https://doi.org/10.61092/iaea.t5ga-7qcy

INDC(NDS)-0677
Distr. Web ST+G

INDC International Nuclear Data Committee

Summary Report from the Technical Meeting on

Current Status of Neutron Standards

IAEA Headquarters
Vienna, Austria

1-5 December 2014

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
IAEA Nuclear Data Section
Vienna, Austria

October 2015

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 in Austria
October 2015

INDC(NDS)-0677
Distr. Web ST+G

INDC International Nuclear Data Committee

Summary Report from the Technical Meeting on

Current Status of Neutron Standards

IAEA Headquarters
Vienna, Austria

1-5 December 2014

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
IAEA Nuclear Data Section
Vienna, Austria

October 2015

TABLE OF CONTENTS

1. INTRODUCTION

The Meeting was opened by Robin Forrest, the Head of the Nuclear Data Section of the IAEA. He welcomed participants and paid attention to the need of finalizing the work in the time when new standards will be needed for preparation of new versions of evaluated nuclear data libraries.

Roberto Capote presented the main aims of the Meeting: to discuss new experimental data to be included in the GMA Standards database and to release a preliminary version of the Standards, which will demonstrate the trends of the new evaluation. These trends could be shown in the materials of the Meeting, although the evaluation can be completed after the meeting with inclusion of all experimental data presented and discussed at the Meeting. In addition to the traditional standards, the new GMA evaluation should include the extension of the energy range of the standard for the ^{197}Au(n,γ) cross section below 100 keV (as an important standard for capture cross section measurements for astrophysical applications), improving of the cross sections which are not used as the standards but are included in the combined fit of the standards and are important for reactor applications – the ^{238}U(n,γ) cross section between 10 and 100 keV, and the ^{238}U fission cross section between 0.5 MeV and 2 MeV. The other important reference cross sections and spectra which should be evaluated in the framework of the Standards Data Development Project are the prompt gamma-production cross sections for neutrons in the energy range from thermal to 15 MeV, the ^{252}Cf spontaneous fission neutron spectrum, the ^{235}U(n_{th},f) prompt fission neutron spectrum and the high energy reference cross sections for the ^{235}U(n,f), ^{238}U(n,f), ^{209}Bi(n,f) and ^{nat}Pb(n,f) reactions for the neutron energy range 200-1000 MeV. The final release of the standards and reference cross sections and spectra should be completed in 2016.

A. Carlson was elected Meeting Chairman and V. Pronyaev was elected as Rapporteur. The preliminary agenda of the meeting was agreed upon. It was decided that the first two and a half days wwould be devoted to the presentations of the participants and the last two and half days – to the discussions and establishment of the decisions and recommendations. The order of the topics for the meeting was taken as the following:

- Prompt fission neutron spectrum (PFNS) for the ^{235}U(n_{th},f) reaction;
- Spontaneous fission neutron spectrum for ^{252}Cf;
- Light elements standards: ^{1}H(n,p), ^{6}Li(n,t), ^{10}B(n,$\alpha_1\gamma$), ^{10}B(n,α_0), C(n,n);
- ^{197}Au(n,γ) reaction cross section 0.2 MeV to 2.5 MeV and at thermal;^{197}Au(n,γ) reaction cross section below 100 keV;
- ^{238}U(n,γ) reaction cross section below 100 keV;
- ^{235}U(n,f) and ^{238}U(n,f) standards up to 200 MeV neutron energy;
- ^{239}Pu(n,f) cross section up to 200 MeV neutron energy;
- Prompt gamma-production cross sections for neutrons in the energy range from thermal to 15 MeV;
- High-energy (E_n > 200 MeV) neutron reference cross sections;
- Thermal constants evaluation used in the standards evaluation.

2. SUMMARY OF PARTICIPANTS' PRESENTATIONS

Brief summaries of participants' presentations are given below, including their most important statements and conclusions. The full versions of presentations are available through the hyperlinks given in Appendix III of this report.

2.1. A. Trkov

An evaluation of the PFNS for $^{235}U(n_{th},f)$ using the GANDR code was reported. For the least-squares fit, experimental data were taken as shape data with a model basis function consisting of a combination of Maxwell and Watt energy distributions. A complete information on PFNS evaluation is contained in the Nuclear Data Sheets paper accepted for publication in January 2016. The average energy of the PFNS is 2.00(0.01) MeV, compared with 2.03 MeV, the value used in most evaluated data libraries.

2.2. V. Pronyaev

The results of a non-model evaluation of the $^{235}U(n_{th},f)$ PFNS using the GMA code and experimental data taken a) as absolute ratios of $^{252}Cf(s.f.)$ spectra to $^{235}U(n_{th},f)$ PFNS, or b) as shape of ratios of $^{252}Cf(s.f.)$ spectra to $^{235}U(n_{th},f)$ PFNS were presented. The least-squares normalization set to 1 with the uncertainty equal to the uncertainty of the standard evaluation's average prompt fission neutron yield (0.15%) was used. A third order power polynomial fit of the PFNS evaluated in the energy range 0.025 to 12.3 MeV was used for smoothing of the non-model fit. The extrapolation of the spectra to 0 and 30 MeV neutron energies was done. The extrapolation to zero energy seems reasonable because of the weak energy dependence of the spectrum in the ratio to Maxwellian (kT=1.32 MeV). To investigate the extrapolation to 30 MeV, the energy dependence of the polynomial smoothed spectrum in the energy range between 6 and 10 MeV was analyzed. It was found that in this energy range the dependence is very close to a linear dependence in log-lin scale. Because for reactor applications the contribution from PFNS neutrons in the region of 10 to 30 MeV is very small, it was decided to use this dependence for the extrapolation to 30 MeV. The average energy of the PFNS when using absolute ratios in the evaluation is 1.98 MeV and for using shape ratios it is 2.00 MeV, compared with 2.03 MeV, the value used in most evaluated data libraries.

2.3. W. Mannhart

A new evaluation of the $^{235}U(n_{th},f)$ PFNS using a Bayesian approach was done. Experimental data used in the fit were taken as the absolute ratio of $^{252}Cf(s.f.)$ spectra to $^{235}U(n_{th},f)$ PFNS. To linearize the fitted data, the "double ratio" approach was used, namely the absolute ratio of the $^{252}Cf(s.f.)$ PFNS to a Maxwellian spectrum with kT=1.42 MeV was divided by the absolute ratio of the $^{235}U(n_{th},f)$ PFNS to a Maxwellian spectrum with kT=1.32 MeV. Attention was paid to the analysis of the uncertanty components related to the neutron energy resolution in the TOF measurements of the PFNS. This component substantially increases the uncertainty in the high energy "hard" part of the spectra, when often transition from narrow to wide energy steps is carried out. The PFNS evaluation obtained has a minimal 1.5% uncertainty near the average energy of the spectrum (2 MeV). The cubic spline fit, extrapolation of the spectrum above the range of the evaluation in the "double ratio" space and the final normalization to 1 was done using a non-model evaluation of the data.

2.4. A. Carlson

Measurements made after the last release of the standards were presented. Results that will probably not be available in time for this evaluation are in bold:

Daub et al. made measurements of the hydrogen total cross section at low neutron energies. The data were measured from 150 keV to 800 keV. The results are systematically slightly larger than the evaluated values but generally within their uncertainties of 1.1 to 2%. **Additional work at Ohio**

University on the hydrogen standard now emphasize the small angles in the center of mass system (CMS) at about 10 and 14 MeV where very few data are available.

Accurate absolute measurements of the ^{6}Li(n,t) cross section at 4 meV by Yue et al.at NIST are very consistent with the results of the most recent standards evaluation. **Hambsch is planning measurements of the ^{6}Li(n,t) cross section relative to the ^{235}U(n,f) standard from a few keV to 3 MeV.** Giorginis and Bencardino have made measurements and are now analyzing ^{6}Li(n,t) cross section data relative to the ^{238}U(n,f) standard for the 1.8 to 2.1 MeV region.

Hambsch is making branching ratio, angular distribution and cross section measurements for the ^{10}B(n,α) reaction up to about 3 MeV. **An Ohio University collaboration made measurements of the ^{10}B(n,$\alpha_1\gamma$), ^{10}B(n,α_0), ^{10}B(n,p) and ^{10}B(n,t) cross sections at the WNR facility at LANL relative to the 238U(n,f) standard. Analysis of these data is still ongoing.**

Carbon transmission measurements have been made by Gritzay et al. There are also measurements of the carbon total cross section by Anh, et al. made with reactor filtered beams at 54 and 148 keV that agree with the standards evaluation. Daub et al. also made measurements of the carbon total cross section. They agree with the standard within uncertainties but are lower than it.

A ^{238}U(n,γ)/Au(n,γ) cross section ratio measurement by Wallner et al. at 430 keV agrees with the standards evaluation. ^{238}U(n,γ) cross section 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. The LANL measurements by Ullmann et al. of the ^{238}U(n,γ) cross section generally agree with the standards evaluation over their entire energy range - 10 eV to 100 keV. In part of the energy region of that measurement the data were obtained relative to the ^{235}U(n,f) cross section where it is not a standard!

Measurements up to about 1 Gev previously reported by Calviani et al. and Audouin et al. are being published in a combined n_TOF paper by Paradela et al. It now is reported as four data sets that agree with each other within their uncertainties and also with the standards evaluation. They also agree with the Lisowski et al. results but differ with the Shcherbakov et al. data above about 20 MeV. **An experiment has been designed at the University of Kentucky and preliminary measurements have been made of the ^{238}U(n,f) cross section by Miller and Kovash. The data are being measured relative to hydrogen scattering for neutron energies above 100 MeV at WNR.** Two separate measurements have been made at LANL of the ^{239}Pu(n,f) cross section by Tovesson and Hill relative to the ^{235}U(n,f) cross section. The high energy experiment agrees well with the standards evaluation up to about 15 MeV. Above that energy the measurements are somewhat lower than the standards evaluation. There is unusual structure in the low energy experiment at energies above about 30 keV. Thus only data below that energy may be useful for the evaluation. **Very accurate fission cross section ratio measurements that include ^{239}Pu(n,f) data are being measured at the LANL WNR facility. The data are being obtained with a Time Projection Chamber in a collaboration headed by LANL and LLNL. Some data analysis has been done.**

We have broadened the standards research effort by considering, in addition to the traditional activities related to standards, extending the energy ranges of the standards, including “reference data” that are not as well-known as the standards but can be very useful in certain types of measurements, and certain neutron spectra data.

2.5. G. Hale

The status of the ^{1}H(n,n), n+^{6}Li (^{7}Li system), n+^{10}B (^{11}B system) and n+^{12,13}C reactions was discussed. The energy range for the R-matrix fit of the ^{1}H(n,n) cross section has been extended up to 50 MeV. It may be possible for the energy range for the ^{6}Li(n,t) cross section to be extended up to 4 MeV in neutron incident energy now. The most important channel for determination of parameters is the (t,α) channel where numerous high precision measurements are available. The latest high precision value of ^{6}Li(n,t) cross section measured by Yue at 3.3 meV is very close to the Standards

2006 evaluation. It was pointed out, that the Lamaze data can be used only up to 0.5 MeV and the recent Georginis result at 2 MeV is very close to the evaluation. A new approach for estimation of the uncertainties of cross sections evaluated using the R-matrix for light element standards was considered. It is proposed to use the parameter confidence intervals and not standard one sigma evaluated error for characterization of uncertainties for light element standards evaluations. This will increase the uncertainty by the value of the square root of the number of parametrers to which the data are sensitive (see e.g. Avni, The Astrophysical Journal, 210, p.642 (1976)).

2.6. Xi Tao

The work on the development of the FDRR code including the evaluation of covariance matrices of uncertainties has continued. The present results obtained with the FDRR code which is supposed to be used for the multichannel R-matrix fit of cross sections for light element in a wide energy range (up to 2 MeV) are still very contradictory. The verification of the code in the R-matrix mode is needed. A small meeting was organized with G. Hale, Xi Tao, Wenming Wang and S. Kunieda, to agree not only on the data to be used for code verification (Test2b case) but also on the prior parameters to be used in the chi-square minimization.

2.7. S. Kunieda

The results of calculations with the R-matrix AMUR code for the Test2b ^{6}Li(n,t) data used in the verification of the R-matrix codes and for n+^{16}O reactions important for CIELO project were presented. The results of the ^{6}Li(n,t) work show the influence of systematic (correlated) uncertainties of experimental data on the R-matrix fit (the evaluated cross sections as well as covariance matrix of uncertainties). Unfortunately because the formulation of the purpose of the Test2b test was not clear and also the absence of the specification of prior parameters, the verification results obtained can not be used in the intercomparison. The status of the AMUR code programmed with modern languges and based on a full treatment of experimental uncertainties was discussed. Preliminary results of the fit for differential p+^{7}Li reaction data were shown. Cross section reactions induced by neutrons with energy up to 5.2 MeV were evaluated for ^{16}O using four experimental total cross section data sets and one for inverse reaction, ^{13}C(α,n). Presented R-matrix analysis is nearly independent of systematic difference in measurements. Renormalization coefficient of Harissopoulos 2005 data is shown to be equal to 1.462 ± 1%, for Ohkubo data is 1.018 ± 0.35%. Present result supports “old” ^{13}C(α,n)^{16}O measurements, Bair and Haas (73) giving higher (n,α) values.

2.8. S. Kopecky

The results of high-precision measurements of ^{197}Au(n,γ) and ^{238}U(n,γ) cross sections done at Geel were compared with the 2006 Standards evaluation and with the results of other new measurements and revised old data. It was shown that the structure in the cross sections at the bins used in the standards evaluation is also seen in these data up to 20 keV. The average measured ^{197}Au(n,γ) cross section is 1.5% below the 2006 standard cross section in the energy range 3 to 80 keV. A large difference with the 2006 standards for the ^{238}U(n,γ) cross section in the 3 – 80 keV region is observed for some bins, but on the average, the cross section measured at Geel is higher below 20 keV and lower above 20 KeV than the 2006 standards.

