National Institute of Standards and Technology
Neutron Cross Section and Fluence Standards Program

PROGRESS REPORT

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Activities

- Measurements of Neutron Cross Section Standards
  - Needed for improvement of standards evaluations
- Evaluation of Standards
  - Most cross sections are relative to the standards
  - An improvement in a standard leads to improvements in all measurements relative to that standard
- Other work

Nuclear Reaction Activities: H(n,n)H Standard Angular Distribution Work

This work was initiated to resolve problems with the hydrogen database.

- We previously made measurements at 14.9 MeV at the Ohio University accelerator facility. The data were obtained by detecting the recoil proton.

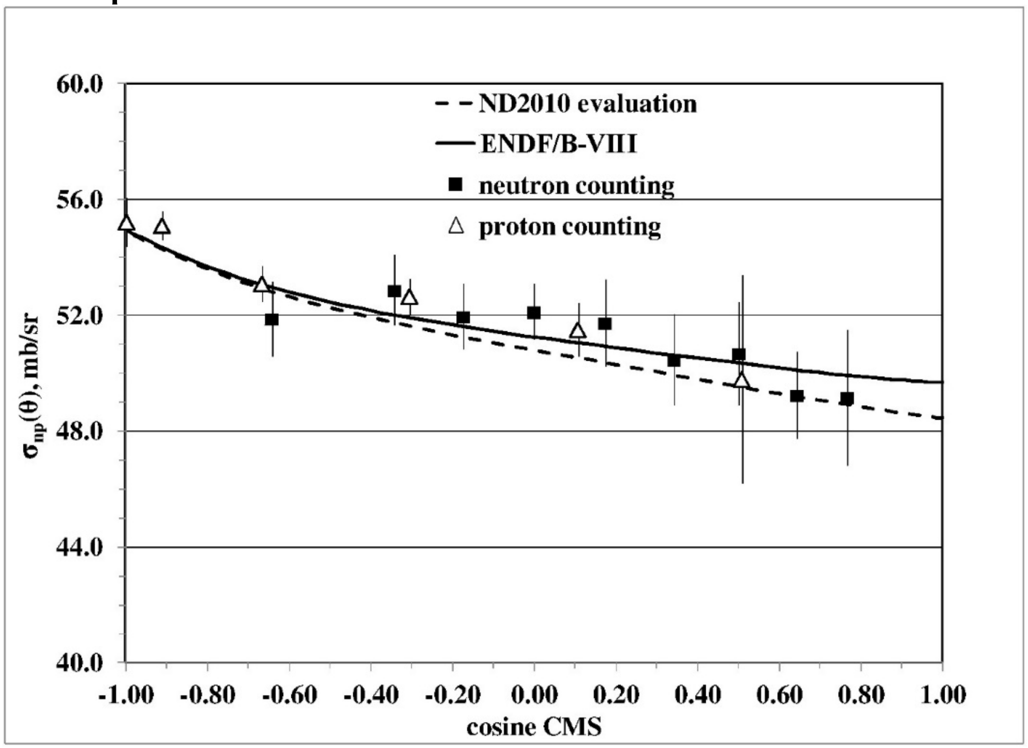
- New measurements at 14.9 MeV were made there, detecting the neutron in coincidence with the associated proton so that data could be obtained at smaller CMS angles. **Work now just completed and published**.

- (collaboration of NIST with Ohio University, Lincoln Memorial University and the University of Guelma)

N.V. Kornilov, A High-Precision Tagged Neutron n-p Scattering Measurement at 14.9 MeV, Nucl. Sci. Eng. 194, 335 (2020)

Nuclear Reaction Activities: H(n,n)H Standard Angular Distribution Work

- Results for both experiments are shown here compared with the ENDF/B-VIII standards evaluation.
- The results and the ENDF/B-VIII evaluation are all in excellent agreement but there is a trend toward lower values at small CMS angles for both experiments.



