could result in such small uncertainties, and whether there were more reasonable corrections or algorithms to employ. Work was done on the small uncertainty problem through comparisons of several tests of model independent and R-matrix codes using a common database. The R-matrix codes used in this study were EDA (LANL), SAMMY [15] (ORNL), and RAC (Tsinghua University). The generalized least squares codes used were GLUCS [16] (University of Vienna), GMAP (IAEA and IPPE) and SOK [17] (LANL). A code based on an analytical approximation model, PADE2 [18] (IPPE) was also used. It was necessary to select a database containing measurements that could be properly used in the comparison. For example some of the codes could not handle certain types of input data correlations. For the comparison tests, it was assumed that no correlations exist between the data sets. The only correlations within the data sets were assumed to be short energy range (statistical) and long energy range (normalization). The generalized least squares codes were easily found to be in good agreement. Comparisons of the R-matrix codes proved to be more difficult since the input and analysis conditions were difficult to standardize. Studies with SAMMY were particularly useful in understanding differences obtained with different codes since it was possible to do SAMMY fitting that corresponded essentially to that done by RAC and in a different scheme it was possible to do fitting that corresponded essentially to that by EDA. Good agreement was eventually obtained for the cross sections obtained from the R-matrix analyses. The small differences obtained with the codes could be explained as a result of different procedures, different chi-square expressions and some PPP effects that may be present in the RAC results. The variances and covariances also agreed well with some local differences. A measure of that agreement was given by a comparison of the sum of all elements of the covariance matrix of the evaluated data, which agreed within 1% for EDA and RAC. These differences were probably mainly due to numerical precisions of the solutions.

The large amount of data for charged-particle-induced reaction channels may be an important factor in the large reduction in the calculated uncertainty. Many charged-particle data, especially differential elastic scattering cross sections, are claimed to have very small uncertainties. It is possible that systematic errors may not have been fully estimated. The option of increasing the uncertainties of outlying data for charged-particle data was used in RAC. These changes and the changes in the neutron database uncertainties noted previously for discrepant data led to somewhat larger uncertainties for the results.

An important result of the present work is that it is essential to consider the covariances, not just the variances, in applications of cross sections to practical systems.

Evaluation Procedure

It was decided that a combination procedure similar to that used for the ENDF/B-VI standards evaluation would be used to obtain the standards. All the standards except the H(n,n), ^{3}He(n,p) and C(n,n) cross sections were evaluated using the GMAP code, with a combining procedure, using input from the RAC and EDA R-matrix analyses, and a thermal constants evaluation. The Axton evaluation [19] of the thermal constants with the associated variance-covariance data for

^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu was used as input to the GMAP code since it includes accurate cross sections which have been measured relative to the neutron cross section standards. Thus this evaluation would have an impact on the determination of the standards.

The R-matrix analyses used charged-particle data and the lithium and boron neutron databases, including total and scattering cross section data for these nuclides. The only lithium and boron data for direct use in the GMAP code were the ratio measurements or data sets that were correlated. The R-matrix and GMAP data are totally independent of each other. There are no common data sets and no data sets that have correlations between the R-matrix and GMAP data. All correlated data were analyzed by GMAP directly. For the $^{6}Li(n,t)$, $^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$ R-matrix work, the cross sections obtained from the RAC and EDA analyses were not identical. The cross sections from the RAC and EDA analyses were averaged (unweighted) and used as the R-matrix input to GMAP. The covariance matrix used with these central values was that from the RAC code since its results appeared more physically reasonable. The R-matrix input and thermal constants data were treated like the additions of other data sets to the GMAP code. At each energy point, half the difference between the RAC and GMAP results was treated as a model uncertainty that was added to the RAC covariance of uncertainties. This then takes into account the differences obtained between the RAC and EDA analyses. The results of these analyses are shown in Fig. 2-4.

Smoothing of the Evaluation

The results of the combination procedure were not smooth. For the $^{6}Li(n,t)$, $^{10}B(n,\alpha_1\gamma)$, and $^{10}B(n,\alpha)$ cross sections smoothing was not required since the highest weight went to the cross sections used in the R-matrix analyses. For the heavy element standards, there were some models that could provide insight on how to define the curves. It was determined that a simple smoothing algorithm would be satisfactory for most cases. It was used sparingly for the heavy element cross sections. A patch using the shape of the Maslov [20] evaluated curve was applied in the 50-60 MeV region for the $^{235}U(n,f)$ cross section where a rather large fluctuation, assumed to be statistical, occurred.

Results of the Evaluation

The cross sections obtained for the $^{6}Li(n,t)$, $^{10}B(n,\alpha)$, $^{10}B(n,\alpha_1\gamma)$, $Au(n,\gamma)$, $^{235}U(n,f)$, and $^{238}U(n,f)$ standard cross sections as well as the $^{238}U(n,\gamma)$ and $^{239}Pu(n,f)$ cross sections are shown in Fig. 5-14. In Fig. 5-7, the data are the combined results shown in Fig. 2-4, respectively. They are re-plotted without the additional data for clarity. All uncertainties shown are one standard deviation values. The standards obtained from this work were given to the CSEWG in November, 2005 as the proposed standards for the ENDF/B-VII library.