2.9. A. Wallner

The results for standard cross sections obtained with the AMS method can be used for benchmarking for spectrum averaged cross section measurements and in the evaluation of cross sections where the irradiation is done with monoenergetic neutrons. The method can also be used for measurements of very low cross sections and for some cross sections which can not be measured by traditional methods (i.g. activation method). Good consistency is observed between the results of this measurement and the ENDF/B-VII.1 Maxwellian spectrum averaged cross section for the ^{238}U(n,γ) cross section near kT=30 keV (the standard cross section is close to that in ENDF/B-VII.1, but it does not cover the entire energy range). There is also good agreement between these AMS measurements and those for monoenergetic neutrons with energies of 0.426 MeV and 2.1 MeV. However a 10 to 15% difference is observed between measurements and calculations for 0.52 MeV and 1 MeV. The ratio of the value measured with the AMS technique to that calculated using the ENDF/B-VII.1 averaged cross sections for the $^{238}U(n,\gamma)$ to $^{197}Au(n,\gamma)$ cross section ratio for a Maxwellian-like spectrum at 25 keV and at 426 keV are consistent witin the limits of the uncertainties of the measurements. These results and those of microscopic measurements of the $^{197}Au(n,\gamma)$ cross section done at Geel, n_TOF and the latest Maxwellian spectrum averaged cross section measurements done with different methods may led to the revision of the data in the KADONIS database used in astrophysics.

2.10. G. Noguere

Feedback on the $^{235}U(n,f)$ standards based on analysis of integral experiments was presented. A new evaluation with SAMMY of the cross section integral between 7.8 – 11 eV, which can be used for the normalization of cross sections in the resonance range done in the frameworks of the CIELO project gives a value of 241.6 b∗eV (equal to the current ENDF-B/VII.1 value) compared with the Standard 2006 recommended value of 246.40±1.24 b∗eV. No large differences with the 2006 Standards thermal values and with the JEFF-3.1.1 evaluation were observed. Because the standards contain evaluations only for some reactions and constants and are incomplete for use in integral and benchmark calculations, files from JEFF-3.1.1 were used in comparisons of experimental and calculated results. But most conclusions can be the same for both evaluations. Good agreement was observed in the boron-uranium normalization reactivity measurements at the MINERVE facility. Excellent agreement with temperature reactivity experimental data from the EOLE facility for uranium oxide fuel between 10 and 80 degrees was obtained. For this comparison, a very low-energy positive resonance was added to increase capture below the thermal point. Experimental data from irradiated fuel in thermal systems show the need for a small increase of the $^{235}U(n,\gamma)$ cross section which is consistent with the evaluation of the thermal constants in the standards 2006 evaluation. PROFIL and PROFIL-2 results for reaction rates obtained at the PHENIX reactor are consistent with the standards evaluation for the $^{235}U(n,f)$ cross section for a fast reactor spectrum. Results of a new neutron resonance shape analysis with the CONRAD code for neutrons with energy between 2 meV to 11 eV was presented. The AGS methodology was used for presentation of the covariance matrix of uncertainties of the evaluated cross sections. A simultaneous fit of all included experimental data gave an evaluated thermal fission value of 582.7±4.4 b, compared with 584.33±1.24 b from the Standards 2006 evaluation and the cross section integral between 7.8 – 11 eV of 244.5±2.9 b∗eV compared with 246.40±1.24 b∗eV in the Standards 2006 evaluation. The results are preliminary because a careful test of experimental corrections is in progress now.

2.11. I. Duran

The results of fission cross section measurements at the n_TOF facility using PPAC detectors were presented. Each PPAC detector allows the measurement of 9 targets simultaneously. Two targets in each detector are ^{235}U and ^{238}U used as standards. ^{nat}Pb and ^{209}Bi targets were also used in the measurements. The primary results of these measurements are the ratios between different fission cross sections with the contribution to the standards evaluation through the $^{238}U(n,f)/^{235}U(n,f)$ cross section ratio and possible extension of the standards to high energy (1 GeV) using these ratios and also ratios of the $^{nat}Pb(n,f)$ and $^{209}Bi(n,f)$ cross sections to the $^{235}U(n,f)$ and $^{238}U(n,f)$ cross sections. Targets in some PPAC detectors were tilted at 45° relative to the neutron beam to improve the geometrical acceptance of the detector and decrease the efficiency correction of the detector up to 2% at most. The IAEA 2006 standard for the integral of the ^{235}U fission cross section in the energy range 7.8 – 11 eV was used for normalization of the cross sections. The results of absolute ratio measurements for one PPAC perpendicular and two tilted target positions were presented and compared with results of measurements obtained with a fission ionization chamber. A maximum spread of the 4 data sets is observed at hundreds MeV neutron energy and is less than 8%. An opportunity to use the ^{209}B(n,f) and ^{nat}Pb(n,f) cross sections as neutron high-energy standards between 200 MeV and 1 GeV was discussed. It was shown that using a combination of consistent neutron measurements done in different setups, proton-induced fission cross section measurements and the results of comprehensive model calculations, it is possible to create an evaluation of the high-energy ^{209}Bi(n,f) cross section standard up to 800 MeV.

2.12. P. Romain

The status of ^{235}U evaluated data in the fast neutron energy range was considered. A new BRC(2014) evaluation based on TALYS calculations was prepared with higher fission and lower capture cross sections in the range 0.5 – 3 MeV, a lower inelastic scattering cross section at these energies and with lower average energy of the prompt fission neutron spectrum (1.97 MeV) than in the ENDF/B-VII.1 evaluation. Different versions of the evaluated data files were created by combination of a new ORNL evaluation in the resolved resonance range with the JENDL-4 (CIELO, version 2 file) and with the BRC(2014) (CIELO, version 3) evaluation in the fast range. The C/E values for k_{eff} were calculated for criticality benchmarks with fast neutron spectra and with different reflectors or without a reflector (Godiva). A bias of about -300 pcm is observed for the CIELO (version 2) file compared with ENDF/B-VII.1, which generally is more consistent with the experimental data. The results with the CIELO (version 3) file are in better consistency with experimental data. They have with a positive bias relative to ENDF/B-VII.1 between tens and 150 pcm. Good consistency for the CIELO (version2) file is observed for the ZEUS intermediate spectrum benchmarks. The calculations for the Godiva assembly with the transition from CIELO version 2 to version 3 was done by sequential replacing 7 sets of parameters and cross sections of version 2 to version 3. The largest influence on k_{eff} are changes in average prompt neutron yield, capture, inelastic and fission cross section. Similar transitions were done for the ZEUS-1 critical assembly benchmark. The largest sensitivity for this assembly is to prompt fission neutron spectra and to the capture cross section. A new version of capture with higher values of cross sections in the keV – hundreds keV range was obtained with the CIELO (version 3 new) file. With the new capture cross section, a good description was obtained for the Godiva (C/E=0.99938) and ZEUS-006 benchmarks. The same improvement is observed in the calculations for the JEMIMA critical assembly but not for BIGTEN which contains a large quantity of ^{238}U.

2.13. S. Simakov

Feedback from the IAEA CRP "Testing and Improving the International Reactor Dosimetry and Fusion File (IRDFF)" was reported. The NDS of the IAEA currently coordinates a CRP on the IRDFF extension and validation (https://www-nds.iaea.org/IRDFFtest/), which involves around 20 experts from different labs worldwide. The first RCM was held 1 - 5 July 2013 (Summary Report INDC(NDS)-0639), the second one will be convened 16 to 20 March 2015.

The present version of IRDFF-1.05, released in Oct 2014, contains 79 reactions. IRDFF incorporated several reactions from the standards: ^{6}Li(n,t)^{4}He (below 2.8 MeV), ^{10}B(n,α_0)^{7}Li and ^{10}B(n,α_1)^{7}Li (below 1.0 MeV), ^{197}Au(n,γ)^{198}Au (from 4.8 keV to 2.6 MeV), ^{235}U(n,f) (from 25 keV to 200 MeV) and ^{238}U(n,f) (from 1 MeV to 200 MeV) and uses standard or reference neutron spectra for validation.

The presentation reported the results of the IRDFF benchmarking in the ^{252}Cf(s.f.) and ^{235}U(n_{th},f) spectra. The best agreement between experimental and evaluated spectrum averaged cross sections (SPA) was observed for the standard ^{252}Cf(s.f.) spectrum. Use of two spectra for ^{235}U(n_{th},f), one based on the Madland-Nix model and the other derived from time-of-flight measurements (Scale method), shows similarly acceptable results below 10 MeV, however a different tendency for the higher threshold reactions. It was also shown that the impact of spectra extension above 20 MeV do not exceed 1 - 2%.

The SPA for dosimetry and other reactions with thresholds higher then 8 – 10 MeV were calculated for the ^{252}Cf(s.f.) and ^{235}U(n_{th},f) spectra. The assessed SPA are rather small (between 0.01 and 1000 μb) and hence it is unlikely that they can be measured by conventional activation techniques. The applicability of alternative methods such as AMS, which have in some cases sensitivity to the accumulated long lived reaction products, can be used for cases of intensities available for neutron sources. Finally, requests for measurements of SPA or point energy cross sections needed for the validation of existing or newly evaluated dosimetry reactions was presented.

Because for very high mean neutron energy, the averaged reaction cross sections for the ^{252}Cf spontaneous spectrum and the ^{235}U PFNS are generally very low, a discussion led to the possibility of an experiment with deep penetration of beam fast neutrons in the region of above 10 MeV where the contribution from the prompt fission neutron spectrum is very small. It was suggested that full MC calculations starting from an initial reactor beam should be done to see if the high energy (hard) part of the PFNS spectrum is not disturbed by source fast neutron penetration through neutron thermalizing media and the fission plate. These calculations are even more important for experiments with in-reactor measurements.

2.14. B. Marcinkevicius

The preliminary results of a combined evaluation of ^{235}U(n,f), ^{238}U(n,f), ^{209}Bi(n,f) and ^{nat}Pb(n,f) reaction cross sections as a reference cross section for neutron energies from 20 to 900 MeV were presented .

The previous IAEA Technical Meeting “Toward a New Evaluation of Neutron Standards”, held 8 - 12 July 2013 recommended to establish a new reference cross section for high energy applications - ^{209}Bi(n,f). This presentation reported the work done and the first results: collection of the available experimental data, analysis of data uncertainties, theoretical calculations and preliminary evaluated (n,f) cross sections using the generalised least squares code GMA. Since in most of experiments, the ^{209}Bi(n,f) reaction was measured simultaneously with the ^{nat}Pb(n,f) reaction it was included in the analysis too.

The ^{209}Bi(n,f) and ^{nat}Pb(n,f) cross sections were evaluated together with other reactions (standards are highlighted as bold): **^{6}Li(n,t)**, ^{6}Li(n,n), ^{10}B(n,α_0), **^{10}B(n,α_1)**, ^{10}B(n,n), **^{235}U(n,f)**, **^{238}U(n,f)** and ^{239}Pu(n,f). (the lithium and boron cross sections are not standards in this energy range!) During the evaluation it was noted that the experimental data below 34 MeV are sparse and have large statistical uncertainties that result in large unphysical oscillations of the output cross sections. To get smoother cross sections, ^{209}Bi and ^{nat}Pb fission cross sections calculated at low energies by theoretical models were included. For this CEM3.03 imbedded in MCNP-6.1 [1] and TALYS-1.6 [2] were used.

The preliminary evaluation of ^{209}Bi(n,f) and ^{nat}Pb(n,f) cross sections provided stable results from 46 up to 200 MeV with uncertainty varying between 3 – 10%. At lower energies the uncertainty increases up to 30% due to lack of reliable experimental data.

Following a recommendation of the 2013 meeting, an attempt was made to extend the evaluated ^{209}Bi(n,f) and ^{nat}Pb(n,f) cross sections up to an energy of 1 GeV. However it turned out that at energies above 200 MeV all available ^{209}Bi(n,f) and ^{nat}Pb(n,f) cross sections were measured relative to ^{238}U(n,f) or ^{235}U(n,f) cross sections. There is not even one absolute (n,f) cross section measurement in this energy region even for the reference nuclei ^{238}U, ^{235}U and ^{239}Pu. Due to this reason the uncertainty of evaluated cross sections exceeds 30% above 200 MeV. That is unacceptable for reference cross sections. To reduce the uncertainty proton induced fission data for ^{238}U measured above 200 MeV by A. Kotov et al. [3] relative to p-p scattering was added to the analysis. Their experimental ^{238}U(p,f) data were rescaled by the cross sections ratio ^{238}U(n,f) to ^{238}U(p,f) obtained from CEM3.03 calculations. The cross sections uncertainties for all (n,f) reactions at energies above 200 MeV then drop below 10%, as is illustrated for the case of ^{238}U(n,f) in Fig. 1.

This analysis indicated that measurements of the absolute neutron induced fission cross sections (e.g. relative to n-p scattering) on uranium, bismuth, lead and plutonium have high priority for establishing neutron reaction standards above 200 MeV.

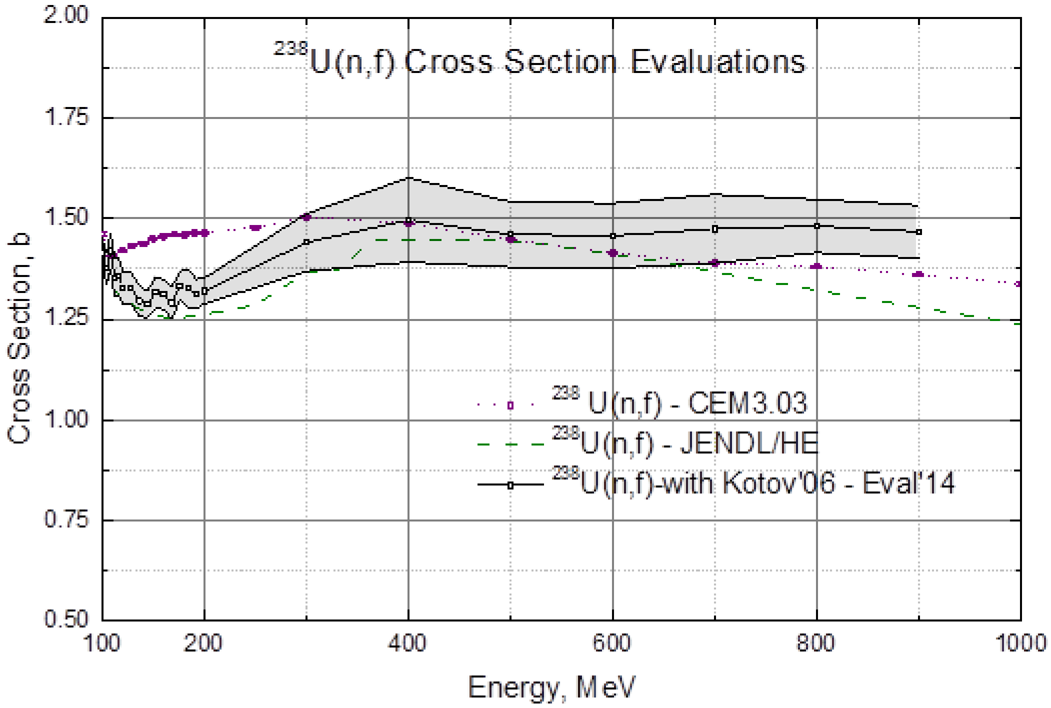

Fig. 1. *Preliminary evaluation of the ^{238}U(n,f) reaction cross section up to 1 GeV (black solid curve with uncertainty corridor) after inclusion of the absolute ^{238}U(p,f) data of A. Kotov et al..*

References:

[1] S.G. Mashnik, A.J. Sierk, and R.E. Prael, Nuclear Data Sheets **118** (2014) 320–322.

