National Institute of Standards and Technology

Nuclear Data Verification and Standardization Program

PROGRESS REPORT

USNDP Meeting
Brookhaven National Laboratory
November 18, 2013

THE NEUTRON CROSS SECTION STANDARDS

Reaction	Energy Range
H(n,n)	1 keV to 20 MeV
^{3}He(n,p)	thermal to 50 keV
^{6}Li(n,t)	thermal to 1 MeV
^{10}B(n,α)	thermal to 1 MeV
^{10}B(n,α$_1$γ)	thermal to 1 MeV
C(n,n)	thermal to 1.8 MeV
^{197}Au(n,γ)	thermal, 0.2 to 2.5 MeV
^{235}U(n,f)	thermal, 0.15 to 200 MeV
^{238}U(n,f)	2 to 200 MeV

Nuclear Structure Activities:

- None are supported by DOE funding.

- A modest effort, largely experimental, (about 1 FTE) in structure and decay studies is supported by NIST. The effort is in support of needs for radioactivity and radiopharmaceutical applications.

- **Nuclear Reaction Activities: Neutron Cross Section Standards – Measurements**

  - **H(n,n)H Angular Distribution Work**

    - This work was initiated to resolve problems with the hydrogen database used for the ENDF/B-VI hydrogen evaluation. We previously made measurements at 10 and 14.9 MeV at the Ohio University accelerator facility. The data were obtained by detecting the recoil proton.

(collaboration of NIST, Ohio University, LANL and the University of Guelma)

H(n,n)H Angular Distribution Work (cont.)

- At small CMS scattering angles it is difficult to obtain small uncertainties for data obtained by detecting the recoil proton.

- There is only one experiment where measurements were made at very small scattering angles. Those data have very large uncertainties with large scatter.

- We started an experiment where the primary objective is detection of the scattered neutron instead of the scattered proton so that measurements can be made at small scattering angles.

- The work is being done at the Ohio University accelerator facility. Preliminary data with limited uncertainty were obtained at laboratory neutron scattering angles from 20 degrees to 65 degrees in 5 degree steps for 14.9 MeV incident neutrons.

- To reduce the uncertainties and make measurements at smaller angles, it is essential to accurately determine the efficiency of the neutron detector.

(collaboration of NIST, Ohio University, LANL and the University of Guelma)

H(n,n)H Angular Distribution Work (cont.)

- For neutron energies above 6 MeV, a technique using reactions where the projectile and target are identical is being studied. Because they are identical, the angular distribution **must** be symmetrical in the CMS. So the neutron yield at an angle Θ must be the same as that at 180- Θ in the CMS. But the energies of the neutrons are different in the LAB system. Thus in the LAB system, for a bombarding energy such that the backward portion of the angular distribution falls in the energy range below 6 MeV where the efficiencies are well known, we can deduce the efficiency for the higher energy group in the forward hemisphere.

- Our study indicated that the $^{6}Li(^{6}Li,n)^{11}C$ reaction would be the best for our use, however for the targets we successfully made, ^{6}LiF and $^{6}LiCl$, the backgrounds were very large. Measurements with C(C,n) were successful however the Q value of -2.6 MeV is a limitation. Targets are being made for a D(d,n) source. The Q value of 3.3 MeV will allow data to be taken at small angles for 10 MeV neutrons. Going to 14.9 MeV will require further study.

(collaboration of NIST, Ohio University, LANL and the University of Guelma)

Nuclear Reaction Activities: Neutron Cross Section Standards–Measurements

^{6}Li(n,t) Work

➢At the NCNR measurements have been completed of the ^{6}Li(n,t) cross section standard at ~ 4 meV neutron energy. These are the first direct and absolute measurements of this cross section in this neutron energy range using monoenergetic neutrons. A primary effort has been focused on measuring the neutron fluence accurately. That has now been determined with an uncertainty of less than 0.05%.

➢Work continues on determining mass uncertainty of the ^{6}Li target. The present mass uncertainty is about 0.25%. The deposits were made at IRMM. Studies have been made to compare the mass with the value obtained when it was characterized a number of years ago. Comparisons have also been made with a number of other deposits made at the same time at IRMM. It is expected that an ultimate total uncertainty less than 0.3% for the cross section can be obtained from this experiment.

(collaboration with the University of Tennessee and Tulane University)

Nuclear Reaction Activities: Neutron Cross Section Standards –Fluence Data

Fluence Determination Work

- Improvements in the determination of the source strength for NBS-I continue. This work will have an impact on cross section measurements that have used this source as a standard and any future measurements made using this source.

  - work continues on a determination of the neutron intensity of NBS-I for comparison with the established value obtained from manganese sulfate bath measurements and calculations. This work relies on an absolute determination of the fission rate of a bare ^{252}Cf source using a well-defined solid angle for detection. That rate is converted to neutron fluence using nu-bar of ^{252}Cf. Then the absolute neutron rate from that source can be compared with that of NBS-I by measurements of the activation produced in a $MnSO_4$ bath by the two sources. The new work is in principle only limited in accuracy by the uncertainty in nu-bar of ^{252}Cf, 0.12%. Preliminary results with a 0.9 % uncertainty have been obtained. Additional work is underway that should lead to a 0.3% uncertainty in the calibration.

