

Status Report of Subgroup 7 to the NEANSC WPEC
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Nuclear Data Standards Evaluation
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Introduction

The need for improved evaluations of the neutron cross section standards is universally accepted. These standards are the basis for the neutron reaction cross section databases. Improvements in a standard lead to improvements in all measurements which have been or will be made relative to that standard. It has been 13 years since the last comprehensive evaluation of the standards. Significant improvements have been made in the standard cross section database since that time, particularly for the $H(n,n)$, $^{10}B(n,\gamma)$, and $^{235}U(n,f)$ reactions. For example, as may be seen in figure 1, recently finalized measurements of the hydrogen scattering cross section at 10 MeV neutron energy are in better agreement with phase shift determinations by Arndt [1] than with the ENDF/B-V or ENDF/B-VI evaluations. Evaluations continue to be done using standards which are now out-of-date. This has led to requests for new evaluations of the standards. The feasibility of such an evaluation was enhanced by the release of the database which was used by Poenitz [2] for the simultaneous evaluation component of the ENDF/B-VI standards evaluation.

The present evaluation will include the $H(n,n)$, $^6Li(n,t)$, $^{10}B(n,\gamma)$, $^{10}B(n,\gamma_1)$, $Au(n,\alpha)$, $^{235}U(n,f)$, and $^{238}U(n,f)$ standard cross sections. The evaluations will be performed using the generalized least squares simultaneous evaluation program GMA and the R-matrix code EDA. New evaluations for the $^3He(n,p)$ and $C(n,n)$ cross sections will not be made because little new data have been obtained since the ENDF/B-VI evaluation and what has been obtained is consistent with that work.

Progress on the evaluation

The first step leading to a new evaluation of the standards is encouraging, motivating and coordinating new measurements which can be used in the evaluation. Much of this effort took place through the WPMA subgroup which was focused on improving the standard cross sections. Many experiments have been completed; however, most of the experiments are still in the data taking or data analysis stage. Consideration should be given to extending the deadline after which experiments will not be considered for inclusion in the standards evaluation.

Work continues investigating possible experiments for the standards database. For each experiment a detailed process is being followed. This process includes checking the documentation for corrections that may need to be made and looking for possible errors or missing information. This procedure leads to estimates of the uncertainties and correlations within that experiment and correlations with other experiments. This information is used to form covariance matrices for the measurements so that a full covariance analysis can be performed for the evaluation.

The need for standards above 20 MeV has caused the subgroup to decide to extend the energy range to higher energies for appropriate standards. Hale plans to evaluate the hydrogen cross sections up to 150 MeV neutron energy. There is a need for fission standards up to 200 MeV. The measurements of the $^{235}\text{U}(n,f)$, and $^{238}\text{U}(n,f)$ standards which are relative to the hydrogen standard will have to rely on another evaluation for the energy region from 150 to 200 MeV. The decision on which evaluation to use will depend on how well the new Hale evaluation agrees with other evaluations in the 150 MeV energy region. Through the evaluation process, the standards measurements below 20 MeV could have a significant impact on the higher energy fission standards. An important product of this work would be an improved normalization of those high energy standards. This should improve the accuracy of the high energy fission standards, which are at energies where it is difficult to make absolute measurements.

In table 1, standards related experiments which have been investigated, at least to some degree, are listed. This table is not complete. Only experiments for which data have been obtained or measurements are underway (or nearly started) are listed. The initial emphasis has been on the traditional standards in their normal regions of applicability. Particularly important are the corrections and expanded uncertainties for the Nakamura and Shirato hydrogen scattering measurements which had a significant impact on the ENDF/B-VI hydrogen evaluation.

Plans have been formulated for performing the evaluation. The first evaluation which must be completed is that for hydrogen scattering. This cross section has been considered to be absolute since it is generally better known than the other standards. Many standard cross sections have been measured relative to this cross section. When the new hydrogen evaluation is complete, standards measurements relative to it will be renormalized using the new hydrogen evaluation. This evaluation is in progress at LANL by Hale.

The other standards will be evaluated using a procedure which uses GMA and EDA. GMA will be used for all the standards. It can be used with ratio data and properly handles correlations. EDA will be used for the $^6\text{Li}+n$ and $^{10}\text{B}+n$ cross section evaluations. This R-matrix code can include angular distribution, charged particle cross section and various polarization type data to improve the information on the relevant standard cross sections. All experiments which are correlated, all ratio measurements (except those relative to the hydrogen standard), and all of the data on standards other than $^{10}\text{B}+n$ and $^6\text{Li}+n$ will be used in the generalized least squares simultaneous evaluation using GMA. The remaining database will be separated into two parts, one for the GMA analysis and the other for the EDA analysis. Enough high quality data must be present in the EDA database to ensure convergence. The databases used for the GMA and EDA analyses are uncorrelated.