Nuclear Reaction Activities: Standards Measurements, ^{6}Li(n,t) Cross Section

- At the NIST Neutron Center for Neutron Research a measurement was made of the ^{6}Li(n,t) cross section standard. This is the first direct and absolute measurements of this cross section in this neutron energy range using monoenergetic neutrons.
  - A primary effort was focused on measuring the neutron fluence accurately. It was determined with an uncertainty of 0.06%.
  - There is concern about the IRMM mass determination of the sample. That value yields a cross section value with an uncertainty of 0.3% that is 1% lower than the ENDF/B-VIII value.
  - Most of the uncertainty is from uncertainty in the ^{6}Li mass.
  - A better determination of the mass must be made.

(collaboration of NIST with the University of Tennessee and Tulane University)

Nuclear Reaction Activities: Standards Measurements, $^{6}Li(n,t)$ Cross Section

- For a better determination of the mass the following must be done:
- To start the process, a sample from the same batch as that used in the experiment is compared, by neutron counting, to the one used in the experiment.
- That sample was submitted for mass determination using Isotope Dilution Mass Spectrometry (IDMS). The pandemic has severely limited activity at that facility. So this work has not been completed. When it is completed, the amount of ^{6}Li in that sample will be known. To do this work the sample is sacrificed.
- From the IDMS result and the ratio from the neutron counting experiment, the amount of ^{6}Li in the sample used in the experiment will be determined.
- Complications may come if there are questions about the NIST standard reference sample used for the IDMS.

Nuclear Reaction Activities- Measurements

- A new measurement is underway at NIST of the $^{235}U(n,f)$ cross section at a low monoenergetic neutron energy using the same basic setup used for the $^{6}Li(n,t)$ measurement.
    - A well characterized sample was obtained. It has a well defined mass,
        - however the areal uniformity of the mass distribution is not known.
            - Studies are underway on that distribution.
    - Initial data was obtained but more data are required. Fraction of a percent uncertainty results are expected.
    - Very few absolute low energy monoenergetic measurements have been made of this cross section.
    - They were all done in the 1950s and 1960s.

Nuclear Reaction Activities- Measurements

Previous $^{235}U(n,f)$ 2200 m/s cross section measurements (No Maxwellian Data)

Author	Date	CS (b)	DCS (%)	Reference
Saplakoglu	1959	593.17	2.2	*2nd Geneva Conf.* ***4,*** *157*
Raffle	1959	581.97	3.1	*AERE/R-2998*
Deruytter	1961	589.73	1.3	*J. Nucl. Energy* ***15***, *165*
Maslin	1965	583.71	1.4	*Phys. Rev.* ***139***, *852*

Nuclear Reaction Activities- Measurements

NBS-I Source Strength and Mn Bath Work

- Work continues on improvements in the determination of the source strength for NBS-I, the U.S. national fast-neutron source standard.
    - This work will have an impact on many cross section measurements that have used this source as a standard and any future measurements made using it.
- Calibration measurements for NBS-I have been made using a ^{252}Cf neutron source, based on its accurately known nu-bar. They are being analyzed.
- The value and uncertainty of the ^{16}O(n,α) cross section are problems in the determination of the absolute efficiency of our (and all) Mn bath(s). They are under investigation.

Nuclear Reaction Activities- Measurements

National Repository for Fissionable Isotope Mass Standards

- These are well characterized samples that have been obtained from various labs that no longer are in the nuclear measurement field. They are routinely monitored.
  - These samples are available for loan in physics and nuclear engineering applications.

Nuclear Reaction Activities: - Evaluations

- Experimental data in the standards database have been improved as a result of NIST involvement or encouragement.
- These data will be used in the evaluation of the neutron cross section standards.
- Work is continuously done to investigate new experiments for improvements that may be needed.
- Close cooperation with Prof. Zhang of the China Spallation Neutron Source facility which is a major source of standards data.
  - Data on H(n,n), ^{6}Li(n,t), ^{10}B(n,α_1), ^{10}B(n,α), ^{238}U(n,f) and ^{235}U(n,f) have been obtained at this facility and they continue to work on the standards

Nuclear Reaction Activities: - Evaluations

- NIST was actively involved in the October 2020 Neutron Standards meeting.
  - Carlson was an organizer of the meeting and he chaired the meeting.
  - Carlson gave a paper on "Recent Standards Activity." It contained summaries of work started, completed and proposed for standard cross sections of H(n,n), ^{6}Li(n,t), ^{10}B(n,α), ^{10}B(n,$\alpha_1\gamma$), C(n,n), Au(n,γ), ^{235}U(n,f), and ^{238}U(n,f) and ^{252}Cf nubar.
  - A paper was given on the work at NIST ^{6}Li(n,t) and ^{235}U(n,f) work by P. Mumm
  - Carlson is now working on the summary of the meeting: The IAEA 2020 Consultants Meeting on Neutron Data Standards.

