National Institute of Standards and Technology

Nuclear Data Verification and Standardization Program

PROGRESS REPORT

USNDP Meeting
Santa Fe, NM
November 3, 2010

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,$\alpha_1\gamma$)	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 supports NIST applications.

•Nuclear Reaction Activities: Neutron Cross Section Standards – Measurements

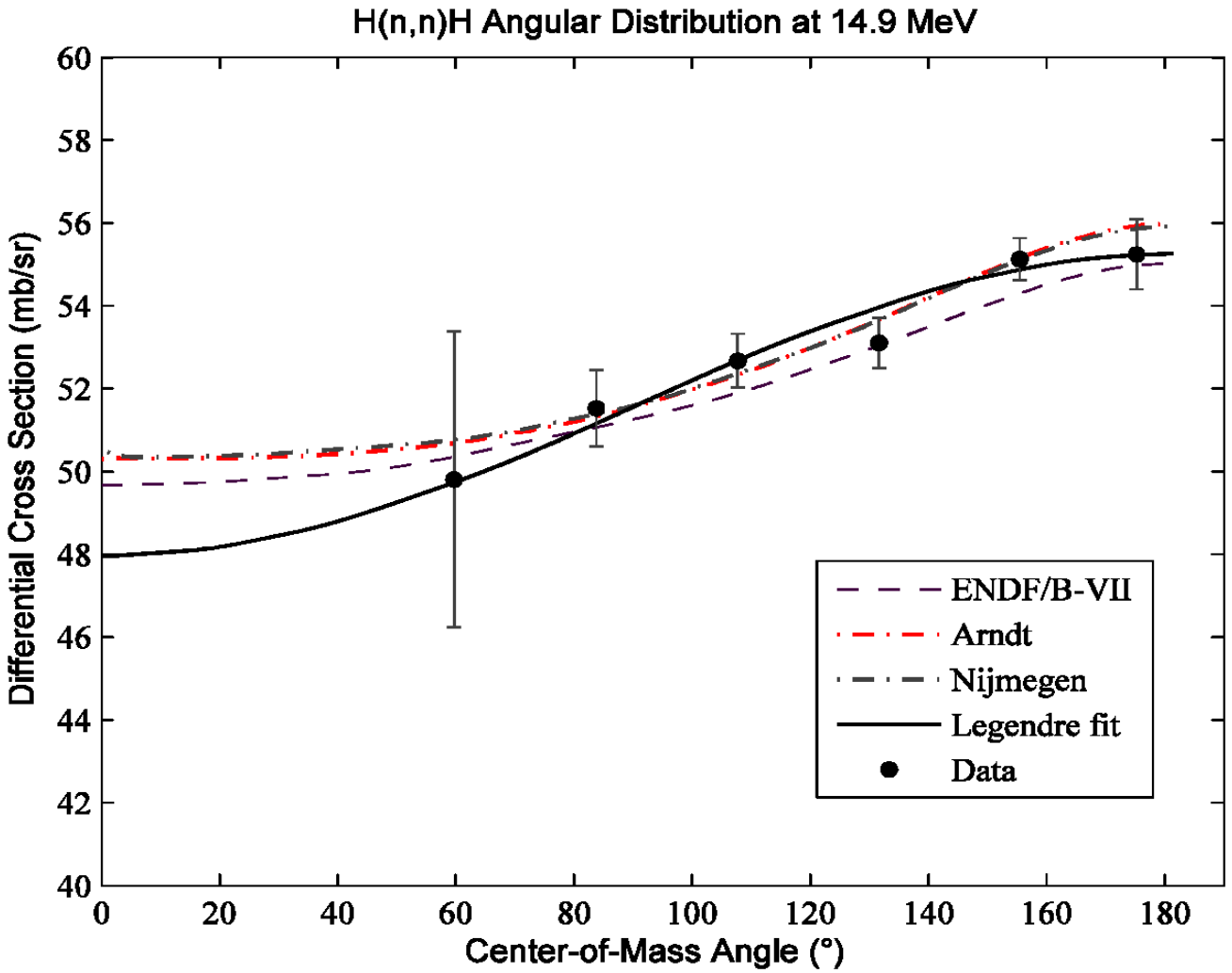
H(n,n)H Angular Distribution Work

• The measurements at 14.9 MeV were recently published in Phys. Rev. C. This work was initiated to resolve problems with the hydrogen database used for the ENDF/B-VI hydrogen evaluation. To improve that database, measurements were made at laboratory proton recoil angles of 0 degrees, ± 12 degrees (one on each side of the beam direction), ± 24 degrees, ± 36 degrees, ± 48 and ± 60 degrees at the Ohio University accelerator facility. The data were obtained by detecting the recoil proton.