Initial plans are to avoid a separate combination procedure as was done for the ENDF/B-VI evaluation. The process would be to run EDA to convergence for both the $^6\text{Li}+n$ and $^{10}\text{B}+n$ systems. The output cross sections and their variance-covariance matrices from

EDA will then be used as input to GMA; essentially the same procedure as was used for Axton's thermal constants evaluation in the ENDF/B-VI standards evaluation. The GMA output for the ${}^6\text{Li}+n$ and ${}^{10}\text{B}+n$ systems will have some scatter. That data will be fit with EDA to get the smoothed data which are required for an evaluation. Proper ways for doing the smoothing for the other data are under consideration.

The ENDF/B-VI standards evaluation produced by the United States Cross Section Evaluation Working Group (CSEWG) was adopted by all libraries. There was a concern about that evaluation due to the small size of the uncertainties, especially from the R-matrix part of the evaluations. As a result the CSEWG Standards Subcommittee produced a set of expanded uncertainties such that if a modern day experiment were performed on a given standard cross section using the best technique, approximately 2/3 of the results should fall within these expanded uncertainties.

For the new international evaluation of the standard cross sections, which includes new experimental data, it is necessary to understand in detail how standard error propagation in simultaneous evaluation or R-matrix analyses can result in such small uncertainties, and whether there are more reasonable corrections or algorithms to employ. Toward that goal, an IAEA CRP has been proposed. This CRP is important since it would increase involvement in the evaluation and an international body would validate the evaluation process, especially concerning the uncertainties. The first phase of this work will focus on understanding and resolving the differences in the mean value and the output covariance of the results obtained using common input test data for a number of R-matrix, and generalized least squares codes including independent evaluation of uncertainty from the full sensitivity matrix. This work should lead to identification of possible differences between R-matrix and generalized least squares fitting that may have contributed to the small error estimates that resulted from the 1987 ENDF/B-VI evaluation. This work will also lead to documentation of full covariance and sensitivity matrices for further development of these methodologies. Under consideration for use in this study are R-matrix codes used at LANL (EDA); ORNL (SAMMY); Ohio University, USA (ORMAP); Kyushu University, Japan; and Tsinghua University, China. The generalized least squares codes being considered are those used at Obninsk and the University of Vienna (GLUCS); those used at ANL and JAERI (GMA) and the Kyushu code used in conjunction with KALMAN. It is hoped that covariance specialists such as S. Badikov, D. Muir and W. Mannhart will be available for consultation when the results of this work become available.

Also under consideration will be methods for doing the evaluation, such as a single step global process, which were not feasible with the computer capability in 1987. Following this first phase, using the tools developed from that activity and the critically reviewed and assembled experimental data, the new evaluation will be done. The time frame for the completion of the evaluation will have to be increased. It is not clear how long the process would take but it will be a minimum of 3-4 years. For this reason more time should be made available for the completion of ongoing experiments and their analyses.

Table 1. Experiments for Consideration for the New Standards Evaluation

⁺⁺ means the data have been reviewed and are in the library

⁺ means the data are available and the review process is underway

no superscript means that final data are not available (possibly final data not taken yet)

H(n,n)

⁺Nakamura, J. Phys. Soc. Japan 15 (1960) 1359, 14.1 MeV, needs correction for proton scattering; tail problems; note Table II uncertainty is statistical only (mb/sr)

⁺Shirato, J. Phys. Soc. Japan 36 (1974) 331, 14.1 MeV, needs correction for proton scattering; tail problems

⁺Ryves, 14.5 MeV, $\Phi(180E)/\Phi(90E)$, Ann. Nucl. Energy 17, 657 (1990)

⁺Bateman, 10 MeV, angular distribution from 60E to 180E, Fusion Eng. & Design 37, 49 (1997);
Data is now finalized.

⁺Buerkle, 14.1 MeV, angular distribution from 89.7E to 155.7E, Few-Body Systems 22, 11 (1997)

Olsson (Uppsala group), 96 & 162 MeV, angular distribution from 70E to 180E

Benck, (Louvain la Neuve) 28-75 MeV, angular distribution from 40E to 140E

Peterson (IUCF) 185-195 MeV, angular distribution from 90E to 180E. In progress

³He(n,p)

⁺⁺Borzakov, 0.26 keV to 142 keV, relative to ⁶Li(n,t), Sov. J. Nucl. Phys. 35, 307 (1982)

⁶Li(n,t)

Bartle, 2 to 14 MeV, angular distribution, Proc. Conf on Nuclear Data for Basic and Applied Science, Sante Fe (1985), p. 1337

Koehler, 1 keV to 2.5 MeV, angular distribution data (ratio of forward and backward hemispheres responses), private comm.

