National Institute of Standards and Technology

Nuclear Data Verification and Standardization Program

PROGRESS REPORT

USNDP Meeting
November 6-7, 2003

Staff (total of about 0.6 FTE):
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NIST, independent of DOE funds, supplies almost half of the total support for the standards program. There is the equivalent of about 1 FTE working on the program.

Nuclear Structure Activities:
None are supported by DOE funding. A modest effort (1 FTE) in structure and decay studies is supported by NIST funds.

Nuclear Reaction Activities:
Neutron cross section standards
Introduction
Significant improvements have been made in the standard cross section database since the last complete evaluation of the neutron cross section standards, 16 years ago. The emphasis has been on the H(n,n), ^{10}B(n,α), and fission standards. Since the standards are the basis for the neutron reaction cross section libraries, it is important to reevaluate them taking into account new experimental data and improved evaluation techniques. In response to requests for improvements in the standards the CSEWG formed a Task Force, the WPEC formed a subgroup and the IAEA formed a Coordinated Research Project (CRP). NIST has maintained a leadership role in each of these groups. These groups are working cooperatively to improve the evaluation process.

The new evaluation will include the H(n,n), ^{3}He(n,p), ^{6}Li(n,t), ^{10}B(n,α), ^{10}B(n,$\alpha_1\gamma$), Au(n,γ), ^{235}U(n,f), and ^{238}U(n,f) standard cross sections. The energy region will be extended to ~200 MeV for some of the standards to provide new standards in this important energy region.

NIST has become an active participant in a number of experiments in order to effectively motivate and monitor standards experiments which are needed for the standards evaluation. This involvement includes measurements of the angular distribution of neutrons scattering from hydrogen which is one of the most important standards.

Progress on the evaluation
WPEC Standards Subgroup:
In order to assist in obtaining the international involvement needed for this evaluation, the WPEC formed a new Subgroup to promote international cooperation on the nuclear data standards. Its most important contribution has been the motivation of needed experimental work, especially on the ^{10}B cross sections. NIST has taken the lead role in encouraging, motivating and coordinating of new measurements that can

be used in the standards evaluation.

- NIST Chairs the WPEC Standards Subgroup
- Final results obtained by Giorginis and Khriachkov that were recommended by NIST on the $^{10}B(n,\alpha)$ cross sections.
- NIST determined that problems existed for the measurements by Guohui Zhang et al. of the $^{10}B(n,\alpha)$ cross sections. Under examination they have been withdrawn by the authors. They plan to redo the measurements in the Spring of 2004.
- At the suggestion of NIST, Nolte et al. have made measurements at 14 and 19 MeV of the $^{235}U(n,f)$ cross section and the $^{238}U(n,f)/^{235}U(n,f)$ cross section ratio.
- Preliminary results are now available for the important hydrogen scattering cross section at 200 MeV. The post doc working on that analysis will be coming to NIST.

Investigation of possible experiments for inclusion in the standards database:
Work continues on the encouraging, motivating and coordinating of measurements that can be used in the evaluation. Studies of possible experiments for the standards database continues. For each experiment a process is followed that includes checking the documentation for corrections that may need to be made and looking for possible errors or missing information. Poor documentation is a very frequent problem. The investigative procedure can lead to improved estimates of the uncertainties within an experiment and correlations with other experiments. This information is used to assist in forming covariance matrices for the measurements so that a proper analysis can be performed for the evaluation. Also corrections to new or old experiments will be incorporated in the experimental results. Recently documentation was received from Poenitz containing corrections and comments concerning experiments used for the GMA database in the ENDF/B-VI standards evaluation. Some effort has been and will be spent looking at that documentation.

- Table 1 lists standards related experiments which are under investigation. Only experiments for which data have been obtained or measurements are underway (or nearly started) are listed.

IAEA CRP Activities:
The CRP on the improvement of the standard cross sections has held two Research Coordination Meetings (RCM). The second one was held at NIST October 13-17, 2003. The CRP has included membership from Austria, Belgium, China, Germany, Japan, the Republic of Korea, Russia and the USA. The main objectives of the CRP are the following: Improve the methodology for determination of the covariance matrix used in cross section evaluations; Upgrade the computer codes using this methodology; Study the reasons for uncertainty reduction in R-matrix and model independent fits; Evaluate cross sections and covariance matrices for the light elements, H(n,n), $^{3}He(n,p)$, $^{6}Li(n,t)$, $^{10}B(n,\alpha_1\gamma)$, and $^{10}B(n,\alpha)$; Establish the methodology and computer codes for combining the light element with the heavy element evaluations leading to a final evaluation of the neutron cross section standards.