•Also published in Phys. Rev C were improvements to our work at 10 MeV by including mean angles for the measurements and normalizing the data to the ENDF/B-VII hydrogen scattering cross section.

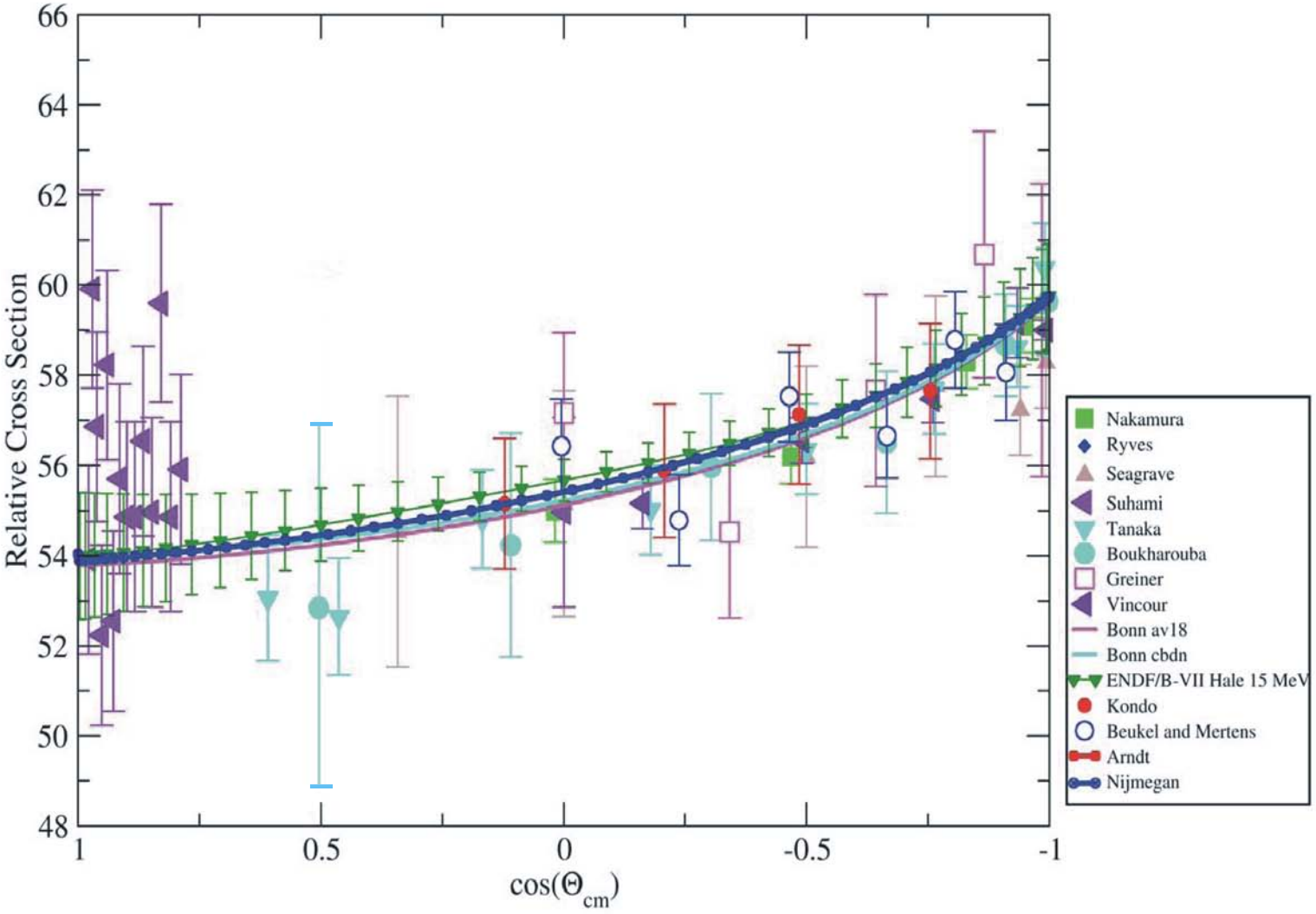
(collaboration of NIST, Ohio University, LANL and the University of Guelma)

Measurements by Boukharouba *et al.*(shown as Data) compared with Evaluations and Calculations (detecting recoil protons)