[2] A.J. Koning, D. Rochman, and S.C. van der Marck, Nuclear Data Sheets **118** (2014) 187–190.

[3] A.A. Kotov, L.A. Vaishnene, V.G. Vovchenko, et al., Phys. Rev. C7**4** (2006) 034605.

2.15. R. Capote

The problem of the thermal constants evaluation as a part of the combined standards fit was discussed. It is strongly related with the data compensation problem. For the standards 2006 evaluation, the Axton evaluation (1986) obtained in a least squares fit of experimental thermal spectrum averaged cross sections and data at thermal (0.0253 eV) energy was used as input data. One new experimental data (elastic scattering cross section at thermal point) was added to the combined fit. The calculated value of the K1 parameter (the best characterization of the k_{eff} value) for ^{235}U is well within the limits of the latest evaluation of K1 by Hardy. The K1 parameter was obtained from the analysis of large ORNL spherical critical assemblies with uranyl nitrate solutions (ORNL C8, ORNL T5, ORNL C1, and ORNL T1). Modern MCNP calculations using thermal constants close to those of the standards evaluation (ENDF/B-VII.1 file) underestimate their criticality at about -200 pcm. The results of these calculations are also dependent on the prompt fission neutron spectrum given in the file, but the calculated K1 parameter very weakly depend on the PFNS characterization for those assemblies. All this marginalizes the role of the K1 parameter in the thermal constants adjustment. Also the calculated value of K1, within the limits of the uncertainties of the Hardy evaluation, can be obtained if one uses as input to the standards evaluation the Axton thermal constants evaluation obtained from the fit of microscopic cross sections and parameters at the 0.0253 eV point only. It was proposed to use this evaluation by Axton as a prior in the new standards evaluation.

3. RECOMMENDATIONS

3.1 General

The use of parameter confidence intervals (see e.g., Y. Avni, The Astrophysical Journal, 210, p. 642-646 (1976)) instead of the “standard” determination of uncertainties in chi-square minimization considering all parameters in the fit as “important” will increase the uncertainty of the R-matrix model evaluated data for light elements and as a result increase the uncertanty of the other standard cross sections evaluated in the combined GMA non-model fit.

3.1.1. How the Results of the preliminary Standards fit should be presented

I. As combined evaluations with the GMA code of all data included in the least squares fit:
a) in the form of a table containing the results of the evaluation with the columns: energy, cross section, absolute and percent uncertainties, and the lower triangle of the correlation matrix for each reaction which was used in the combined fit. Data for the thermal constants can be given in a separate table with their correlation matrix;
b) in the ENDF-6 format with data in MF3 and MF33 files for all cross sections which were used in the combined fit with all covariance matrices including non-negligible matrices describing the cross-reaction correlations. Data for the thermal constants can be given in a separate table in free text (MT=451) with their correlation matrix.

II. As recommended Standards:
a) in the form of a table containing the results of the evaluation only for reactions recommended for use as standards with the columns: energy, cross section, absolute and percent uncertainties and the lower triangle of the correlation matrix for each reaction. The energy ranges are limited by the ranges recommended for the use of a given standard. The data for the thermal constants can be given in a separate table with their correlation matrix;
b) in the ENDF-6 format with the data in the MF3 and MF33 files limited by the energies determined as the ranges for the standards. The MF33 file should contain only non-negligible cross-reaction correlations. The data for the thermal constants can be given in a separate table in free text of the file (MT=451) with their correlation matrix.

3.2. Actions and particular recommendations

^{1}H

Hale will send ^{1}H standard data (elastic scattering cross section and angular distrbutions up to 50 MeV) to Pronyaev for revision of data in the GMA database measured relative to the ^{1}H standard. Cross sections and percent uncertainties for the energy nodes used in the GMA evaluation should be given.

^{6}Li

Hale will send data (cross sections, total uncertainties and lower triangles of the correlation matrix given at the GMA energy nodes) for the ^{6}Li(n,t) and ^{6}Li(n,n) reactions up to 2.8 MeV to Pronyaev for inclusion in the combined GMA fit.

^{10}B

Hale will send to Pronyaev ^{10}B(n,n), ^{10}B(n,α_0) and ^{10}B(n,$\alpha_1\gamma$) evaluations of cross sections and uncertainties for inclusion in the new combined fit of the standards. Using the trial GMA fit, the possibility of inclusion of Geel's ^{10}B branching ratio results (2013) between 0.5 and 1 MeV in the evaluation will be considered (Pronyaev). Below 0.5 MeV the Geel partial cross sections differ substantially from the previous standards evaluation, but the branching cross section ratio ^{10}B(n,a$_0$)/^{10}B(n,a$_1$) for the 57 m flight path at low energies is very consistent with the 2006 Standard.

^{197}Au(n,γ)

The results of the n_TOF and Geel experiments should be included in the combined GMA fit. The new expanded uncertainty for the ^{10}B(n,$\alpha_1\gamma$) reaction cross section used as the monitor reaction should replace the previous one used in determining the Geel AGS covariance matrix and the energy dependent uncertainty should increase up to about 1% at 80 keV from the use of the ^{10}B(n,$\alpha_1\gamma$) cross section as a flux monitor. MACS values for kT=30 keV obtained with the new evaluation of the standard should be calculated and reported. The results of the preliminary GMA evaluation for the ^{197}Au(n,γ) cross section obtained with inclusion of the data, discussed and recommended at this meeting are shown at the Figs. 2 and 3 as a ratio to the 2006 evaluation. In general, the new evaluated cross section is lower and shows stronger structure in the keV region compared with the previous evaluation. The results of the Geel measurements that have low total uncertanty (about 1.5%) will have strong influence on the evaluation. Their influence on the cross section evaluation is shown in Fig. 4.

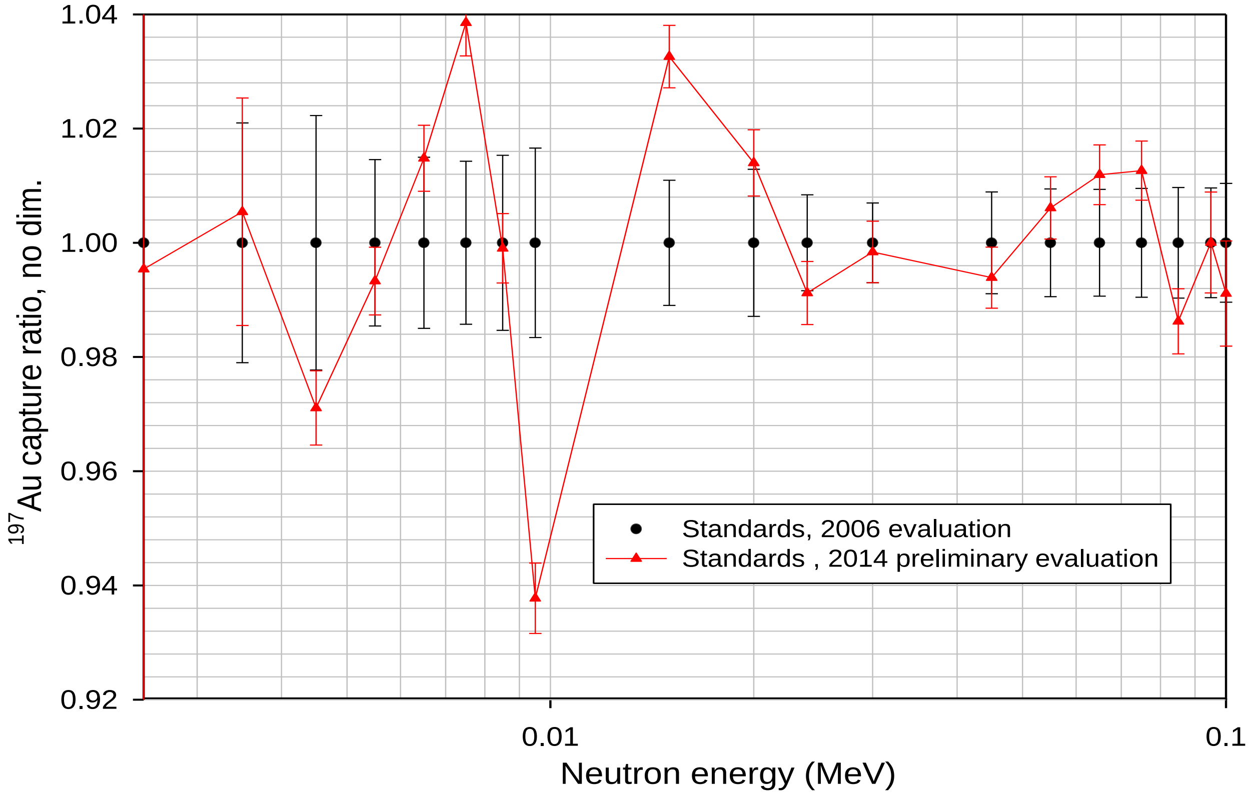

Fig. 2. *Ratio of the present (2014) preliminary evaluation to the 2006 standards evaluation (given as I with one sigma uncertainties) for the ^{197}Au(n,□) cross section for the energy range 2.5 – 100 keV.*

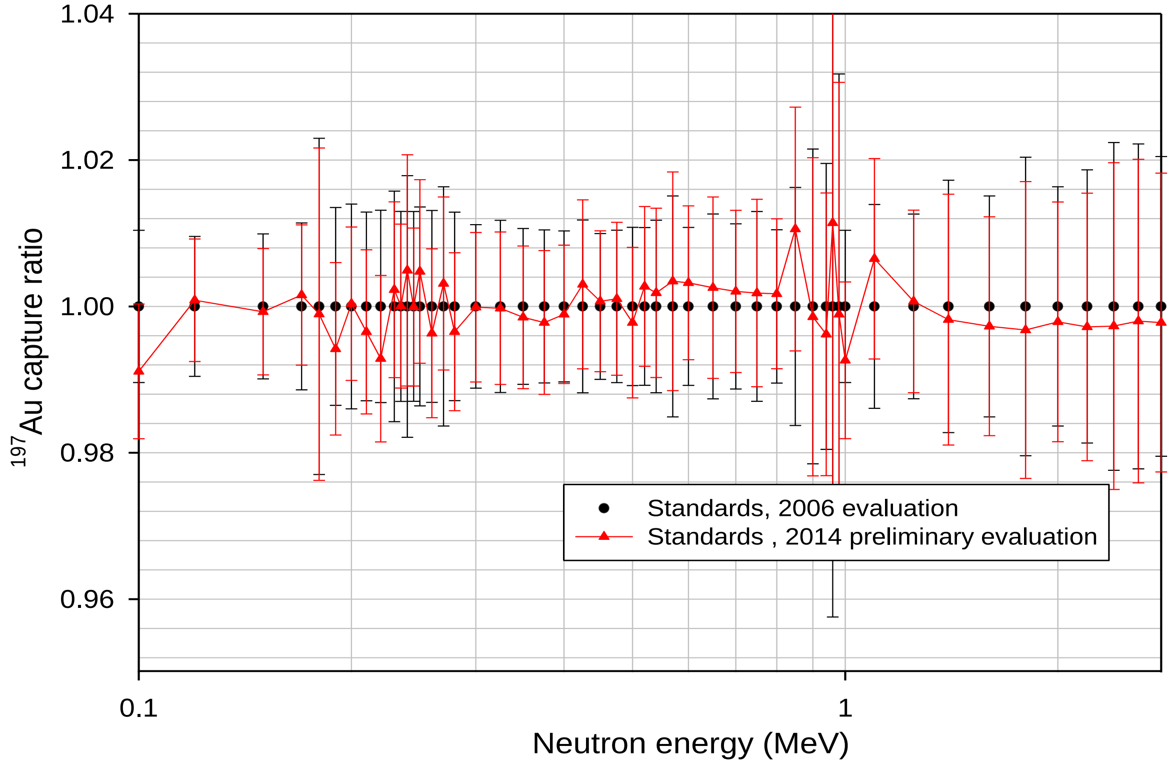

Fig. 3. *Ratio of the present (2014) preliminary evaluation to the 2006 standards evaluation (given as 1 with one sigma uncertainties) for the energy range 0.1 to 2.8 MeV.*

