INDC(NDS)-0641
Distr. Web ST+G

INDC International Nuclear Data Committee

Summary Report from the Technical Meeting

Toward a New Evaluation of Neutron Standards

8 – 12 July 2013
IAEA, Vienna

Prepared by

V.G. Pronyaev
Institute for Physics and Power Engineering
Obninsk, Russia

and

A.D. Carlson
National Institute of Standards and Technology
Gaithersburg, MD, USA

and

R. Capote Noy
International Atomic Energy Agency
Vienna, Austria

July 2013

IAEA Nuclear Data Section
Vienna International Centre, P.O. Box 100, 1400 Vienna, Austria

Selected INDC documents may be downloaded in electronic form from
http://www-nds.iaea.org/publications
or sent as an e-mail attachment.
Requests for hardcopy or e-mail transmittal should be directed to
NDS.Contact-Point@iaea.org
or to:
Nuclear Data Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna
Austria

Printed by the IAEA

July 2013

INDC(NDS)-0641
Distr. Web ST+G

Summary Report from the Technical Meeting

Toward a New Evaluation of Neutron Standards

8 – 12 July 2013
IAEA, Vienna

Prepared by

V.G. Pronyaev
Institute for Physics and Power Engineering
Obninsk, Russia

and

A.D. Carlson
National Institute of Standards and Technology
Gaithersburg, MD, USA

and

R. Capote Noy
International Atomic Energy Agency
Vienna, Austria

July 2013

TABLE OF CONTENTS

1. INTRODUCTION...7

2. SUMMARY OF PRESENTATIONS...8

2.1 History, R. Capote...8
2.2 Status of the Data Development Project – Measurements made or underway since the last international evaluation of the standards, A.D. Carlson...8
2.3 Light-element neutron standards, G.M. Hale...11
2.4 FDRR code and calculation of ^{7}Li system, Xi Tao...12
2.5 R-matrix analysis for n+^{16}O cross sections – preliminary results, S. Kunieda...12
2.6 New cross section values for ^{10}B(n,α)^{7}Li and first ideas about ^{6}Li(n,t)^{4}He, F.-J. Hambsch...13
2.7 Theory and technique in the FDRR code, Xi Tao...13
2.8 Cross section measurements at GELINA in support of the standards project, F.-J. Hambsch (on behalf of B. Becker, S. Kopecky, P. Schillebeeckx, H.I. Kim, C. Massimi, M. Moxon, I. Sirakov)...14
2.9 Accelerator Mass Spectrometry and neutron-induced reactions, A. Wallner...14
2.10 Overview of experimental data, V.G. Pronyaev...14
2.11 ^{48}Ti(n,n'γ_{948}) gamma production reaction as a candidate for a reference, S.P. Simakov...15
2.12 The search for more suitable γ-ray cross section reference candidates, G.M. Hale (on behalf of R. Nelson)...15
2.13 A new attempt in evaluating the experimental database of the PFNS of U-235+n (thermal), W. Mannhart...16
2.14 ^{252}Cf sources and energy spectra, S.P. Simakov...16
2.15 Why do we obtain low evaluated cross sections and PFNS uncertainties?, D. Neudecker...16
2.16 Cross-section standards in ENDF/B-VII.1 and future evaluations, T. Kawano...17
2.17 Some thoughts on evaluating the neutron cross section standards, D.L. Smith...17
2.18 On unitarity condition in the R-matrix fit, G.M. Hale...18

3. REVIEW OF THE ACTIONS FROM THE LAST MEETING...18

4. DISCUSSIONS AND LIST OF ACTIONS...18

4.1. Cross section standards...18
4.2. Gamma production reference cross sections...21
4.3. ^{235}U(n_{th},f) prompt fission neutron reference spectrum...22

5. OTHER TOPICS...24

6. MILESTONES FOR THE STANDARDS RELEASE...25

6.1. Project Timeline...25

APPENDICES
1 – Agenda...27
2 – List of Participants...29
3 – Hyperlinks to participants' presentations...31
4 – Group picture...33

1. Introduction

Updated standards evaluations for national cross section libraries (e.g. ENDF/B, JENDL, CENDL and JEFF) are needed as new versions of those libraries are anticipated. Also improvements made in the database and evaluation techniques for the standards can suggest that a new version of a library should be undertaken.

A collaboration supported by an IAEA Data Development Project, was established in 2008 after the completion of the last standards evaluation in 2006 [1,2]. Before this project was initiated, there were very long periods between standards evaluations that can now be significantly shortened. The anticipation is that a new standards evaluation can be available whenever one is needed by a major evaluation library. The main objectives of this project are to continuously and critically review new experiments for inclusion in the standards database, and to consider extensions in energy of some of the standards. Other goals are to study improved evaluation procedures and codes for performing the evaluations, maintain those codes, and investigate inclusion of reference data that are not as well-known as the standards but are being widely used as reference in relative measurements of certain types of cross sections. Also included is an effort to improve evaluations of ^{235}U thermal and ^{252}Cf spontaneous fission neutron spectra.

Detailed summaries of much of the work done are available in IAEA reports INDC(NDS)-0540 [3] and INDC(NDS)-0583 [4]. A recently published paper contains an updated review of the status of the IAEA project [5]. In addition to this project, the recently established Collaborative International Evaluated Library Organization (CIELO) [6], has called for an update of some of the standard reactions. Therefore, the IAEA called a Technical Meeting with the goal to establish a roadmap for a new standards release in 2016, ten years after the 2006 release [1].

The Technical Meeting was opened by Nuclear Data Section Head R.A. Forrest, who stressed the importance of neutron standards and highlighted the support of the standard data development project by IAEA member states. Thirteen consultants attended the meeting. R. Capote Noy (IAEA, Vienna, Austria) served as Scientific Secretary, A.D. Carlson (NIST, USA) was elected Chairman of the meeting and V.G. Pronyaev (IPPE, Russia) agreed to act as rapporteur. The approved Agenda is attached (Appendix 1), as well as a list of participants and their affiliations (Appendix 2). Presentations by participants are listed in Appendix 3 (available online at www-nds.iaea.org/nds-technical-meetings/TM-Std-Jul-2013/); they were included in the Agenda by sorting on similar subjects. Two and a half days were planned for participants' presentations. The topics will be considered in the following order: light-element standards, R-matrix codes and data fit, new measurements of capture and fission cross sections and their influence on the standards evaluation, status of the reference gamma-production cross sections, measurements and evaluations of the ^{235}U thermal neutron induced prompt fission neutron spectrum as a reference spectrum, general problems of evaluation methodology, incorporation of the standards data into the general purpose files and implementation of tasks and actions of the last standards meeting.

---

[1] S.A. Badikov *et al*, IAEA Technical Report STI/PUB/1291 (Vienna, Austria, 2007).
[2] A.D. Carlson *et al.*, Nucl. Data Sheets **100**, 3215 (2009).
[3] V.G. Pronyaev, A. Mengoni, A.D. Carlson (Eds.), IAEA Report INDC(NDS)-0540 (2008).
[4] V.G. Pronyaev, A.D. Carlson, R. Capote Noy, A. Wallner (Eds.), IAEA Report INDC(NDS)-0583 (2010).
[5] A.D. Carlson *et al.*, J. ASTM Intl. **9**, doi:10.1520/JAI104095 (2012).
[6] Collaborative International Evaluated Library Organization Pilot Project, NEA WPEC Subgroup 40 (SG40). Information available at **http://www.oecd-nea.org/science/wpec/sg40-cielo/**

The following two and a half days were devoted to discussions on the most important subjects of data measurements and evaluations, preparation of the timeline for the release of new standards and reference data. Finally, the tasks and actions to reach this goal were formulated.

2. Summary of presentations

Summaries of the participants' presentations are given below giving an outline of the most important content of each presentation. The presentations themselves are accessible through hyperlinks (Appendix 3).

2.1 History, R. Capote

Short history of the standards evaluation carried out under the auspices of three parties, namely CSEWG/USA, IAEA and WPEC/OECD was given. Concerning the time schedule for the next release of the standards and reference data, it was unanimously decided that this should be done by July 2016. The release will include the evaluated data (cross sections, constants and spectra, percent uncertainties and correlations) in the form of tables and in the ENDF-6 format (cross sections and covariances for MF3 and MF33 including cross-reaction, cross-material blocks when they will be needed) as well as working materials presented at the concluding meeting of this Data Development Project (July 2016) with description of the evaluations. Two technical meetings in support of this activity are planned to be held by the IAEA in December 2014 and the summer of 2016.

2.2 Status of the Data Development Project – Measurements made or underway since the last international evaluation of the standards, A.D. Carlson

Review of the status of all measurements done after release and not included in the last standards evaluation (since 2004) was presented.

