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

PROGRESS REPORT

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Activities

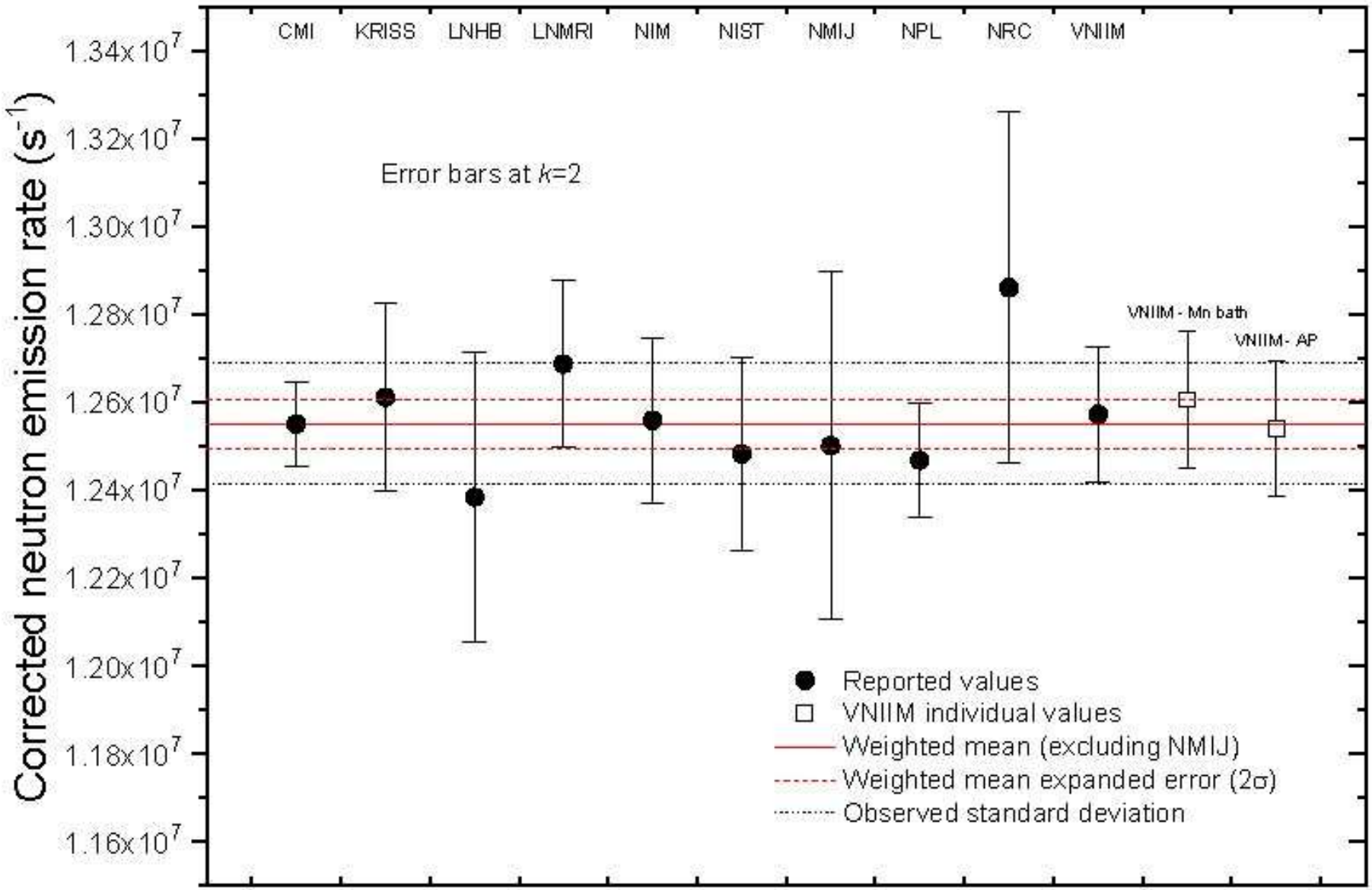
- Measurements of Neutron Cross Section Standards
  - Needed for improvement of standards evaluations
- Evaluation of Standards
  - Most cross sections are relative to the standards
  - An improvement in a standard leads to improvements in all measurements relative to that standard
- Other work

Nuclear Reaction Activities- Measurements

Comparison of measurements of neutron source emission rate CRR(III)-K9.Cf

- NIST is a participant in an international project measuring source intensity
- A single ^{252}Cf source is sent to a number of laboratories throughout the world
  - Brazil, Canada, China, Czech Republic, Britain, France, Italy, Japan, Russia, and USA
- The measured rate at each laboratory using their techniques is sent to an impartial pilot institute
  - The results were tabulated and led to a publication in Metrologia
- Such work is valuable to ensure that each laboratory is obtaining consistent results
  - Results that deviate from the mean require investigation to find sources of error

