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ACTINIDE EVALUATIONS IN THE RESONANCE REGION

Summary Report of the IAEA Technical Meeting of the
International Nuclear Data Evaluation Network (INDEN)

IAEA Headquarters, Vienna, Austria
21 – 24 October 2019

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December 2020

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ABSTRACT

A Consultants Meeting on the Resonance Parameters of Fissile Actinides of the International Nuclear Data Evaluation Network (INDEN) was held at the IAEA headquarters in Vienna from 21 to 24 October 2019. The meeting was a follow-up of the working group on evaluations in the resonance region of actinide nuclei. Special focus was on issues in the evaluation in the unresolved resonance region (URR). On-going evaluation work was discussed, and new experimental and evaluation projects targeted at improving the evaluations reviewed.

December 2020

Contents

1. Introduction

A Consultancy Meeting was held at IAEA Headquarters in Vienna, Austria, from 21-24 October 2019, to address current problems in the evaluation of nuclear data in the resonance region for actinide nuclei with focus on major fissile nuclei. This work was carried out in the framework of the International Nuclear Data Evaluation Network (INDEN), with nine experts from four Member States and two International Organizations attending the meeting. R. Capote served as Scientific Secretary of the meeting and coordinator of the INDEN network. Y. Danon was elected chairman of the meeting and M. Flemming rapporteur.

2. Presentation Summaries

2.1. Improving evaluation in the RRR for ^{239}Pu

R. Capote Noy (IAEA) reviewed evaluations of neutron induced reactions on U-235 target in the resonance region. The n_TOF collaboration measured the ratio of the thermal fission cross section to the integral of the fission cross section in the energy range 7.8-11 eV. Both quantities were declared to be neutron standards by Carlson *et al* 2018. An excellent agreement of the n_TOF measured and standard evaluated ratio was found within the 1.3% quoted uncertainties of the standard ratio. Note that the evaluated ratio is about 0.8% higher than the three independently measured n_TOF ratios, which may point out to a possible small reduction of the thermal fission cross section.

The important energy dependence of the alpha ratio ($\equiv\sigma_\gamma/\sigma_f$) below 3 eV for neutron induced reactions on U-235 target was also reviewed. The behaviour of the alpha ratio is critical for the performance of thermal reactors. The interplay of thermal PFNS, the nubar energy dependence and the alpha energy dependence in the epithermal region up to 3 eV defines the temperature reactivity coefficients and determines the performance of the evaluated file in criticality benchmarks (HEU solutions and thermal lattices). It was noted that both new evaluations (JEFF-3.3 and ENDF/B-VIII.0) are higher than the previous ENDF/B-VII.1/JEFF-3.1 evaluation. Also noted that the JEFF-3.3 evaluated alpha ratio is systematically lower than the ENDF/B-VIII.0 evaluation from 0.1eV up to 2 eV. Such differences should be resolved using available experimental data; recent RPI data and new planned experiments at n_TOF/JRC Geel could be useful on that regard.

The second part of the presentation was devoted to review the status of the Pu-239 evaluation in the resonance region (RR). The joint PFNS evaluation at the thermal point for major fissile actinides carried out by the Standard group indicated a reduced PFNS average energy by up to 30 keV for thermal neutron induced fission in Pu-239. New experimental data will be soon released both by CEA (France) and Chi-Nu (LANL, USA) collaborations that cover the incident neutron energy range from about 500 keV up to 30 MeV. New comprehensive PFNS evaluations will be needed. The reduction of the PFNS average energy for thermal neutron induced reactions will have to be compensated by revisions in the cross-section evaluations in the region below 5eV as well by the reevaluation of the nubar energy dependence below 5 eV. New planned experiments could be useful on that regard as reflected in the NEA HPRL.

A new preliminary Pu-239 RR evaluation undertaken by ORNL/IAEA collaboration was presented (pu239e80p10). The new evaluation relies on a new thermal PFNS with average energy of 2.08 MeV and feature an excellent agreement with evaluated Thermal Neutron Constants by Carlson et al, as well as being the resonance parameters compatible with softer PFNS.