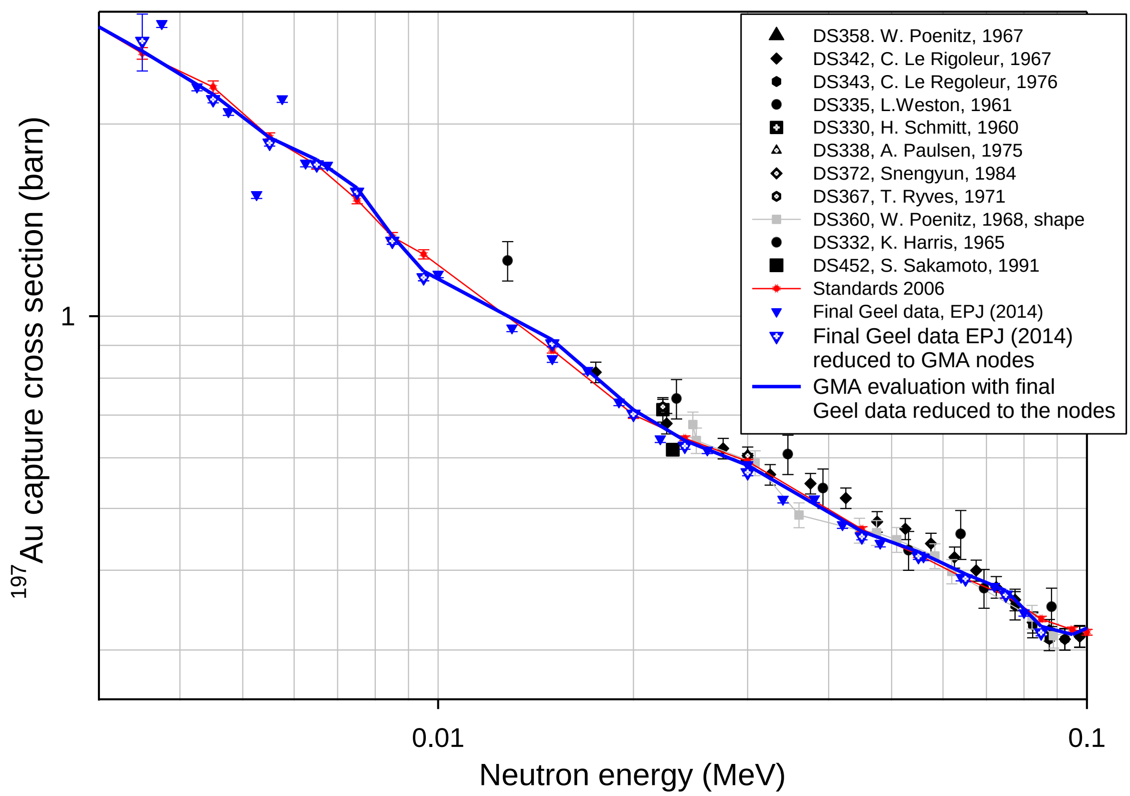

Fig. 4. *Comparison of the Geel experimental data with the results of the 2006 standards evaluation and the present evaluation which includes the Geel data in the combined GMA fit.*

^{208}U(n,γ)

The DANCE data (J.L. Ullmann et al., 2014) will be used up to 10 keV and above 200 keV, because they are not corrected for the contribution from ^{27}Al resonances from the encapsulation of the sample. Using these energy ranges also ensures that the data were measured relative to the ^{6}Li(n,t) and ^{235}U(n,f) cross sections in the energy regions where they are standards. The normalization was to resonance cross sections, not the standard set of reactions and due to this, they can be included in the fit only as shape data. The Harwell (M. Moxon, 1969) data could be used now with corrections introduced by Moxon in 2006. The Geel data (B. Becker et al., 2014) should be included in the fit with a revised component of uncertainties for the ^{10}B(n,$\alpha_1\gamma$) cross section used for flux determination. The ENDF/B-VII.1 evaluation by Derrien of the resonance parameters in the energy range 100 eV to 10 keV should be included in the fit as a pseudo-experimental data set. It can be prepared with the covariances using the ENDF/B-VII.1 file and the GLUCS code for correlation matrix presentation. Two n_TOF data sets (F. Mingrone et al., and T.Wright et al, 2014) obtained in the region from 3 keV to 80-90 keV in measurements with two different detectors should be included in the fit. The increase, averaging up to 2 % and substantial structure in the cross section are observed in the eV and keV region (see Fig. 5). Small variations, which are within the limits of the uncertainties are observed in the energy range above 100 keV (Fig. 6). In general, the new cross section is very consistent with new preliminary JEFF evaluation which is based on the results of optical model calculations with adjusted parameters. A small difference is observed only in the minimum at about 400 keV. A comparison of the preliminary GMA evaluation with the results of AMS cross section measurements near 0.46 MeV, 0.52 MeV, 1 MeV and 2.1 MeV demonstrates good consistency at 0.46 MeV and 2.1 MeV, but a large discrepancy at 0.52 and 1 MeV. A model evaluation done at Geel (I. Sirakov) shows (Fig. 7) that most probably the results of the AMS measurements at 0.52 MeV and 1 MeV have large systematical uncertainties, because it is difficult to expect changes of 14% in experimental value of a cross section with a change in energy from 0.46 to 0.52 keV, and that the cross section at 1 MeV is lower or equal to that at 0.46 or 0.52 MeV.

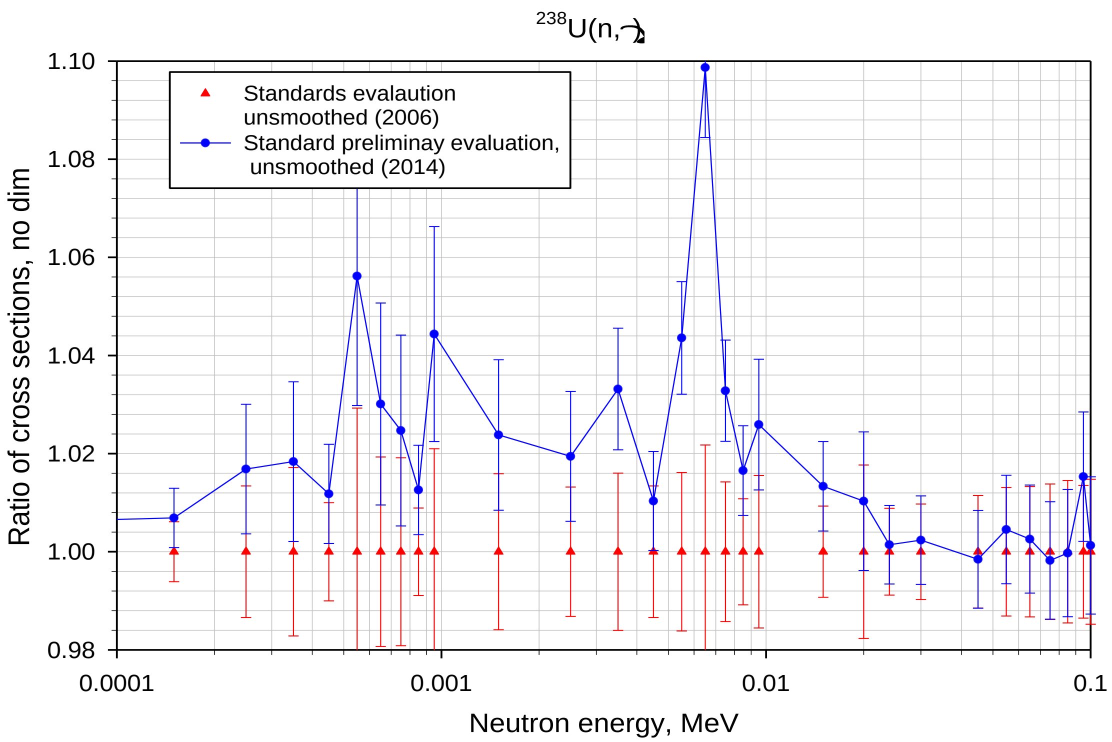

Fig. 5. *Ratio of the results of the preliminary evaluation (2014) containing new data to the 2006 standards evaluation for the energy range below 0.1 MeV.*

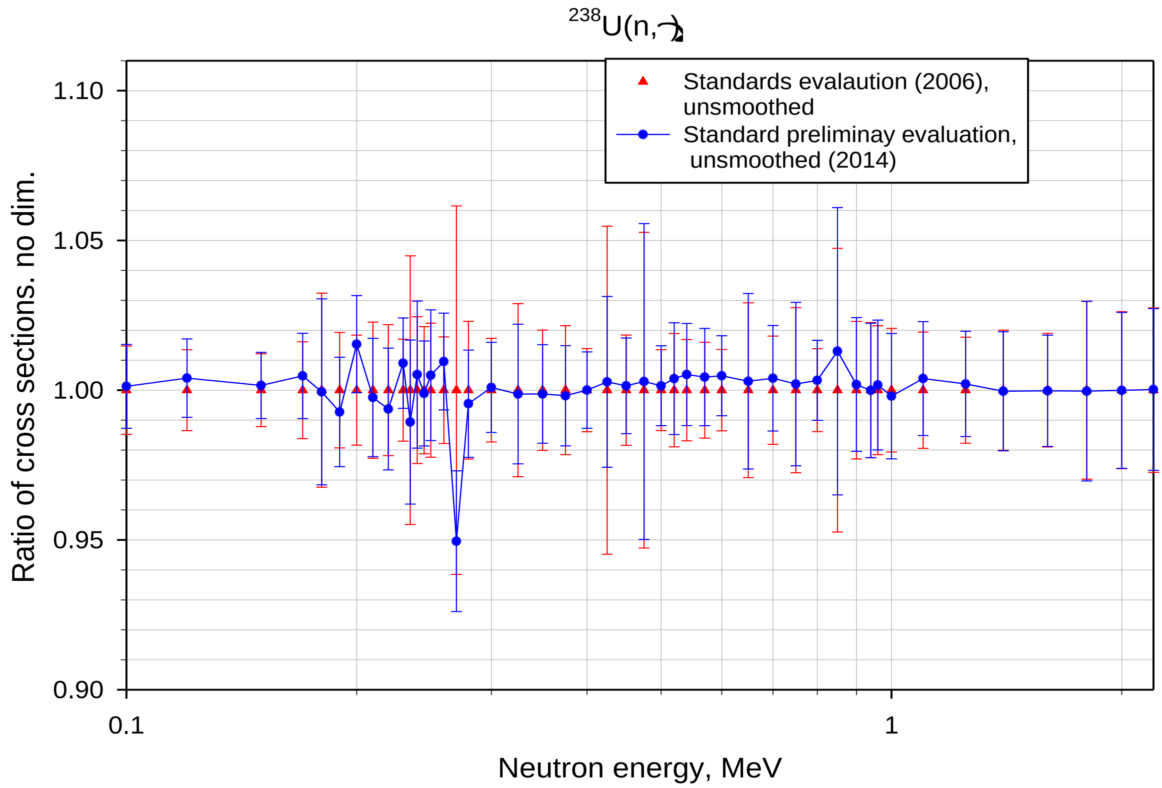

Fig. 6. *Ratio of the results of the preliminary evaluation (2014) containing new data to the 2006 standards evaluation for the energy range above 0.1 MeV.*

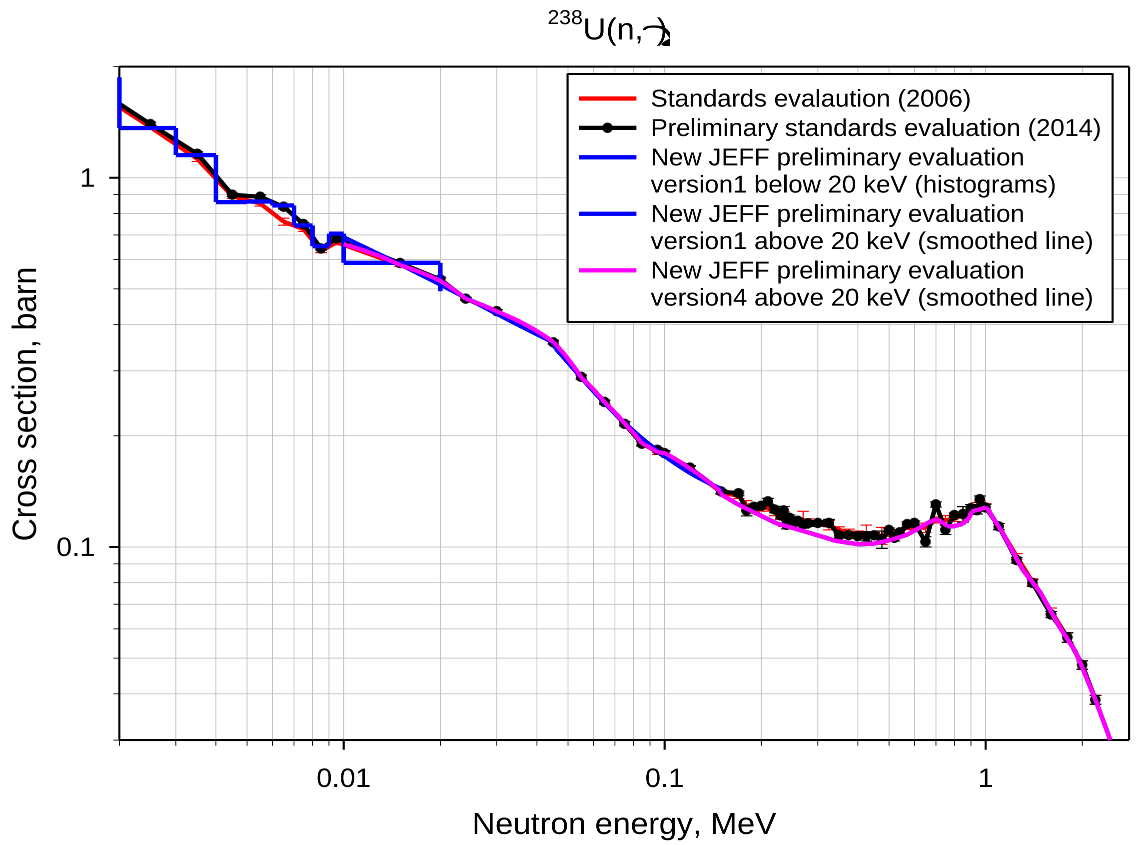

Fig. 7. *Comparison of different non-model (standards) and model (JEFF) evaluations of the ^{238}U(n,γ) cross section. The GMA evaluation (2014) should be smoothed for neutron energies above 0.18 MeV.*

^{235}U(n,f)

There are no new direct measurements of the ^{235}U(n,f) cross section[1]. There are measurements of other fission cross sections relative to the ^{235}U(n,f) cross section which will be included in the fit (see below). It is mentioned in a publication devoted to the n_TOF facility neutron flux characterization (M. Barbagallo et al., EPJ, A49,p. 156 (2013)) , that in the energy range 10 to 30 keV there are differences in the flux determination using the ^{235}U(n,f) cross section from the ENDF/B-VII.1 library (close to the standard values) compared with using other detectors and calculations at their facility. This should be taken into account because either there are problems with the ^{235}U(n,f) standard in this energy range, or the absolute data obtained at n_TOF with this flux characterization may be biased and the uncertainty of the n_TOF data should be increased in this energy range.

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

There are three n_TOF measurements of the absolute ratio for the ^{238}U(n,f)/^{235}U(n,f) cross section ratio with different detectors: Fast Ionization Chamber (FIC) and 2 Parallel Plate Avalanche Counters (PPAC) with different position of the sample relative neutron beam. There is also one PPAC relative measurement of that ratio. The measurements cover the energy region from about 0.5 MeV to near 1 GeV. The results are generally consistent except for one PPAC measurement which is higher near 1 GeV by about 10 % compared with the other results. The weighted average of their datasets is in very good agreement with the 2006 standards results.