Gledenov, .025 eV, ??, 87KIEV 2 237

Zhang Guohui, 3.67 and 4.42 MeV, angular distribution, Comm. Of Nuclear Data Progress No.21 (1999) China Nuclear Data Center

¹⁰B(n, ν_1)

⁺⁺Schrack, 0.2 MeV to 4 MeV, relative to Black Detector (at ORNL), NSE 114, 352 (1993)

⁺Schrack, 10 keV to 1 MeV, relative to H(n,n) prop ctr (at ORNL), Proc. Conf. on NDST, Gatlinburg (1994)p. 43

⁺Schrack, .3 MeV to 10 MeV, relative to ²³⁵U(n,f) ion chamber (at LANL), Private comm.

¹⁰B(n,ν) Branching Ratio

⁺⁺Weston, 0.02 MeV to 1 MeV, Solid State detectors, NSE 109, 113 (1991)

Hamsch and Göpfert, keV to MeV, Frisch gridded ion chamber, in progress.

¹⁰B(n,ν)

Haight, 1 MeV to 6 MeV, angular distribution at 30E, 60E, 90E and 135E, private comm.

¹⁰B total cross section

Wasson, 0.02 MeV to 20 MeV, NE-110 detector, Proc. Conf. on NDST, Gatlinburg (1994), p. 50

Plompen, 0.3 MeV to 18 MeV, scintillator, LiI and Li-glass detectors, Proc. Conf. on NDST, Gatlinburg (1994), p. 47 and Proc. Conf. on NDST, Trieste (1997), p. 1283

Brusegan, 80 eV to 730 keV, Li-glass detector, Proc. Conf. on NDST, Gatlinburg (1994)p. 47 and Proc. Conf. on NDST, Trieste (1997)p. 1283

¹⁰Be(p,n) ¹⁰B

Massey, E_p from 1.5 MeV to 4 MeV, data at 0E, private comm. New measurements to be made at lower energies (~.5 MeV). Also possibly ¹⁰Be (p,ν)

Au(n,γ)

⁺⁺Sakamoto, 23 keV and 967 keV, photoneutron source, activation experiment, NSE 109,215 (1991)

⁺⁺Davletshin, .16 MeV to 1.1 MeV, relative to H(n,n), Sov. J. At. Energy 65, 91 (1988), (Corrected data from Sov. J. At. Energ. 58, 183 (1985))

⁺⁺Davletshin, .16 MeV to 1.1 MeV, relative to H(n,n), Sov. J. At. Energy 65, 91 (1988),

⁺⁺Davletshin, .62 MeV to .78 MeV, relative to ²³⁵U(n,f), Sov. J. At. Energy 65, 91 (1988),

Kazakov, Yad Konstany, 44, 85 (1990)

Demekhin, 2.7 MeV, Proc. 36th All Union Conf. on Nuclear Data, p. 94 (1986)

Voignier, ~.5 MeV to ~3 MeV, private comm.

$^{235}\text{U}(\text{n},\text{f})$

Newhauser, 34, 46, and 61 MeV MeV, absolute

⁺Carlson, 0.3 MeV to 3 MeV, relative to black detector, Proc. IAEA Advisory Group Meeting on Nuclear Standard Reference Data, Geel Belgium, p.163, IAEA-TECDOC-335 (1985)

⁺Carlson, 2 MeV to 30 MeV, relative to H(n,n), Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, "U", p. 165

⁺Johnson, 1 MeV to 6 MeV, relative to a dual thin scintillator, Proc. Conf. on NDST Mito (1988) p.1037

⁺Iwasaki, 14 MeV, relative to H(n,n) and associated particle, Proc. Conf. on NDST Mito (1988) p. 87

⁺Lisowski, 3 MeV to 200 MeV, relative to H(n,n), Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, "U", p. 177

Merla, ⁺⁺2.56, ⁺4.45, ⁺⁺8.46, ⁺14.7, ⁺18.8 MeV ?, associated particle, Proc. Conf. on NDST Juelich (1991) p.145

$^{238}\text{U}(\text{n},\text{f})$

Newhauser, 34, 46, and 61 MeV MeV, absolute

Baba, 0.5 MeV to 7 MeV and 14 MeV, relative to $^{235}\text{U}(\text{n},\text{f})$, J. Nucl. Sci. & Techn.,26,11 (1989)

