Status Report of Subgroup 7 to the NEANSC WPEC
May 2002

Nuclear Data Standards
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Introduction

The neutron cross section standards are the basis for the neutron reaction cross section databases. Improvements in a standard lead to improvements in all measurements that have been or that will be made relative to that standard. It has been almost 15 years since the last comprehensive evaluation of the neutron cross section standards. 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 Evaluations continue to be done using standards that are now out-of-date.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 CSEWG formed a Task Force and the IAEA formed a Coordinated Research Project (CRP). These groups are working cooperatively to update the previous work by including standards measurements made since the last evaluation was completed and to improve the evaluation process. An important area of study is the reason for the relatively small uncertainties present in the ENDF/B-VI standards evaluation.

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. For some of the standards, the energy region will be extended to 200 MeV to provide new standards in this emerging important energy region. Efforts will be made to investigate the need for a new thermal constants evaluation. A new evaluation will not be made for the C(n,n) cross section 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

Many experiments which could be used in the evaluation have been completed; however, a large number of experiments are still in the data taking or data analysis stage. Work continues on the encouraging, motivating and coordinating of new measurements which can be used in the evaluation.

Studies of possible experiments for the standards database continues. 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. 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.

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. Significant recent work has been done on the H(n,n), ^{10}B(n,α), ^{235}U(n,f) and ^{238}U(n,f) cross sections. H(n,n) measurements with an average uncertainty of less than 1% at 10 MeV neutron energy by Boukharouba et al. have resolved a problem with the shape of the angular distribution given by evaluations of this cross section. High accuracy absolute H(n,n) measurements at 190 MeV with about 1% accuracy using tagged neutrons were recently obtained. These data, which were obtained by Vigdor are now being analyzed. Since these data have been obtained with high accuracy and are absolute, they have the potential to resolve an important discrepancy at back angles. This discrepancy has led to large increases in the uncertainty associated with this cross section. Preliminary work on the ^{10}B(n,α) cross sections by Hambsch and Bax is in better agreement with the ENDF/B-VI evaluation than the Weston and Todd measurements. Measurements by Giorginis and Khriachkov, and Zhang et al. of the ^{10}B(n,α) cross sections will help to extend the range of this standard to higher neutron energies. Measurements of the ^{235}U(n,f) and ^{238}U(n,f) cross sections by Nolte et al. are very important since they are the only recent absolute data on these cross sections in the energy region above 20 MeV. The ^{235}U(n,f) data are especially relevant since the only other data with small uncertainties are those of Lisowski et al. which are used as the standard in the energy region above 20 MeV. The Nolte et al. cross section data are slightly higher than the Lisowski et al. results. Nolte is planning additional work to improve on the results he now has and possibly to extend the energy range.

The IAEA Consultants' Meeting on the improvement of the standard cross sections which was held last year has led to a CRP. There are members of the CRP from Austria, China, Germany, Japan, the Republic of Korea, Russia and the USA. The CRP has just started its agenda of activities. The main objectives of the CRP are the following: Improve the methodology for determination of the covariance matrix in R-matrix fits; Upgrade the computer codes using this methodology; Study the reasons for uncertainty reduction in R-matrix 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,α); Establish the methodology and computer codes for combining the light element with the heavy element evaluations.

The CRP will increase involvement in the evaluation and allow an international body to validate the evaluation process, especially concerning the uncertainties. The small uncertainties obtained in the ENDF/B-VI evaluation process are of great concern. 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. An initial effort of the CRP is an investigation of the small uncertainty problem through several tests of codes. There is a comparison of the R-matrix parameters, cross sections obtained from those parameters and the uncertainties of the values obtained, for several R-matrix codes which fit data from a common database. It is necessary to select a database containing measurements which can be properly used in the comparison. For example some of the codes can not handle certain types of input data correlations. A similar comparison is underway for simultaneous evaluation least-squares codes. Again the database must be carefully selected so that the types of data and correlations present in the measurements are consistent with the codes being investigated. Comparison of combining procedures is also contemplated. 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 obtained in 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.

The R-matrix codes being used in this study are EDA (LANL), SAMMY (ORNL), a form of KALMAN (Kyushu University) and RAC (Tsinghua University). The generalized least squares codes being used are GLUCS (Obninsk and the University of Vienna), GMA (ANL and JAERI) and KALMAN.

Another CRP effort involves theoretical calculations, from first principles, for the lighter systems, beginning with ^{3}He + n. This work could provide information on the determination of parameters used in the R-matrix description such as distant level parameters. It could then possibly provide improved values of those parameters or improved uncertainties in them, so more realistic R-matrix uncertainties could be ascertained.

In its later phase, the CRP or a continuation of the CRP will study methods for doing the final 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 phase, using the tools developed from that activity and the critically reviewed and assembled experimental data, the new evaluation will be done. 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.

An invited talk was given on the international evaluation of the neutron cross section standards at the ND2001 International Conference on Nuclear Data for Science and Technology last October. A Subgroup meeting was held at the conference in which progress reports were given on experimental and evaluation work related to the standards evaluation.