Some benchmark data testing has been done using these data. The quantity K1 calculated from the evaluation is 721.6 b. This should be compared with the “preferred” value of 722.7 b determined by Hardy [21]. The agreement is quite good when one considers that the uncertainty in the Hardy value is 3.9 b. Preliminary criticality calculations using these data [22] are generally in better agreement than those obtained with the ENDF/B-VI standards.

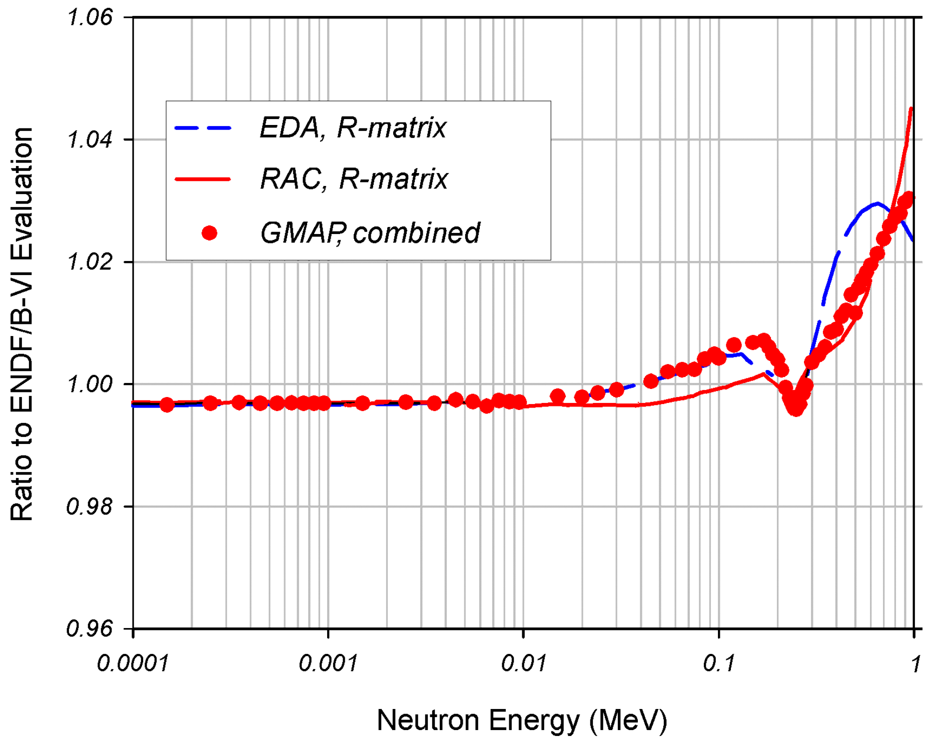

FIG. 2- *Comparison for the* ^{6}*Li(n,t) cross section of the ENDF/B-VI evaluation with the EDA R-matrix analysis, the RAC R-matrix analysis and the combined result. The combined result is the final result from this evaluation.*

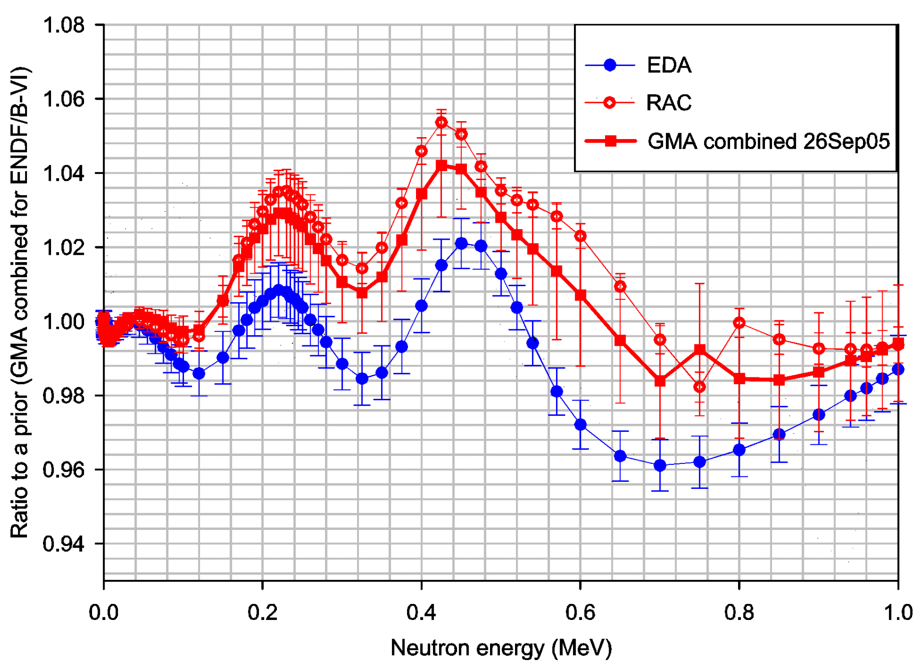

FIG. 3- *Comparison for the* ^{10}*B(n,α) cross section of the ENDF/B-VI evaluation with the EDA R-matrix analysis, the RAC R-matrix analysis and the combined result. The combined result is the final result from this evaluation.*