The preliminary result of a GMA combined evaluation including all new n_TOF data sets is shown in Fig. 8 compared with the n_TOF results, the 2006 standards evaluation and some experimental data. Because the data measured at the n_TOF with PPAC have common uncertainty, the correlations between these components of uncertainties have been accounted for in the fit. Not all experimental data are included in this comparison to make new data and the preliminary evaluation more visible, but they are all included in the fit. As can be seen, the changes in the evaluation are relatively small, and are well within the limits of the uncertainties of the 2006 standards.

[1] At the time of print new n_TOF measurements from 5-200 eV are being presented at WONDER 2015 by Duran *et al.*

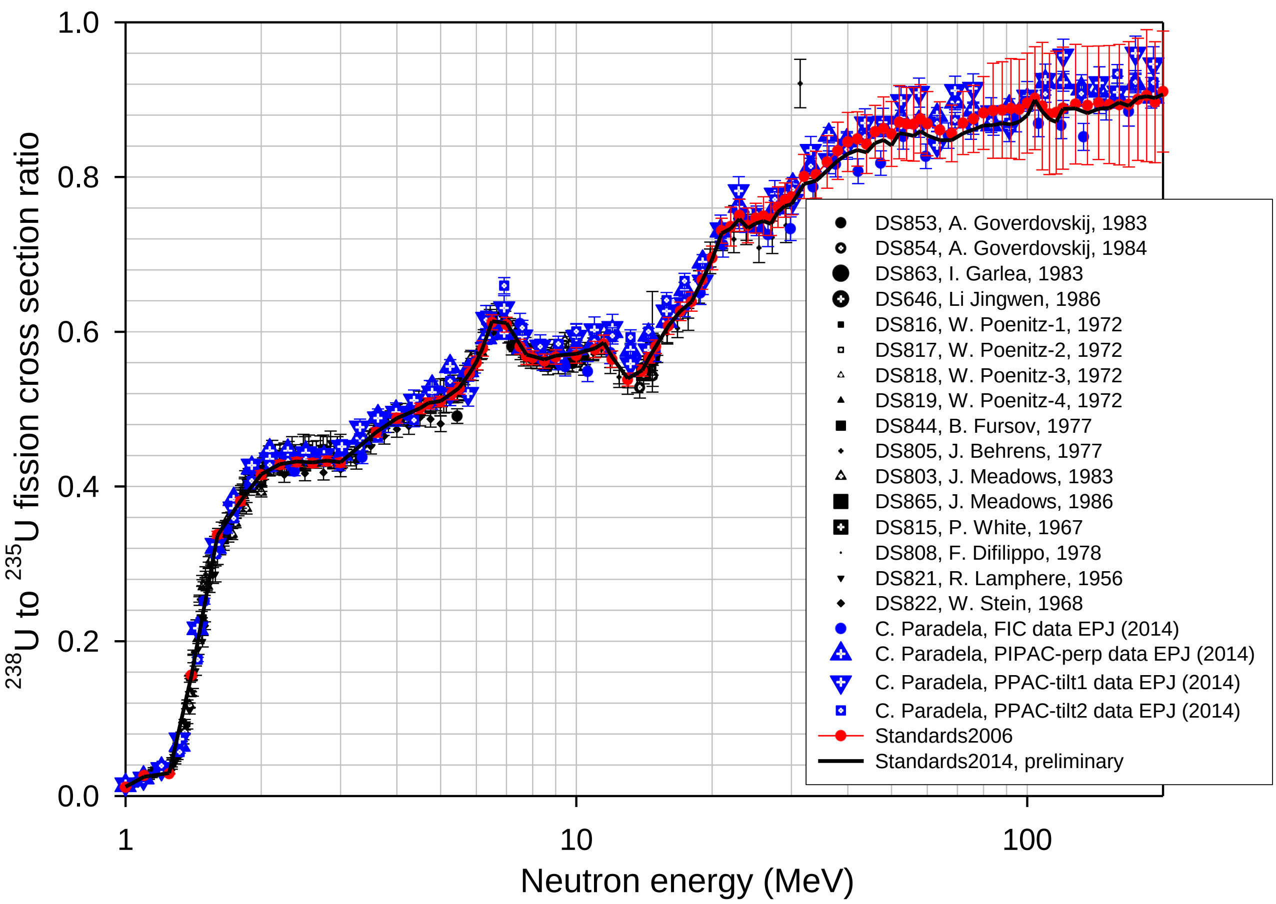

Fig. 8. *A comparison of the 2006 evaluation of the standards with this preliminary evaluation (2014) and some experimental data including the latest n_TOF measurements (the Paradela data sets).*

There are other published n_TOF measurements (D. Tarrio et al., Phys. Rev., C83, 0644220 (2011)) for the Pb(n,f) and ^{209}Bi(n,f) cross sections both relative to the ^{235}U(n,f) and ^{238}U(n,f) cross sections. From those data the ratio of the ^{238}U(n,f)/^{235}U(n,f) cross sections can be derived. That ratio can be calculated based on either the lead or bismuth measurements and compared with the standard values between 40 and 200 MeV. The comparison shows a systematic difference at about 10% (see Fig.9). There is a possible problem with a mass determination of the uranium sample(s) in the detector which contains Pb, ^{209}Bi, ^{238}U and ^{235}U samples. Because of this, the derived ratio ^{238}U(n,f)/^{235}U(n,f) can be used only as a ratio of shape data. It was decided that reference cross sections will be evaluated for high-energy fission cross sections for the energy range from about 40 MeV to about 1 GeV for Pb(n,f) and ^{209}Bi(n,f) and between 200 MeV and about 1 GeV for ^{235}U(n,f), ^{238}U(n,f). All four reactions will be evaluated in a combined GMA fit (see the presentation by B. Marcinkevicius above). For this, the new cross section standards evaluation for ^{235}U(n,f) and ^{238}U(n,f) in the energy range below 200 MeV will be used as a pseudo-experimental data set.

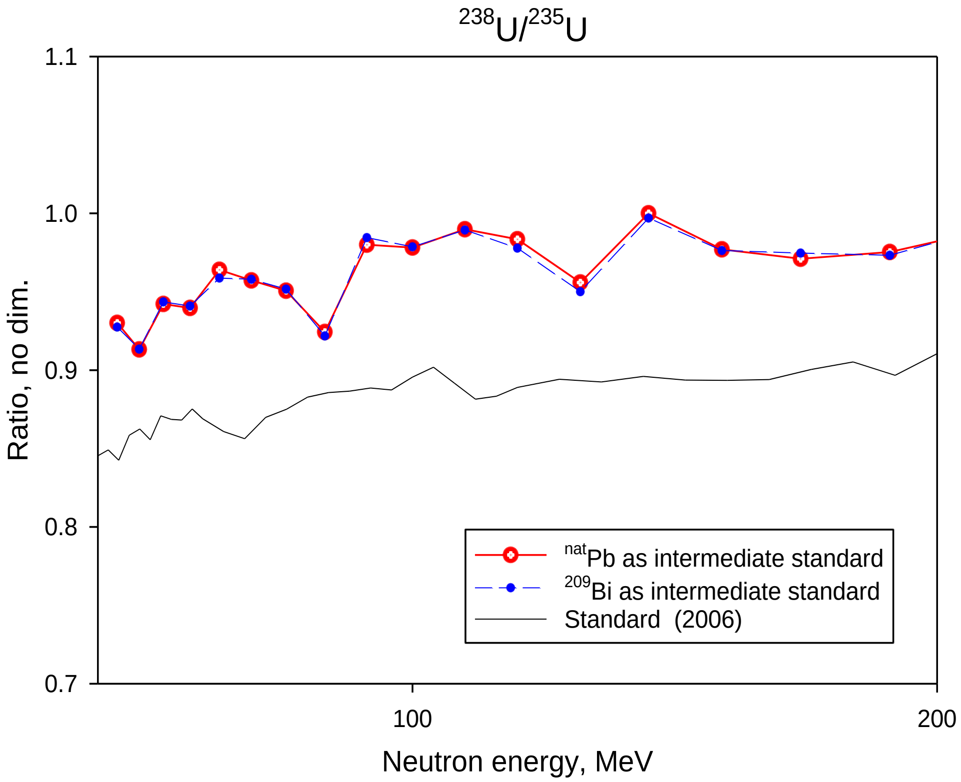

Fig. 9. *Ratio of the $^{238}U(n,f)/^{235}U(n,f)$ cross sections derived from the results of simultaneous measurements of the $^{235}U(n,f)$, $^{238}U(n,f)$, $^{nat}Pb(n,f)$ and $^{209}Bi(n,f)$ cross sections compared with the 2006 standards evaluation.*

^{238}U(n,f) cross section below 2 MeV

The 2006 standards evaluation included ^{238}U(n,f) cross section results to as low as 1 MeV. However that cross section is recommended for use as a standard only above 2 MeV due to the rapid change in the cross section below that energy. At the last standards meeting (2013) it was decided, that because of its importance for practical applications, the cross section should be adequately presented in the range between 0.5 and 2 MeV. For this, the data used in the GMA fit for the ^{238}U(n,f) cross section were extended below 1 MeV to 0.5 MeV using a dense energy grid to show the resonance structure. More detailed data representing the fluctuations was obtained for the cross sections in the energy range between 0.5 and 2 MeV by using the shape of experimental data with medium resolution and passing them through the energy nodes of the GMA evaluation. For data comparison and presentation, the ratio of ^{238}U(n,f)/^{235}U(n,f) cross sections will be used. The data obtained by Behrens (DS805) and Difilippo (DS808) shown in Fig. 10 were used for the shape assignment. The results of such an extended combined GMA fit are shown in Fig. 10. This substantially improves the data compared with the 2006 evaluation where only points shown by stars between 1 and 2 MeV were used with linear-linear interpolation between them. Thus data in the file can be presented with detailed shape between 0.5 and 2 MeV for cross sections and with group structure determined by GMA nodes for the covariances. It should be noted that the standard range is still defined only above 2 MeV.

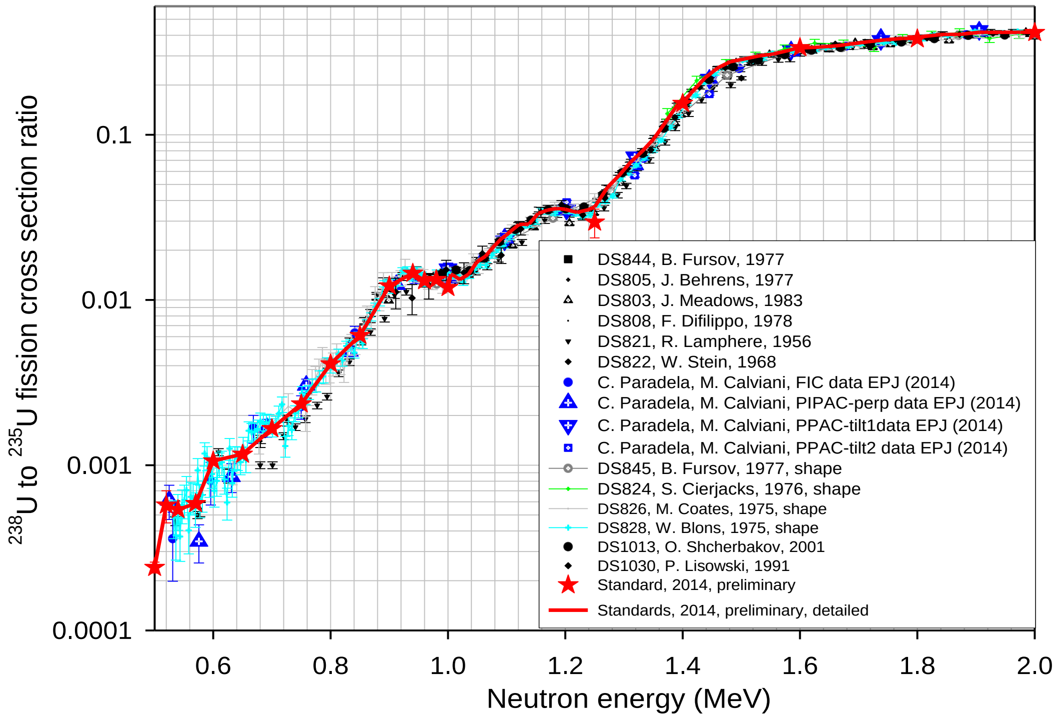

***Fig. 10.** Ratio of the ^{238}U(n,f)/^{235}U(n,f) cross sections evaluated with the combined GMA evaluation of all experimental data (stars) compared with the more detailed medium energy resolution presentation of this data, and experimental data. The star data points between 1 and 2 MeV are the results obtained in the 2006 standards evaluation.*

^{239}Pu(n,f)/^{235}U(n,f)

The Tovesson LANL results are new data for the ^{239}Pu(n,f)/^{235}U(n,f) cross section ratio. They are actually two separate measurements, one for energies from 0.01 eV to 200 keV and the other from 200 keV to 200 MeV. In the lower energy experiment, there is structure in the cross section above 30 keV caused most probably by the sample container. So it was decided to use the data in the fit only below 30 keV. These data are shown in Fig. 11.

Above 200 keV the data are consistent with the 2006 standards up to 15 MeV but they fall below the 2006 Standards above this energy, although these deviations are within the limits of the uncertainties (see Fig. 12). There should be additional analyses of the data and uncertainties before they will be included in the fit. However a GMA fit was done with data below 30 keV taken as ^{239}Pu(n,f)/^{235}U(n,f) cross section ratio shape with increased uncertainties for outlying points and above 0.2 MeV as an absolute ^{239}Pu(n,f)/^{235}U(n,f) ratio with an additional component of uncertainty for outlying data in the energy range from 15 to 168 MeV. The total uncertainty in the high energy range estimated by the authors is about 2.2 – 2.3 %, which is much lower than the uncertainty of the 2006 Standards evaluation. The results of the preliminary standards evaluation with inclusion of the LANL data in the form as described above is shown in Fig. 13. As we see from the figure, the influence of new data with increased uncertainty in the energy range, where they are considered as outliers, at the combined evaluation of ^{239}Pu(n,f) is rather small.