Additional efforts will be also needed for the reevaluation of Pu-239 cross sections in the fast neutron region with focus on elastic/inelastic data. Significant issues have been identified from the analysis of measured reaction rates in critical assemblies for neutron dosimetry reactions as shown in a recent IRDFF publication. Similar discrepancies are seen in preliminary results presented by Danon *et al* at RPI in measured angular dependence of the neutron yield in fast neutron induced reactions on Pu-239 targets (so called quasi-differential measurements).

2.2. Status of the ^{239}Pu evaluation in the resonance range for JEFF

G. Noguere (CEA) reviewed the effects of new evaluation work on MOX fuel calculations, showing improvements in the performance of JEFF-3.2 on MISTRAL-2 with the recent CAB water TSL, Leal O-16 and CEA Pu-240 evaluations. Temperature dependence remains a concern with an approximately 0.7 pcm/K bias. The issue is not found in UOX fuels and is a specific feature for MOX. This is a consequence of the fission to capture ratio in Pu-239 as a function of temperature, which is dictated by the first Pu-239 resonances. There remains considerable interest in solving this issue and the HPRL general request 11 specifically addresses this need.

For the next JEFF Pu-239 library, several changes have been or will be put in place. Issues in the EXFOR data from Harvey have been identified and solved by accessing the original, pre-binned data from ORNL as provided to Olivier Bouland in the 1990s. It was generally noted that the processing of data into some energy discretisation is necessary to interpret these data, but re-binning clearly creates a new dataset and access to original data should be encouraged wherever possible. The resolved resonance parameters are being extended up to 4.5 keV using cross-comparison of ESTIMA analyses of the resolved parameters and results from the OPTMAN optical model code. Agreement on the 10^4S_0 parameter between the two at better than 3% and the extended 'statistically generated' parameters were shown in pointwise against averaged data from Shea and Tovesson. Recent capture measurements from Mosby were then normalised to agree with integral trends from the PROFIL experiments on the PHENIX reactor (as Mosby are 'shape' data), with the integral from 37 to 100 eV as 39(1) barns.

New additions to CONRAD allow the combination of direct and two-step (n,γf) fission, with multiple channels for different spin-parities. This introduces interferences between resonances and complicates the covariances, with work ongoing. The introduction of a new CEA PFNS has shown similar results to the effect of the "pu239e80p10" IAEA PFNS, with a nearly +400 pcm change in PST-001.1. This and the persistent isothermal temperature reactivity coefficients found in MOX fuel systems show that the outstanding temperature-dependent Pu-239 alpha issue is going to be a priority for any future evaluation work.

2.3. Resonance evaluation of ^{239}Pu in the resonance region up to 4 keV

L. Leal (IRSN) presented work that was prepared for the PHYSOR-2020 conference. While existing Pu-239 evaluations in ENDF/B-VIII.0 and JENDL-4.0u have resolved resonances up to 2.5 keV, the current work extends this up to 4 keV using high-resolution transmission and fission data taken at the Oak Ridge Electron Linear Accelerator (ORELA) using 80 and 86 m flight paths. Some issues had been noted with the URR treatment between 2.5 and 4 keV, motivating this work. Data from Harvey, Weston, Bollinger, Gwin and Mosby were used in the analysis and their specific energy ranges, flight paths and references are provided in the Table II of the paper. Integral values are normalised to the recommended values of the Standards from 2006. It was noted in the meeting that these have changed in recent Standards evaluations and could be revisited in future work.

To test the new evaluation, the ENDF/B-VIII.0 Pu-239 file was altered to take the new resonance evaluation up to 4 keV. Severalcritical benchmarks were calculated, including the recent Thermal/Epithermal eXperiments (TEX) run in the US Nuclear Criticality Safety programme. A superior agreement was found for several of the TEX configurations, notably the cases 3-5 with EALF values that are less than 4 keV.