The initial efforts of the CRP have led to many results, though much of this work is preliminary and ongoing. The work includes: Improvement to the experimental data in the standards database; R-matrix evaluations of the hydrogen scattering cross section, the $^{6}Li(n,t)$ cross section and the $^{10}B(n,\alpha_1\gamma)$, and $^{10}B(n,\alpha)$ cross sections; Work on microscopic calculations leading to independent determinations of R-matrix poles; Generalized least squares evaluations for the ^{6}Li(n,t), ^{10}B(n,α), ^{10}B(n,$\alpha_1\gamma$), Au(n,γ), ^{235}U(n,f), and ^{238}U(n,f) standard cross sections; Combining of R-matrix and generalized least squares evaluations; Studies of the effect of Peelle's Pertinent Puzzle (PPP) and its effect on the standards evaluation; Studies of the small uncertainties resulting from evaluations; Comparisons of R-matrix and model independent least squares codes for values of the cross sections and covariances produced; Methods for handling discrepant data; methods for smoothing evaluated data; Effects of experimental resolution on evaluated results. The RCM's were chaired by the NIST representative.

- Wrote (with V. Pronyaev and G. Hale) the first RCM summary report
- Chairing CRP
- Worked on improvement of database
- Worked on resolution of discrepant data problems
- Planning and Preparations for second RCM at NIST
- Coordinated CRP effort (with V. Pronyaev)

Planning a standards meeting at ND2004:

- A side meeting is planned in conjunction with the ND2004 conference to discuss the details of the standards evaluation.

Experimental and other work:

- Hydrogen scattering angular distribution measurements at 15 MeV neutron energy are underway. (collaboration with Ohio University and LANL)
- The NIST National Repository for Fissionable Isotope Mass Standards continues to acquire and monitor samples.
- Work was done for the 11th International Symposium on Reactor Dosimetry as a member of the Program Committee.
- Improvements continue on a measurement of the ^{6}Li(n,t) cross section standard at ~ 4 meV neutron energy.

Dissemination:

- An invited talk (and subsequent paper) on database studies for the international evaluation of the standards was given at the 11th International Symposium on Reactor Dosimetry.

Table 1. New Experiments for the Standards Database

[++] means the data have been reviewed and are in the library
[+]means the data are available and the review process is underway
no superscript means that final data are not available

H(n,n)

[++]Nakamura, J. Phys. Soc. Japan 15 (1960) 1359, 14.1 MeV; error in transformation from laboratory to CMS angles; needs correction for proton scattering, an estimate of error associated with neglecting these corrections was made; tail problems; note Table II uncertainty is statistical only (mb/sr).

[++]Shirato, J. Phys. Soc. Japan 36 (1974) 331, 14.1 MeV, needs correction for proton scattering; tail problems.

[+]Ryves, 14.5 MeV, $\sigma(180°)/\sigma(90°)$, Ann. Nucl. Energy 17, 657 (1990).

[++]Buerkle, 14.1 MeV, angular distribution from 89.7° to 155.7°, Few-Body Systems 22, 11 (1997). The angular range is too limited.

[++]Boukharouba, Phys Rev C 65, 014004, 10 MeV, angular distribution from 60° to 180°, additional work planned for 15 MeV.

Uppsala data:
[+]Rönnqvist, Phys Rev C45, R496 (1992), 96 MeV angular distribution from 116° to 180°
[+]Rahm, Phys. Rev. C57, 1077 (1998) 162 MeV, angular distribution from 72° to 180°,

[+]Benck, (Louvain la Neuve), Nucl. Phys. A615, 222 (1997) and Proc. Conf. on NDST, Trieste (1997) p.1265, 28-75 MeV, angular distribution from 40° to 140°. Angular range is too limited.

Vigdor (IUCF) 185-200 MeV, angular distribution from 90° to 180°. Data have been obtained. Sarsour is analyzing the data and has preliminary data at 200 MeV, Private Comm.

^{3}He(n,p)

[++]Borzakov, 0.26 keV to 142 keV, relative to ^{6}Li(n,t), Sov. J. Nucl. Phys. 35, 307 (1982). OK

^{3}He total cross section

[++]Keith, 0.1 to 500 eV, BAPS DNP Oct 1997 paper IG.03 and thesis of D. Rich, U of Indiana. OK.

