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

The measurements of most neutron cross sections are made relative to neutron cross section standards. These reference standards eliminate the need to measure the neutron fluence in a cross section measurement. Improvements in these standards increase the accuracy of all measurements made relative to them. The last complete evaluation of the standards, which was for ENDF/B-VI, took place almost 15 years ago. These standards were accepted internationally to ensure that all evaluation projects were using the same standards. The need for improved evaluations of the neutron cross section standards is universally accepted. Significant improvements have been made in the standard cross section database since that time, particularly for the H(n,n), ^{10}B(n,α), and ^{235}U(n,f) reactions. Evaluations continue to be done using standards which are now out-of-date. This has led to requests for new evaluations of the standards. In response to those requests, working groups were formed by a number of nuclear data organizations. In addition to the WPEC subgroup, the U.S. Cross Section Evaluation Working Group formed a Task Force and the IAEA is forming a Coordinated Research Project (CRP). These groups are working cooperatively to update the previous work by including standards measurements made since that evaluation was completed and to improve the evaluation process.

The new international evaluation will include the H(n,n), ^{3}He(n,p), ^{6}Li(n,t), ^{10}B(n,α), ^{10}B(n,$\alpha_1\gamma$), Au(n, γ□), ^{235}U(n,f), and ^{238}U(n,f) standard cross sections. A new evaluation is not planned for the C(n,n) cross section since the few new measurements which have been obtained since the ENDF/B-VI evaluation are in excellent agreement with that evaluation.

Progress on the evaluation

Work continues on the encouraging, motivating and coordinating of new measurements which can be used in the evaluation. Much of this effort took place through the former WPMA subgroup which was focused on new measurements of the standard cross sections. Many experiments have been completed; however, most of the experiments are still in the data taking or data analysis stage.

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. For example, investigation of the Nakamura hydrogen scattering experiment revealed an error in the conversion from the laboratory to the center of mass system, the lack of corrections for proton scattering and problems with tails in the experimental distributions. The investigative procedure leads to estimates of the uncertainties and correlations within an 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.

With the increasing need for cross section data at energies above 20 MeV, it is important to have evaluated standards available in that higher energy region. Thus for some standards, the Subgroup has decided to extend the energy region to about 200 MeV. 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}U(n,f), and ^{238}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. 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.

An IAEA Consultants' Meeting on the improvement of the standard cross sections will be held on April 2-4, 2001, shortly before the Santa Fe WPEC meeting. At this meeting the focus will be the topics for study by the CRP and the CRP membership. This CRP is important since it will increase involvement in the evaluation and an international body will validate the evaluation process, especially concerning the uncertainties. In order to most effectively use the resources which will be available under the CRP, the time schedule for completion of the standards evaluation should be extended. The normal programmatic process for the CRP would lead to a three year effort which begins in 2002.

An important task for the CRP is to try 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. 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); the Ohio University, USA (ORMAP); the Kyushu University, Japan; the University at Erlangen, Germany; and the 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.

Also under consideration for the CRP or a continuation of the CRP will be methods for doing the evaluation, such as a single step global process, which were not feasible with the computer capability available in 1987 when the ENDF/B-VI evaluation was completed. 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 depend on a number of factors such as the difficulties associated with an improved method for performing the evaluation process, if a method for implementing that procedure is practical. The deadline after which experiments will not be considered for inclusion in the standards evaluation will be decided at some later date, dependent on the progress of the CRP.

If a new method for doing the evaluation does not become available, plans have been made for performing the evaluation using a procedure which is somewhat improved compared with the ENDF/B-VI standards evaluation. The first evaluation which must be completed is that for the hydrogen scattering standard. This evaluation is in progress at LANL by Hale using EDA. 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. The ^{3}He(n,p) cross section will also be evaluated by Hale using EDA. The remaining standards to be evaluated will use a procedure involving GMA and EDA. GMA will be used for all those standards. It can be used with ratio data and properly handles correlations. EDA will be used for the ^{6}Li+n and ^{10}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}B+n and ^{6}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 will be uncorrelated. The thermal constants should be included in the standards evaluation due to the ratios of certain standards at thermal to other thermal data. These data will be included in the standards evaluation by using the results of the evaluation by Axton of the thermal constants with the associated variance-covariance data as an independent data subset to the GMA simultaneous evaluation. The combination procedure used for the ENDF/B-VI standards evaluation will not be used. Instead, the output cross sections and their variance-covariance matrices from the ^{6}Li+n and ^{10}B+n analyses from EDA will be used as input to GMA. The GMA output for the ^{6}Li+n and ^{10}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.