In 2000, the CSEWG decided to develop a new version, ENDF/B-VII, of its library. It is anticipated that the library will be completed in 2004 and released in 2005. To follow this schedule, new standard cross sections should be partially submitted in 2003 to allow adjustment of key evaluations and their validation, followed by submittal of the complete set of standards in 2004. The evaluation of the standards depends strongly on the progress of the CRP. The CRP would normally be a three year effort from 2002 to 2005. Unfortunately the CRP started somewhat later than was anticipated when the ENDF/B-VII schedule was established. To maintain the schedule and still make use of the CRP activities for the ENDF/B-VII evaluation, a schedule may have to be established where the standard cross sections are obtained by 2003 or 2004, but the detailed uncertainty information is obtained at a later time. It should be emphasized that the activities of the CRP are strongly research orientated so it is difficult to establish a firm schedule for completion of the tasks. To maintain such a schedule, experimental measurements which are to be included in the evaluation must be completed early in 2003.

At the last CSEWG meeting, work by Young and MacFarlane (LANL) relevant to the ^{235}U(n,f) cross section was discussed. They are concerned that new evaluations of this cross section should give improved estimates of both k-eff and the spectral indices for a series of critical assemblies built at LANL. They find that a new evaluation of this cross section for JENDL 3.3 by Kawano et al., provides improved estimates of these quantities compared with the ENDF/B-VI evaluation. The Kawano et al. evaluation is higher than ENDF/B-VI by several percent in the energy region from about 1 MeV to 5 MeV. The Kawano et al. evaluation is a simultaneous evaluation which uses only fission cross sections (^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu and ^{241}Pu). The ENDF/B-VI evaluation which is a combination of simultaneous evaluation and R-matrix analyses, uses a broader base of experimental cross sections since it includes all the standards. The Kawano et al. evaluation does have the advantage over the ENDF/B-VI evaluation that it uses the newer data (1987 to the present). An internal report was written by Kawano et al. comparing the ^{235}U(n,f) cross sections for JENDL 3.3 with those of ENDF/B-VI. Though detailed analyses have not been done with the updated version of the database that was used for ENDF/B-VI (which will be the database for the international evaluation of the standards), it appears that changes as large as those seen in the Kawano et al. evaluation are unlikely. This may be a result of discrepant data in the database. During the ENDF/B-VI evaluation very unusual results were observed to occur with correlated discrepant data. 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 simultaneous evaluation results. This had the effect of making χ^2 per degree of freedom essentially one. Pronyaev has suggested that such procedures may not be suitable since least square solutions for strongly discrepant data are not stable. Thus efforts will be made to work only with consistent data sets. This will involve extensive investigations of the older data to look for problems with methods, etc. Due to time constraints and the fact that there are thousands of data points, consideration may have to be given to analytical procedures for handling this process.

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)

+Boukharouba, Phys Rev C 65, 014004, 10 MeV, angular distribution from 60° to 180°, additional work planned for 14 MeV

Vigdor (IUCF) 185-195 MeV, angular distribution form 90° to 180°. Data have been obtained and they are under analysis.

$^{+}$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, ✓(180°)/✓(90°), Ann. Nucl. Energy 17, 657 (1990)

$^{+}$Buerkle, 14.1 MeV, angular distribution from 89.7° to 155.7°, Few-Body Systems 22, 11 (1997)

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

Benck, (Louvain la Neuve), Proc. Conf. on NDST, Trieste (1997), 28-75 MeV, angular distribution from 40° to 140°

^{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

Guohui Zhang, 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,α_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 ^{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, ND2001, keV to MeV, Frisch gridded ion chamber, in progress.

^{10}B(n,α)
Haight, 1 MeV to 6 MeV, angular distribution at 30°, 60°, 90° and 135°, private comm.

Hambsch and Bax, ND2001, keV to MeV, angular distribution, Frisch gridded ion chamber, in progress.

Giorginis and Khriachkov, MeV energies, angular distribution, VdG data

Guohui Zhang, 4.17, 5.02, 5.74, 6.52 MeV angular distribution, submitted for publication to NSE '

^{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 0°, private comm. New measurements to be made at lower energies (~.5 MeV). Also possibly ^{10}Be (p,*)

Au(n,1)

$^{++}$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)

Nolte, 30 to 150 MeV, ND2001, preliminary

Newhauser, 34, 46, and 61 MeV MeV, absolute, *removed from database*

$^{+}$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)

Nolte, 30 to 150 MeV, ND2001, preliminary

Newhauser, 34, 46, and 61 MeV MeV, absolute, *removed from database*

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,✻) & ^{56}Fe(n,p), Proc. Conf. on NDST Juelich (1991), p.514

^{238}U(n,l)

$^{++}$Kobayashi, 0.024 MeV, 0.055 MeV, 0.146 MeV, relative to ^{10}B(n,✻$_{1}$l), 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,$*_{1}$1), 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 (2000)

$^{+}$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",