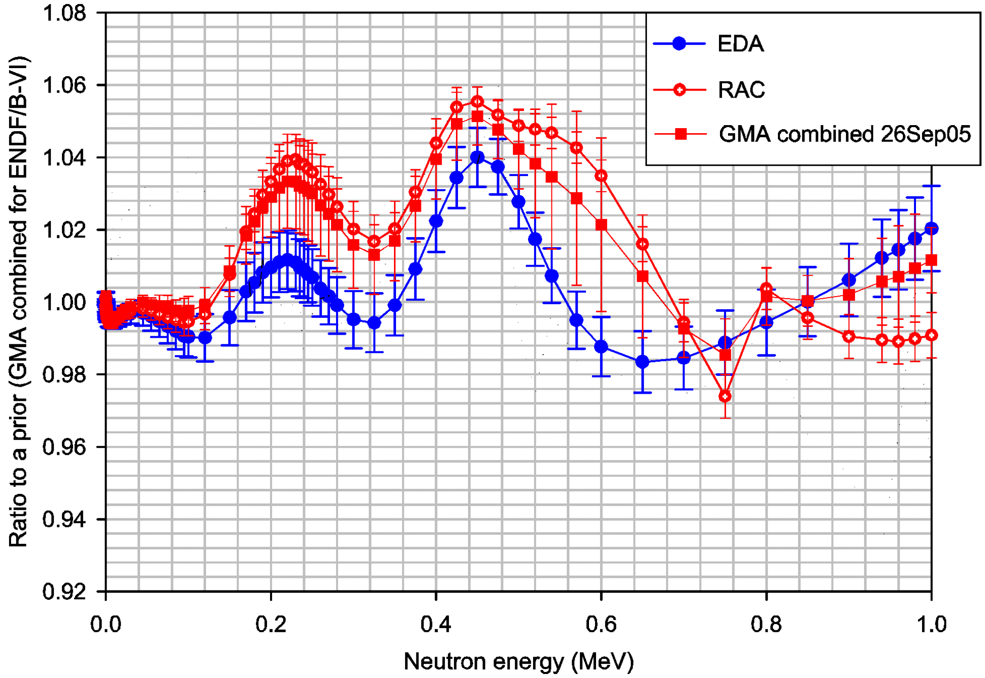

FIG. 4- *Comparison for the* $^{10}B(n,\alpha_1\gamma)$ *cross section of the ENDF/B-VI evaluation with the EDA R-matrix analysis, the RAC R-matrix analysis and the combined result. The combined result is the final result from this evaluation.*

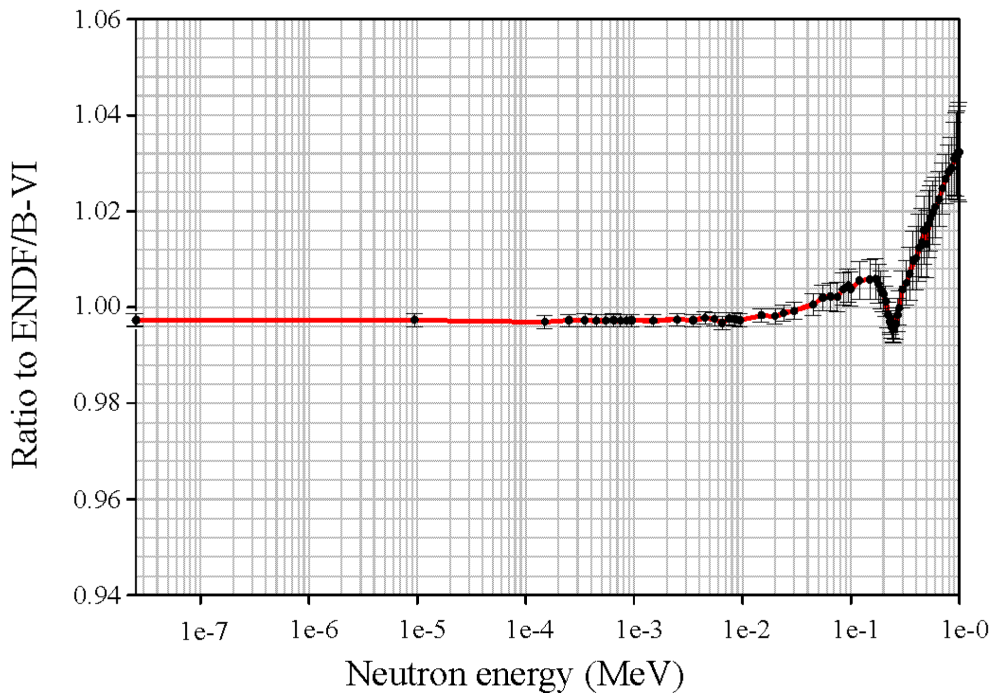

FIG. 5- *Comparison of the* $^{6}Li(n,t)$ *cross section from this evaluation with the ENDF/B-VI evaluation.*