2.4. Updates to R-matrix evaluations off Fissile actinides: ^{233,235}U, ^{239}Pu

M. Pigni (ORNL) reviewed the nature of the resolved resonance range and its importance in applications such as modelling of critical systems, which can be sensitive to the rapidly fluctuating cross sections in these energy ranges. The standard approach is to use the R-matrix theory as an approximation of the S matrix and to fit a set of resonance parameters with high energy resolution time of flight measurements. As mentioned in other discussions, there is a philosophical issue with the apparent lack of use of high-resolution measurements in the unresolved resonance range, due to the lack of complete resolution of peaks. To accurately model the measured cross section fluctuations and include these data into evaluated data files, a new procedure has been developed. This involves the definition of a set of populations of levels and amplitudes that are extrapolated based on systematics and trends from the evaluated resolved resonance range. Using these 'realistic' parameters, informed by the results from lower-energy evaluation where all resonances can be fully resolved, the fit can produce a continuous S-matrix in the Reich-Moore resonance approximation and the averaging of this function over selected energy intervals generates an averaged cross section that is consistent with the trends of the measured data.

A detailed description for the process as discussed during the meeting is provided in Appendix 1.

2.5. URR measurements, evaluation and testing for tantalum

Y. Danon (RPI) described work done to develop a methodology for testing unresolved resonance range self-shielding accuracy using naturally mono-isotopic tantalum. Significant differences exist in modern Ta-181 evaluations, particularly in simulations that are sensitive to the URR and it has been listed as a priority for the US NCSP programme. Ultimately, the findings of this work can be applied to other isotopes, including actinides. To probe the URR in tantalum, an experiment was setup to measure energy-averaged cross sections between 200 and 300 000 eV, where the transitions between RRR, URR and the fast region could be observed with all major evaluations. Transmission experiments are highly sensitive to self-shielding, so this provides an ideal case to study the effect of different evaluation formalisms on the self-shielding values and offer a validation opportunity. With standard probability tables generated by the NJOY21 code, reasonable agreement was found with the ENDF/B-VIII.0 evaluation up to the end of the URR, with a more than 5 sigma disagreement in transmission in the fast energy range transition (5 keV). In comparison, the JEFF-3.3 evaluation URR extends up to 100 keV and these large discrepancies are not present. A study was carried out with a set of different evaluation methodologies: (1) one extended URR range covering the RPI experimental energy domain (2) a multi-range URR and (3) an extended RRR up to the fast energy range with 'statistically sampled' resonances generated from averaged optical model parameters. The results show that the RRR representation should be used where possible and that the ENDF/B-VIII.0 evaluation should have this extended up to approximately 2.4 keV (as with JEFF-3.3 and JENDL-4.0). Above this energy, a URR treatment should be used well beyond the ENDF/B-VIII.0 value of 5 keV, with the JEFF-3.3 limit of 100 keV showing clear advantages. Calculations with ENDF/B-VIII.0 on U-238 show a similarly promising self-shielding effect around 20 to 200 keV.

2.6. ^{235}U(n,f) evaluations in the resonance range

I. Duran (FICA-USC) presented work done at n_TOF on the absolute measurement of the U-235 fission cross section. Within the resolved resonance region of the current evaluated libraries, new measurements were performed in *C.Paradela et al. EPJ WoC 111(2016)02003* that recommend an integral mean value for the 7.8 to 11.0 eV of 246.4 eV b, while the new international Standard give 247.5 eV b – and the uncertainty is estimated at 1 eV b instead of the Standard's 3 eV b. The ratio of this value to thermal cross section was also determined and should be considered for use in future evaluations and the Standards, as well as other well-measured resonance integral values and ratios. High-resolution measurements above the current 2.25 keV cut-off between the resolved and unresolved regions showed good agreement with the previous Weston data. However, the high-resolution data is not reflected in the evaluations, which transition to URR at 2.25 keV. Luiz Leal (IRSN) noted that there are unofficial evaluations that have not been adopted by libraries. It was agreed that, while the high-resolution data is extremely valuable, all resonance evaluations must balance the loss of some resonance structure with the benefits of retaining some semi-resolved data. Even where fluctuations are clearly discernible, (semi-empirical knowledge of the level densities informs evaluators that some fraction of the resonances are missing and the URR has been introduced precisely to address this issue: statistical rules complement measurement to provide the integral information required in simulations. Measurements with improved resolution can indeed allow evaluators to increase the energy threshold for the U/R transition, but these require effort-intensive re-evaluations to consistently increase the threshold value. The ENDF/B-VIII.0 evaluation, for example, included some renormalisation of URR cross sections without significant energy-dependent re-evaluation and/or re-discretisation. Evidence suggests that this decision should be revisited, either with an extended re-evaluations and/or update for the URR. One specific issue occurs at the 5.903(8) keV aluminium peak, which has been observed by PPACs and is under-corrected in the ENDF/B-VIII.0 evaluation.