^{6}Li(n,t)

[+]NIST collaboration, thermal measurement with high accuracy using cryogenic calorimeter, Private Comm. OK

[++]Knitter, (1983) NS&E 83, 229; ^{6}Li(n,t)^{4}He angular distribution, 0.035-325 keV, new corrections required for particle leaking effect. Giorginis is investigating

++Drosg, 0.50 MeV to 4.1 MeV, NIM B94, p.319 (1994), using concept based on the two groups from the source reaction. Set 1011. OK

Bartle, 2 to 14 MeV, angular distribution, Proc. Conf on Nuclear Data for Basic and Applied Science, Sante Fe (1985), p. 1337 (questionable value, due to energy range and information not available).

Schwarz, 1 to 600 keV, NP 63, p.593, some based on hydrogen scattering cross section. Assumptions need study!

Koehler, 1 keV to 2.5 MeV, angular distribution data (ratio of forward and backward hemispheres responses), private comm.

Yu Gledenov, .025 eV, 87KIEV 2 237 (1988) no data given

+Guohui Zhang, 3.67 and 4.42 MeV, angular distribution, Comm. Of Nuclear Data Progress No.21 (1999) China Nuclear Data Center, also NSE 134, 312 (2000). Also 1.85 MeV and 2.67 MeV, NSE 143, 86 (2003). Has “particle leaking” effect.

^{10}B(n,$\alpha_1\gamma$)

Maerten, 320 keV to 2.8 MeV, GELINA linac, relative to ^{235}U(n,f) and carbon standards, private comm. from H. Weigmann. Not enough information on uncertainties is available.

++Schrack, 0.2 MeV to 4 MeV, shape data relative to Black Detector (at ORNL), NSE 114, 352 (1993). Set 113. OK

+Schrack, 10 keV to 1 MeV, shape data relative to H(n,n) prop ctr (at ORNL), Proc. Conf. on NDST, Gatlinburg (1994)p. 43. Set 1034 OK

+Schrack, .3 MeV to 10 MeV, relative to ^{235}U(n,f) ion chamber (at LANL), Private comm. Set 1033 OK

^{10}B(n,α) Branching Ratio

++Weston, 0.02 MeV to 1 MeV, Solid State detectors, NSE 109, 113 (1991). Set 1024. May have systematic errors.

++Hambsch and Bax, ND2001, 0.04 MeV to 1.0 MeV, Frisch gridded ion chamber, in progress. Set 1015. Background problems

^{10}B(n,α)

Haight, 1 MeV to 6 MeV, angular distribution at 30°, 60°, 90° and 135°, private comm.

Hambsch and Bax, ND2001, keV to MeV, angular distribution, Frisch gridded ion chamber, in progress.

Giorginis and Khriachkov, MeV energies, angular distribution, VdG data. The integrated cross sections are available. Private communication (2003). OK

+Guohui Zhang, 4.17, 5.02, 5.74, 6.52 MeV angular distribution, submitted for publication to NSE. Problems with particle leaking.

^{10}B total cross section
$^{+}$Wasson, 0.02 MeV to 20 MeV, NE-110 detector, Proc. Conf. on NDST, Gatlinburg (1994), p. 50. OK

Wattecamps, Van de Graaff, 1 to 18 MeV, large statistical uncertainty, NE-213 detector, Proc. Conf. on NDST, Gatlinburg (1994), p. 47. OK

Plompen, Van de Graaff, 0.3 MeV to 1.9 MeV, NE-213 detector, 3 independent monitors, Proc. Conf. on NDST, Trieste (1997), p. 1283. OK

Brusegan, Linac data, 80 eV to 730 keV, Li-glass detector, Proc. Conf. on NDST, Gatlinburg (1994)p. 47, Proc. Conf. on NDST, Trieste (1997)p. 1283 and private comm. OK

^{10}Be(p,n) ^{10}B
Massey, E_p from 1.5 MeV to 4 MeV, data at 0°, private comm. New measurements to be made at lower energies (~.5 MeV). Also possibly ^{10}Be (p,α). No final data.

C total cross section
$^{+}$Schmiedmayer and M. C. Moxon, Proc. Conf. Nuclear Data for Science and Technology Mito, Japan, May 30 June 3, 1988, p. 165, 50 eV to 100 keV, linac, excellent agreement with ENDF/B-VI.

$^{+}$Kirilyuk, *et al.*, Proc. of the Int. Conf. on Neutron Physics, Kiev, 1987, vol. 2, p. 298, filtered beam measurement at 2 keV,very good agreement with ENDF/B-VI.

Au(n,γ)
$^{+}$Yamamoto, thermal, linac, NEANDC(J)-155,59,9008, 1990. Little impact due to high accuracy of evaluated cross section.

