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Recent Work Leading Towards a New Evaluation of the Neutron Standards

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A new version of the ENDF/B library has been planned. The first step in producing this new library is evaluating the neutron standards. An evaluation is now underway with support from a Data Development Project of the IAEA. In addition to the neutron cross section standards, new evaluations are being done for prompt fission neutron spectra and a number of reference data. Efforts have been made to handle uncertainties in a proper way in these evaluations.

I. INTRODUCTION

Since most measurements of neutron cross sections are made relative to a standard, it is important to maintain an active measurement and evaluation program to improve those standards. In the next sections the changes that led to improved evaluations with more defendable uncertainties will be discussed. All uncertainties in this paper represent coverage factors corresponding to one standard deviation.

II. PREVIOUS CROSS SECTION STANDARDS EVALUATIONS

For ENDF/B-I there really were no specific evaluations identified as community standards. The first use of standards was in ENDF/B-II. The ENDF/B-III efforts led to laboratories/individuals taking on the responsibility for specific standards evaluations for which they had expertise and interest. Uncertainties did not play a large part in this version.

With ENDF/B-IV more objective evaluation techniques for the standards came about largely focused on the light-element standards with the use of R–matrix analyses. For the heavy-element standards, older evaluation methods were used - basically drawing a curve on a graph of acceptable data. Such evaluations are difficult to document and it is not clear how to determine meaningful uncertainties and covariance information.

First efforts to use an objective evaluation method for the heavy element standards occurred with ENDF/B-V [1] when Poenitz did an evaluation of the ^{235}U(n,f) cross section.

For the ENDF/B-VI evaluation [2] of the standards, considerable effort was devoted to improved evaluation procedures. In previous evaluations a hierarchical approach was followed. This approach does not include absolute and ratio data on the same basis as they were measured. For example, a ratio of the ^{10}B(n,α) to the ^{6}Li(n,t) cross sections would be used in the ^{10}B(n,α) cross section evaluation but not in the ^{6}Li(n,t) cross section evaluation.The difficulties with that procedure led to a combining approach. The combining procedure was achieved by using a simultaneous evaluation using generalized least-squares with separate R–matrix analyses.

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Least-squares methods allowed the combining of input data consistent with the experimental uncertainties. A database was established that could handle the full information content available. Thus data were evaluated simultaneously to assure proper use of the available information. Ratio measurements were properly handled so there would be an impact on each of the cross sections in the ratio. Correlations among the experimental data both within an experiment and with other experiments were taken into account in the simultaneous evaluation. The R–matrix fits for the evaluation of the light element standards allowed a large class of data in addition to angle integrated neutron cross sections to be used in these analyses. An important condition was that there cannot be any correlations between the database used for the simultaneous evaluation and the database used for the R–matrix evaluations. This procedure led to a consistent evaluation in which correlations and ratio measurements were properly taken into account. To satisfy the correlation condition, the boron and lithium experimental data were separated into two uncorrelated groups, one for use in the R–matrix analyses and the other for use in the simultaneous analysis. All the standards except the H(n,n), ^{3}He(n,p) and C(n,n) cross sections were evaluated using the simultaneous evaluation and R–matrix analyses. Separate R–matrix evaluations were performed for the H(n,n), C(n,n) and ^{3}He(n,p) cross sections. Total cross section and scattering measurements for ^{6}Li and ^{10}B were contained in the database since they put constraints on the reaction data. Measurements of ^{235}U and ^{239}Pu fission cross sections in a ^{252}Cf spontaneous fission neutron spectrum in addition to ^{238}U(n,γ) and ^{239}Pu(n,f) data were included since they improved the quality of the standards. Another subset which was used as input to the simultaneous evaluation was an evaluation of the thermal data for ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu by Axton with the associated variance-covariance data.

The R–matrix analyses for the light–element standards were done by Hale using the code EDA [3]. The simultaneous evaluation was done with the program GMA [4] written by Poenitz. A separate code written by Peelle was used to combine the simultaneous evaluation and R–matrix analyses and produce the final cross sections and uncertainties. All experiments which are correlated and all ratio measurements (except those to the hydrogen standard) were put into the simultaneous evaluation data subset. In the R–matrix analyses, the experimental data were weighted based on the quoted random uncertainties and it was assumed that no correlations other than the overall normalization were present among the data from a particular experiment.

It was found that very unusual mean values and reduced uncertainties can be obtained with discrepant correlated data. This was the first observation of the Peelle Pertinent Puzzle (PPP) effect [5]. A method was established to minimize problems associated with discrepancies by down weighting discrepant data. It had the effect of reducing χ^2 per degree of freedom to essentially 1. In some cases very small uncertainties in the combined output of the evaluation were found even with this down weighting and increasing of the R–matrix uncertainties by a factor of the square root of χ^2 per degree of freedom.

The ^{252}Cf spontaneous fission neutron spectrum is used as a standard for fluence determination. An independent generalized least-squares evaluation of that spectrum by Mannhart [6] was used as the standard for ENDF/B-VI. The evaluation includes the spectrum and its covariances.

III. AN INTERNATIONAL EVALUATION OF THE CROSS SECTION STANDARDS (ENDF/B-VII)

This is the first standards evaluation [7] that was done internationally so that full use of world wide capabilities could be available for the evaluation. The evaluation was a cooperative effort of the CSEWG, the WPEC and the IAEA. The work involved updating the previous work by including new measurements and improving the evaluation process. Before the evaluation process was started a number of tasks were initiated.

A. Handling of Discrepant Data

To reduce the effect of discrepant data, deviations of experimental neutron measurements from the output of the evaluation were compared with the uncertainties on the data. The outliers were defined as those with a difference from the evaluated value 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 estimated from an analysis of the energy dependence of the discrepancy. This resulted in a much better χ^2 per degree of freedom and larger uncertainty in the evaluated results. The change in the evaluated cross section was small.

B. Code Comparisons

There was an extensive effort comparing evaluation codes, both R–matrix and model-independent, to ensure that the results obtained were not code dependent. The average uncertainty of the evaluated values due to different procedures used is about 0.2% - 0.3% and this difference was added to the uncertainty assigned in the final evaluation.

The code intercomparison led to an investigation on how to minimize the PPP effect. Several different methods were explored.

The average difference between results obtained from the various codes and options used to minimize PPP is