National Institute of Standards and Technology

Nuclear Data Verification and Standardization Program

PROGRESS REPORT

USNDP Meeting
Brookhaven National Laboratory
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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.
  - A paper published this year provided corrections to half-lives measured at NIST due to slippage of source positioning.
  - Work on uncertainty analysis using Monte Carlo techniques for reaction-rate calculations in stellar environments was published.

•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 were obtained at laboratory neutron scattering angles from 20 degrees to 65 degrees in 5 degree steps for 14.9 MeV incident neutrons. The plan is to extend the range so that data are obtained from 15 to 70 degrees with higher accuracy.

•It is essential for these measurements 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 9 MeV, a technique using reactions where the projectile and target are identical is being used. 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 9 MeV where the efficiencies are well known, we can deduce the efficiency for the higher energy group in the forward hemisphere. Analysis of the measured counts at the appropriate angles can then give us the efficiency for the 14 MeV neutron energy range.

•Our study indicated that the $^{6}Li(^{6}Li,n)^{11}C$ reaction would be the best for our use, however for the only suitable targets we successfully made, ^{6}LiF and $^{6}LiCl$, the backgrounds were very large. Measurements with C(C,n) were successful. Additional work is planned with the D(d,n) and $^{13}C(^{13}C,n)$ reactions. This is an ongoing project.

(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%.

•The limitation on the accuracy of the ^{6}Li(n,t) cross section measurement is the 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)

^{10}B(n,α) Work

•The same experimental setup being used for the NIST collaborative measurements of the ^{6}Li(n,t) cross section at ~ 4 meV may be used to measure the ^{10}B(n,α) cross section also. Plans for making those measurements are being delayed while work is being done to investigate possible problems with losses of ^{10}B with evaporated deposits.

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.

•Additional work continues on an independent determination of the neutron intensity of NBS-I for comparison with the established value obtained from manganese sulfate bath measurements and calculations. The new work is in principle only limited in accuracy by the uncertainty in nu-bar of ^{252}Cf, 0.12%. Preliminary results indicate a 1.7 % difference with a 0.9 % uncertainty for this determination compared with the NBS-I value. It is expected that a 0.3% uncertainty in the calibration will be possible.

• 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 –Evaluations

•A special issue of Metrologia that is devoted to neutron metrology was recently published. We wrote the section on neutron cross section standards-their history, how they are measured, evaluated and used.

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

IAEA Consultants' Work

•In order to improve the standards on a continuing basis, an IAEA Nuclear Data Development Project "Maintenance of the Neutron Cross Section Standards" was initiated through NIST efforts.

- •This project has pursued improvements in the experimental database, considered additional standards, maintained evaluation codes and will periodically update the standards so they are available for new versions of data libraries.
- •Two Consultants' Meetings have been held for this Data Development Project. Both meetings were chaired by the NIST participant.

Recent Activities Related to the Data Development Project

- Updating of the standards database.
  - The experiments completed or underway since the completion of the standards evaluation were reviewed.
    - The experiments suggest improvements have been made for the H(n,n), Li(n,t), ^{10}B(n,α), Au(n,γ), and ^{238}U(n,γ) cross sections.
    - There are inconsistencies for the ^{3}He(n,p), C(n,n), ^{238}U(n,f) and ^{239}Pu(n,f) cross sections.

Recent Activities Related to the Data Development Project (cont.)

- 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.

Recent Activities Related to the Data Development Project (cont.)

•Neutron spectra (cont.)

- 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.

- For the standards evaluation the GMA code was used to properly evaluate ratio data. Then there was an impact on both quantities in the ratio.

  - It seemed reasonable to use the GMA code for a simultaneous evaluation of these two fission spectra. Initial efforts have been made on this evaluation including smoothing using a model. Work continues to improve the results.

Recent Activities Related to the Data Development Project (cont.)

- Reference cross sections for measurements of prompt gamma-ray production cross sections. (cont.)
  - 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

Recent Activities Related to the Data Development Project (cont.)

- 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 evaluation (by about 5-7% from 15 to 25 keV) which is used in astrophysics applications.
  - The Ratynski evaluation relies on Macklin capture data and Ratynski-Käppeler Karlsruhe pseudo-Maxwellian capture data.
  - The standards evaluation uses a large database of various types of data.
  - New data by Wallner et al., Lederer et al., Borella et al., Lampoudis et al. and Schillebeeckx et al. all support the standards evaluation.
  - New measurements were made by Feinberg et al. that simulate the broad beam used in the Ratynski et al. measurement. The 2 types of results were about 5% higher than the Ratynski evaluation and the Macklin measurements, thus agreeing well with the standards evaluation. However the difference is only about 2σ.

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 a member on the International Program Committee for the International Symposium on Radiation Dosimetry, ISRD-14 (2011). 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.

•NIST has a member on the International Program Committee for the International Conference on Nuclear Data for Science and Technology (ND2013)

Staff Data
(not including structure work of 1 FTE, entirely supported by NIST)

STAFF	FTE	HEADS	FTE (USNDP)
Permanent	0.3	1	0.15
Temporary	0.2	1	0
Professional			
Contractors	1.0	2	0.4
Total	1.5	4	0.55

Recommendations

•Though the international evaluation of the standards has been completed, maintaining an active program of measurements and evaluation activities is essential for improvement of the standards. We maintain a modest experimental program and encourage work on the standards through collaborations and independent research. Some of the evaluation activities are being done under the IAEA Nuclear Data Development Project "Maintenance of the Neutron Cross Section Standards". 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.