Measurements have been made for all the cross sections used in the evaluation process for the standards since the completion of the last standards evaluation. They include the ^{238}U(n,γ) and ^{239}Pu(n,f) cross sections in addition to the standard cross sections. Those data were included since there are many ratio measurements of those cross sections with the standards and absolute data are available on them. Thus they will have an impact on the standards in the evaluation process, that includes ratio data. Many of the measurements are in agreement with the standards evaluation. Although the results of different new measurements are often consistent within their uncertainties with the standards evaluations, there are some energy ranges where new high precision measurements may influence the central values and uncertainties of the evaluations

H(n,n)

Concerns about the very few measurements of the hydrogen scattering cross section at low neutron energies has led to work by Daub *et al.* from 150 keV to 800 keV. The results were systematically slightly larger than the evaluated values but generally within their uncertainties of 1.1 to 2%. Moreh, Block and Danon at RPI made measurements that indicate there isn't an anomalous drop of about 40% in the n-p differential scattering cross section for 10 - 200 eV neutrons, compared with accepted values, as was suggested. Additional work at the Ohio University Accelerator Laboratory on the hydrogen angular distribution now emphasizes the smaller angles in the CMS at about 10 and 14 MeV where very little data are available. This work required detection of the recoil neutrons. Their other measurements at 10 and 14 MeV used proton recoil detection that limited the angular range to larger CMS angles. Work has also been done at 14 MeV by Kondo *et al.* at Osaka University but their angular range was limited. Problems still exist with the hydrogen scattering angular distribution in the hundred MeV region and the prospects for new measurements are very weak. The latest measurements have been obtained at about 200 MeV by Sarsour *et al.* at Indiana University and by Rahm *et* *al.* at Uppsala University. There are inconsistencies between these measurements as large as 10% at CMS back angles. There is a particular need for data that extend over a large angular range and in the higher energy regions.

^{3}He(n,p)
Measurements have been made of the ^{3}He total cross section by Keith *et al.* Also measurements have been made of the n-^{3}He coherent scattering length and the spin dependent portion of the n-^{3}He coherent scattering length at NIST. Measurements of the the n-^{3}H have been proposed. This proposed measurement would be complementary to the n-^{3}He work.

^{6}Li(n,t)
A very accurate measurement of the ^{6}Li(n,t) cross section at 4 meV by Yue *et al.* has been completed. Angular distribution measurements for the ^{6}Li(n,t) reaction at higher neutron energies have been completed by Zhang *et al.* at Peking University and by Devlin *et al.* at LANL. A LANL evaluation that includes the Devlin *et al.* data indicates that the cross section should be higher at high neutron energies. There is no change in the present standards energy region. Hambsch plans measurements at the GELINA facility of the ^{6}Li(n,t) cross section from a few keV to 3 MeV. Some diagnostic work has been done. At the IRMM Van de Graaff facility, Giorginis and Bencardino have made ^{6}Li(n,t) cross section measurements with a one-dimensional Time-Projection-Chamber (TPC). The data are being analyzed.

^{10}B(n,α)
At IRMM, using GELINA, Hambsch *et al.* have made and continue to make branching ratio, angular distribution and cross section measurements for the ^{10}B(n,α) reaction.
Giorginis and Khryachkov have made measurements of the ^{10}B(n,α) cross section at the IRMM Van de Graaff facility. Zhang *et al.* have made measurements of the ^{10}B(n,α) angular distribution at energies above the present standards region. For some of these data there are concerns due to particle leaking and the loss of ^{10}B. Angular distribution measurements have been made for the ^{10}B(n,α_1), ^{10}B(n,α_0), and ^{10}B(n,p) reactions by Massey *et al*. at WNR (LANL). The ^{10}B(n,p) cross section from this work is about an order of magnitude larger than that in the ENDF/B-VII evaluation. Target thickness causes some difficulty in separating the α groups. The data are under analysis.

C(n,n)
Reactor filtered beam measurements have been made of the C(n,n) angular distribution for 5 angles at 3 energies by Gritzay *et al.* The data differ significantly from the standards evaluation. Further work is being done on this experiment. They also have made measurements of the carbon total cross section. They are generally in good agreement with the standards evaluation. However at the lower energies they are somewhat low and at the highest energy they are significantly higher. They suggest that the resonance in ^{13}C at 152.9 keV may cause this increase. For this to be the case, however, would require that its neutron width be much greater than the reported 3.7 keV. However, measurements of the carbon total cross section with an iron-filtered linac beam by Danon *et al*. agree very well with the standards evaluation. Also preliminary reactor filtered beam data by Anh at 54 and 148 keV agree well with evaluations. Daub made total cross section measurements from 150 keV to 800 keV. Their data are consistently slightly lower than the standards values but within their uncertainties of 1-2%.

Au(n,γ)
An extension of the n_TOF data by Massimi *et al*. for the gold capture measurement up to about 400 keV was done by Lederer *et al*. In the standards energy region, the Lederer *et al*. results generally agree well with the standards evaluation within the uncertainties.

Work on gold capture was done by Wallner *et al*. who made a $^{238}U(n,\gamma)/Au(n,\gamma)$ cross section ratio measurement at 430 keV. The measurement used a new independent method, accelerator mass spectrometry, so it will not have some unknown systematic uncertainties that may be present in other measurements. The cross section ratio obtained agrees with the standards evaluation.

$^{238}U(n,\gamma)$

$^{238}U(n,\gamma)$ measurements have been made recently at the GELINA and n_TOF facilities using the same sample. At GELINA, Lampoudis *et al*. made measurements using a C_6D_6 detector. At n_TOF, the measurements were made with a different C_6D_6 detector by Mingrone *et al*. and with a BaF_2 detector by Wright *et al*.. They anticipate average values will be available from 20 keV to 1 MeV. Measurements by Ullmann *et al*. were made for the energy range from 10 eV to 100 keV. Data were obtained at both the WNR and LANSCE facilities at LANL. The results appear to agree with the standards evaluation. The data should be available in July 2013.

$^{235,238}U(n,f)$

Measurements have been made of the $^{238}U(n,f)/^{235}U(n,f)$ cross section ratio at the n_TOF facility by Calviani *et al*., using a fission chamber, and by Audouin *et al*., using a parallel plate avalanche counter. These data sets were recently finalized. The Calviani *et al*. data are about 3% higher than the Audouin *et al*. data. The standards evaluation falls between these two data sets. Considering the uncertainties, the data sets are in good agreement with the standards evaluation.

$^{239}Pu(n,f)$

New measurements have been made at LANL of the $^{239}Pu(n,f)$ cross section by Tovesson and Hill. The data are relative to the $^{235}U(n,f)$ cross section. They agree well with the standards evaluation up to about 10 MeV. Above that the measurements are somewhat lower than the standards evaluation. Very accurate fission cross section ratio measurements including those used in the standards evaluation are underway at the LANL WNR facility. The data are being obtained with a TPC in a collaboration headed by LANL and LLNL.

Au(n,γ) at low energies

To support the needs of certain applications, such as astrophysics, the energy range below about 100 keV for gold capture has been added to the standards activities as a "reference" cross section. 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, where it is not considered a standard. 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, whereas the standards evaluation uses a large database of various types of data. Several groups have made contributions in an effort to remove this discrepancy. New measurements by Wallner *et al*. of the $^{238}U(n,\gamma)$ and $^{235}U(n,\gamma)$ cross sections relative to the Au(n,γ) cross section were made for a Maxwell-Boltzman simulated spectrum expected to be equivalent to that used by Ratynski and Käppeler. The accelerator mass spectrometry method was used. The ratio of the $^{238}U(n,\gamma)$ to Au(n,γ) cross sections agree with the standards evaluation within the uncertainties. Lederer *et al*. extended the energy range of the analysis of the n_TOF Au(n,γ) cross section measurements of Massimi *et al*.. The MACS from these data at 30 keV is 1% smaller than the MACS obtained by the standards evaluation and 4.7\% higher than the one obtained by Ratynski and Käppeler. GELINA Au(n,γ) cross section measurements by Borella *et al.*, Lampoudis *et al.* and Schillebeeckx *et al.* all support the standards evaluation. Also measurements have been made by Feinberg *et al.* at IRMM of the $^{197}Au(n,\gamma)$ cross section using $^7Li(p,n)^7Be$ neutrons with a proton energy near 1912 keV. Data were obtained using two different energy spreads. Both measurements were about 5% higher than the Ratynski evaluation and the Macklin measurements. The problem does not appear to be with the spectrum since Lederer *et al*. and separately Feinberg *et al.* obtained results for the spectrum consistent with those of Ratynski and Käppeler.

Fission neutron spectra

No new measurements have been made of the ^{252}Cf spontaneous fission neutron spectrum standard. A new evaluation is not justified. There are new measurements of the ^{235}U(n,f) thermal neutron induced prompt fission neutron spectrum made by Kornilov *et al*. and Vorobyev *et al*. Though this spectrum is not a standard, it was decided it should be treated as reference data since it is important for nuclear energy applications. It is also used as a reference spectrum for testing cross sections. There are concerns about the evaluation of this spectrum at the lower and higher neutron energies. The most recent measurements of the ^{235}U(n,f) thermal neutron induced prompt fission neutron spectrum have been made with a ^{252}Cf source located outside the beam. Thus ratio measurements of these spectra were obtained. Pronyaev is using the GMA code to simultaneously evaluate these two fission spectra. This is an ongoing project. There is also an independent evaluation of the ^{235}U(n,f) thermal neutron induced prompt fission neutron spectrum being done by Mannhart.