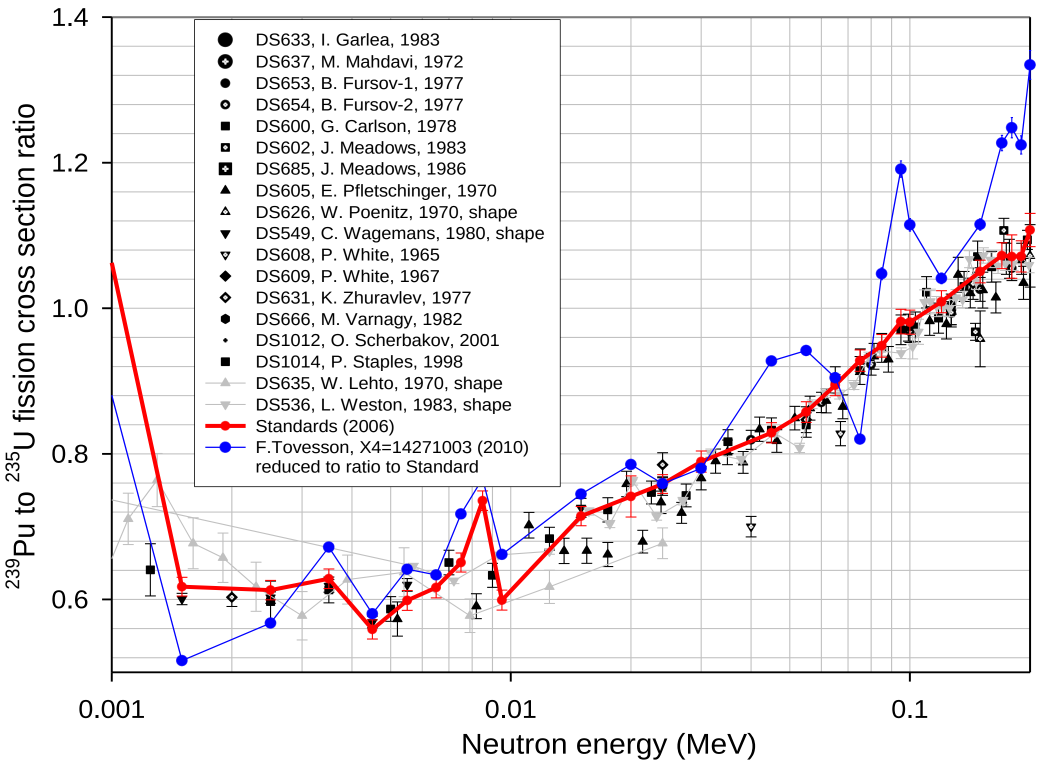

Fig. 11. *Comparison of the LANL (Tovesson 2010) measurements below 0.2 MeV with the 2006 standards evaluation and other experimental data.*

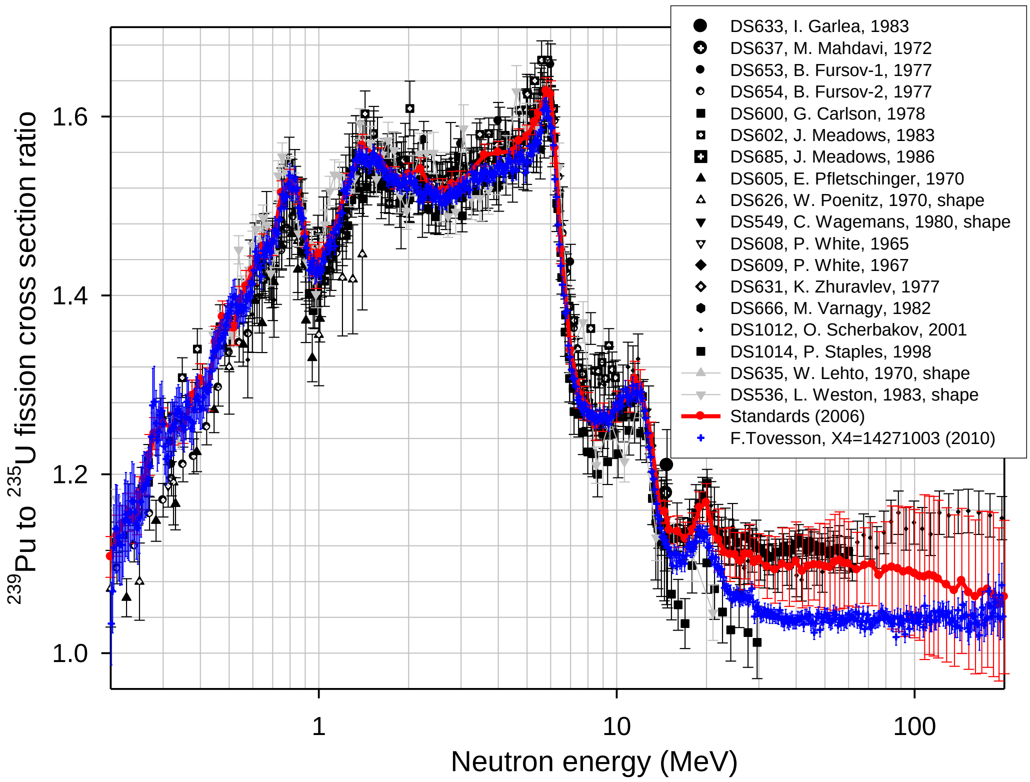

Fig. 12. *Comparison of the LANL measurements (Tovesson 2010, total uncertainty as given by the authors) above 0.2 MeV with the 2006 standards evaluation and other experimental data.*

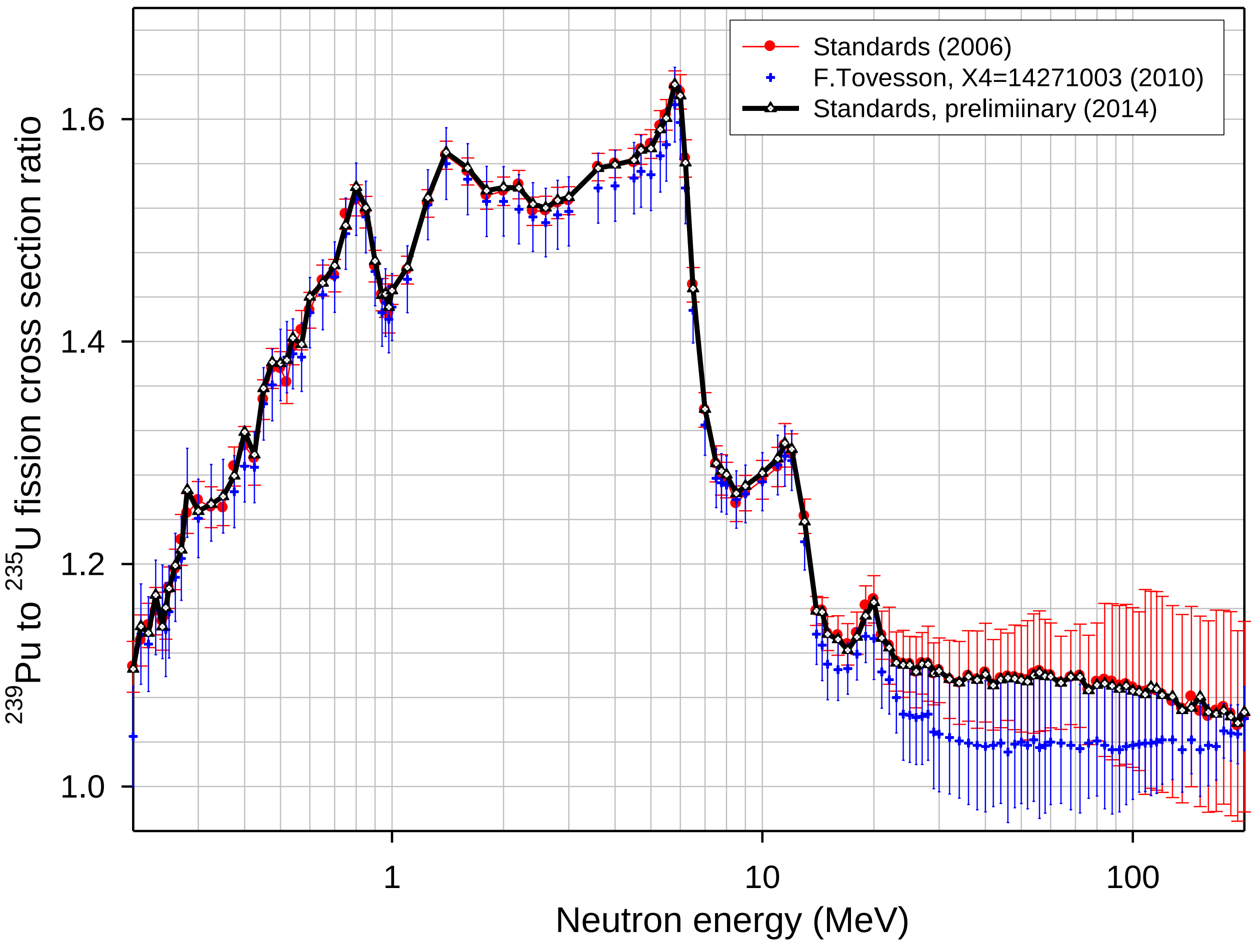

Fig. 13. *Comparison of the preliminary standards evaluation with the LANL measurements (Tovesson 2010, data reduced to the GMA nodes, uncertainties are increased between 14 and 168 MeV) and the 2006 standards evaluation.*

3.2.1. Gamma-production reference cross section

There was a discussion about whether only one cross section would be acceptable as a gamma-production reference cross section. However it is important that the cross section be smooth over its region of use. Having a single reference cross section would be difficult to do because it would have to be smooth over energies between thermal neutron energy and 15 MeV with no problems due to thresholds from inelastic scattering reactions, resonance structure in its cross section near thresholds of inelastic scattering, low cross sections and possible contributions from the reactions of other isotopes (if the reference sample is not mono-isotopic). Thus three reference reactions have been proposed which cover as a set the entire energy range, have smooth energy dependence and relatively high γ-production cross sections. There is a drawback of this approach since there is more than one gamma-production reference cross section. If measurements are done over a large energy range, the reference data must be obtained appropriately, possibly using as many as three reference cross sections. However this is the same problem one has with the cross section standards when measurements are being made over a large energy range.

It was proposed that the existing standards evaluation for the $^{10}B(n,\alpha_1\gamma)^7Li$ cross section be used for the neutron incident energy range from 10^{-5} eV to 1 MeV. It has a 478 keV gamma-ray. The data should be given in the form of tables and in the ENDF-6 format.

A preliminary evaluation of the $^{7}Li(n,n'\gamma)$ cross section is suggested as a reference gamma production cross section in the energy range 0.8 - 5 MeV. It also produces the 478 keV gamma-ray so it is convenient to use in conjunction with the $^{10}B(n,\alpha_1\gamma)^{7}Li$ cross section. Because the gamma-ray is the same as the one from the $^{10}B(n,\alpha_1\gamma)$ reaction, it may reduce the uncertainty of reference yield measurements. The evaluation should be prepared and given in the form of tables and in ENDF-6 format (Simakov, Plompen, Nelson, Pronyaev). Most of the data are very consistent in this energy range.

Also the production of the 984 keV γ-ray from the $^{48}Ti(n,n'\gamma)$ cross section is suggested as a reference cross section above ~4 MeV. A preliminary evaluation for that cross section has been done by Simakov. It could be updated with the use of the Baysian approach taking into account the IRK (Vienna) evaluation for $n+^{48}Ti$ for the energy range 3-15 MeV (Simakov, Nelson, Pronyaev).

All three reference reactions have energy intervals which overlap.

The results of the GMA evaluation for the $^{48}Ti(n,n'\gamma)$ cross section with no smoothing above 3 MeV is shown in Fig. 14. Also shown in the figure are GMA results obtained using smoothing data from TALYS calculations with optimized parameters in the least squares fit and using the TENDL2010 evaluation for smoothing. These results are compared with the JEFF-3.2 (same as JEFF-3.1.2) GLUCS Bayesian evaluation. The GLUCS evaluation in the energy range 3 to 9 MeV is about 7 – 8% below the GMA evaluation. In this energy range the inelastic cross section is practically equal to the non-elastic cross section and the optical model reaction cross section. Direct measurements of the non-elastic cross sections for ^{nat}Ti made more than 50 years ago give values below 1.3 barn from 3 to 9 MeV. Taking into account that the 984 keV gamma-ray yield at these energies consists of about 95% from the non-elastic cross section, the gamma production cross section in this range where the cross section appears flat, estimated from the non-elastic cross section, should be below 1.24 barn with an uncertainty of about 6-8%. The GLUCS evaluation should provide a better fit to the cross section in this energy range than the GMA evaluation. This discrepancy should be resolved.