$^{++}$Tolstikov, 0.49 to 0.69 MeV, Van de Graaff, relative to ^{235}U(n,f), Yad Konstanty,4, 46 (1994). Set 1020. OK.

$^{++}$Sakamoto, 23 keV and 967 keV, photoneutron source, activation experiment, NSE 109,215 (1991). Set 452. May have systematic error.

$^{++}$Davletshin, .16 MeV to 1.1 MeV, relative to H(n,n), Sov. J. At. Energy 65, 91 (1988), (Corrected data from Sov. J. At. Energ. 58, 183 (1985)). Two sets 347 & 348. OK

$^{++}$Davletshin, .62 MeV to .78 MeV, relative to ^{235}U(n,f), Sov. J. At. Energy 65, 91 (1988). Set 349. OK

$^{++}$Davletshin, .813 MeV to 2.435 MeV, relative to ^{235}U(n,f) YK,(1), 41 (1992). Set 1018. OK

$^{++}$Davletshin, .37 MeV to 1.0 MeV, relative to ^{235}U(n,f),   YK,(1), 13 (1993). Set 1019 OK

$^{++}$Kazakov, Yad Konstanty, 44, 85 (1985); AE,64,(2),152,1988, Van de Graaff, relative to ^{6}Li(n,t) .0035 to .105 MeV. Set 1021. OK

$^{++}$Kazakov, Yad Konstanty, 44, 85 (1985); AE,64,(2),152,1988, Van de Graaff, relative to $^{10}B(n,\alpha_1)$ .115 to .41 MeV set 1022. May have systematic errors

$^{+}$Demekhin, 2.7 MeV, Proc. 36th All Union Conf. on Nuclear Data, p. 94 (1986). No data

$^{++}$Voignier, ~.5 MeV to ~3 MeV, NSE, 93, 43 (1986), long counter, capture gamma spectrometer, private comm. Set 1016. OK

^{235}U(n,f)

$^{++}$Carlson, 2 MeV to 30 MeV, relative to H(n,n), Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, "U", p. 165. Set 524 OK

$^{++}$Merla, $^{+}$2.6, $^{+}$4.45, $^{+}$8.46, $^{+}$14.7, $^{+}$18.8 MeV ?, associated particle, Proc. Conf. on NDST Juelich (1991) p.510. Sets 591, 590, 592, 593, 587. OK

$^{++}$Lisowski, 3 MeV to 200 MeV, relative to H(n,n), Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, "U", p. 177, and private communication. Set 1028 OK

$^{+}$Nolte, 14 to 150 MeV, ND2001, and Private Comm. to increase energy range, Preliminary data. Concerns about 96 MeV point. Additional work underway

$^{++}$Buleeva, 0.624 MeV to 0.785 MeV, relative to H(n,n), Sov. J. Atomic Energy 65, 930 (1988). Set 522. OK

Grundl comment, ^{252}Cf spontaneous fission spectrum averaged cross section. NOTE; only the last NIST measurement (Schroder) should be used in the evaluation. The earlier data are improved upon with each new measurement.

$^{++}$Kalinin, 1.88 MeV, 2.37 MeV CCW, associated particle, Sov. J. Atomic Energy 71,(2),181,1988 Set 1026 OK

$^{++}$Carlson, 0.3 MeV to 3 MeV, absolute fluence from black detector, Proc. IAEA Advisory Group Meeting on Nuclear Standard Reference Data, Geel Belgium, p.163, IAEA-TECDOC-335 (1985). Set 523. OK

$^{++}$Johnson, 1 MeV to 6 MeV, absolute fluence from a dual thin scintillator, Proc. Conf. on NDST Mito (1988) p.1037. Set 1025 OK

$^{++}$Iwasaki, 14 MeV (13.5 to 14.9 MeV), relative to H(n,n) and associated particle, Proc. Conf. on NDST Mito (1988) p. 87. Set 1027 OK

$^{++}$Weston and Todd, NSE 111, 415 (1992), relative to $^{10}B(n,\alpha)$, 0.15 keV to 1.5 keV. Set 1023 OK

^{238}U(n,f)

$^{++}$Merla, 5 MeV +, associated particle, Proc. Conf. on NDST Juelich (1991) p.510. Set 810. OK

$^{++}$Winkler, 14.5 MeV, relative to $Al(n,\alpha)$ & $^{56}Fe(n,p)$, Proc. Conf. on NDST Juelich (1991), p.514. Set 809. OK

$^{++}$Lisowski, 0.8 MeV to 357 MeV, relative to H(n,n), Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, "U", p. 177, and private communication. Set 1030. OK, possible problems at highest energies compared with Shcherbakov

$^{+}$Nolte, 14 to 150 MeV, ND2001, and Private Comm. to increase energy range, Preliminary data. Concerns about data from 30 MeV to 100 MeV

$^{+}$Newhauser, 34, 46, and 61 MeV MeV, absolute, Proc. Conf. on NDST Juelich (1991), *removed from database.*

$^{+}$Meadows, 14.74 MeV, CCW, ANE,15,421 (1988), relative to ^{235}U(n,f).