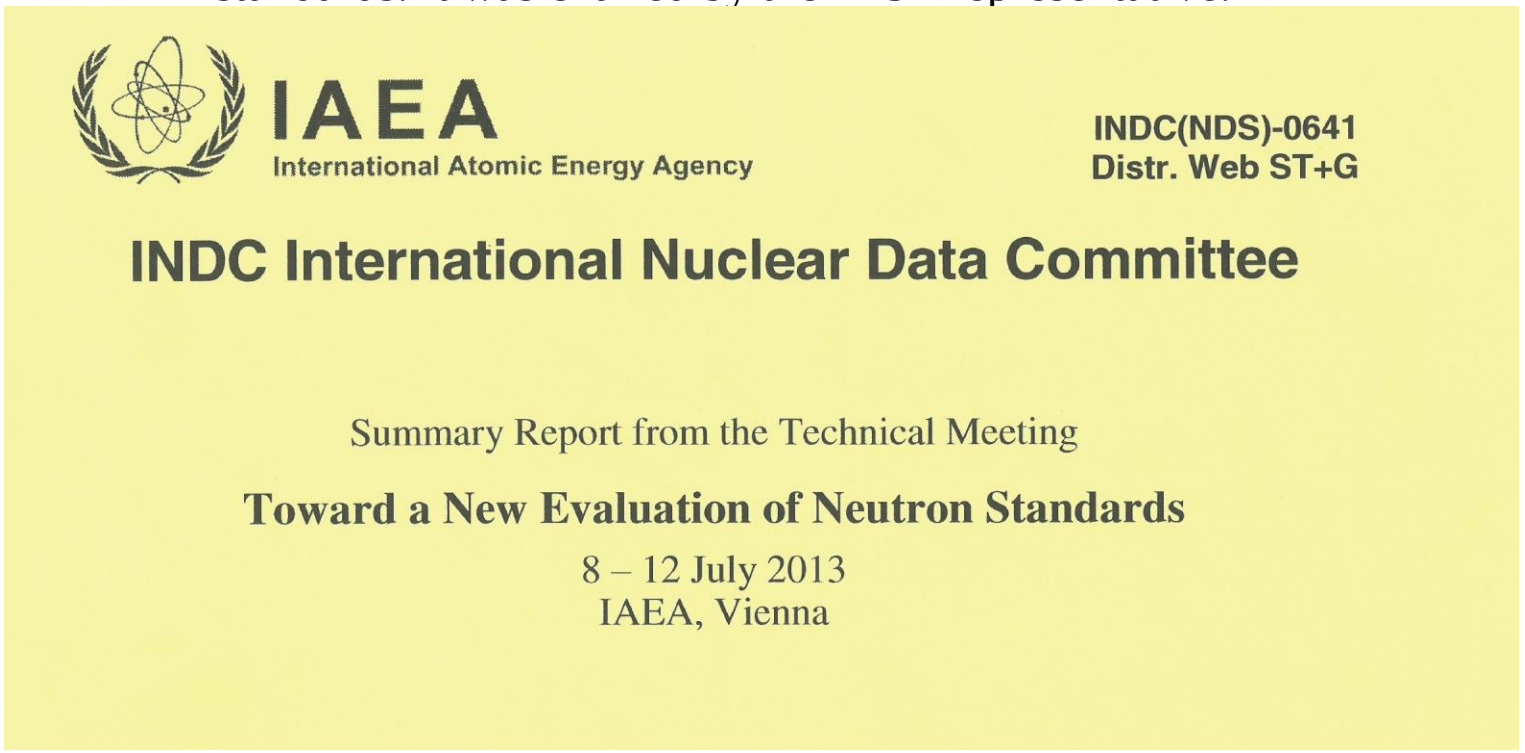
  - Work is planned in which NBS-I will be absolutely calibrated using a technique employing an α-γ coincidence with the $^{10}B(n,\alpha_1\gamma)$ reaction.

Nuclear Reaction Activities: Neutron Cross Section Standards

- Improvements continue to be made to the experimental data in the standards database as a result of NIST involvement or encouragement

Nuclear Reaction Activities: Neutron Cross Section Standards –Evaluations

- At the last CSEWG meeting the decision was made to have a new ENDF/B evaluation.
  - It is necessary to evaluate the standards before such an evaluation can be undertaken.
  - An IAEA Technical Meeting was scheduled for July to work on the standards. It was chaired by the NIST representative.