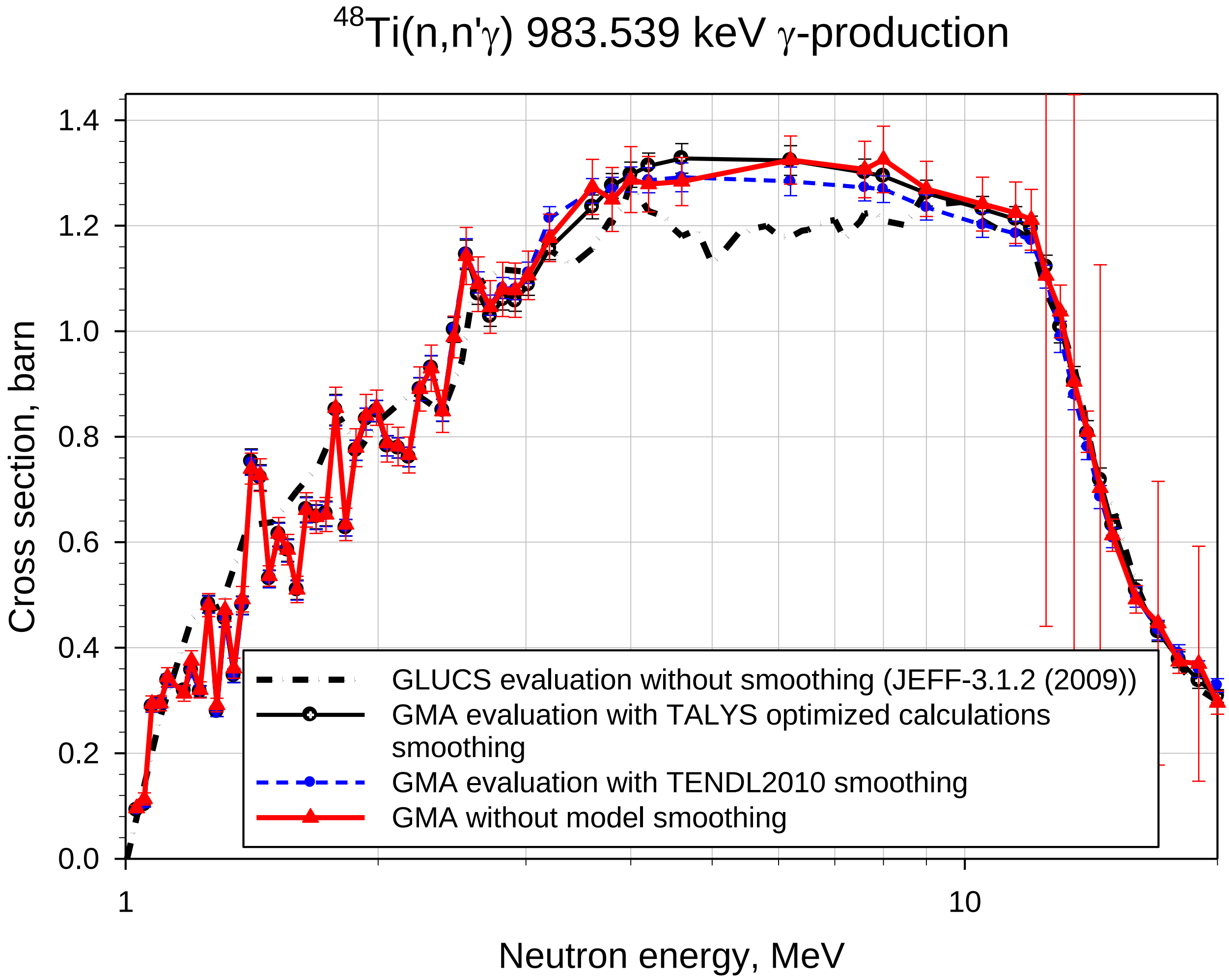

Fig. 14. *Comparison of different GMA evaluations with different smoothing and without model smoothing (non-model fit) with the GLUCS simultaneous Bayesian evaluation of all the cross sections.*

3.2.2. ^{252}Cf spontaneous fission neutron spectrum

An investigation by Mannhart of experiments done after the last standards evaluation indicates there is no justification for performing a new evaluation of this spectrum. There will however be small changes in the spectrum as a result of the simultaneous evaluation of the ^{235}U(n$_{th}$,f) prompt fission neutron spectrum and the ^{252}Cf spontaneous fission neutron spectrum.

3.2.3. ^{235}U(n$_{th}$,f) reference prompt fission neutron spectrum

Fits for this spectrum were done by Mannhart using a Bayesian analysis and separately by Pronyaev using GMA. Different estimations of experimental uncertainties were used in these fits. The GMA fit was done using two different approaches. One used experimental data as absolute ratios of ^{252}Cf(s.f.) to ^{235}U(n$_{th}$,f) and the other used experimental data taken as shapes of ratio of these spectra. In the latter case a least-squares normalization of the energy integral of the ^{235}U(n$_{th}$,f) PFNS to 1 was used with the percent uncertainty equal to the uncertainty of the evaluated average prompt fission neutron yield at thermal energy of incident neutrons. It was found that in the fit of the shape of the ratio data, the evaluated spectrum has average energy 20 keV higher than in the fit of the absolute ratio data, but still 30 keV below that in the ENDF/B-VII.1 library (2.03 MeV).

The following steps were used to obtain the uncertainties of the shape data used in GMA. The total uncertainties of the data used in GMA should be the same as was estimated by Mannhart for all experimental data sets. Because the total uncertainties initially determined and used in GMA are less than those prepared by Mannhart, but have the same statistical component, the difference in uncertainties of data sets prepared by Mannhart and those prepared for GMA was introduced as an additional systematic uncertainty not related with the normalization component and given in GMA separately. Then the covariance matrix for GMA was prepared from these three components and compared with the matrix used by Mannhart. By changing the cross energy correlation length for the additional systematic uncertainty component, it was possible to get the covariance matrices of the experimental data for GMA close, as much as possible, to the matrix prepared by Mannhart. Then GMA was run in two modes: the mode where most data were taken as absolute ratios and results can be directly compared with the Mannhart evaluation (and should be close to it) and the mode where all data were treated as shape data (normalization uncertainty in the GMA fit was not used in this case). The least-squares normalization of the spectrum integral to 1 with an uncertainty equal to the uncertainty of the evaluated average prompt fission neutron yield was used as a constraint in this fit. Because of the possible existence of unknown (unrecognized) systematic uncertainties related with the spectra normalization, the results of the spectra shape of ratio data fit looks more realistic than the results of the fit of spectra of absolute ratios.

The comparison of the results of the evaluation done by Mannhart and with the GMA code for spectra absolute ratios and the same covariances is shown at Fig. 15. The comparison of the evaluated percent uncertainties is shown at Fig. 16. The good consistency between two evaluations is observed. This good consistency tends to verify the codes being used since the GMA fit was done using the uncertainties and data employed in the analysis by Mannhart, although double ratios were used by Mannhart for his fit, whereas for GMA, single ratios were used with Smith's recipe (perhaps stating Smith and Pronyaev would be better to avoid thinking it is the Chiba and Smith work) to minimize the Peelle Pertinent Puzzle problem.

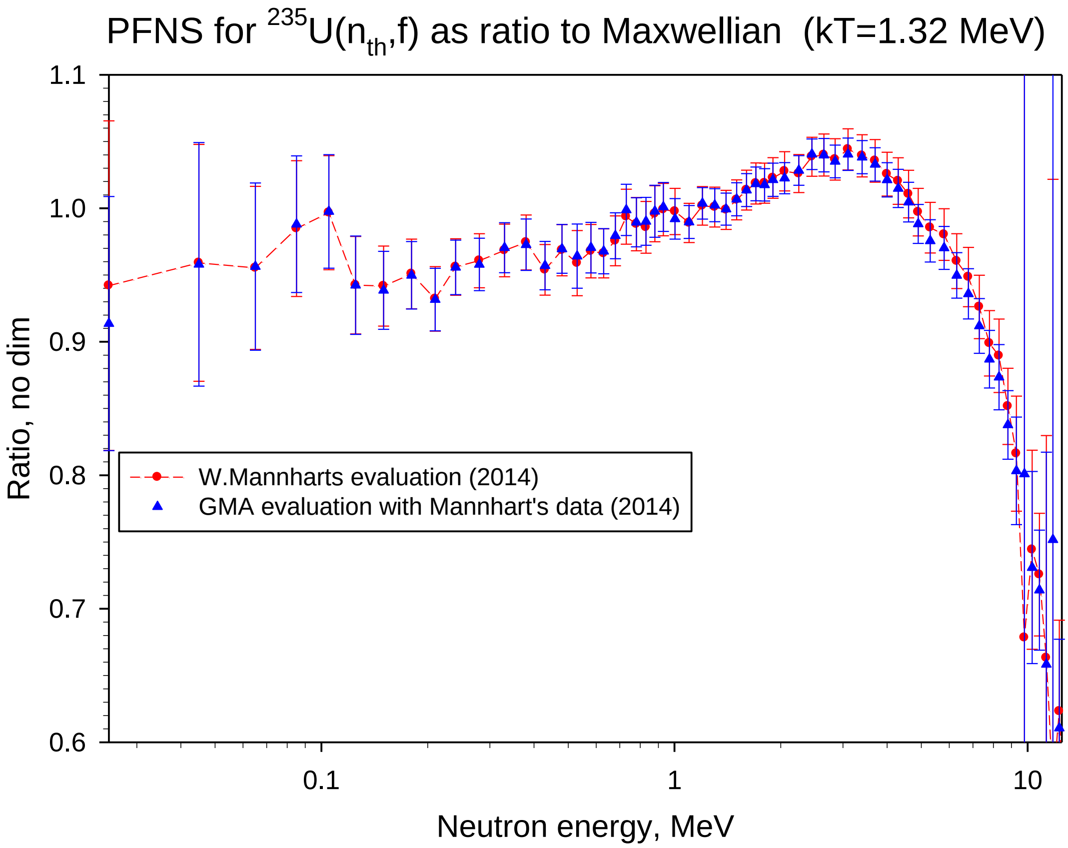

Fig. 15. *Comparison of Mannhart's evaluation with the GMA evaluation when the same data and uncertainties of the experimental data were used in both fits.*

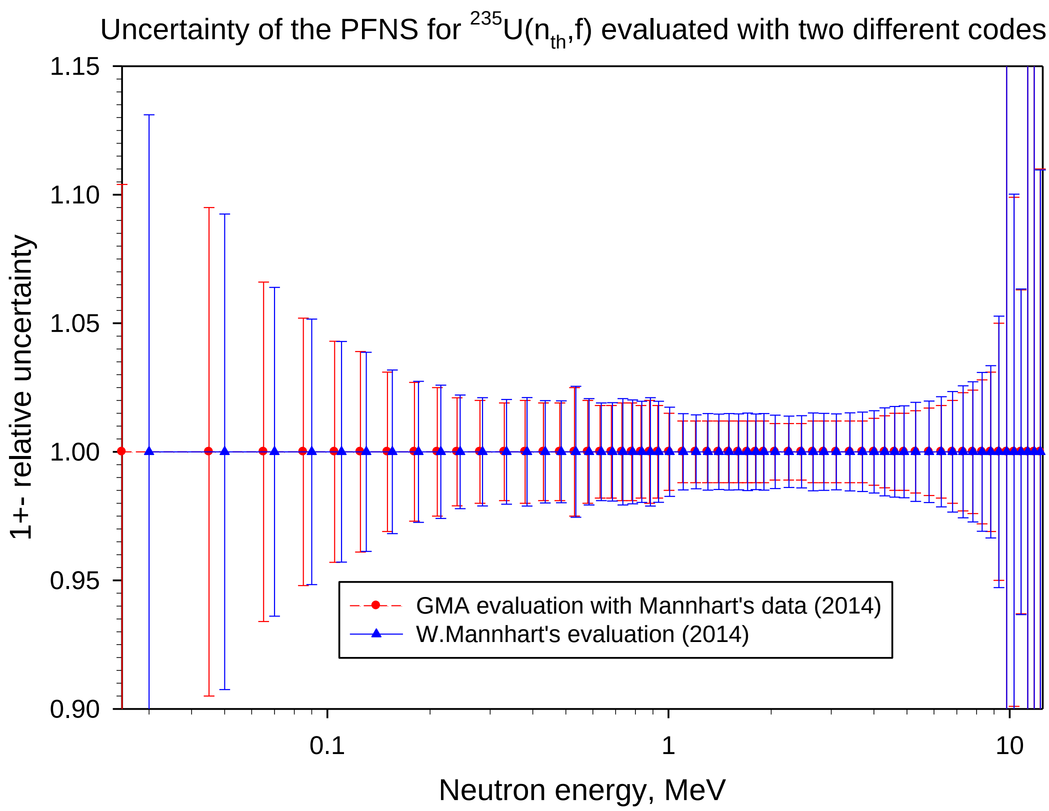

Fig. 16. *Comparison of the uncertainties obtained from the Mannhart evaluation with those obtained with the GMA evaluation when the same data and uncertainties of the experimental data are used in both fits.*

The GMA preliminary evaluation of the PFNS using shape data was done with the following conditions:

1. All experimental data except those of Wang Yufeng were taken as shape of ratio spectra. The Wang Yufeng PFNS data were considered shape data with only data points above 1 MeV included in the fit.
2. All uncertainties (covariances) for experimental data were derived as much as possible to be close to the Mannhart uncertainties.
3. The basis function (composition of Watt and Maxwellian spectra) obtained by Trkov in his independent fit with the GANDR code of experimental PFNS was taken as a shape data set used in the GMA fit. The basis function was used in the energy range from 10^{-11} to 20 MeV. Large non-informative uncertainties were assigned to the basis function in the energy range where experimental data are given, so the uncertainties of the experimental data dominate fully in the fit for this energy range. At low and high energies outside this range the "experts" (definition of experts should be considered) estimation of the uncertainties is given.
4. The smoothed standard evaluation of the ^{252}Cf(s.f.) PFNS by Mannhart was used in the combined (simultaneous evaluation) fit.

The results of the preliminary fit are shown in Figs 17 and 18. The main conclusion is that the evaluation is stable and the central values of the evaluation obtained in the fits of the shape of ratio data using different conditions are very weakly dependent on (1) the covariances of the experimental data, (2) the presentation of the standard for the ^{252}Cf(s.f.) PFNS (point-wise or smoothed) and (3) smoothing of the spectrum used (e.g. third order power fit of ratio of ^{235}U(n_{th},f) PFNS to Maxwellian with kT=1.32 MeV). The variances (or percent uncertainties) obtained by Mannhart and in the GMA fit with least-square normalization are also nearly the same. Some difference is observed in the correlation matrix of the evaluated data which can be explained by the different types of data used in the fits: absolute ratio by Mannhart and the shape of ratio data with normalization constraint for GMA.

