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

It has been almost 16 years since the last complete 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. The standards are the basis for the neutron reaction cross section libraries. In response to requests for improvements in the standards, 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 new standards measurements and to improve the evaluation process.

The new 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. The energy region will be extended to ~200 MeV for some of the standards to provide new standards in this important energy region.

Progress on the evaluation

This year the cut-off date for accepting measurements for the evaluation will occur. It is important to have the experiments completed in a timely manner, that are still in the data taking or data analysis stage. Some experiments that have been completed require more information/documentation so they can be properly used in the evaluation. Work continues on the encouraging, motivating and coordinating of such measurement activities so they can be used in the evaluation.

Work on the experiments considered for the standards database continues. There has been significant support for this work from laboratories involved with the WPEC. For each experiment that has been completed the documentation is investigated for possible corrections that may need to be made and for errors or missing information. The investigative procedure will lead to estimates of the uncertainties and correlations within an experiment and correlations with other experiments. This information will be used to obtain covariance matrices for the measurements that will be used in the evaluation process.

Recent evaluation work by Kawano suggests that corrections obtained by Poenitz made significant differences in the evaluations of the ^{235}U(n,f) cross section. It is expected that the Poenitz corrections had significant effects on other standards evaluations also. The documentation for these corrections has not been available until recently. Poenitz has sent to NIST, databooks, correspondence, etc. containing the information he found in his extensive study of the standards database for the ENDF/B-VI standards evaluation. Investigations of this documentation are now underway.

Significant work, which is underway or completed, has been done on the H(n,n), ^{6}Li(n,t), ^{10}B(n,α), ^{235}U(n,f) and ^{238}U(n,f) cross sections. Recent work includes:

- H(n,n) measurements with an average uncertainty of less than 1% at 10 MeV neutron energy made by Boukharouba et al. which have resolved a problem with the shape of the angular distribution. New measurements are planned by this group at ~15 MeV to improve the database.
- Absolute H(n,n) measurements at 190 MeV with about 1% accuracy using tagged neutrons were recently obtained by Vigdor et al.. It is expected that preliminary results will be available this year. The data have high accuracy and are absolute, so they have the potential to resolve an important discrepancy at back angles which has required an ~10% uncertainty to be used in applications using this cross section standard at high energies and near 180° in the center of mass system.
- A ^{6}Li(n,t)^{4}He measurement at sub-thermal neutron energy has been made by Chowdhuri et al. The measurement was made using very well characterized ^{6}LiF targets for which the reaction products are detected in a very accurate solid angle. The neutron fluence for this measurement was determined using a cryogenic radiometer. With this radiometer, the fluence was obtained from measurements of the heat produced in a metallic lithium target by the reaction products from the ^{6}Li(n,t)^{4}He reaction. The neutron fluence is the heat produced divided by the well-known Q value for this reaction. The result is the most accurate measurement of this important cross section.
- Preliminary measurements related to the ^{10}B(n,α) cross sections have been made by several groups. The branching ratio data of Hambsch and Bax are 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.
- Additional data after the ND2001 conference have been obtained by Nolte et al. for the ^{235}U(n,f) and ^{238}U(n,f) cross sections. These data 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 new Nolte et al. data include measurements at 14 MeV and 19 MeV which allows comparisons with the better-defined database at these lower energies. The 14 MeV and 19 MeV data are all higher than the ENDF/B-VI evaluations. Above 20 MeV, the Nolte et al. cross section data are slightly higher than the Lisowski et al. results for the ^{235}U(n,f) cross section. However the ^{238}U(n,f) measurements of Nolte et al. are significantly higher (~10%) from about 30 MeV to 100 MeV neutron energy. Further measurements and additional analysis of the existing data are planned by Nolte et al.