Results of the ^{252}Cf Inter-comparison Work



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

- At the NIST Neutron Center for Neutron Research experimental data was made of the ^{6}Li(n,t) cross section standard. This is the first direct and absolute measurement of this cross section in this neutron energy range using monoenergetic neutrons (3.3 meV).
  - The cross section was obtained for which the neutron fluence with an uncertainty of 0.06%.
  - Unfortunately there is concern about the IRMM mass determination of the sample. Most of the uncertainty in the cross section is from the ^{6}Li mass uncertainty
  - Though significant amounts of data were obtained, additional data will be obtained when the reactor is at full power (20 MW). Due to technical problems, it is now at 1 MW-too low for successful cross section work.
  - **A better determination of the mass must be done.**

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

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

- To determine the mass, a deposit from the same batch as that used in the experiment is compared, by neutron counting using reactor neutrons, to the one used in the experiment.
- That deposit will be submitted for mass determination using the NIST Isotope Dilution Mass Spectrometry (IDMS). The pandemic and a reduction in staffing of that IDMS facility have severely reduced progress. So we await work at that facility. A new IDMS facility within our Division is being established, but it presently can't satisfy the accuracy requirement. To do this work that deposit (not the original one) 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.
- We are still hopeful results will be available for the next evaluation of the neutron cross section standards.

Nuclear Reaction Activities- Measurements

- A measurement is underway at NIST of the $^{235}U(n,f)$ cross section at 3.3 meV, using the same basic setup used for the $^{6}Li(n,t)$ cross section measurement.
  - A well characterized $^{235}U(n,f)$ sample was obtained. It has a well defined mass with a 1% uncertainty obtained by comparison with various samples.
    - Plans are underway to measure the mass by alpha counting to improve the accuracy of the mass of the $^{235}U(n,f)$ sample. It involves using the well known ^{234}U half life and the established $^{235}U/^{234}U$ atom ratio.
  - However the areal uniformity of the mass distribution is not known well.
    - Studies are underway on that distribution.
  - Initial data were obtained but more data are required. Final data should provide about a percent uncertainty. Progress has stopped since the reactor is now running at 5% of normal power.
  - 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) cross section measurements at about 25 meV (No Maxwellian Data used)

Author	Date	CS (b)	DCS (b)	Reference
Saplakoglu	1959	593.17	13	*2nd Geneva Conf.**4**, 157*
Raffle	1959	581.97	18	*AERE/R-2998*
Deruytter	1961	589.73	8	*J. Nucl. Energy **15**, 165*
Maslin	1965	583.71	8	*Phys. Rev. **139**, 852*
NIST	~2025		~ *6*	(at 3.3 meV)
ENDF/B-VIII		587.29		

The Neutron Cross Section Standards

Reaction	Energy Range
H(n,n)	1 keV to 20 MeV
^{3}He(n,p)	0.0253 eV to 50 keV
^{6}Li(n,t)	0.0253 eV to 1 MeV
^{10}B(n,α)	0.0253 eV to 1 MeV
^{10}B(n,$\alpha_1\gamma$)	0.0253 eV to 1 MeV
C(n,n)	10 eV to 1.8 MeV
Au(n,γ)	0.0253 eV, 0.2 to 2.5 MeV, 30 keV MACS
^{235}U(n,f)	0.0253 eV, 7.8-11 eV, 0.15 MeV to 200 MeV
^{238}U(n,f)	2 MeV to 200 MeV

Our direct involvement in measurements at NIST, Ohio University, LANL and ORNL are now concluded. We now encourage and motivate measurements that will have an impact on the standards

CSNS Measurements Encouraged by NIST

- The measurements at the Chinese Spallation Neutron Source have been published
- Light element standards
  - work by Jiang, *et al*. on the hydrogen angular distribution from 6-52 MeV
  - Data on the ^{6}Li(n,t) angular distribution by Bai *et al*. for energies up to 3 MeV
  - Angular distribution data obtained by Jiang *et al.* for the boron standards from 1 eV to 2.5 MeV
  - Ratios of the ^{10}B(n, α)^{7}Li reaction to the ^{6}Li(n, t)^{4}He reaction by Liu *et al*. to several MeV
- Fission Data
  - The ^{235}U(n,f) and ^{238}U(n,f) cross sections relative to n-p scattering by Chen *et al* from 10 to 66 MeV
  - The ^{238}U(n,f)/^{235}U(n,f) cross section ratio by Wen, *et al*. from 1 to 20 MeV.