An invited talk will be given on this international evaluation of the neutron cross section standards at the ND2001 International Conference on Nuclear Data for Science and Technology in October. A Subgroup meeting to discuss the progress made on the experimental and evaluation efforts is planned during the conference.

Table 1. New Experiments for the Standards Database

$^{++}$ 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; error in transformation from laboratory to CMS angles; needs correction for proton scattering, an estimate of error associated with neglecting these corrections was made; 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, [(1800)/[(900), Ann. Nucl. Energy 17, 657 (1990)

$^{+}$Bateman, 10 MeV, angular distribution from 600 to 1800, Fusion Eng. & Design 37, 49 (1997); additional work was done on this experiment. Data is now finalized and submitted for publication (Boukharouba et al.)

$^{+}$Buerkle, 14.1 MeV, angular distribution from 89.70 to 155.70, Few-Body Systems 22, 11 (1997)

Olsson (Uppsala group), 96 & 162 MeV, angular distribution from 700 to 1800

Benck, (Louvain la Neuve) 28-75 MeV, angular distribution from 400 to 1400

Peterson (IUCF) 185-195 MeV, angular distribution from 900 to 1800. In progress but new leadership on the experiment and analysis (Yuezheng Zhou)

^{3}He(n,p)

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

^{3}He total cross section

+Keith, 0.1 to 500 eV, BAPS DNP Oct 1997 paper IG.03 and thesis of D. Rich

^{6}Li(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, also NSE 134, 312 (2000)

^{10}B(n,$\alpha_1\gamma$)
$^{++}$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 ^{235}U(n,f) ion chamber (at LANL), Private comm.

^{10}B(n,α) Branching Ratio
$^{++}$Weston, 0.02 MeV to 1 MeV, Solid State detectors, NSE 109, 113 (1991)

Hambsch and Bax, keV to MeV, Frisch gridded ion chamber, Van de Graaff and linac data, in progress.

^{10}B(n,α)
Haight, 1 MeV to 6 MeV, angular distribution at 300, 600, 900 and 1350, private comm.

^{10}B 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

^{10}Be(p,n) ^{10}B
Massey, E_p from 1.5 MeV to 4 MeV, data at 00, private comm. New measurements to be made at lower energies (~.5 MeV). Also possibly ^{10}Be (p,α)

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 ^{235}U(n,f), Sov. J. At. Energy 65, 91 (1988), Kazakov, Yad Konstanty, 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}U(n,f)
Newhauser, 34, 46, and 61 MeV MeV, absolute, needs additional analysis.

$^{+}$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, and private communication.

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

^{238}U(n,f)
Newhauser, 34, 46, and 61 MeV MeV, absolute

Baba, 0.5 MeV to 7 MeV and 14 MeV, relative to ^{235}U(n,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, and private communication.

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

Shcherbakov, 1-200 MeV, relative to ^{235}U(n.f), ISTC 609-97, see also Fomichev, 0.7 MeV to 200 MeV, relative to ^{235}U(n.f), Proc. Conf. on NDST, Trieste (1997), p.1283

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

^{238}U(n,K)

$^{++}$Kobayashi, 0.024 MeV, 0.055 MeV, 0.146 MeV, relative to ^{10}B(n,$\alpha_1\gamma$), 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}B(n,$\alpha_1\gamma$), J. Atomic Energy, 65, 920 (1989)

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

Voignier, ~0.5 to 1 MeV, private comm.

^{239}Pu(n,f)

Shcherbakov, 1-200 MeV, relative to ^{235}U(n.f), ISTC 609-97

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

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",