⁺Lisowski, 0.8 MeV to 350 MeV, relative to H(n,n), Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, "U", p. 177

⁺Merla, 5 MeV +?, associated particle, Proc. Conf. on NDST Juelich (1991) p.145

Fomichev, 0.7 MeV to 200 MeV, relative to $^{235}\text{U}(\text{n},\text{f})$, Proc. Conf. on NDST, Trieste (1997), p.1283

⁺⁺Winkler, 14.5 MeV, relative to Al(n, ∇) & $^{56}\text{Fe}(\text{n},\text{p})$, Proc. Conf. on NDST Juelich (1991), p.514

$^{238}\text{U}(\text{n},\text{O})$

⁺⁺Kobayashi, 0.024 MeV, 0.055 MeV, 0.146 MeV, relative to $^{10}\text{B}(n,\gamma_1)$, Proc. Conf. on NDST Juelich (1991), p. 65

⁺Quang, 23 keV and 964 keV, photoneutron source, activation experiment, NSE 110, 282 (1992)

⁺⁺Adamchuck, 10 eV to 50 keV, relative to $^{10}\text{B}(n,\gamma_1)$, J. Atomic Energy, 65, 920 (1989)

⁺⁺Buleeva, 0.34 MeV to 1.39 MeV, relative to $\text{H}(n,n)$ and $^{235}\text{U}(n,f)$, Sov. J. Atomic Energy, 65, 930 (1989)

Voignier, ~0.5 to 1 MeV, private comm.

²³⁹**Pu(n,f)**

⁺Staples, 0.5 MeV to 400 MeV, relative to $^{235}\text{U}(n,f)$, NSE 129, 149 (1998)

Lisowski, 0.8 MeV to 350 MeV, relative to $\text{H}(n,n)$, Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, "U",

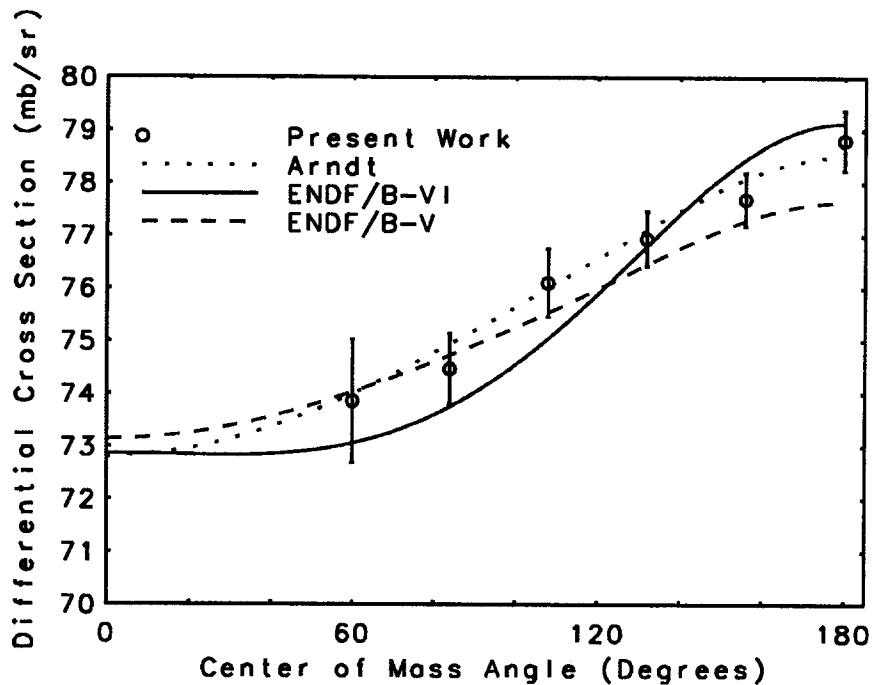


Figure 1. Final results of the hydrogen scattering cross section measurements at 10 MeV neutron energy by the Ohio University-NIST-LANL collaboration. The data are determinations of the shape of the angular distribution. A Legendre polynomial fit to the data is used to normalize the measurements to the total cross section from the Arndt evaluation.

References

- [1] R. A. Arndt, I. I. Strakovsky, and R. L. Workman, Scattering Analysis Interactive Dialin (SAID), Solution FA-98, Private Communication (1998).
- [2] W. P. Poenitz and S. E. Aumeier, The Simultaneous Evaluation of the Standards and Other Cross Sections of Importance to Technology, ANL/NDM-139 [ENDF-358] (1997)