Gamma-Ray Production Reference Cross Sections

These reference cross sections are not standards but they are used in some applications as effective standards. There are generally some limitations on them compared with the traditional standards. It is preferred that the standards community review and evaluate them. Fe(n,n') 847 keV cross section satisfies many of the requirements. In fact it has been used as a reference standard in a number of experiments but it is not really the best candidate. Preferred candidates are:

^{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) for use as a reference cross section above about 4 MeV where fluctuations in the excitation function are minimal. More work needs to be done to improve the experimental database. New measurements at LANL using GEANIE have been made and are being analyzed. An improved evaluation by Simakov has been done for ^{48}Ti(n,n'γ) however it uses only one data set in the energy range 7 to 20 MeV.

The ^{7}Li(n,n'γ) 478 keV gamma line production cross section also appears to be a reasonable candidate especially at the lower energies. There is little high quality data at higher neutron energies except the LANL work.

The available data with analysis of the uncertainty components will be sent to Pronyaev for inclusion in the GMA databse. They will be used in the combined standards least-squares fit.

2.3 Light-element neutron standards, G.M. Hale

A new R-matrix evaluation for ^{1}H+n with covariances will cover the energy range up to 200 MeV. The R-matrix evaluation for the ^{6}Li(n,t) cross section will be extended to higher energy which will allow a better determination of the cross section in the region where it is used as a standard. No new R-matrix work was done for the ^{10}B+n system but there are some new experimental data (above 1 MeV neutron energy) inclusion of which will affect the standard evaluation below 1 MeV. A new approach to the ^{nat}C evaluation is based at separate R-matrix isotopic evaluations for ^{12}C+n and ^{13}C+n systems. A new methodology for obtaining the cross section covariances from covariances of the adjusted R-matrix parameters was applied and reported in 2008 for ^{1}H+n and ^{6}Li+n evaluations (Nucl. Data Sheets, 109, 2812 (2008)). Evaluated central values were not changed for ^{1}H+n system but were changed above the standards region for the ^{6}Li+n system due to extension of the energy range in the evaluation above 1 MeV with the inclusion of new data.

In the new analysis, the percent uncertainties of ^{1}H+n and ^{6}Li+n evaluations have been substantially increased and are considered now by experts as realistic. There are several reasons for this increase. The uncertainties given with the earlier versions (1991 and earlier) were no better than "educated guesses," based on variations of the evaluated cross sections with (minor) changes in the experimental data base. However, it was realized in the early 2000s, when the uncertainties and covariances were actually obtained from first-order error propagation of the parameter covariance matrices, that the uncertainties could be larger than those estimates based on variations of the mean values (first moments) of the distribution. In addition, the covariances (second moments) are subject to much larger variations in response to changes in the experimental data base than are the first moments. This was especially true for the hydrogen evaluation, where for the ENDF/B-VII evaluation, for example, the uncertainties even for n-p scattering were unreasonably constrained by the requirement that the thermal capture cross section be fixed at a prescribed value, rather than determined by the experimental data. A later determination of the uncertainties in 2008 relaxed this condition, but it led to uncertainties as large as 1% in the n-p scattering cross section around 8 MeV, which was about twice as large as the previous educated guess values. Although the increase of the present cross-section uncertainty at higher energies is not yet understood, there is a feeling that it is more realistic than the previous versions. It can also be pointed out that there is the sensitivity of the parameter covariances obtained in a least-squares fit to the condition used to terminate the numerical search procedure (i.e. find a chi-squared minimum). If the procedure is not terminated with an epsilon condition on the magnitude of the gradient vector of chi-squared (as, e.g., the R-matrix code RAC did not), the covariance matrix obtained can be quite different because in practice the assumed quadratic dependence of chi-squared on the parameters holds only in a very localized region about the minimum. For all these reasons, we may believe that parameter covariance matrices (and thus their propagated cross-section covariances) are considerably less well determined for non-linear least-squares problems than are the mean values (evaluated cross sections).

2.4 FDRR code and calculation of ^{7}Li system, Xi Tao

The new R-matrix code FDRR which includes different approximations to the R-matrix formalism was presented. It can be used for fits of cross sections for light mass nuclides, where many channels are open and also above the thresholds of multiparticle reactions. All channels open for a given nuclide and energy are accounted for. The code still does not work with covariances and treats uncertainty in the parameter adjustment procedure as a statistical one. The preliminary result of the fit for ^{7}Li system using integral cross sections, angular distributions and polarization experimental data for ^{6}Li+n and t+^{3}He incoming channels in the energy range from 10 keV to 20 MeV for neutrons was shown. The code is in the development stage. There are still the problems with the description of the channels which have contributions from the Coulomb interaction.

2.5 R-matrix analysis for n+^{16}O cross sections – preliminary results, S. Kunieda

The new R-matrix code AMUR was presented which has the options of treating the statistical and systematical (the case of fully energy correlated component) uncertainties by two ways: with separate treatment of these two components as statistical and normalization and with covariance matrices constructed from these two components. It was concluded, that with the same non-informative prior and 50% systematic uncertainties assigned to the limited number of experimental data sets used in the fit of $^{16}O(n,\alpha)^{13}C$, inverse $^{13}C(\alpha,n)^{16}O$ reaction and 10% systematic uncertainty for ^{16}O(n,tot) reaction, very strong reduction of percent uncertainties is observed due to the model influence. The evaluated central values and percent uncertainties are about the same in both cases with very high level of the cross-energy correlations introduced by the model. A conclusion was that the R-matrix results for central values are essentially independent of the systematic uncertainties.

2.6 New cross section values for $^{10}B(n,\alpha)^{7}Li$ and first ideas about $^{6}Li(n,t)^{4}He$, F.-J. Hambsch

New measurements have been done for $^{10}B(n,\alpha)$ at the 60 m flight path. Previously only branching ratio and angular distributions have been measured and published. The present measurements also include cross sections.. The new BR data above 1 MeV show much better statistics, compared to the old data. The old BR data which are in EXFOR should be truncated above 1 MeV incident neutron energy. For the purpose of absolute normalization, the new experiments were done with two ^{235}U samples placed back-to-back with the ^{10}B samples in a double grid fission ionization chamber. The ^{235}U samples are only several μg. Due to the difference in molar mass of the ^{235}U and ^{10}B samples and hence the scattering centers, there is a counting statistics problem for the ^{235}U sample. The beam is uniform over its area and larger than the sample. The present status (2013) of the results of the measurements was reported. The kinematic separation of signals from registered particles was shown to be very good also due to the fact that thin 10B samples were used. A fit with Legendre polynomials was performed for correcting of alpha particle angular distributions for leaked particles and particles emitted along the sample. The data on the shape of the angular distributions can be used in the R-matrix fit. The incident neutron energy was varied between 0.2 and 3 MeV. The comparison of the results with previous measurements was shown. The statistics of the events above 1 MeV neutron energy were substantially improved in these recent measurements. In comparison with the other data, the branching ratio has a greater increase with the energy above 200 keV. The $^{10}B(n,\alpha)$ cross section is too high in comparison with the other experimental data for the energy range below 200 keV. This needs to be further investigated. Data for 10B obtained earlier by Georginis were discussed. The dataset in EXFOR of Giorginis is higher than the present cross section data. Also here further investigation is necessary. Initial measurements for the $^{6}Li(n,t)$ reaction with a two-gridded ionization chamber have been made. For the first time digital signal acquisition is implemented. The advantage compared to traditional analogue system is that reanalysis of the data can be easily done off-line as the full digitalized trace is available. Two samples for ^{6}Li and ^{235}U were used at the time of flight GELINA facility with a 60 m flight path. Additional measurements will be made starting in November. A post-doctoral student will do the analysis of the new data for the $^{6}Li(n,t)$ cross section.

2.7 Theory and technique in the FDRR code, Xi Tao

The physical approximations used in the FDRR code were discussed. It was shown that in some approximations, the energy shift is canceled by allowing energy-dependent boundary conditions. But this assumption destroys the orthogonality of the eigenfunctions in the R-matrix approach. The width for the gamma channel can be parametrized as energy dependent for each resonance. Channels with multiparticle emission were simulated by the effective two-body decay channels (like bi-neutron and residual nucleus for (n,2n) reactions). The total number of adjustable parameters is about 200 but only half of the parameters are usually adjusted (because of near zero sensitivity to the others at a given energy). Intercomparison was done between FDRR and RAC R-matrix fits. There were comments that for the 4 presented approximations, three (which are type of Multi Level Breit-Wigner, Adler-Adler and Reich-Moor) are not very useful for light nuclides evaluations in the energy regions where they are used as standards and are applied mostly for heavy nuclei and higher energies. Further development of full R-matrix calculations, as an option, is desirable.