$^{++}$Baba, 4.6 MeV to 6 MeV, Van de Graaff relative to ^{235}U(n,f), J. Nucl. Sci. & Techn.,26,11 (1989). Set 1035

$^{++}$Shcherbakov, 1-196 MeV, relative to ^{235}U(n.f), ISTC 609-97, see also Fomichev, 0.7 MeV to 200 MeV, relative to ^{235}U(n.f), Proc. Conf. on NDST, Trieste (1997), p.1283, also ND2001 set 1013. OK except possibly at the highest energies (incosistent with Lisowski there)

$^{+}$Li Jingwen, 14.7 MeV, CCW, ratio to ^{235}U(n,f) CNP,11,(3),17,89.

Eismont, Trieste conf, p.494, 33.7, 46 and 60.6 MeV, relative to hydrogen scattering cross section. See also Gatlinburg conference results at 135 and 160 MeV. Data not finalized. They have concerns about neutron fluence determination for getting smaller uncertainty.

$^{+}$Garlea, 14.7 MeV, relative to ^{235}U(n,f) cross section, RRP,37,(1),19,92.

^{238}U(n,γ)

$^{+}$Corvi. Thermal range, linac, Mito conf (1988).

$^{+}$Macklin, linac, 1 to 100 keV, ANE,18,567,91, relative to ^{6}Li(n,t) cross section.

$^{+}$Kazakov, Yad Konstanty, 37, (1986); Van de Graaff, 4-440 keV, liquid scintillator, VDG.

$^{++}$Kobayashi, 0.024 MeV, 0.055 MeV, 0.146 MeV, relative to ^{10}B(n,$\alpha_1\gamma$), Proc. Conf. on NDST Juelich (1991), p. 65. Set 448 OK

$^{++}$Quang, 23 keV and 964 keV, photoneutron source, activation experiment, NSE 110, 282 (1992). Set 453 Ok except point at 964 may have systematic error.

$^{++}$Adamchuck, 150 eV to 45 keV, relative to ^{10}B(n,$\alpha_1\gamma$), J. Atomic Energy, 65, 920 (1989). Set 446 OK

$^{++}$Buleeva (Davletshin), 0.34 MeV to 1.39 MeV, relative to H(n,n), Sov. J. Atomic Energy, 65, 930 (1989). Set 436 OK except possible systematic errors at highest energies. Also 0.62 MeV and 0.78 MeV relative to Au(n,γ) Set 437 OK

++Voignier, ~0.5 to 1.1 MeV, NSE,93,43 (1986), capture gamma spectrometer, long counter, Van de Graaff. Set 1017 Method gives large uncertainties.

^{239}Pu(n,f)
++Weston, linac, 0.15 keV to 15 keV, fission chamber, ^{10}B(n,α) standard, NSE 111,415 (1992). Set 1024 OK

++Merla, 4.9, 8.65, 14.7 and 18.8 MeV, associated particle, Proc. Conf. on NDST Juelich (1991) p.510; see also Alkhazov, YK,1986,(4),19,198612. Sets 611, 617, 615, and 616. OK

+Meadows, 14.74 MeV, CCW, ANE,15,421,8808, relative to ^{235}U(n,f).

+Shcherbakov, 0.6-196 MeV, relative to ^{235}U(n.f), ISTC 609-97 (2000). Set 1012. OK but problems at high energy compared with Lisowski.

+Staples, 0.8 MeV to 62 MeV, relative to ^{235}U(n,f), NSE 129, 149 (1998). Set 1014. OK except differences compared with Lisowski and Shcherbakov at highest energies.

+Lisowski, 0.5 MeV to 256 MeV, relative to H(n,n) and ^{235}U(n,f) , Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, "U". Set 1029 OK problems at highest energies compared with Shcherbakov

++Garlea, 14.7 MeV, relative to ^{235}U(n,f) cross section, RRP,37,(1),19,92. Set 633 Value is high