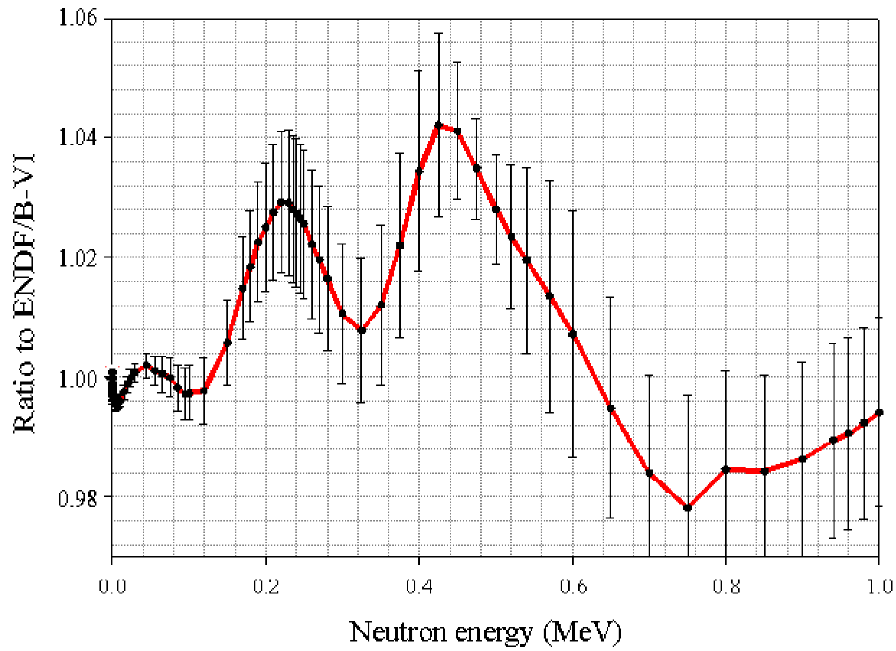

FIG. 6- *Comparison of the* $^{10}B(n,\alpha)$ *cross section from this evaluation with the ENDF/B-VI evaluation.*

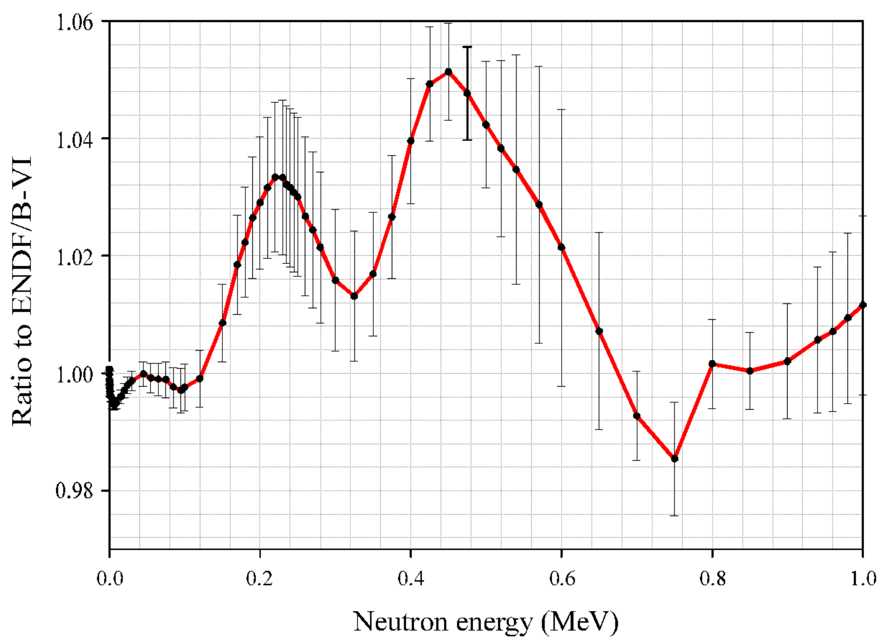

FIG. 7- *Comparison of the* $^{10}B(n,\alpha_1\gamma)$ *cross section from this evaluation with the ENDF/B-VI evaluation.*

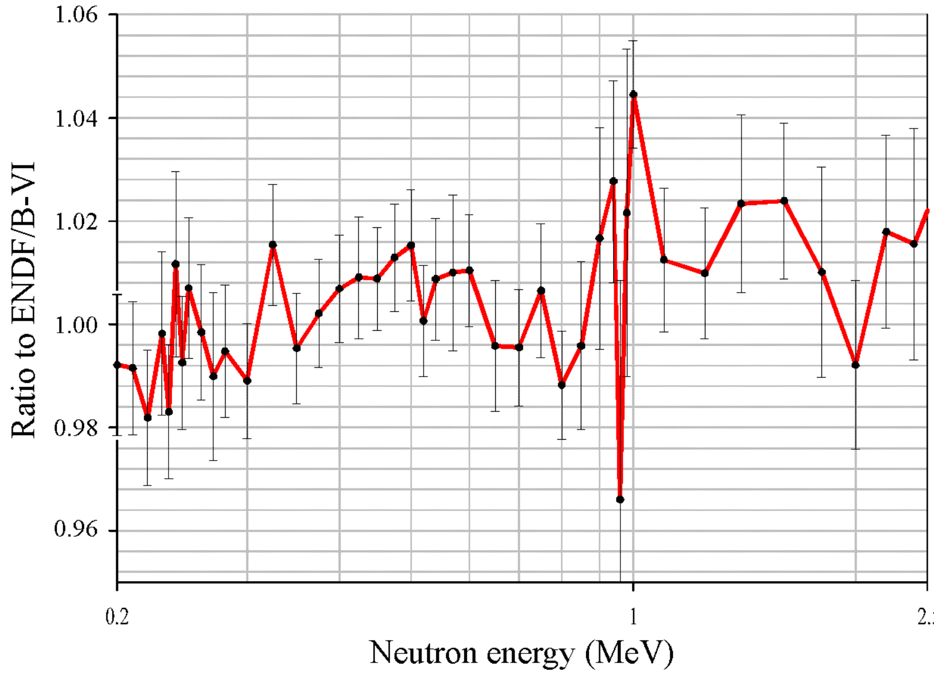

FIG. 8- *Comparison of the Au(n,γ) cross section from this evaluation with the ENDF/B-VI evaluation.*