2.8 Cross section measurements at GELINA in support of the standards project, F.-J. Hambsch (on behalf of B. Becker, S. Kopecky, P. Schillebeeckx, H.I. Kim, C. Massimi, M. Moxon, I. Sirakov)

Cross section measurements at GELINA for neutron induced reaction in ^{197}Au were presented. For the unresolved resonance region, they included transmission measurements at a 50 m flight path stationa and capture measurements at a 12.5 and 30 m station. The results of measurements of the Au(n,γ) cross section obtained for two flight paths were discussed together with a parameterization of the average cross section in terms of an average resonance parameters. Two papers with a complete description of the measurements and data analyses, including a novel way to present the complete covariance information in a compact presentation are prepared for publication. Capture measurements using the total energy detection principle at a 60 m flight path station were also performed for ^{238}U. The measurements were performed with the accelerator operating at 800 Hz. To avoid a strong influence of overlap neutrons a relative thick overlap filter was used such that the resonance at 6 eV cannot be used for normalization. New measurements at a 12.5 m station are scheduled and should be finished in 2014.

2.9 Accelerator Mass Spectrometry and neutron-induced reactions, A. Wallner

The results obtained with the use of the Accelerator Mass Spectrometry (AMS) technique for neutron capture cross section measurements were reported. The samples were irradiated at Karlsruhe with a simulated Maxwell-Boltzmann neutron spectrum with a characteristic temperature of about 25 keV and with other broad spectrum neutron sources for other energies. Work was done in the framework of the European Union Projects. The range of nuclides studied covered from ^{9}Be to different isotopes of U. Samples have a typical mass of 20-50 mg. The ^{197}Au(n,γ) reaction was used as a monitor. The typical systematic uncertainty of the AMS measurements is 1-3%, which is rather low for capture cross section measurements. In addition, the ratio of Th/U capture cross sections was determined for higher energies with sample activations at IRMM (0.5-3 MeV). It was shown that the ENDF/B-VII.1 evaluation for the ^{197}Au(n,γ) cross section (taken from standards combined evaluation for 2.8 MeV > En > 5 keV) is consistent with the results of their measurements. Their measurements of spectrum averaged cross sections for the samples irradiated at Karlsruhe for 25 keV spectra are systematically lower than the KADONIS evaluation; the latter is a compilation of nuclear data (mainly neutron capture reactions) provided to the astrophysics community.

2.10 Overview of experimental data, V.G. Pronyaev

The influence of the new experimental data (light elements, capture and fission cross sections) on the standards evaluation was shown. The results of high precision ^{197}Au(n,γ) cross section measurements done at IRMM for neutrons with energy between 4 and 80 keV will induce some changes in the combined fit of the cross sections in the keV region. With new n_TOF consistent results for threshold and sub-threshold ^{238}U(n,f) cross sections obtained in the measurements with two different detectors, these data in the database can be substantially improved. The results of new ^{239}Pu(n,f) and ^{239}Pu(n,f)/^{235}U(n,f) (primary) measurements obtained at LANL for energies above 200 keV are consistent with the standards evaluation below about 14 MeV but are systematically lower for higher energies. The reason of this discrepancy is unclear and should be analyzed. The increase of the uncertainties for the ^{1}H(n,p) and ^{6}Li(n,t) cross sections in the R-matrix (EDA code) 2008 evaluation will probably lead to larger uncertainties of the other standards.

The results of GLUCS and GMA non-model least-squares fits for (n,n'γ) reactions on ^{48}Ti, ^{54}Cr and ^{56}Fe were shown. It was proposed by Vonach to use them as a reference cross sections for the gamma-ray production for natural samples of Ti and Fe between 4 and 15 MeV where the cross sections are smooth. For ^{nat}Ti the contribution to the 984 keV gamma-line will be from the ^{48}Ti(n,n'γ) and ^{49}Ti(n,2n) reactions and for ^{nat}Fe the contribution to the 847 keV gamma-line will be from the ^{56}Fe(n,n'γ) and ^{57}Fe(n,2n) reactions.

A PFNS evaluation using a combined GLSQ fit with the only data included being ^{252}Cf(sf) and ^{235}U(n_{th},f) was discussed. All data were reduced to the primarily measured form (mostly absolute ratios of ^{252}Cf(sf) to ^{235}U(n_{th},f)). The results of a smoothing procedure when model spectrum and covariances obtained in MC physical model calculations were used for smoothing were discussed. Problems with using a GLSQ fit for normalizing the spectrum through the introduction of a constraint with extremely low uncertainties were discussed. It was shown, that the use of MC physical model calculations in the GLSQ fit as a pseudoexperimental data set allows the normalization of spectra with an appropriate uncertainty and with minimal influence on the non-model evaluation of uncertainties. Because in simple physical models the PFNS shape depends weakly on the incident neutron energy, the possibility of including PFNS measured for incident neutrons below 0.5 MeV in the combined fit of PFNS for thermal neutron induced fission was discussed. It was decided to not do it at this stage of the evaluation, because it will complicate the analysis of evaluated results.

2.11 ^{48}Ti(n,n'γ_{948}) gamma production reaction as a candidate for a reference, S.P. Simakov

A comprehensive analysis and evaluation of the ^{48}Ti(n,n'γ) 984 keV gamma-line production cross section was presented. The analysis included model calculations with the use of the TALYS and EMPIRE codes, with adjustment of selected parameters taken from the RIPL-3 library. The adjustment included the optimization of the optical model potential for the use of the multi-channel coupling scheme, spins and parities of discrete levels, and branching coefficients for gamma transition between them, properties of the low-lying collective states of vibrational nature, and level density parameters for all open exit channels. A large body of different experimental data was described. It was shown that the use of discrete level information from the RIPL-3 library as the default generally does not allow a good fit of the gamma production cross sections for the (n,n'γ) reaction. Finally, the model parameters were adjusted to fit the results of the non-model least squares fit with GMA. An accurate measurement of the 984 keV gamma-line production cross section at natural Ti is needed in the energy range 4 MeV to 20 MeV. At present, only the ^{48}Ti(n,n'γ) LANL measurements cover the entire energy range where the cross section can be used as a reference cross section. It was mentioned that there are unpublished measurements by D. Larson (ORNL) for ^{48}Ti(n,n'γ). Also revised LANL data for ^{56}Fe will be available soon in EXFOR. The results of new measurements for the ^{56}Fe gamma-production cross sections at IRMM, which are expected to be released soon, are consistent with LANL results except for two narrow energy regions.

2.12 The search for more suitable γ-ray cross section reference candidates, G.M. Hale (on behalf of R. Nelson)

The measurements of gamma-production cross sections have been done for a few materials. The most promising results from the point of view of using them as gamma production reference cross sections are Ti for the neutron incident energy range 4 to 15 MeV, Li in the form of LiF for the neutron incident energy range 1.0 to 6 MeV and less favorable, Fe, in the energy range 4 to 15 MeV. The reaction ^{48}Ti(n,p)^{48}Sc -> beta decay -> ^{48}Ti*, which yields the 984 KeV gamma-line, and similar ^{56}Fe(n,p) -> beta decay -> ^{56}Fe* but with a shorter half-life of beta decay, may contribute as the time-dependent backgrounds for these possible reference cross sections. The number of ^{7}Li(n,n'γ) data sets covering the energy range of interest 1 to 6 MeV is large, but careful analysis of experimental data will be needed to remove the discrepancies or it may be necessary to increase the uncertainty of some data sets. The ^{7}Li(n,n'γ) 478 keV gamma line production cross section, although not smooth, does not have strong fluctuations and there is overlap in the energy range (4 to 8MeV) with ^{48}Ti(n,n'γ) where both can be recommended for use as a reference cross sections.

2.13 A new attempt in evaluating the experimental database of the PFNS of U-235+n (thermal), W. Mannhart

A combined fit was done for ^{252}Cf(sf) and ^{235}U(n_{th},f) prompt fission neutron spectra for thermal neutrons. For this the ^{252}Cf(sf) prompt fission neutron spectrum smoothed by a spline fit (as it is given in the file for the ^{252}Cf standard) was used. The covariance matrix of uncertainties for these data was taken as obtained in a non-smoothed non-model evaluation. All ^{235}U data were treated as absolute ratios except the Wang data which are taken as shape of spectra data. The details of the uncertainty determination were presented. Using ^{235}U ratios as primary measured data reduces the uncertainty due to their partial cancellation in the components related with corrections for resolution. It was concluded, that Vorobyev's data are in disagreement with the other measurements. Propagation of the uncertainty in the resolution function for absolute measurements and for ratio measurements may lead to strong inconsistency in using both types of data in the same fit. The uncertainties in the high energy part of the spectra (above 8 MeV) due to resolution function corrections are large for the absolute data and small for ratio measurements. The preliminary spline fit of the evaluated ^{235}U prompt fission neutron spectrum for thermal neutron induced fission was done using the same approach as was done for the ^{252}Cf(sf) prompt fission neutron spectrum evaluation. The Wang shape data have a strong influence on the fit, strongly reducing of the uncertainties and this needs additional studies. Generally the ^{235}U spectrum is different from that given in ENDF/B-VII.1 (=ENDF/B-VI.8) in shape, with substantially more neutrons below 1 MeV.