The first IAEA CRP on the improvement of the standard cross sections was held in September of 2002. There are members of the CRP from Austria, China, Germany, Japan, the Republic of Korea, Russia and the USA. The main objectives of the CRP 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,α); 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 initial efforts of the CRP have focused on the uncertainties obtained from evaluations of cross sections. 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 model independent or R-matrix analyses can result in such small uncertainties, and whether there are more reasonable corrections or algorithms to employ. Work has been done on the small uncertainty problem through comparisons of several tests of codes. Comparisons are underway of cross sections and their uncertainties obtained for several R-matrix codes that fit data from a common database. It is necessary to select a database containing measurements that 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 model independent 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. For these comparison tests, five data sets were used: those of Fort, Fort & Marquette, Friesenhahn et al., Lamaze et al. and Poenitz and Meadows. In some cases a thermal point and a total cross section were also used. For the comparison tests, it was assumed that no correlations exist between these data sets. The only correlations within the data sets are assumed to be short energy range (statistical) and long energy range (normalization).

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.

Results from the model independent least-squares work include:

- An important coding problem in GMA was found by Vladimir Pronyaev. It is still not clear whether it was actually present in the code used for the ENDF/B-VI standards evaluation, but it is likely that it was. With this error, GMA accumulated in the adjustment vector for the 'prior' only the contribution from the last set of data. This correction does not influence the covariance matrix of the evaluated data.
- The corrected GMA code produces results in good agreement with GLUCS, even when discrepant data are used.
- The results obtained using SOK are higher than those from GMA and GLUCS. These higher results actually look better than those from GMA or GLUCS when comparisons are made with the input data. The SOK code fits the logarithm of the cross section. The results from SOK without using the logarithm of the cross section agree very well with GMA and GLUCS. The difference appears to a result of the "Peelle Pertinent Puzzle" (PPP) problem resulting from the use of discrepant data. Using the logarithm removes that problem. Other solutions are also under consideration (weighting by % uncertainties; Box-Cox)

Results from the R-matrix code comparisons include:

- Excellent agreement among the codes EDA, SAMMY and RAC was obtained when non-relativistic calculations were done. A 4% difference was observed near the resonance in a comparison between non-relativistic and relativistic calculations.
- The R-matrix codes, since they do have physics built into them, did not give much weight to the one discrepant data set used in the test. The PPP problem does not seem to effect this work.
- RAC was compared with GMA in terms of cross sections and also covariances.
- Simulation studies were done with RAC. This code can handle input covariances. These studies suggest that not including medium energy range correlations can lead to an underestimation of the uncertainty. Further study in this area is needed. It could indicate that the R-matrix code used for the evaluation must be able to include medium energy range correlations.
- SAMMY has the advantage of being able to work with raw data. Thus the construction of covariances is simplified since input data covariances are diagonal.
- Addition work is planned with exactly the same input data to check the covariances obtained with EDA, SAMMY and RAC.

Microscopic theoretical calculations are being done using the resonating group model (RGM) with realistic three-nucleon forces to obtain information about the ^{3}He(n,p) cross section through studies of the ^{4}He system. The RGM results show more poles in the energy region where the cross section can be used as a standard, although some poles are very broad. Transforming the RGM results to R-matrix poles should allow them to be used in the R-matrix analysis. This work should lead to improved values of the parameters and more realistic uncertainties in the cross sections. Near final results should be available next year. For A=7, it is totally impractical to consider three-nucleon forces due to the very large amounts of computer time required even with the best computers. The A=7 case will be studied with two-nucleon forces to provide information needed for the ^{6}Li(n,t) standard.

It is clear that more work needs to be done to understand the experiments and possible problems with them that may cause discrepancies to exist. During the ENDF/B-VI GMA evaluation process very unusual results were observed 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. It would clearly be better to find the sources of the discrepancies. Then the evaluation could be done with consistent data sets. This is a very large task. There is a more conservative effort underway which involves looking at experiments which have large weights in the evaluation. 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, work is being done on analytical procedures for handling discrepant data. One project underway adds a medium energy range correlation component to the experimental data in GMA. This results in a much better χ^2 per degree of freedom and larger uncertainty in the evaluated results. There are changes in the cross sections that need to be justified.

There is still much work to be done on this evaluation. Plans have already been made to test new combining procedures. There is a need for standards for the new ENDF/B-VII library. It is anticipated that the library will be completed in 2004 and released in 2005. The evaluation of the standards depends strongly on the progress of the CRP. It may be necessary to provide an interim library of standards for that library without the detailed uncertainty information, which will be supplied 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.