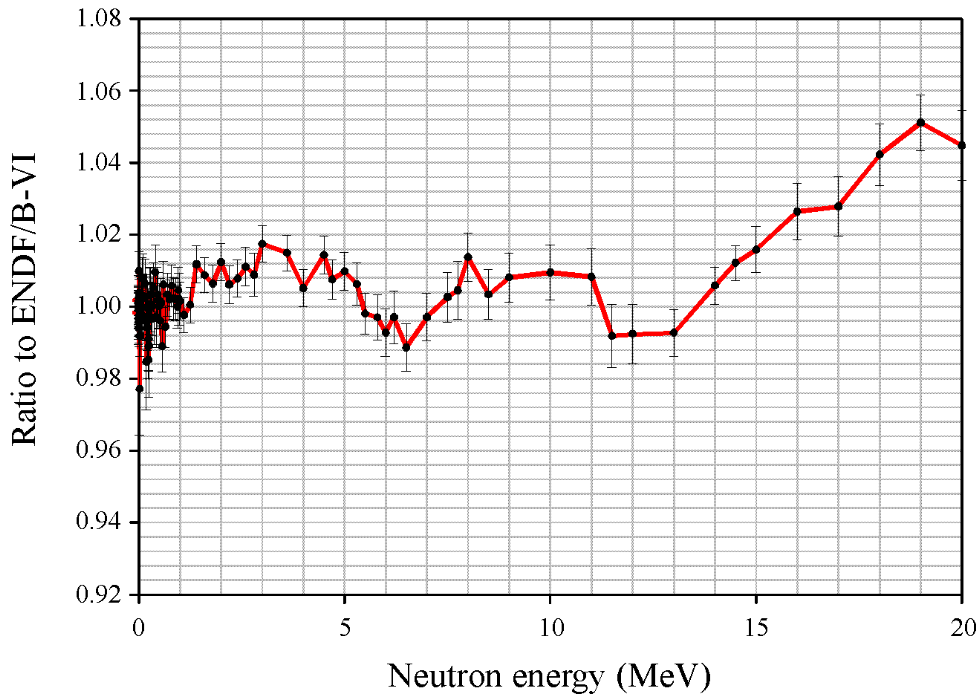

FIG. 9- *Comparison of the* ^{235}*U(n,f) cross section up to 20 MeV from this evaluation with the ENDF/B-VI evaluation.*

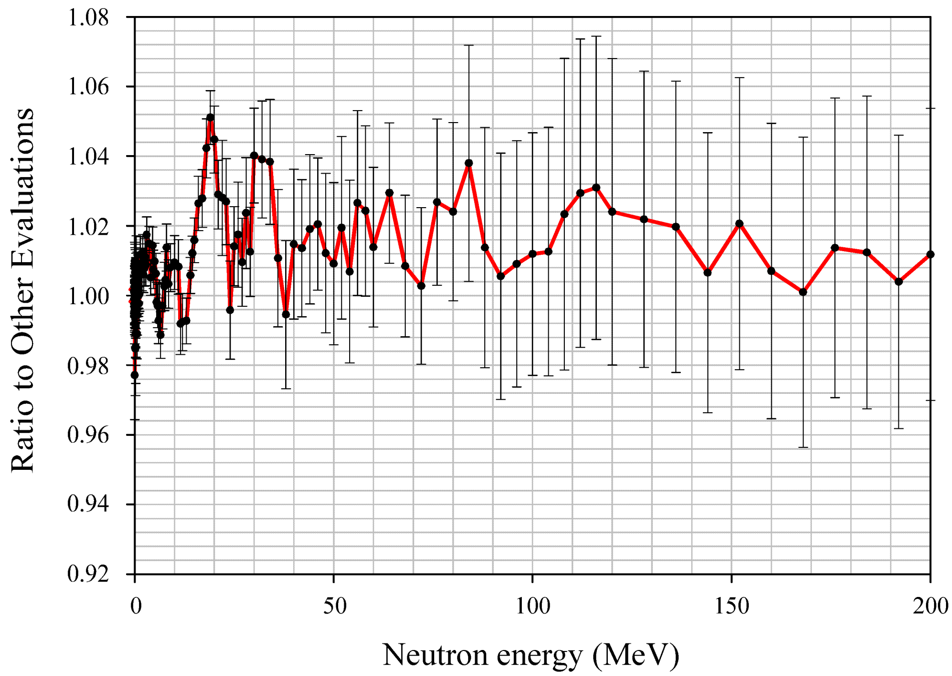

FIG. 10- *Comparison of the* $^{235}U(n,f)$ *cross section from this evaluation with the ENDF/B-VI evaluation up to 20 MeV and with updated values [23] above 20 MeV.*