2.14 ^{252}Cf sources and energy spectra, S.P. Simakov

The characterization of the neutron spectrum from an encapsulated ^{252}Cf(sf) neutron source was discussed. It includes the influence of the capsule and chemical form in which the ^{252}Cf is used in the source. Characteristics of different ^{252}Cf(sf) sources used in the past were given. Certified data of neutron sources with intensities between 10^6 to 10^9 n/sec were presented with uncertainties in the intensity estimated by the producer between 5 and 10%. Lev Trykov's results obtained in IPPE for the ^{252}Cf(sf) neutron and gamma spectrum characterization were presented. The highest energy group for the neutron spectrum in these measurements was 13 – 13.5 MeV. Below 3 MeV the neutron spectrum of encapsulated Cf source was shown may be disturbed up to 10-15% by multiple scattering on the capsule materials. These results are also important because neutron spectrum measurements were done by alternative to the TOF method that is commonly used. A proposal for inclusion of these data in the fit or for the validation of the ^{252}Cf(sf) PFNS was discussed.

2.15 Why do we obtain low evaluated cross sections and PFNS uncertainties?, D. Neudecker

The reasons for obtaining small evaluated relative uncertainties in model and non-model GLSQ fits were discussed for cross section as well as PFNS evaluations. It was shown that, taking into account correlations between uncertainties of different experiments, can lead to an increase of evaluated uncertainties if the common uncertainty component of the different experiments is substantial. Common uncertainty components can occur when, e.g., the same sample or the same set-up is used for different experiments. To obtain reliable evaluated uncertainties in a fit using model and experimental data, the model prior uncertainties should include not only the uncertainties of the model parameters but also uncertainties stemming from the deficiencies of the model when the model is highly deficient. In general, the uncertainty of a model prior is expected to be higher than the uncertainty of the experimental data. However, in the case of a PFNS prior supplied by the Los Alamos model, the relative uncertainty in some energy range can be very small compared to experimental information (e.g. near the pivot point in Maxwellian-like models) which may lead to evaluated data similar to model data and low associated uncertainties. The low model uncertainty at the pivot point and the extremely strong correlations and anti-correlations of the prior covariance matrix seem to be caused by normalization. The conditions which introduce the normalization constraint in the covariance matrix were discussed. A fully correlated component added to a prior model covariance matrix increases the uncertainty in the pivot point, but breaks the normalisation property of the evaluated covariance matrix. If the model prior covariance matrix with the additional fully correlated component is used in an evaluation, the evaluated uncertainties correspond better to the experimental information.

2.16 Cross-section standards in ENDF/B-VII.1 and future evaluations, T. Kawano

The procedure for incorporation of the standards evaluations (for light elements as well as for capture and fission cross sections for heavy nuclides) in the ENDF/B-VII library was reviewed. The aim was to use the standards evaluations as close as possible to the original values when incorporating them in the general purpose files. Minor modifications were needed to use the wide-group standards evaluation. In some cases, the standards evaluation was replaced by a model fit of the standards to smooth the data. The development of computer codes to use models for fitting of experimental data and interpolation and extrapolation of evaluations in the areas where experimental data are unavailable was presented. The example of ambiguities in the calculations of the inelastic scattering cross sections for actinides caused by different approaches to account for the correction for the width fluctuation/correlation was shown. The refining of the fission models used in evaluations was discussed. Different approaches to calculate width fluctuation corrections were considered. A new Moldauer-type approximation to the GOE three-fold integration correction was proposed. Microscopic calculations of collective levels properties beyond the RPA approach, allowed a more accurate account of the direct reaction mechanism contribution in inelastic neutron scattering. The use of Monte Carlo simulation of the fission process and the statistical description of prompt fission neutron emission from all pairs of fission fragments, gives a better description of spectra than the more simple Madland-Nix (MN) model. Compared with the MN model it predicts an increase in the low energy part of the spectrum and a decrease in the high energy part and better describes the experimental data. It describes well the partial nu-prompt data.

2.17 Some thoughts on evaluating the neutron cross section standards, D.L. Smith

The problems with justifying the need for producing and releasing new standards, and the validation of the evaluation methodology were discussed. For validation of the evaluation methodology, specially designed simple tests (stress tests) should be used. The work with discrepant data is very important. If the evaluation is performed automatically using formal procedures, but without attention to the possible effects of data discrepancies, then the obtained results can be misleading. The discrepancies should be resolved through close contact with the experimenters who generated the data. The key issues of the evaluation process such as non-linearities in the space of the evaluated observables; the simplifications in the formation of covariance matrices of experimental data; the Peelle Pertinent Puzzle with fixes used to minimize it in conditions of incomplete information about uncertainties; and the introduction of strong correlations by the models in the fits were mentioned as major barriers in the objectivity of the evaluation process. It could be worthwhile for the data evaluators community to invite experienced applied statisticians for critical review of the methods currently used in nuclear data evaluation.

2.18 On unitarity condition in the R-matrix fit, G.M. Hale

The unitarity condition in the R-matrix model determines the total cross section in the maximum of the resonance for given spin. This is an important model constraint which may seem to be in contradiction with experimental data. A simple computer model with a single resonance and two partial channels was used to show how the cross sections change with variation of the widths for the resonance.

3. Review of the Actions from the last meeting

The list of Actions from the last (2010) meeting was reviewed. The good progress on the ^{197}Au(n,γ) and ^{238}U(n,γ) cross section measurements, motivated by the possibility of resolving old discrepancies in the fit of these data, was achieved. The actions set on other topics were only partially implemented due to their on-going character or too optimistic timelines. It was proposed to include them, with corrections where needed, in the list of actions for the next meeting.

4. Discussions and List of Actions

4.1. Cross section standards

^{1}H(n,p)

R-matrix evaluation of ^{1}H(n,p) cross section and angular distributions should be considered as a task with first priority, because many cross sections in the standards evaluation are measured relative to ^{1}H(n,p) and will be needed in the renormalization and uncertainty adjustment. The evaluation should be extended up to 200 MeV in the R-matrix fit of the data. It is expected that with the refined approach of derivation of cross section covariances from covariances of parameters (Nucl. Data Sheets, 109, 2812 (2008)), the uncertainty of the cross sections will be considered as realistic in the whole energy range 10^{-5} eV – 200 MeV. It is suggested that the Arndt database of experimental data can be widely used in the R-matrix fit for energies above 20 MeV.
Action: Hale adds Daub total cross section data to the evaluation.
Action: Carlson contacts Ohio University about forward angle data at 10 MeV.
Action: For evaluated cross sections and covariances, Hale will use the energy grid and group boundaries for covariances developed for the evaluation of the fission cross section standards. Hale will provide the evaluation of the hydrogen standard up to 200 MeV by October 2014, including central values, percent uncertainties, correlation and the relative covariance matrix as well as differential cross sections at the angles used by Lisowski (LANL) in his fission cross section work and also at zero degree angle in the laboratory system.

^{3}He(n,p)

This standard has low priority. NIST coherent scattering data (both polarized and non-polarized) are available. Probably there is still a problem with fitting of very small uncertainty of total cross sections from NIST – Indiana. No actions are foreseen.

^{6}Li(n,t)

R-matrix evaluation of ^{6}Li(n,t) cross section is considered as a task with second priority, because the main changes in the fit are expected for neutron energies above 1 MeV, where the cross section is now not recommended for the use as standard. But because the uncertainties of the R-matrix ^{6}Li cross sections will be different (Nucl. Data Sheets, 109, 2812 (2008)) from the previous evaluation and ^{6}Li(n,t) and ^{6}Li(n,n) cross sections are included in the combined GMA fit of standards, they are needed prior to December 2014 when the preliminary evaluation of the Standards should be released. IRMM data by Giorginis can be included in the fit, but they are still being analyzed (the energy range is from 1.5 to 5 MeV).

Action: Hambsch supplies the Giorginis e-mail address to Carlson so he can communicate with him concerning finalization of experimental data. (done)
Action: Hambsch will make measurements of the cross section up to 3 MeV and angular distributions from 0.1 to 3 MeV. This data may be released only by the next meeting (December 2014).
Action: Carlson provides NIST's high accuracy value.
Action: For cross section presentation Hale will use the energy grid developed for the hydrogen evaluation. The evaluation will be given to at least 2 MeV including central values, percent uncertainties, correlation matrix and relative covariance matrix.
Action: Hale and Pronyaev will supply TEST2b case input for Tao and Wang and also for Kunieda.
Action: Hale will run TEST2b case with EDA, obtain uncertainties of cross sections using refined approach and send cross sections, percent uncertainties, correlation and relative covariance matrices to Pronyaev**.**
Action: Tao and Wang, and Kunieda will run TEST2b case and provide output to Pronyaev for intercomparison with EDA fit.
Action: Pronyaev will examine outputs and prepare the conclusion about intercomparisons.
Action: Tao and Wang will revise the FDRR R-matrix code, so systematic and statistical uncertainties in experimental data will be taken into account in the parameters search. Also covariance matrix of evaluated cross sections should be produced as the result of evaluation.
Action: Kunieda will update the AMUR code to handle polarization observables in the fit.
Action: Hale will provide the database for the ^{7}Li compound system to all participants working with R-matrix codes.