New evaluation work done by USC was shown and integral values in the 3.51-27 keV energy range were compared against the 2018 values published in *Nuclear Data Sheets*. Values up to 10 keV were in good agreement but those above 10 keV shows some differences – both between the NSC values, the NDS 2018 publication and the online IAEA resources. Roberto Capote (IAEA) explained that the online resources on www-nds.iaea.org/standards/ reflect the values published in the INDC(NDS)-0681 reference. While there are clear references to the different Standards published over the years, it was agreed that a unique online reference system would be valuable.

On the thermal/epi-thermal energy range, several integral ratios were measured due to their low sensitivity to energy accuracy. Several of these energy ranges are already well-known, although a new one around 17.5 to 22 eV could be included, as well as integrals around 9-12.5 eV for Pu-239 fission. Suggested values for these are provided in the report.

2.7. A comparison of ENDF/B-VIII.0 to some other evaluations for different criticality calculations in thermal systems

Following the release of the ENDF/B-VIII.0 and JEFF-3.3 evaluations in 2017/2018, numerous integral tests have been carried out by a range of experts in universities, TSOs and industry. These are often complex tests that involve the reaction physics of many isotopes and other modelling features, but by isolating dependence on key features one may find insights directly on the nuclear data used.

Oscar Cabellos (UPM) presented work done in three studies:

1. *Nuclear criticality safety assessments for spent fuel casks*

   A large set of 533 LCT cases of the ICSBEP were calculated using the ENDF/B-VIII.0 and JEFF-3.3 libraries, and simple linear regression of the trends of C/E against ^{235}U enrichment showed non-negligible negative trends for ENDF/B-VIII.0 and positive trends for JEFF-3.3. While such statistical analyses without experimental correlations (particularly between cases of the same benchmark set) must be interpreted with caution, these are typical tests that pose a problem for multiple applications.

2. *A computational benchmark proposed by the NEA WPNCS Subgroup 3*

   Under the NEA Working Party for Nuclear Criticality Safety, Subgroup 3 has focused on temperature effects of criticality benchmarks. A computational benchmark was proposed to take a typical 17x17 PWR fuel assembly with either 1 metre water reflector or an infinite lattice. Temperature is then varied in the simulations and libraries are compared with each other to find trends at a range of fuel compositions representing different fuel burn-ups. Trends against JEFF-3.3 showed a significantly lower criticality value with ENDF/B-VIII.0 at 0 burn-up that increases with temperature to over 400 pcm at 588K. Sensitivity calculations identified neutron capture at 0.1-0.2 eV as the most impactful, with an increase from 293K to 588K that fits with the inter-library comparison.

3. *A computational benchmark on the so-called 'Doppler Reactivity Defect'*

   The Doppler Defect is a comparison between hot full power (~900K) and hot zero power (~600K) experience in typical LWR reactors. The specifications for the benchmark to study the effect is the Mosteller 'Computational Benchmarks for the Doppler Reactivity Defect' LA-UR-06-2968 (April 2006). In the comparison, only UO_2 fuel is considered with up to 5 wt.% using ENDF/B-VIII.0, -VII.1, -VII.0, JEFF-3.3 and JEFF-3.1.1.