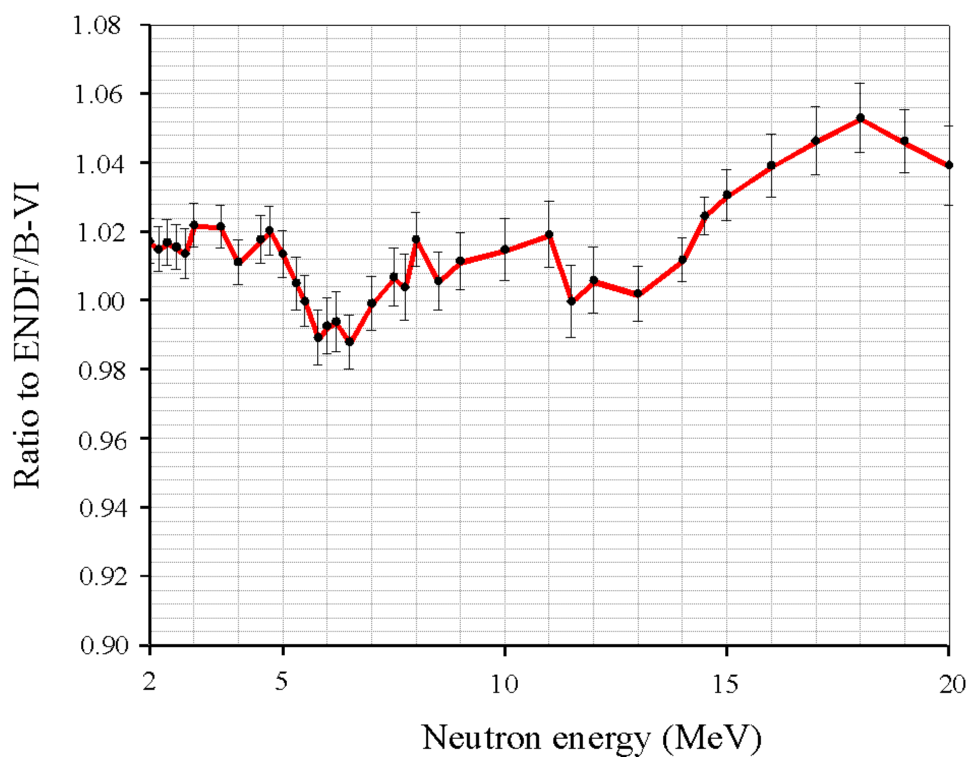

FIG. 11- *Comparison of the* $^{238}U(n,f)$ *cross section from this evaluation with the ENDF/B-VI evaluation.*

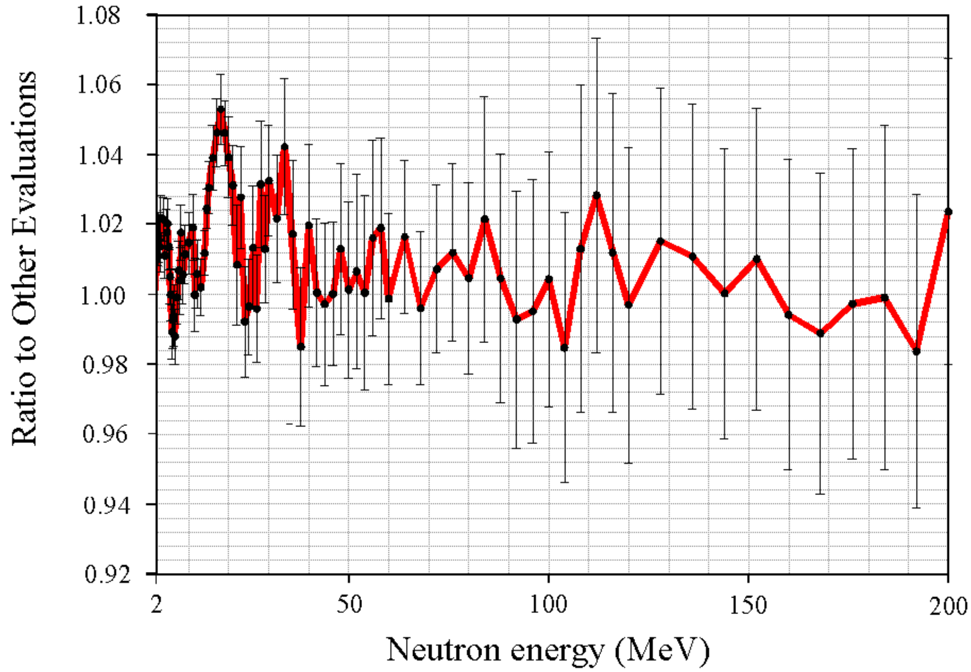

FIG. 12- *Comparison of the* ^{238}*U(n,f) cross section from this evaluation with the ENDF/B-VI evaluation up to 20 MeV and with updated values [23] above 20 MeV.*