^{10}B(n,α)

R-matrix evaluation of ^{10}B(n,α_0), ^{10}B(n,α_1) and branching ratio between these two channels is considered as a task with second priority, because the main changes in the fit are expected for neutron energies above 1 MeV where cross sections are not recommended for the use as standard. But because there can be some influence of the fit in the high energy region on the region below and because the uncertainties of the ^{10}B cross sections with the upgraded method will be substantially higher (Nucl. Data Sheets, 109, 2812 (2008)) the new evaluation should be included in the combined fit of standards. At least the results of revised calculations of uncertainties should be available before the December 2014 when the preliminary evaluation of the Standards should be released. The branching ratio data by Hambsch published in 2007 (Nucl. Sci Eng. 156 (2007) 103) should not be used for neutron energies above 1 MeV.
Action: Hambsch will analyze his data and obtain cross section ratio to ^{235}U(n,f) up to 3 MeV and angular distributions for the energy range from 0.1 to 3 MeV. He will provide detailed analysis of systematic components of uncertainties.
Action: Carlson will monitor the work on ^{10}B(n,p) cross section and angular distributions by Massey.
Action: Hale will provide the database for the ^{10}B compound system to all participants working with R-matrix codes.
Action: Kunieda and Tao and Wang will use the full Hale database when ^{6}Li(n,t) test2b case is satisfactory.

C(n,n)
The elastic scattering cross section and angular distributions for natural Carbon have low priority for the standards evaluation. The combined standards evaluation does not include carbon data. But new evaluations at LANL, based on separate R-matrix fits of ^{13}C and ^{14}C compound systems are in progress. The new evaluation for ^{nat}C elastic scattering cross section standard and its covariance will be obtained as weighed contribution of isotopic cross sections and covariances. The results of measurements of total cross section at E_n~144 keV by Gritzay using filtered beam technique are very high. Note that Anh (Vietnam) and Dannon (RPI) are both in good agreement at E_n ~144 keV with the previous C(n,tot) evaluation. In any case, Gritzay total cross section data generally agree with previous standards evaluation at energies other than E_n~144 keV and should be considered in this evaluation.
Action: Hale adds Daub total cross section data to the evaluation.
Action: Hale adds Wallner $^{13}C(n,\gamma)$ cross section data obtained with AMS technique at E_n ~143 keV using data finalized and prepared for publication.
Action: Carlson will contact Dannon about the possibility of ^{13}C total cross section measurements.
Action: Simakov will check on Gritzay progress on both total and angular distribution measurements.

^{197}Au(n,γ)
Although good progress was achieved in obtaining new high-precision experimental data and validation of the cross section in the well characterized broad spectrum measurements, including simulated Maxwellian-Boltzman type of spectra, work on cross section measurements with the TOF technique and cross section validation using the AMS method will be continued.
Action: Wallner will investigate progress of new TOF measurements which can be more reliable in the 10 -100 keV energy region than previous ones.
Action: Capote will check progress on Mastini average cross section measurements with 28 keV and 50 keV Maxwell-Boltzman spectra simulated in $^{7}Li(p,n)$ reaction with thick targets and broadened proton beam.
Action: Pronyaev will put IRMM data obtained in the energy range 4 to 80 keV in the GMA database. Also n_TOF data by Lederer with larger uncertainty will be included in the database.

^{238}U(n,γ)
Although this cross section is not a standard it is included in the combined fit of standards because it may contribute to the improvement of the standards through measured ratios to other cross sections. Also a good knowledge of this cross section is important for reactor applications.
Action – Kawano will request Ullmann (LANL) data. Also enquire about the possible origin of the structures in the wide binned cross sections at neutron energies above 20 keV.
Action – Wallner will inquire about status of n_TOF data. Hambsch will check the status of GELINA data. These measurements were made with the same sample and if data will be available the correlation in the uncertainty component related to the sample characterization should be accounted in the covariances for these experimental data sets.
^{238}U(n,f)

There is a request for a more detailed evaluation presentation of the cross section in the sub-threshold range from the neutron dosimetry reaction community; and for benchmarking of structural materials inelastic scattering cross sections in critical assemblies and reactors (e.g. average cross section of neutrons removed below the threshold of ^{238}U fission).

Action: Pronyaev extends the fit of the $^{238}U(n,f)$ cross section to the threshold and sub-threshold region (below 2 MeV – to 0.5 MeV) with an appropriate step in energy for a more detailed representation of the cross sections in this region. For this either a full combined fit or separate GLSQ fit for a subset of the data in this range with adjacent data for the high energy region will be done.

^{238}U(n,f)/^{235}U(n,f)

Primary data for many $^{238}U(n,f)$ cross section measurements are the absolute ratios to the $^{235}U(n,f)$ cross section. The TPC project will provide high quality data. When data are available they will be included in the standards database. There are measurements of $^{209}Bi(n,f)$ cross section done relative to the $^{235}U(n,f)$ and $^{238}U(n,f)$ cross sections by n_TOF collaboration. The absolute ratio of $^{238}U(n,f)$ to $^{235}U(n,f)$ cross section can be estimated from these data. $^{209}Bi(n,f)$ cross section was proposed by those authors as a possible high energy fission cross section standard.

Action: Capote will check on progress on n_TOF fission cross section work. There may be new measurements at threshold energies.

Action: Pronyaev will add Audouin and Calviani n_TOF cross sections measured with different detectors in the sub-threshold and threshold energy range data to the database. Also, the energy range of the evaluated data should be extended to 0.5 MeV. Narrower bins for more detailed presentation of the cross section should be used in extended energy range.

Action: Pronyaev will examine the possibility of obtaining $^{238}U(n,f)/^{235}U(n,f)$ ratio from $^{209}Bi(n,f)$ cross section measurements (Phys Rev C83 044620 (2011)) that can be used in the standards evaluation.

^{239}Pu(n,f)

Results of latest LANL measurements (Tovesson and Hill) done for neutrons with the energy below 200 keV have unphysical fluctuations of the cross section. For TOF measurements above 200 keV in neutron energy, the data agree with the standards evaluation within the limits of the uncertainties, although for energy above 15 MeV they are below the results of other measurements available in this energy range.

Action – Carlson will inquire about the uncertainty analysis in both sets of measurements and possible problems in measurements below 200 keV.

4.2. Gamma production reference cross sections

$^{7}Li(n,n'\gamma)$ with 478 keV gamma-ray production in the energy range of incident neutrons from 1.5 to 8 MeV and 983 keV gamma-rays produced by incident neutrons on ^{nat}Ti in the energy range 5 to 18 MeV with contribution of $^{48}Ti(n,n'\gamma)$ and $^{49}Ti(n,2n\gamma)$ to the same residue nucleus are good candidates for the reference cross sections.

There are two new preliminary results of measurements for $^{7}Li(n,n'\gamma)$ (LANL and IRMM), which are discrepant. The number of data sets in the energy range of interest is large, but existing discrepancies between results of the latest measurements should be analyzed and resolved. The measurements of γ-production at separate points in the incident energy region 4 - 5 MeV can resolve this discrepancy (e.g. these measurements can possibly be done at the Kentucky University VDG). Measurements can possibly also be done there for ^{nat}Ti, first for the purpose of verification of the methodology by comparison with the LANL ^{48}Ti data and then for $^{7}Li(n,n'\gamma)$.

The last non-model evaluation of the $^{48}Ti(n,n'\gamma)$ cross section done in framework of the present project (S.P. Simakov, 2013) is based on the results of a single LANL measurement covering the entire energy range from threshold to 20 MeV. Other experimental data are below 4 MeV and at 14 MeV however with large uncertainties. The evaluation cannot be based on the results of a single measurement even adjusted in the least squares fit to the values obtained in a few separate points. Also the LANL measurements were done with a ^{48}Ti enriched target, there is a need to have experimental data obtained with a natural Ti target. Below threshold of the ^{49}Ti(n,2nγ) reaction in 9.3 MeV, the 984 keV gamma-ray production cross section in the ^{nat}Ti target is a result of the gamma-ray production at the ^{48}Ti nuclei.

The 847 keV γ-line in natural iron is often used in measurements as a gamma-production reference cross section (even if it's use can be limited by a large amount of iron in the environment as a structural material). As in the case of ^{nat}Ti, two reactions contribute in the 847 keV gamma-line production - ^{56}Fe(n,n'γ) and ^{57}Fe(n,2nγ). But because of the low content of ^{57}Fe in natural iron, it introduces only a small addition to the contribution from the ^{56}Fe(n,n'γ) reaction. The cross section can be considered as smooth for energies above 5 MeV. The measurements done at LANL in 2004 and re-analyzed in 2012 are generally consistent with the preliminary result of a measurement obtained at IRMM if two small energy regions are excluded. There is non-model evaluation of the ^{56}Fe(n,n') cross section by IRK-IPPE for the JEFF library which is based at a combined fit of cross sections for all neutron induced reactions in ^{56}Fe and take into account all relations between total and partial cross sections. New IRMM measurements, when they will be available, together with the LANL data, can be included in the update of the IRK-IPPE evaluation. The GLUCS code can be used for this, taking as apriori data (cross section and covariances) the IRK-IPPE evaluation and obtaining a new evaluation by adding new experimental data in the Bayesian approach.