14 MeV Angular Distribution Data

Note problem near zero degrees



All data have been converted to 14 MeV

H(n,n)H Angular Distribution Work

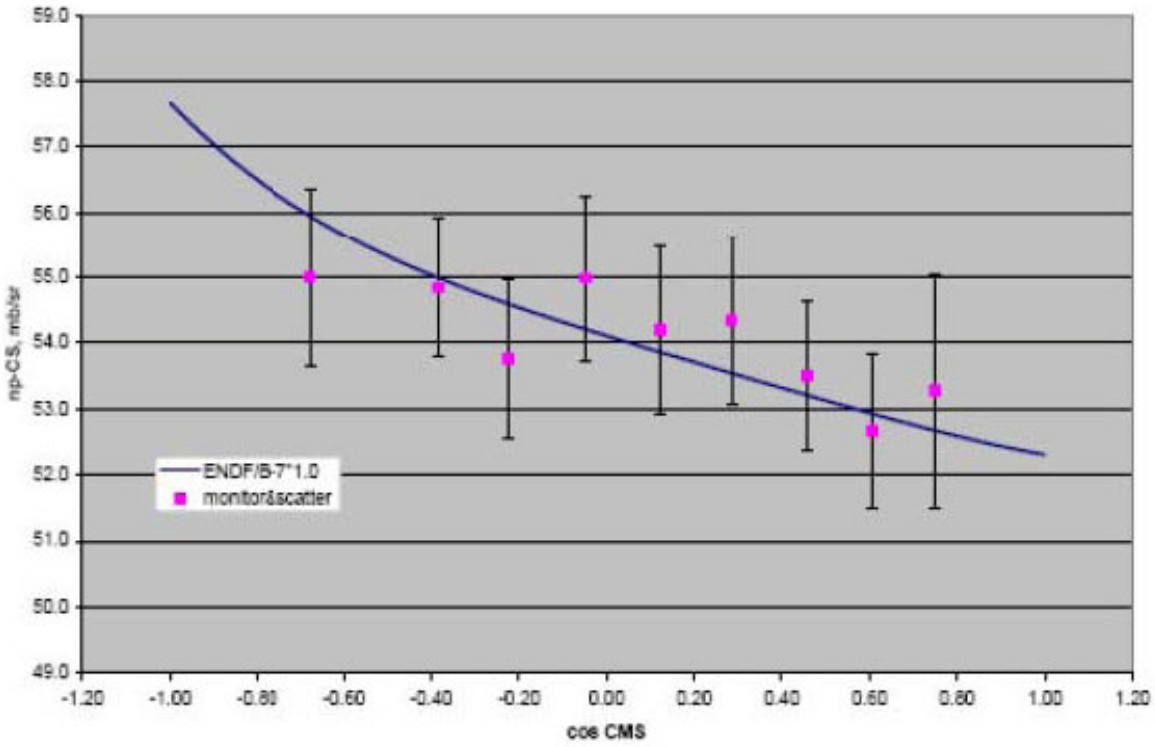
•In order to make measurements at smaller scattering angles an experiment has been started where the primary objective is detection of the scattered neutron instead of the scattered proton.

•The work is being done at the Ohio University accelerator facility. Measurements have been made at laboratory neutron scattering angles from 20 degrees to 65 degrees in 5 degree steps for 14.9 MeV incident neutrons but not at the desired accuracy. The plan is to extend the range so that data are obtained from 15 to 70 degrees. Then measurements will be made at 10 MeV incident neutron energy to help fill in the gap at small angles in the work done by this collaboration at 10 MeV.

Plans are being made to continue hydrogen angular distribution measurements using a Time Projection Chamber which will provide higher counting rates than are possible with the other methods.

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

Preliminary Data for the Ohio U. Experiment at 14.9 MeV (detecting recoil neutrons)



Average results from this work compared with the latest ENDF/B evaluation. The uncertainties shown are due to statistics only. The data are shape measurements and were normalized to the ENDF/B results.

Nuclear Reaction Activities: Neutron Cross Section Standards–Measurements

^{6}Li(n,t) Work

•Measurements are now underway 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 sections in this neutron energy range using monoenergetic neutrons. A primary effort has been focused on measuring the fluence accurately. The fluence (efficiency) has now been determined with an uncertainty of less than 0.1%. The solid angle uncertainty is about 0.1%.

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%. It is expected that a 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 basic experimental setup being used for the NIST collaborative measurements of the ^{6}Li(n,t) cross section at ~ 4 meV will be used to measure the ^{10}B(n,α) cross section also.

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.