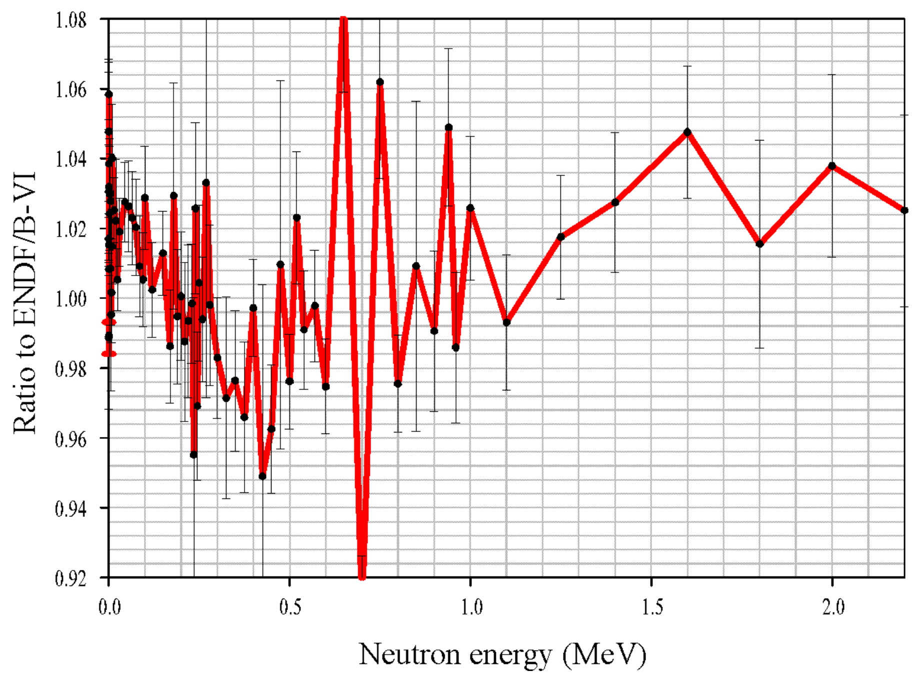

FIG. 13- *Comparison of the* ^{238}*U(n,γ) cross section from this evaluation with the ENDF/B-VI evaluation.*

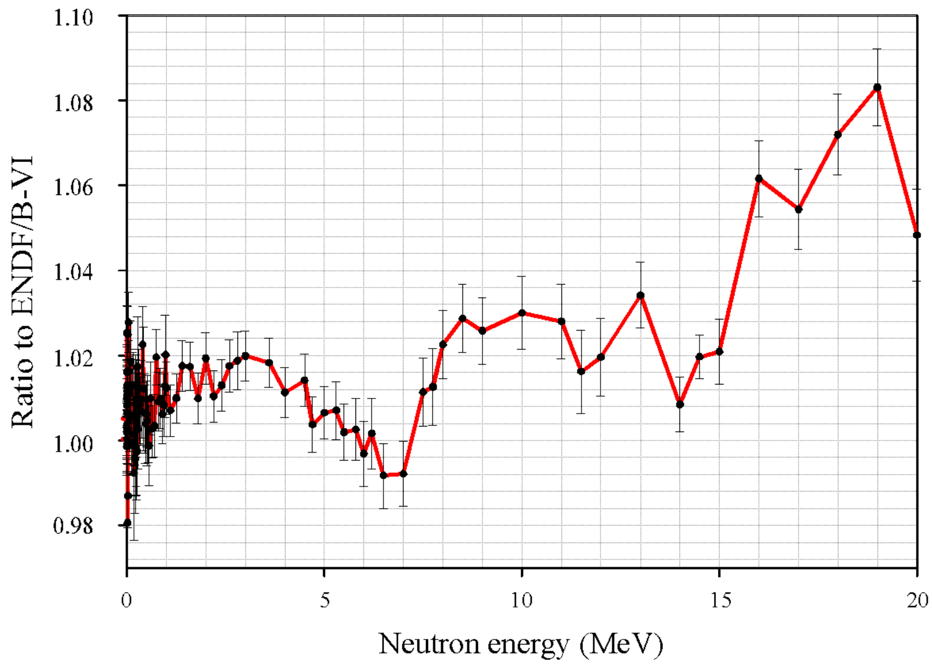

FIG. 14- *Comparison of the ^{239}Pu(n,f) cross section from this evaluation with the ENDF/B-VI evaluation.*

It is anticipated that additional work will be done on the hydrogen standard cross section to extend it to 200 MeV. Evaluations for the ^{3}He(n,p) and C(n,n) standards were not made. Those standards will be carried over from the ENDF/B-VI files.

Conclusions

Standards have been re-evaluated for use by the international nuclear data evaluation projects. Their first use has been in the new ENDF/B-VII library. This has been a successful international effort. It is important to continue to maintain the database and improve the analysis procedure used in determining the standards. A new IAEA Data Development Project has been approved that is focused on the maintenance of the neutron cross section standards. This project could provide a method for obtaining standards evaluations that will be up-to-date when they are needed by the various nuclear data evaluation projects.

References

[1] Pronyaev, V. G., Badikov, S. A., Chen, Z., Carlson, A. D., Gai, E. V., Hale, G. M., Hambsch, F.-J, Hofmann, H. M., Larson, N. M., Smith, D. L., Oh, S.-Y.,Tagesen, S., and Vonach, H., "The Status Of The International Neutron Cross Section Standards File, " *Proc. Int. Conf. on Nuclear Data for Science and Technology, Sept. 26-Oct. 1, 2004,* to be published.

[2] Pronyaev, V. G., Badikov, Carlson, A. D., S. A., Chen, Z., , Gai, E. V., Hale, G. M., Hambsch, F.-J, Hofmann, H. M., Larson, N. M., Smith, D. L., Oh, S.-Y.,Tagesen, S., and Vonach, H., “An International Evaluation of the Neutron Cross Section Standards”, to be published in an IAEA Technical Report.

[3] Hambsch, F.-J., Carlson, A. D., Vonach, H., "Status of the Neutron Cross Section Standards Database, "*Proc. Int. Conf. on Nuclear Data for Science and Technology, Sept. 26-Oct. 1, 2004,* to be published.