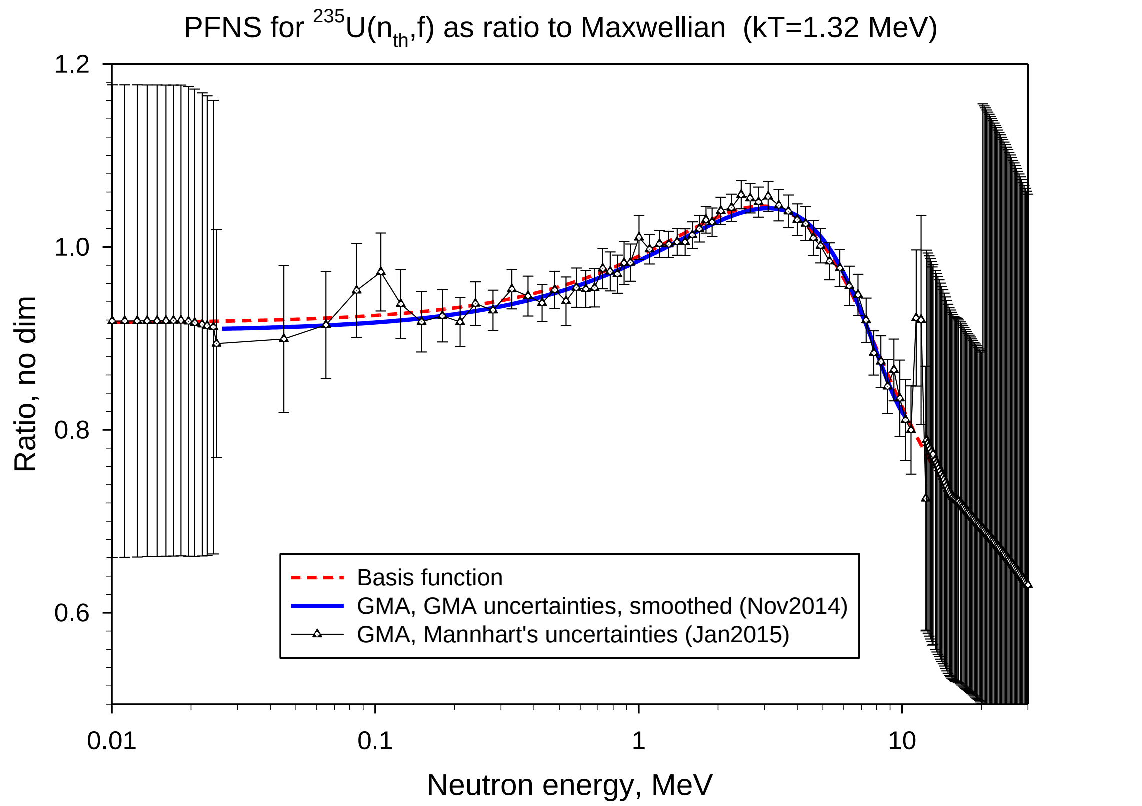

Fig. 17. *Comparison of the PFNS results for a preliminary GMA evaluation using the uncertainties of Mannhart with the result of a GMA fit using GMA uncertainties. Shown also is the basis function.*

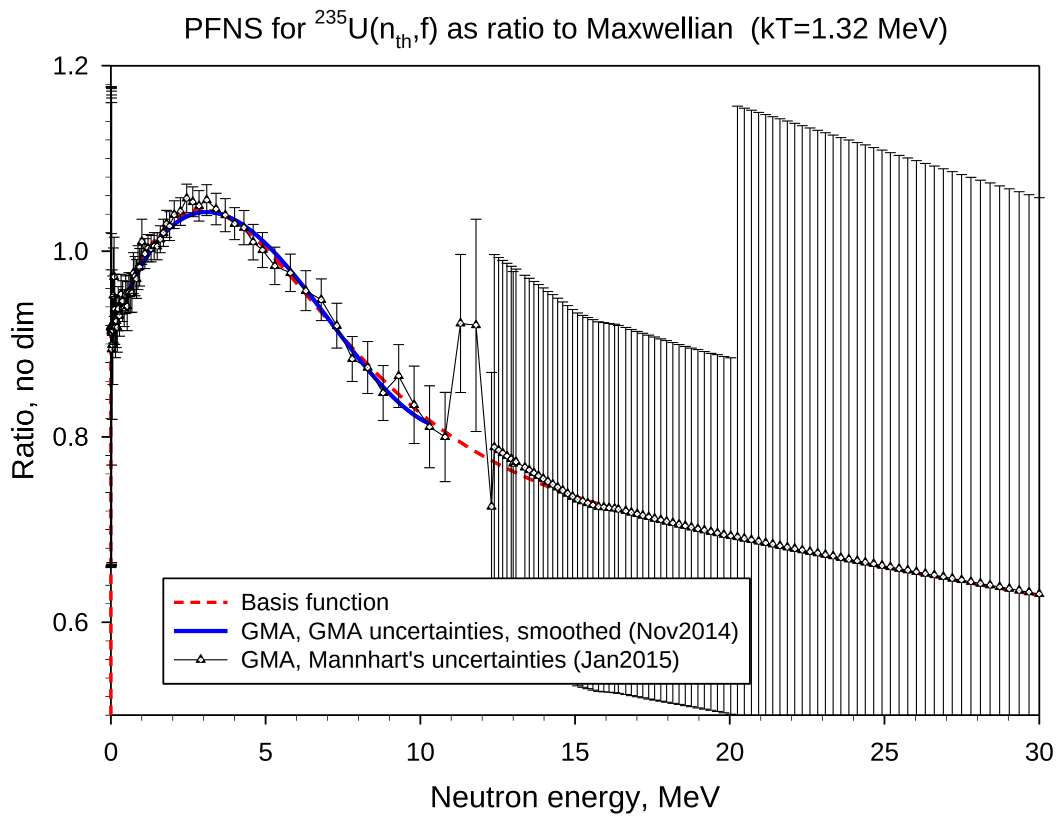

Fig. 18. *Same as that of Fig. 17 but with a linear scale for the energy.*

3.2.4. *Thermal constants*

The GMA evaluation of the thermal constants is based on the Axton evaluation (1986) used as a pseudo-experimental data set in the fit and new experimental data which were available since 1986. A large change in the evaluation was observed for ^{235}U thermal elastic scattering. In the 2006 standards and the standards evaluation that preceded it, the Axton's fit of microscopic (at 0.0253 eV neutron energy) and macroscopic (thermal spectrum averaged values) was used in the combined GMA fit. There is also another evaluation of the thermal constants by Axton, where only microscopic data were used in the fit. Because the problem of data compensation in benchmark calculations is considered very important for the CIELO project and the new PFNS evaluations introduce large deviations of C/E for criticality benchmarks for systems with different spectra, it was advised to do the GMA fit with Axton's evaluation of thermal constants based exclusively on a fit using only microscopic data. This was done and the results of the preliminary GMA evaluation (with inclusion of all new experimental data) are given in Table 1.

As we see, the large changes (out of the limits of previous evaluated uncertainties) are observed for the **^{235}U(n,f)** cross section - **+0.5%**, the **^{235}U(n,γ)** cross section - **-2.6%**, and **^{235}U <ν_{pr}>** - **-0.3%**. The <K1> parameter, best characterizing the system criticality increased from 719.9 barn for the evaluation including both the microscopic and macroscopic experiments to 722.82 barn for the microscopic experiments alone, with the latest evaluated value by Hardy, <K1>=722.7±2.7 barn. But the increase in the evaluated value of the ^{235}U(n,f) cross section (to 587.13±1.39 barn) differs from all present-day evaluations including the latest fit (see the presentation by Noguere above) with a preliminary value of 582.7±4.4 barn. Because the formula for the <K1> parameter does not depend on the PFNS, the direct calculations of C/E for critical assemblies used by Hardy for analysis and determination of the <K1> value are preferable for benchmarking.

Table 1. Comparison of a preliminary GMA evaluation, a combined fit, with two thermal constants evaluations by Axton: based on microscopic, and microscopic and macroscopic experimental data. Definition of constants is given in the Standards2006 publication.

Constant	**Microscopic & macroscopic data**	**Microscopic data only**
GA-U3	0.9996±0.0011	0.9989±0.0012
GF-U3	0.9956±0.0014	0.9967±0.0020
SS-U3	12.11±0.66	12.24±0.69
SF-U3	531.3±1.3	534.4±2.4
SG-U3	45.51±0.68	41.93±1.75
NU-U3	2.4945±0.0040	2.4853±0.0055
GA-U5	0.9789±0.0008	0.9786±0.0009
GF-U5	0.9773±0.0008	0.9777±0.0009
SS-U5	14.087±0.2195	14.090±0.2202

Constant	**Microscopic & macroscopic data**	**Microscopic data only**
SF-U5	584.38±1.03	587.18±1.39
SG-U5	99.304±0.725	96.81±1.70
NU-U5	2.4321±0.0036	2.4250±0.0046
GA-PU9	1.0781±0.0024	1.0770±0.0029
GF-PU9	1.0555±0.0022	1.0549±0.0029
SS-PU9	7.8116±0.9603	7.7901±0.9637
SF-PU9	749.78±1.82	751.99±2.22
SG-PU9	271.39±2.14	270.48±3.16
NU-PU9	2.8809±0.0052	2.8775±0.0060
GA-PU1	1.0440±0.0020	1.0440±0.0020
GF-PU1	1.0453±0.0055	1.0454±0.0064
SS-PU1	12.139±2.610	11.910±2.5713
SF-PU1	1013.9±6.6	1024.9±11.5
SG-PU1	361.55±4.95	361.98±6.19
NU-PU1	2.9451±0.0059	2.9399±0.0065
NU-CF2	3.7675±0.0049	3.7635±0.0049

APPENDIX 1

AGENDA

Technical Meeting on
Current Status of Neutron Standards

IAEA Headquarters, Vienna, Austria
1 – 5 December 2014
Meeting Room M0E79

Monday, 1 December

08:30 – 09:30	Registration (IAEA Registration desk, Gate 1)
09:30 – 10:00	Opening Session Welcoming address – Roberto Capote Noy Election of Chairman and Rapporteur Adoption of Agenda
10:15 – 12:00	Review of the status of IAEA Data Development Project: Presentations by participants
12:00 – 12:30	Administrative matters
12:30 – 14:00	*Lunch*
14:00 – 18:00	Presentations by participants

Tuesday, 2 December
Presentations by participants

Wednesday, 3 December
Discussion on STD reactions**: data, GMA fit, actions**

Thursday, 4 December:

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

Discussion on additional reference reactions, actions

Friday, 5 December

09:00 – 12:30	Review of the Meeting Summary Report
12:30 – 14:00	*Lunch*
16:00	Closing of the Meeting

APPENDIX 2

LIST OF PARTICIPANTS

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

AUSTRIA
Mr Herbert Vonach
Institut für Isotopenforschung und Kernphysik
Universität Wien
Währinger Straße 17
1090 Vienna
Tel.: + 43 2243 37927
E-mail: herbert.vonach@utanet.at

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

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

EUROPEAN COMMISSION
Mr Stefan Kopecky
European Commission, Joint Research Centre
Inst. for Reference Materials and Measurements
Retieseweg 111
Geel 2440
Tel.: +32 14 57 1475
E-mail: stefan.kopecky@ec.europa.eu

FRANCE
Mr Gilles Noguere
SPRC/LEPh
CEA Cadarache
13108 Saint Paul Les Durance
Tel.: +33 4 42 25 27 77
E-mail: gilles.noguere@cea.fr

FRANCE
Mr Pascal Romain
CEA DAM DIF
Bruyères-le-Châtel
91297 Arpajon Cedex
Tel.: +33 1 69 26 40 00
E-mail: pascal.romain@cea.fr

GERMANY
Mr Wolf Mannhart
Physikalisch-Technische Bundesanstalt
Bundesallee 100
38116 Braunschweig
Tel.: + 49 531 592 3006
E-mail: wmannhart@aol.de

JAPAN
Mr Satoshi Kunieda
Japan Atomic Energy Agency
Nuclear Data Center
Tokai-mura, Naka-gun
Ibaraki-ken, 319-1195
Tel.: +81 29 282 1122
E-mail: kunieda.satoshi@jaea.go.jp

RUSSIAN FEDERATION
Mr Vladimir Proniaev
Institute of Physics and Power Engineering
Pl. Bondarenko 1
249033 Obninsk
Kaluga Region
Tel: +74843994589
E-mail: pronyaev@ippe.ru

SPAIN
Mr Ignacio Duran
Universidad de Santiago de Compostela
Facultad de Fisica
Santiago de Compostela
La Coruña 15782
Tel.: + 98 1 563100-13952
E-mail: ignacio.duran@usc.es

UNITED STATES OF AMERICA
Mr Gerald M. Hale
Los Alamos National Laboratory
PO Box 1663
Group T-2, MS B214
Los Alamos, New Mexico 87545
Tel.: +1 505 667 7738
E-mail: ghale@lanl.gov

UNITED STATES OF AMERICA
Mr Allan D. Carlson
National Institute of Standards and Technology
Radiation and Biomolecular Physics Division
Neutron Physics Group
100 Bureau Drive, Stop 8463
Gaithersburg, MD 20899-8463
Tel.: +1 301 975-5570
E-mail: allan.carlson@nist.gov

IAEA
Mr Roberto Capote Noy
Scientific Secretary
Nuclear Data Section
Division of Physical and Chemical Sciences
Tel.: +43 1 2600 21713
E-mail: r.capotenoy@iaea.org

IAEA
Mr Andrej Trkov
Nuclear Physicist
Nuclear Data Section
Division of Physical and Chemical Sciences
Tel.: +43 1 2600 21712
E-mail: a.trkov@iaea.org

IAEA
Mr Stanislav Simakov
Unit Head
Nuclear Data Services Unit
Division of Physical and Chemical Sciences
Tel.: +43 1 2600 21716
E-mail: s.simakov@iaea.org

IAEA
Mr Benjaminas Marcinkevicius
Intern
Nuclear Data Services Unit
Division of Physical and Chemical Sciences
Tel.: +43 1 2600 21727
E-mail: b.marcinkevicius@iaea.org

APPENDIX 3

List of Presentations with Hyperlinks to PPT and PDF papers

#	Author	Title	Link
1	A.D. Carlson	Status of the Data Development Project Neutron Measurements Completed Since The Last International Evaluation of the Standards	PDF
2	I. Duran	Results on neutron-induced fission at intermediate energies,using PPACs at nTOF-CERN	PDF
3	G.M. Hale	R-matrix Work on the Light-Element Standards at Los Alamos	PPT
4	S. Kopecky	^{197}Au and ^{238}U cross section data at GELINA	PPT
5	S. Kunieda	Recent Works in R-matrix Analysis	PPT
6	W. Mannhart	Improved Evaluation of the Experimental Database of the PFNS of U-235 + n (thermal)	PPT
7	B. Marcinkevicius	^{209}Bi(n,f) and ^{nat}Pb(n,f) reactions cross sections as new reference for neutron energies from 20 to 1000 MeV	PDF
8	G. Noguere	Feedback on ^{235}U Contribution of the nuclear data group of Cadarache	PDF
9	P. Romain	Status of ^{235}U evaluation in the high energy region	PDF
10	Xi Tao	Full and Diagonal Reduced R-matrix code: Progress and Perspective	PDF
11	A. Wallner	Atom counting via AMS: nuclear (astro) physics and environment	PDF
12	S. Simakov	Feedbacks from the IAEA CRP "Testing and Improving the International Reactor Dosimetry and Fusion File (IRDFF)"	PDF
13	A. Trkov	^{235}U PFNS for Standards	PDF

APPENDIX 4

Meeting Photo

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 21725
Web: http://www-nds.iaea.org