Nuclear Reaction Activities: - Evaluations

- Co-authored a paper on unrecognized sources of uncertainty
  - In many (if not all) experiments of a given type there exist unrecognized (unknown) experimentally related sources of uncertainty that cannot be eliminated by repeated measurements.
  - These uncertainties might enhance the observed scatter in the data points (if they are random in nature) or introduce biases (if they are correlated).
  - These types of uncertainties ultimately limit the precision and accuracy to which physical quantities can be measured.
  - These unknown uncertainty sources are denoted Unrecognized Sources of Uncertainties

R. Capote, S. Badikov, A.D. Carlson, et al., "Unrecognized Sources of Uncertainties (USU) in Experimental Nuclear Data," Nuclear Data Sheets 163 191 (2020

Nuclear Reaction Activities: - Evaluations

- Co-authored a paper on the OECD-NEA High Priority Request List (HPRL).
  - It is a point of reference to guide and stimulate the improvement of nuclear data for nuclear energy and other applications, and a tool to bridge the gap between data users and producers.

E. Dupont *et al.*, HPRL–International cooperation to identify and monitor priority nuclear data needs for nuclear applications, EPJ Web of Conferences 239, 15005 (2020)

Nuclear Reaction Activities: - Evaluations

- Co-authored a paper on templates used in updating uncertainties of cross-section data in the neutron standards database.
    - These templates can help evaluators in identifying missing or suspiciously low uncertainties for a specific uncertainty source and missing correlations between uncertainties of the same and different experiments, when estimating covariances for measurements entering their evaluation.

D. Neudecker, et al., Applying a Template of Expected Uncertainties to Updating ^{239}Pu(n,f) Cross-section Covariances in the Neutron Data Standards Database, Nuclear Data Sheets 163, 228 (2020)

Nuclear Reaction Activities: - Evaluations

- Authored a paper to improve the understanding of interpolation rules in our standards paper that was published in 2018.
  - When the standards evaluation code, GMA, was written, the focus was on its use for the evaluation of neutron cross section standards where the cross sections are smooth. GMA was designed for use with measurements having moderate energy resolution.
  - GMA's use with fluctuating cross sections requires great care since the number of nodes is limited, even when the appropriate interpolation law is used.
  - The Nuclear Data Sheets paper elaborates on these points.

A.D. Carlson, et al., " "Corrigendum to: \Evaluation of the Neutron Data Standards" [Nucl. Data Sheets 148, p. 143 (2018)]" Nuclear Data Sheets 163, 280 (2020).

Nuclear Reaction Activities: - Program Involvement

- Member of the Program Committee of the 17th International Symposium on Reactor Dosimetry (ISRD-17).
- Member of the International Advisory Committee of the International Conference on Nuclear Data for Science and Technology, ND-2019. Work completed in 2020 with the proceedings of the conference.
- Member of the International Advisory Board for the 5th International Workshop on Nuclear Data Covariances (CW2020).

Proposed Work

- Pursue improvements in the experimental database so they are available for the next evaluation of the standards.
- In an effort to continually improve the standards, continue to recommend and encourage new measurements and perform examinations of the data from them for use in future evaluations of the standards. Continue USU and Template work.
- Calibrate NBS-I using an absolutely calibrated source based on the α-γ coincidence system.
- Continue to acquire and monitor samples in the National Repository for Fissionable Isotope Mass Standards. Make these samples available for loan in experiments
- Determine the mass of the ^{6}Li sample used for the ^{6}Li(n,t) cross section by Isotope Dilution Mass Spectrometry and consistency measurements. Then finalize the ^{6}Li(n,t) cross section data.
- Measure the ^{235}U(n,f) cross section at a sub-thermal energy with high accuracy.