The same procedure can be applied for evaluation of ^{48}Ti(n,n'γ) cross section, considering evaluation prepared at the IRK by the same method as a prior. The TENDL model evaluation of cross section and covariances, included in the fit, can be used for smoothing of the non-model evaluation.

Action: Nelson and Plompen will continue the analysis of the 478 keV gamma-ray production cross section for the ^{7}Li(n,n'γ) reaction with the aim of resolving the discrepancy.
Action: Capote will submit a HPRL request for Ti 984 keV gamma ray production cross section measurements with 5% uncertainty in the energy range between 4 and 20 MeV. Plompen (IRMM) is a possible candidate for doing this work.
Action: Carlson will contact experimenters at Kentucky and/or TUNL about the possibility of new measurements for the 1-5 MeV range. It can be proposed also to make ^{nat}Ti 984 keV gamma-ray production cross section measurements at points in the 4-5 MeV range for verification of the technique of the measurements.
Action: Carlson will communicate with Nelson and Plompen about obtaining their Fe data.
Action – Vonach and Tagesen provide the NDS/IAEA with the latest version of the GLUCS code which may be used in the evaluation of the gamma-production reference cross sections.

4.3. ^{235}U(n$_{th}$,f) prompt fission neutron reference spectrum

There were many discussions about the evaluation of the prompt fission neutron spectrum for the ^{235}U(n$_{th}$,f) reaction. The evaluation of the reference PFNS in this data development project will also contribute to the IAEA/NDS Coordinated Research Project (CRP) on evaluation of PFNS for a wide energy range of incident neutrons and for a number of nuclides. For that purpose, PFNS models are required and the reference evaluation can be used to test PFNS models.
A combined non-model evaluation of ^{252}Cf(sf) and ^{235}U(n$_{th}$,f) spectra will be undertaken and results compared for two approaches used in the framework of this project – Gauss-Markov-

Aitken, implemented in the GMA code, and a Bayesian approach used by Mannhart. It is supposed that after the exchange of data and uncertainties, the fits in both approaches will be based on the same (or very close) experimental spectra and their uncertainties. It was shown analytically by Nancy Larson, that both approaches, even based on different mathematical formulations, are identical if a non-informative prior is used. The GMA method allows the systematic uncertainty for energy dependent data to be given as a sum of two components – a fully correlated uncertainty with the same percent error at any energy point and with a medium energy range correlation component where not only the percent uncertainty will be energy dependent, but also the correlations between uncertainties at two different points will depend on differences in energy between these points (e.g. detector efficiency). The results of the evaluation should be the non-model, or in other words, free from model deficiencies in the fit of the experimental data.

Before using this evaluation as a reference spectrum, it should be smoothed of unphysical fluctuations and normalized. All this can be done at the second step of the evaluation. A spline fit of low orders with carefully selected nodes is generally free from model defects and presents probably the best approximation to what appears by eye to be a good fit. Although the normalization of the spectra with some realistic energy dependence to zero energy and to high energies can be done by putting a constraint (requirement) on the fit of the smoothed spectrum, that the integral under the spectrum should be equal to unity with some small uncertainty, this seems not to be the best procedure, because it may break the smoothness of the points with large uncertainties and change substantially the off-diagonal covariances. A simple normalization of the spectra with the requirement that the integral under the spectra should be implicitly equal to unity is converted to the requirement that the uncertainty of the integral value should be implicitly equal to zero, which in turn, is converted to the requirement that the sum of all elements of the covariance matrix of uncertainty (that is the uncertainty of the integral under the spectrum) should be equal to zero. It is unclear how to implement this constraint in the covariance matrix when relative spectra are evaluated. But in practice, we have high accuracy evaluations of averaged ν-prompt based on experimental data obtained with different methods. The real physical quantity which is used in calculations and prepared from the evaluated data file is the absolute spectrum of the prompt fission neutron yields. Then at the last stage of the evaluation, the normalization can be done using the evaluated averaged ν-prompt value and its uncertainty in the least squares adjustment of the relative spectra multiplied by the evaluated ν-prompt value.

Action: Mannhart will refine his evaluation procedure with possible inclusion of the Wang shape data. The evaluation extends to 12 MeV and may possibly extend to 14 MeV by the end of the year if it is possible to include the Wang data.
Action - Pronyaev will give Mannhart his GMA input and output by July 2013.
Action – Refined Mannhart experimental and evaluated data will be transferred to Pronyaev by October 2013.
Action – Wallner is assessing the possibility of using the AMS technique for the measurement of the $^{235}U(n_{th},f)$ or $^{235}U(n_{cold},f)$ prompt fission neutron averaged cross sections which can be used for validation of the prompt fission neutron spectrum at energies above 8 MeV ($<E_{50}> > 8$ MeV).

Action – Capote sends a HPRL request for measurements of the PFNS optimized for reaching the best accuracy at the low (< 2 MeV) or high (> 4 MeV) energy part of the spectrum .
It should be noted that changes to the ^{252}Cf spectrum obtained in the combined fits should not be made unless the evaluated result is greater than 2 sigma relative to the present ^{252}Cf standard.

5. Other topics

^{27}Al(n,α)

The ^{27}Al(n,α) reaction cross section is considered by many experimenters as a reference cross section for activation measurements. Evaluation of the cross section and covariance matrices was done for the IRDFF Neutron Dosimetry Library by Zolotarev and can be used as a reference cross section (dosimetry library available at http://www-nds.iaea.org/IRDFF/).
Action: Pronyaev will communicate with Zolotarev about the possible inclusion of the ^{27}Al(n,α) reaction cross section evaluations done for Neutron Dosimetry (and possibly two or three more reactions sensitive at other energies) to the reference cross sections for activation measurements.

^{209}Bi(n,f)

Recently it was proposed by Santiago de Compostela group lead by I. Durán and coworkers to include the ^{209}Bi(n,f) reaction as a possible reference reaction above 20 MeV [1]. Data on neutron-induced fission cross sections at intermediate energies are crucial for the development of accelerator-driven systems: ^{nat}Pb and ^{209}Bi play a key role, because liquid lead-bismuth eutectic is the reference spallation-target material [2]. As it was pointed in [1,3], the ^{209}Bi fission cross section is a useful standard in the neutron energy region above about 50 MeV for the following reasons:
a) the excitation function has a threshold of about 25 MeV which eliminates the influence of low energy neutrons;
b) there is a smooth variation of the cross section with neutron energy which makes it insensitive to neutron energy resolution;
c) ^{209}Bi is monoisotopic and a non-radioactive material. It is therefore easy to transport and handle.
Relying on the several measurements performed before 1997, an evaluation of the reference cross sections for ^{209}Bi (n,f) reaction from 21 to 1000 MeV have been done with assigned uncertainties 50% at neutron energies from 20 to 40 MeV, 13-10 % from 40 to 160 MeV and about 30% above 169 MeV [3]. Meanwhile new measurements have been performed up to 173 MeV in Uppsala [4], up to 196 MeV in Gatchina [5,6], up to 150 MeV in Louvain [7], up 1000 MeV in CERN [8]. These new experimental results make it reasonable to revisit the old evaluation. The ^{nat}Pb(n,f) reaction looks also promising from the large amount of available experimental data.

References:

[1] I. Durán, R. Capote, private communication, April 4, 2013
[2] Accelerator and Spallation Target Technologies for ADS Applications: A Status Report. OECD/NEA Report No. 5421, NEA, 2005.
[3] A.D. Carlson, S. Chiba, F.-J. Hambsch, N. Olsson, A.N. Smirnov, INDC(NDS)-0368, IAEA, May 1997.
[4] A. N. Smirnov *et al.*, Phys. Rev. C **70**, 054603 (2004).
[5] O. Shcherbakov *et al.*, J. Nucl. Sci. Technol. Suppl. **2**, 230 (2002).
[6] A.B. Laptev, A.Yu. Donets *et al*., Conf. Fiss. Prop. of Neutron-Rich Nucl.,Sanibel Island 2007, USA, p.462
[7] R. Nolte *et al.*, J. Nucl. Sci. Technol. Suppl. **2**, 311 (2002).
[8] D. Tarrio, L. Tassan-Got, L. Audouin *et al.*, Phys. Rev. C **83**, 044620 (2011)

Action: Simakov will revisit ^{209}Bi(n,f) reaction: review available experimental data, try to update recommended cross sections using GMA and modern standards for ^{235,238}U(n,f).

6. Milestones for the Standards Release

The next meeting is planned for December 2014, The final TM is planned for summer 2016. The final evaluation of standards and reference data should include evaluated cross sections, spectra and uncertainties in tabular form, and in the ENDF-6 format. To avoid a delay in the release of the evaluation, the description of the evaluation will be summarized in the last meeting report and working papers presented at that meeting.

6.1. Project Timeline

July 2014
Deadline for submission of experimental data to be included into the preliminary GMA fit of standards. Hydrogen data must be available at this time for the R-matrix evaluation.