2.8. OECD Nuclear Energy Agency activities

M. Fleming (NEA) reviewed the structure of the NEA nuclear data activities and the work being co-ordinated within the Working Party on International Nuclear Data Evaluation Co-operation (WPEC). The status of the High-Priority Request List (HPRL) was discussed and all recent completions and additions were reviewed, including those on high-priority fission, capture and other channels (which largely coincide with the INDEN evaluation activities). The new Generalised Nuclear Data Structure is nearing first official publication and is intended as a replacement of ENDF-6. While its introduction will require efforts by the nuclear data community, the parallel introduction of open source APIs and the adoption of modern programming paradigms will make many serialisation and data interpretation issues much simpler, in addition to other benefits. The new Subgroup 49, co-ordinated by Mike Herman (LANL) and Dimitri Rochman (PSI), aims to develop methods for storing all evaluation inputs to make a fully reproducible evaluation and projects like INDEN and the new Standards would benefit from such processes. The NEA has implemented a GitLab service to handle these projects and others, such as EXFOR/NRDC contributions and the management of the JEFF library. Well-known databases and applications including JANIS, DICE and NDaST, which employ processed nuclear data and the ICSBEP integral benchmark suite, have had or will have releases in the near future, taking advantage of full covariance data, updated libraries, new serialisation options and many other upgrades.

In subsequent discussions, the fact that general request 11, which includes compound observables requested by Luiz Leal, has not been completed

2.9. The unresolved resonance range: format, parameter and formalism

J.-Ch. Sublet (IAEA) reviewed the importance of processing in providing nuclear data for applications, which are each tailored to specific needs of the systems that are being considered. This is important to keep in mind as different formalisms or processed data forms are not necessarily superior or inferior – but designed for specific use cases.

The use and importance of probability tables was shown with a cross-comparison of results using Tripoli-4.5 and the JEFF-3.1/3.1.1 libraries with different processing routes. On a set of IMF benchmarks (including IMF-007 'Big Ten', IMF-010 and IMF-012) differences could be over 500 pcm in criticality. Different codes have access to and use nuclear data from the URR in different ways, for example, Tripoli accounts for fluctuations in the U-238 inelastic scattering below 100 keV. The way that the URR is self-shielded also varies by processing code and application, where the full MT=1, 2, 4, 18 and 102 are handled by CALENDF.

Regarding the ENDF-6 formalism, only the SLBW LRF=1 formalism is allowed for the URR. No resonance-resonance interference is allowed and only one single-channel inelastic competition reaction is allowed. The LSSF flag has two options: (0) where MF=3 contains the partial background to be added to the cross section or (1) MF=3 contains infinitely dilute cross sections and the MF=2 is used only for the calculation of the self-shielding factors. In the case of LSSF=1, it is necessary for the user to ensure that direct inelastic cross sections have not been added into the compound inelastic. While the direct compound can be added as a background, the angular distributions are the same. As an example, Pu-239 contains approximately 20% direct at 300 keV. A review of a set of W, U and Pu evaluations showed that the URR file 2 parameters were included in several different formalisms. A cross-comparison using NJOY PURR, CALENDF, AUROX and PURM showed differences of several to tens of % in self-shielding values in the URRs of these isotopes, stressing the importance (and complexity) of ensuring consistency from evaluation, through processing and ultimately in applications use.

2.10. Testing the transition from resolved to unresolved resonance region for ^{238}U

S. Kopecky (JRC) reviewed the recent U-238 evaluation in the URR. A series of calculation was performed to understand the sensitivity of available integral benchmarks on the energy of the transition between resolved and unresolved energy range for U-238.

For this purpose, a set of test files was produced. The parameters in the resolved resonance region of these files were based on the parameters given in JEFF-3.2. The average capture cross section recommended by Carlson *et al.* are reproduced by these parameters up to 20 keV. The transmission coefficients and shape elastic cross section from the optical model were used to derive average parameters, i.e. neutron strength functions and hard sphere scattering radius]. The capture transmission coefficients were obtained from a fit to the capture cross section of Carlson *et al.* One file had the transition between the resolved and unresolved resonance region at 10 keV the other one at 20 keV.

With these two evaluated files, two sets of benchmarks, which had been selected from the ICSBEP handbook, were calculated. Overall, no significant differences between the performances of the two files were observed, neither over the full sets nor on a selection of the most sensitive benchmarks.

We are therefore tempted to conclude that none of the available benchmarks is sensitive enough to distinguish the change in the resolved resonance region from 10 kev to 20 kev for U-238.

Two remarks should be added:

Firstly, it might be educational to perform additional calculations for the most sensitive benchmark at higher (reactor) temperatures as differences in the treatment of Doppler broadening might give rise to differences in the calculated results.