[4] Arif, M., Kaiser, H., Werner, S. A., Willis, J. O., "Precision Measurement of the Bound-Coherent-Neutron Scattering Length of ^{235}U," *Phys. Rev.,* Vol. A35, 1987, pp. 2810-2814.

[5] Gwin, R., Spencer, R. R., Ingle, R. W., "Measurements of the Energy Dependence of Prompt Neutron Emission from ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu for E_n=0.005 to 10 eV Relative to Emission from Spontaneous Fission of ^{252}Cf," *Nucl. Sci. Eng.,* Vol. 87, 1984, pp. 381-404.

[6] Poenitz, W. P., Aumeier, S. E., "The Simultaneous Evaluation of the Standards and Other Cross Sections of Importance for Technology," *ANL/NDM-139,* 1997.

[7] Carlson, A. D., Poenitz, W. P., Hale, G. M., Peelle, R. W., Dodder, D. C., Fu, C. Y., Mannhart, W., "The ENDF/B-VI Neutron Cross Section Measurement Standards, "*ENDF-351,* 1993.

[8] Poenitz, W. P., "Data Interpretation, Objective, Evaluation Procedures and Mathematical Technique for the Evaluation of Energy-Dependent Ratio, Shape and Cross Section Data, "*Proceedings of the Conference on Nuclear Data Evaluation Methods and Procedures,* BNL-NCS-51363, Vol. I, pp. 249-289 (1981), B. A. Magurno and S. Pearlstain, Ed., .

[9] Hale. G. M., "Use of R-Matrix Methods for Light Element Evaluations, "*Proceedings of the Conference on Nuclear Data Evaluation Methods and Procedures,* BNL-NCS-51363, Vol. II, B. A. Magurno and S. Pearlstain, Ed., 1981, 509-531 pp.

[10] Chen, Z. P., "Reduced R-Matrix Analysis for ^{17}O System," *Atomic Energy Science and Technology,* Vol. 29, No. 4, 1995, pp. 366-371.

[11] Boukharouba, N., Bateman, F. B., Brient, C. E., Carlson, A. D., Grimes, S. M., Haight, R. C., Massey, T. N., Wasson, O. A., "Measurement of the n-p elastic Scattering Angular Distribution at E=10 MeV," *Phys. Rev.,* Vol. C65, 2002, p. 014004.

[12] Carlson, A. D., Hale, G. M., Pronyaev, V. G., "Summary Report of the First Research Coordination Meeting on Improvement of the Standard Cross Sections for Light Elements, "*INDC(NDS)-438,* IAEA, 2003.

[13] Larson, N. M., "Treatment of Data Uncertainties, " *Proc. Int. Conf. on Nuclear Data for Science and Technology, Sept. 26-Oct. 1, 2004,* to be published.

[14] Chiba, S., Smith, D. L., "A Suggested procedure for Resolving an Anomaly in Least-Squares Data Analysis Known as "Peelle's Pertinent Puzzle" and the General Implications for Nuclear Data Evaluation, "*ANL/NDM-121 ,* 1991.

[15] Larson, N. M., "Updated Users' Guide for SAMMY Multilevel R-matrix Fits to Neutron Data Using Bayesian Equation, "*ORNL/TM-9179/R5 ,* 2000.

[16] Tagesen, S., Hetrick, D. M., "Enhancements to the Generalized Least-Squares Cross-Section Evaluation Code GLUCS, "*Proc. of International Conf. on Nuclear Data for Sci. and Technology, Gatlinburg, USA, May 9-13, 1994,* Am. Nucl. Soc., Inc., LaGrange Park, IL, USA, J.K. Dickens, Ed., 1994, Vol 1, pp. 589-591.

[17] Kawano, T., Matsunobu, H., Murata, T., Zukeran, A., Nakajima, Y., Kawai, M., Iwamoto, O., Shibata, K., Nakagawa, T., Ohsawa, T., Baba, M. and Yoshida, T. "Evaluation of Fission Cross Sections and Covariances for ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, and ^{241}Pu," *JAERI-Research-2000-004,* 2000.

[18] Badikov S. A., Gai, E. V., Guseynov, M. A., Rabotnov N. S., "Nuclear Data Processing, Analysis, Transformation and Storage with Pade-approximants, "*Proc. of International Conference, on Nuclear Data for Science and Technology, 13-17 May 1991, Jűlich, Germany,* Springer-Verlag , 1991, pp. 182-187.

[19] Axton, E. J., "Evaluation of the Thermal Constants of ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu, and the Fission Neutron Yield of ^{252}Cf, "*CBNM (IRMM) Report GE/PH/01/86,* 1986.

[20] V.M. Maslov, V. M. , "Uranium Symmetric/Asymmetric Nucleon-Induced Fission up to 200 MeV," Eur. Phys. J., Vol. A21, 2004, pp. 281–286.

[21] Hardy, J., Private Communication, Memo dated 18 June 1985.

[22] MacFarlane, R. E., Private Communication, 2005.

[23] Carlson, A.D., Chiba, S., Hambsch, F.-J., Olsson, N., Smirnov, A.N., "Update to Nuclear Data Standards for Nuclear Measurements", Summary Report of an International Atomic Energy Agency Consultants' Meeting on Nuclear Data Standards, Dec. 2-6, 1996, Vienna, Austria, INDC(NDS)-368 (1997).