December 2014
A Technical Meeting will take place to discuss

- The R-matrix evaluations
- Preliminary GMA fit with inclusion of all data
- Preliminary combined least squares fit of ^{252}Cf(sf) and ^{235}U(n_{th},f) prompt fission neutron spectra
- Preliminary least squares fit of (n,n'γ) reference gamma-ray production cross sections
- Preliminary evaluation of other reference cross sections

December 2014
Deadline for submission of experimental data to be included in the new standard and reference evaluation.

January 2016
Release of the standard and reference evaluations for validation.

Summer 2016
The final technical meeting will be held where the decision will be taken by participants about the final release of standard and reference evaluations and their descriptions in the form of working papers presented at the meeting and published electronically in the meeting's summary report.

Appendix 1

Technical Meeting on

"Toward a New Evaluation of Neutron Standards"

IAEA Headquarters, Vienna, Austria
8-12 July 2013

Meeting Room VIC B0401

Provisional AGENDA

Monday, 8 July

08:30 - 09:30 **Registration** (IAEA Registration desk, Gate 1)

09:30 - 10:15 **Opening Session**

Welcoming address
Self-introduction of participants
Election of Chairman and Rapporteur
Adoption of Agenda
Introduction and goals of the project – R. Capote

10:15 - 12:15 **Review of the status of IAEA Data Development Project – A.D. Carlson**

Presentations by participants

12:15 – 12:30 Administrative matters

12:30 – 14:00 ***Lunch***

14:00 – 18:00 **Presentations by participants (cont'd)**

Coffee break as needed

Tuesday, 9 July

09:00 - 12:30 **Presentations by participants (cont'd)**

Coffee break as needed

12:30 – 14:00 ***Lunch***

14:00 – 18:00 **Presentations by participants (cont'd)**

Coffee break as needed

19:00 ***Dinner at a Restaurant (see separate information)***

Wednesday, 10 July

09:00 - 12:30 **Discussion on STD reactions: R-matrix fit, actions**

Coffee break as needed

12:30 – 14:00 ***Lunch***

14:00 – 18:00 **Discussion on STD reactions: GMA fit, actions**

Coffee break as needed

Thursday, 11 July

09:00 - 12:30 **Discussion on proposed reference neutron fields:**
Cf-252(sf) and U-235(n,f), actions

Coffee break as needed

12:30 – 14:00 ***Lunch***

14:00 – 18:00 **Discussion on additional reference reactions, actions**

Coffee break as needed

Friday, 12 July

09:00 - 16:00 **Drafting of the meeting summary report and review of agreed actions**

Coffee and lunch break(s) in between

16:00 **Closing of the meeting**

Technical Meeting

"Toward a New Evaluation of Neutron Standards"

IAEA, Vienna, Austria
8 – 12 July 2013

LIST OF PARTICIPANTS

AUSTRALIA

Anton Wallner
The Australian National University
Research School of Physics and Engineering
Building 57, Nuclear Physics
ACT 0200, Canberra
Tel: + 61 2 6125 2074
E-mail: anton.wallner@anu.edu.au

AUSTRIA

Herbert Vonach
Institut für Isotopenforschung
und Kernphysik
Universität Wien
Währinger Strasse 17
1090 Vienna
Tel: +
E-mail: herbert.vonach@utanet.at

CHINA

Xi Tao
China Institute of Atomic Energy
China Nuclear Data Center (CNDC)
P.O. Box 275(41)
Beijing 102413
Tel: + 86-10-69357830
E-mail: taoxixishi@gmail.com

Wenming Wang
China Institute of Atomic Energy
China Nuclear Data Center (CNDC)
P.O. Box 275(41),
Beijing 102413
Tel: + 86-10- 69358562
E-mail: eaglewwm@gmail.com

GERMANY

Wolf Mannhart
Güldenkamp 71
38108 Braunschweig
Tel: +
E-mail: wmannhart@aol.de

JAPAN

Satoshi Kunieda
Japan Atomic Energy Agency
Nuclear Data Center
2-4 Shirane Shirakata
Tokai-mura, Naka-gun
Ibaraki 319-1195
Tel: + 81-029-282-5482
E-mail: kunieda.satoshi@jaea.go.jp

RUSSIA

Vladimir G. Pronyaev
Centr Jadernykh Dannykh
Fiziko-Energeticheskij Institut
Ploshchad Bondarenko
249 033 Obninsk
Kaluga Region
Tel.: +7 48439-94589
E-mail: pronyaev@ippe.ru

USA

Allan D. Carlson
National Institute of Standards
and Technology (NIST)
Radiation and Biomolecular Physics
Division
100 Bureau Drive, Stop 2300
Gaithersburg MD
Tel: + 1 (301) 975-5570
E-mail: allan.carlson@nist.gov

USA cont'd

Donald Smith
Applied Physics Division
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439
E-mail: Donald.L.Smith@anl.gov

Toshihiko Kawano
Los Alamos National Laboratory
T16, MS B243, Theoretical Division
Los Alamos NM 87545
Tel: + 1 505-664-0513
E-mail: kawano@lanl.gov

Gerald M. Hale
Los Alamos National Laboratory
PO Box 1663
Los Alamos NM
E-mail: ghale@lanl.gov

Denise Neudecker
Los Alamos National Laboratory
PO Box 1663
Los Alamos NM
E-mail: dneudecker@lanl.gov

INTERNATIONAL ORGANIZATION

Franz-Josef Hambsch
DG Joint Research Centre (JRC)
Unit D.4. Standards for Nuclear
Safety, Security and Safeguards
Institute for Reference Materials and
Measurements
Retieseweg 111
B-2440 Geel, Belgium
Tel.: + 32 (0)14 571 351
E-mail: franz-josef.hambsch@ec.europa.eu

IAEA

Roberto Capote Noy
International Atomic Energy Agency (IAEA)
Nuclear Data Section
Division of Physical and Chemical Sciences
Wagramer Strasse 5
1400 Vienna
Tel. + 43-1-2600 21713
E-mail: r.capotenoy@iaea.org

Stanislav Simakov
International Atomic Energy Agency (IAEA)
Nuclear Data Section
Division of Physical and Chemical Sciences
Wagramer Strasse 5
1400 Vienna
Tel. + 43-1-2600 21717
E-mail: s.simakov@iaea.org

Paraskevi (Vivian) Dimitriou
International Atomic Energy Agency (IAEA)
Nuclear Data Section
Division of Physical and Chemical Sciences
Wagramer Strasse 5
1400 Vienna
Tel. + 43-1-2600 21708
E-mail: p.dimitriou@iaea.org

Hyperlinks to Participants Presentations

#	Author	Title	Link
1	R. Capote	Toward A New Evaluation Of Neutron Standards	PDF
2	A.D. Carlson	Status of the Data Development Project With an Emphasis on Measurements Made or Underway Since the Last International Evaluation of the Standards	PDF
3	G.M. Hale	Light-Element Neutron Standards	PDF
4	F.-J. Hambsch	New cross sections for $^{10}B(n,a)^{7}Li$ and first ideas about $^{6}Li(n,t)^{4}He$	PDF
5	T. Kawano	Cross Section Standards in ENDF/B-VII.1 and Future Evaluations	PDF
6	S. Kunieda	R-matrix Analysis for n+^{16}O Cross-sections and Preliminary Results	PDF
7	W. Mannhart	A new attempt in evaluating the experimental database of the PFNS of U-235 + n (thermal)	PDF
8	R. Nelson	The Search for More Suitable Gamma-Ray Cross Section Reference Candidates	PDF
9	D. Neudecker	Why do we obtain low evaluated cross section and PFNS uncertainties?	PDF
10	V.G. Pronyaev	Influence of New Experimental Data on Standards Update: Light Elements and capture reactions	PDF
11	V.G. Pronyaev	Influence of New Experimental Data on Standards Update: Fission Cross Sections	PDF
12	V.G. Pronyaev	Influence of New Experimental Data on Standards Update: $^{235}U(n_{th},f)$ Prompt Fission Neutron Spectrum	PDF
13	V.G. Pronyaev	Influence of New Experimental Data on Standards Update: gamma-ray reference production cross section	PDF
14	Xi Tao	FDRR code and calculation of ^{7}Li system	PDF
15	Xi Tao	Theory and techniques in FDRR code	PDF
16	S.P. Simakov	Types of Cf-252 sources and possible impact on evaluation of neutron spectrum	PDF
17	S.P. Simakov	$^{48}Ti(n,n'gamma_{948})$ gamma production reaction as a candidate for a reference	PDF
18	D.L. Smith	Some Thoughts on Evaluating the Neutron Cross Section Standards	PDF
19	A. Wallner	Accelerator Mass Spectrometry & Neutron-induced Reactions	PDF
20	P. Schillebeeck	Cross section measurements at GELINA in support to the standards project	PDF

Photo of the Meeting Participants

Nuclear Data Section
International Atomic Energy Agency
Vienna International Centre, P.O. Box 100
A-1400 Vienna
Austria

E-mail: NDS.Contact-Point@iaea.org
fax: (43-1) 26007
Telephone: (43-1) 2600-21710
Web: http://www-nds.iaea.org