Secondly, for any observable that depends strongly on the leakage through a thick slab of uranium the use of resolved resonance parameters gives results that are more reliable.

2.11. Recent progress of AMUR and future plans of evaluation

N. Iwamoto (JAEA) described the status of, use and future plans for the AMUR multi-channel R-matrix code. Recent evaluations performed include work on O-16 and F-19 total cross section, as well as C-13(α,n) and F-19(n,γ), including Reich-Moore analysis for the F-19 evaluation. AMUR also has the ability to fit data in LRF=1, 2, 3 or 7, as well as general R-matrix, and can reconstruct cross sections with Doppler broadening. It can also generate plots with ROOT and output covariance information in MF33 format but at present not the resonance parameter covariances (MF32). At present, resolution functions will soon be available for the J-PARC MLF ANNRI experiment and plans are in place to develop resolution functions for JRC-Gell GELINA, CERN n_TOF and others, as well as inclusion of corrections for self-shielding, multi-scattering effects and others. Evaluations on the neutron multiplicity for U-235 fission and Cf-252 spontaneous fission are in progress.

Appendix 1

How to generate evaluated data files in the Unresolved Resonance Region (URR)

Following the prescriptions defined in the ENDF manual, the formal procedure to evaluate cross sections in the Unresolved Resonance Region (URR) is described below.

Focusing on case of a fissile actinide nucleus for which the three reaction channels, (n,tot), (n,f), and (n,g), are needed to be evaluated, the availability of measured data for, at least, two of these reaction channels is a basic fundamental assumption to start the evaluation of the resonance parameters and corresponding cross sections in the URR. Since the capture cross sections can be calculated by subtracting total from the fission cross sections, measured capture data may be considered redundant and not ultimately necessary. One should keep in mind the shape of these measured data is such as in the low energy up to an intermediate energy, i.e. $E_{RRR,}$ usually chosen by the evaluator, the resolved resonance-like structure is used to perform R-matrix analyses to evaluate a statistically consistent set of resonance parameters. As soon as the energy increases, only broader and broader fluctuations representing very closely spaced levels can be measured and are reported in the experimental data sets. In evaluating the URR cross sections we focus on the energy range of the measured data above E_{RRR} in the attempt to evaluate a set of resonance parameters with specific statistical assumptions obtained in the fit of resolved resonances.

Based on the availability of the measured data as described above, the evaluation procedure starts in defining a prior set of parameters, namely, resonance energies E_λ and related reduced amplitudes γ_c for each channel c) above the energy E_{RRR} where the fluctuating behavior of the measured data for each reaction channels is visible. The prior set of resonance parameters in the energy region between E_{RRR} up to E_{max} can be generated in two ways both based on the statistics of the resonance parameters evaluated in the energy region below E_{RRR}. The statistics consists on the average values of the level spacing and the neutron, fission, capture strength functions (usually for s-wave only since these quantities are evaluated in the low-energy range). The first method uses probability distributions such as Wigner or Porter Tomas, to randomly generate a set of resonance energies E_ν and related reduced amplitudes γ'_c in the neutron energy range between E_{RRR} up to E_{max}. The second method consists on projecting the set of resonance parameters evaluated below E_{RRR} to energies above it up to the energy E_{max}. Namely, these energies are defined as $E_\nu=E_{RRR}+E_\lambda$ for all λ belonging to the energy interval (0, E_{RRR}). Since E_{max} is usually larger than E_{RRR} the projection procedure may be performed several times. The assumption on the reduced amplitudes for all considered channels defines the reduced amplitudes with constant strengths. If the parameter strengths for partial waves higher than s-wave are needed, their average values can be obtained from optical model calculations.

Both methodologies allow to define a set of prior set of resonance parameters over the energy interval E_{RRR} up to E_{max} that is used to fit with R-matrix codes such as SAMMY, CONRAD, etc., the considered measured data. The fit is performed with all necessary experimental corrections such as resolution broadening, energy resolution, isotopic abundances, etc. Due to the large number of parameters the agreement between the theoretical and experimental fitted observables (transmission, cross section, yield, etc.) is usually satisfactory. Contrary to the fit of resolved resonance data, due to the fluctuating behavior of the fitted cross sections in this energy range, several up to many levels might be needed to fit the broad structures in the fluctuating measured data. Ultimately, this approach allows to generate continuous energy-dependent theoretical cross sections defined within a theoretical formalism (for instance the Reich-Moore approximation of the R-matrix theory) preserving important physical constraints as well as accurately describing the measured data. This also means that the theoretical cross sections for each reaction channel and set of quantum number l and J can be reconstructed from the set of resonance parameters.