IAEA
International Atomic Energy Agency

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INDC International Nuclear Data Committee

Summary Report from the Technical Meeting

Toward a New Evaluation of Neutron Standards

8 – 12 July 2013
IAEA, Vienna

Nuclear Reaction Activities: Neutron Cross Section Standards –Evaluations

- This Technical Meeting resulted from an IAEA Nuclear Data Development Project "Maintenance of the Neutron Cross Section Standards" that was initiated through NIST efforts. A report of the activities at the meeting with all the contributions of the participants is available at http://www-nds.iaea.org/publications/indc/indc-nds-0641.pdf

- There were previous meetings of this project with the focus on improvements in the experimental database, considering additional standards and maintaining evaluation codes. It will now be used for updating the standards for ENDF/B-VIII. Other libraries are also preparing for new versions and they will be able to use the results of our efforts.

Nuclear Reaction Activities: Neutron Cross Section Standards –Evaluations

- Updating of the standards database.
  - At the meeting all experiments completed or underway since the completion of the standards evaluation were reviewed.
  - Most of the experimental data are available for the evaluation. Efforts are underway to get the remaining data for the evaluation.
  - Improvements have been made for the H(n,n), ^{6}Li(n,t), ^{10}B(n,α), Au(n,γ), and ^{238}U(n,γ) cross sections.
  - There are some inconsistencies for the ^{3}He(n,p), C(n,n), ^{238}U(n,f) and ^{239}Pu(n,f) cross sections

Nuclear Reaction Activities: Neutron Cross Section Standards –Evaluations

- Neutron spectra

  - No new measurements have been made of the ^{252}Cf spontaneous fission neutron spectrum. There are new measurements of the $^{235}U(n_{th},f)$ neutron spectrum made by Kornilov (Hambsch) et al. and Vorobyev et al.

  - The most recent measurements of the $^{235}U(n_{th},f)$ neutron spectrum have been made with a ^{252}Cf source located outside the beam. Thus ratio measurements of these spectra were obtained.

  - A combined non-model evaluation of these two spectra will be done and the results compared for two approaches used in the project – the GMA analysis by Pronyaev and a Bayesian analysis by Mannhart.

Nuclear Reaction Activities: Neutron Cross Section Standards –Evaluations

- Reference cross sections for measurements of prompt gamma-ray production cross sections.
  - Many nuclides and reactions were considered
    - ^{nat}Ti with large yields of two gamma-lines, 984 keV from ^{48}Ti(n,n'γ) and 160 keV from ^{48}Ti(n,2nγ) and ^{47}Ti(n,n'γ) reactions appears to be one of the most suitable for use as a reference cross section. More work needs to be done to improve the experimental database.
      - New measurements by Nelson using GEANIE have been made and are being analyzed.
      - An improved evaluation by Simakov has been done.
    - Li(n,n'γ) also appears to be a reasonable candidate
      - New measurements have been made by Nelson with GEANIE
      - There is little high quality data at higher neutron energies except the Nelson work

Nuclear Reaction Activities: Neutron Cross Section Standards –Evaluations

- Au(n,γ) reference cross section for capture cross section measurements for astrophysics (below the standards energy region).
  - Due to the evaluation process used for the standards evaluation, data for the Au(n,γ) cross section were obtained for energies below 200 keV.
  - These results are consistently higher than the Ratynski and Käppeler evaluation (by about 5-7% from 15 to 25 keV) which is used in astrophysics applications.
  - The Ratynski and Käppeler evaluation relies on Macklin capture data and Ratynski-Käppeler Karlsruhe pseudo-Maxwellian capture data whereas the standards evaluation uses a large database of various types of data.
  - New cross section data by Wallner et al., Lederer et al., Borella et al., Lampoudis et al. and Schillebeeckx et al. support the standards evaluation.
  - New measurements were made by Feinberg et al. that simulate the broad beam used in the Ratynski and Käppeler measurement. The 2 types of results agree well with the standards evaluation.
  - Based on these measurements it appears that the standards evaluation should be preferred over the Ratynski and Käppeler evaluation.

Other Work

- The NIST National Repository for Fissionable Isotope Mass Standards continues to acquire and monitor samples. A number of laboratories have borrowed samples from the Repository.

- NIST has members on the International Program Committee for the International Symposium on Radiation Dosimetry, ISRD-15 (2014). The members of the ISRD use cross section data to determine the fluence in reactor applications. The ENDF standards are part of the data used.

FY13 Metrics Table

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FY13 FTE Table

PhD Permanent (0.15)

PhD Temporary (0.4)

Recommendations

- Since there is a need for improved standards for the new ENDF/B evaluation, we are working with the IAEA Nuclear Data Development Project "Maintenance of the Neutron Cross Section Standards" to supply them. With that project we have been maintaining an active program of measurements and evaluation activities that are essential for improvement of the standards.

- We also maintain a modest experimental program and encourage work on the standards through collaborations and independent research.

- When the new standards evaluation has been completed, we will continue the activities being done under the IAEA Nuclear Data Development Project. This project will pursue improvements in the experimental database, consider additional standards, maintain evaluation codes and periodically update the standards so they are available for new versions of nuclear data libraries.