Nuclear Reaction Activities: Neutron Cross Section Standards –Evaluations

• A comprehensive paper was published in Nuclear Data Sheets. This work documents the activities that led to the international evaluation of the neutron cross section standards. The standards and other evaluated data from this effort became ENDF/B-VII files. The paper is over 100 pages long and is one of two papers in the December issue of the journal.

• A section on neutron cross section standards is being written for a special edition of the journal Metrologia on Neutron Metrology. The section will discuss how the standards are measured, evaluated and used. It should be published next year.

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

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 2010 International Conference on Nuclear Data for Science and Technology. Also an invited talk was given at the conference, “An Update of the Nuclear Data Standards Activities”, which describes the activities of the Nuclear Data Development Project, “Maintenance of the Neutron Cross Section Standards”.

•NIST has two members on the International Program Committee for the International Symposium on Radiation Dosimetry, ISRD-14 (2011). A session on “nuclear data for dosimetry” and a workshop on “cross sections and nuclear data” are being organized by NIST.

Staff Data

- Scientific Permanent staff: 1, USNDP funded at 0.03 FTE
- Scientific Temporary staff : 1, USNDP funded at 0.15 FTE
- Retired: David Gilliam, left NIST in June, was USNDP funded at 0.02 FTE

IAEA Consultants' Meeting

•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 in response to a proposal written by NIST.

- •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 data libraries
- •The first meeting was held in October of 2008 and the second meeting was held in October 2010. Both meetings were chaired by the NIST participant.

Summary of the Second IAEA Consultants' Meeting (Oct. 2010) on the Nuclear Data Development Project "Maintenance of the Neutron Cross Section Standards".

The topics of the meeting were:

- Updating the standards experimental database.
- Update for an evaluation of the ^{252}Cf spontaneous fission neutron spectrum.
- Update for an evaluation of the ^{235}U(n_{th},f) neutron spectrum.
- Adding "Reference" cross section to our evaluation effort. These do not have the quality of the standards but they are convenient for certain applications.
    - Reference cross sections for measurements of prompt gamma-ray production cross sections.
    - Au(n,γ) reference cross section for capture cross section measurements for astrophysics (below the standards energy region).
- Use of models to smooth cross sections, spectra and covariances.

Summary of the Second IAEA Consultants' Meeting (Oct. 2010) on the Nuclear Data Development Project "Maintenance of the Neutron Cross Section Standards".

- 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.

Summary of the Second IAEA Consultants' Meeting (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.

•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 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. This was done and it included smoothing using a model. There were some problems with the preliminary results of the work. There was a critical review of the process with many helpful suggestions for the next calculations.

•An IAEA Coordinated Research Project (CRP) was recently initiated to provide new evaluations of prompt fission neutron spectra of major actinides including covariance matrices. The work of this CRP will be utilized in the present studies of fission neutron spectra that can be used for fluence determination.

Summary of the Second IAEA Consultants' Meeting (cont)

•Reference cross sections for measurements of prompt gamma-ray production cross sections.

- •Several candidates were investigated taking into account factors such as structure and magnitude of the cross section, status of the database, sample properties, and evaluations performed.
- •Considerable study was done on the Fe(n,n'γ) and Cr(n,n'γ) cross sections. They both suffer from background problems since iron and chromium are present in the materials near the experiment.
- •Other nuclides investigated were Nb, Au and Ti
  - •Nb - problems due to a long-lived isomer.
  - •Au - problems due to the gamma-ray close to strong background lines, also isomer present.
  - •Ti - appears to be the **most suitable**. It has better physical properties than Cr and is less abundant in shielding than Fe. However the database needs to be improved.

Summary of the Second IAEA Consultants' Meeting (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 the standards energy region (below200 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.
- •Three experiments were performed by the participants of the CM. **All three agree with the results of the standards evaluation.**
- •Käppeler will be investigating possible problems with his work though it appears to be an excellent experiment.

Summary of the Second IAEA Consultants' Meeting (cont)

- Developing a procedure to improve the smoothing process.
  - The objective is to remove non-physical fluctuations (statistical structure) and maintain real structure such as the cusps that occur from competition with inelastic scattering. In the standards evaluation, a 3-point smoothing was used. The present effort used statistical model calculations for the Au(n,γ) and ^{238}U(n,γ) cross sections as shape data, with high correlation between neighboring points, in the GMAP code. The procedure appears to have been successful. As noted previously work is also being done on spectra evaluations.
  - Future work may be done using a similar procedure for fission cross section evaluations.

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.