In this scenario starting from the obtained set of resonance parameters $\mathbf{p} = (\mathbf{E}_\nu, \gamma_\mathbf{n}, \gamma_\mathbf{f}, \gamma_\mathbf{g})$ (depending on the specified set of quantum number lJ) and the corresponding reconstructed cross sections $\sigma_c^{lJ}(E;\mathbf{p})$ calculated for any incident neutron energy $E \in (E_{RRR}, E_{max})$, one has to calculate the average of these quantities over energy ranges or bins carefully defined between E_{RRR} and E_{max}. This averaging procedure is described as follows and performed to generate ENDF formatted data according to the current specifications of the ENDF manual for LSSF=1 option. The average of the fluctuating cross sections over a set of energy bins is defined such as in each of these energy bins, the averaged cross sections are basically constant. This produces average cross sections $< \sigma_c^{lJ} >_k$ whose shape is not strongly fluctuating anymore but reproduces the gross structure of the fluctuating cross sections previously calculated. The average of the resonance parameters belonging to each energy bin is also performed. The average resonance parameters such as average level spacing $<D^{lJ}>_k$ and strength functions $<S_c^{lJ}>_k$ can be obtained and, with the related average cross section $< \sigma_c^{lJ} >_k$ in the energy bin k, can be stored and formatted in the file 2 and 3. Another procedure would be to use code like FITACS to fit the average cross sections $< \sigma_c^{lJ} >_k$ and obtain the average resonance parameters. These two procedures should generate very similar average resonance parameters. With LSSF=1 option the set of average resonance parameter will be used to generate probability tables needed to add a strongly fluctuating behavior to the average cross sections represented with a gross structure resolution in file 3.

Appendix 2

Technical Meeting of the
International Nuclear Data Evaluation Network (INDEN) on
Actinide Evaluations in the Resonance Region

IAEA, Vienna, Austria
21 to 24 October 2019

Meeting Room M7

Adopted AGENDA

Monday, 21 October

09:00 – 09:30 **Registration** (IAEA Registration desk, Gate 1)

09:30 - 10:00 **Opening Session**

Welcoming address – A. Koning, IAEA/NDS-SH
Introduction – R. Capote, IAEA/NDS
Election of Chairman and Rapporteur
Adoption of Agenda /Administrative matters

10:00 – 12:30 **Presentations by participants**

- R. Capote Noy (IAEA)
- G. Noguere (CEA)
- L. Leal (IRSN)

12:30 – 14:00 Lunch

14:00 - 17:30 **Presentations by participants** (cont'd)

- M. Pigni (ORNL)
- Y. Danon (RPI)
- I. Duran **(**FICA-USC)

Coffee breaks as needed

Tuesday, 22 October

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

- Oscar Cabellos (UPM) – via video conference
- M. Fleming (NEA)
- J.-Ch. Sublet (IAEA)
- S. Kopecky (JRC)
- N. Iwamoto (JAEA)

12:30 – 14:00 Lunch

14:00 - 17:30 Round table discussions

Coffee breaks as needed

19:30 ***Dinner at Restaurant Ragusa (see separate information sheet)***

Berggasse 15, 1090 Wien

Wednesday, 23 October

09:00 - 12:30 Round table discussion (cont'd)

12:30 – 14:00 Lunch

14:00 - 17:30 Drafting of the Summary Report

Coffee breaks as needed

Thursday, 24 October

09:00 - 13:00 **Drafting of the Summary Report** (cont'd)

13:00 **Closing of the meeting**

Coffee break as needed

Appendix 3

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International Nuclear Data Evaluation Network (INDEN) on
Actinide Evaluations in the Resonance Region

IAEA, Vienna, Austria
21 to 24 October 2019

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