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- Measurements

Nubar Measurement

- Work done with the PROSPECT study that led to a measurement of nubar for ^{252}Cf.
- The measurement was made with a large bank of ^{6}Li loaded liquid scintillation detectors. There were 154 individual segments (detectors) with a total of 4 tons of ^{6}Li.
- There is high efficiency for neutron detection, about 70%. The understanding of neutron detector efficiency is being studied thoroughly to hopefully reduce the uncertainty in the absolute measurement that was previously large (2.2%).
- NIST is a collaborator in this work. The PROSPECT experiment is headed by Hansell.

Nuclear Reaction Activities: - Evaluations

- Worked with a collaboration re-evaluating the prompt fission neutron spectrum of spontaneously fission ^{252}Cf
- 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 the groups at the China Spallation Neutron Source (CSNS) using the back-streaming white neutron source (Back-n WNS) has led to major sources of neutron standards data.

Nuclear Reaction Activities: - Evaluations

- Attended the virtual ND2022 conference
  - Gave a paper on the **status of the experimental database for the new evaluation of the neutron standards.**
  - The paper has data that is a starting point for that needed for the new evaluation of the neutron standards.

Nuclear Reaction Activities: - Evaluations

- Attended the recent Covariance Workshop and chaired a session
- Co-authored a paper on **Experimental spectrum average cross sections in ^{252}Cf(sf) neutron field and its impact on evaluation of neutron standards**
  - This work investigates differences between different groups on the determination of these important spectrum averaged cross sections that have a large impact on the normalization of the standards.
  - A new Python based code was written by Schnabel (GMA-py) so ratios of spectrum averaged cross sections in the ^{252}Cf(sf) neutron field can now be used in standard cross section determinations.

Nuclear Reaction Activities: - Evaluations

A hybrid IAEA standards meeting was held on Oct.9-13, 2023 in Vienna

- I chaired the meeting and gave a presentation on the only primary standard - hydrogen scattering.

BELOW IS FOR MEASUREMENT ACTIVITY ONLY

- Final results were given for CSNS work on ^{6}Li(n,t) and ^{10}B(n,α) cross sections
- ^{239}Pu(n,f)/^{235}U(n,f), ^{6}Li(n,t)/^{235}U(n,f) and ^{239}Pu(n,f)/^{6}Li(n,t) cross section ratio work by the NIFFTE collaboration were discussed
- Near final absolute measurements for the ^{235}U(n,f) cross section obtained at the n_TOF facility up to 450 MeV were presented.
- CSNS measurements of the ^{235}U(n,f) cross section relative to hydrogen scattering from 10 to 70 MeV were shown
- Carbon scattering angular distributions from 1 to 8 MeV made at GELINA in a CEA collaboration were given

Nuclear Reaction Activities: - Evaluations

- Attended the CSEWG meeting in 2023
  - Gave a paper on **Recent Standards Work**
  - Many of the measurements in this report will be used in the new evaluation of the neutron cross section standards

A hybrid IAEA standards meeting is planned for Jan. 2025 in Vienna

- This will be a very important meeting since the time scale for producing the next standards evaluation will be discussed.
- New results will be discussed including:
  - Final measurements of ^{239}Pu(n,f)/^{235}U(n,f) cross section ratio by the NIFFTE Collaboration
  - ^{13}C data of Vanhoy
  - New Carbon data of Gkatis at GELINA
  - Publication of n_TOF facility ^{235}U(n,f) cross section up to 450 MeV
  - Work by the NIFFTE Collaboration on the ^{239}Pu(n,f)/^{6}Li(n,t) and ^{235}U(n,f)/^{6}Li(n,t) cross section ratios that is slowly being done

Nuclear Reaction Activities: - Evaluations

- Co-authored several papers 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.
    - Introduction to Templates of Expected Measurement Uncertainties
    - Templates of Expected Measurement Uncertainties for Total Cross Section Observables
    - Templates of Expected Measurement Uncertainties for Average Prompt and Total Fission Neutron Multiplicities
    - Templates of Expected Measurement and Uncertainties for Capture and Charged-Particle Production Cross Section Observables

Nuclear Reaction Activities: - Program Involvement

- Member of the Program Committees of the 17th and 18th International Symposium on Reactor Dosimetry (ISRD-17, 18). Due to covid, ISRD-17 was held in 2023 in Lausanne Switzerland and the ISRD-18 will be in the USA in 2025.
- Member of the International Program Committee of the 15th International Conference on Nuclear Data for Science and Technology.
- Member of the International Advisory Board for the 5th International Workshop on Nuclear Data Covariances.

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 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 3.3 meV with high accuracy.

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