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FISSION PRODUCT YIELDS DATA
Current status and perspectives

Summary report of an IAEA Technical Meeting

IAEA Headquarters, Vienna

23 – 26 May 2016

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ABSTRACT

A Technical Meeting on Fission Product Yields Data: current status and perspectives, was held from 23 to 26 May 2016, at the IAEA, Vienna. The purpose of the meeting was to review the current status of Fission Product Yield data, and discuss the progress in measurements, theories, evaluation and covariances. The presentations, technical discussions and recommendations of the meeting are given in detail in this summary report.

October 2016

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APPENDICES

1. Introduction

A Technical Meeting on ‘’Fission Product Yields: current status and perspectives’’ was held on 23-26 May 2016 at the IAEA Headquarters, Vienna, Austria. The purpose of the meeting was to report and discuss progress in the field of fission yields from the point of view of measurements, theory and systematics, evaluations and validations. Significant developments that have taken place in the past two decades following the completion of the IAEA CRPs on ‘Compilation and evaluation of fission yield nuclear data’, 1991-1996 [1.1], and on ‘Fission Product Yield Data for the Transmutation of Minor Actinide Nuclear Waste’, 1997-2002 [1.2], suggest that a review of the current status of fission yield data in conjunction with the emerging data requirements for applications is merited.

The meeting was opened by Arjan Koning, Head of the Nuclear Data Section, who welcomed the participants and emphasized the importance of their task in defining requirements and priorities for future programs on fission yield data. Stephan Pomp (Uppsala University) was elected Chairperson of the meeting, and Franz-Josef Hambsch (Joint Research Centre-European Commission) was appointed rapporteur. Paraskevi Dimitriou (IAEA Scientific Secretary) gave a short introduction of the motivation and goals of the meeting. The adopted agenda can be found in Annex 1, while the list of participants is given in Annex 2. The meeting began with individual presentations by the participants (a group photograph and list of links to the presentations are provided in Annexes 3 and 4) followed by technical discussions and recommendations. A summary is given in the following sections.

1.1. Application driven needs for fission yields

Fission yields are important both for basic nuclear sciences and applied user fields. In basic sciences, fission yields are fundamental aspects of the probability of fragment formation and therefore play an important role in our understanding of the fission process. They are also directly related to our understanding of the abundances of chemical elements through cosmological nucleosynthesis. In the applied user fields, they are needed for calculating the accumulation and inventory of fission products at various stages of the nuclear fuel cycle, in the conventional nuclear reactor facilities as well as in accelerator-driven systems.

User needs in all areas of the nuclear fuel cycle and accelerator-driven systems have been extensively reviewed in the previous IAEA CRPs [1.1, 1.2], in order to address the data requirements. Here we briefly summarize the most important applications at various stages of the nuclear fuel cycle, to highlight the developments that have taken place in the past decades (if any) leading to a renewed interest in fission yield data at low energies ranging from thermal to, fast and high (14 MeV) energies.

In reactor design and operation, fission product yields (FPY) are used in criticality and reactivity calculations performed for fuel and reactor core management, for reactor safety and for determining the limits of safe operation in new plants and for materials transport. For various types of reactors, fission yields should be known as a function of incident neutron energy. For contamination and gas production, ternary fission yields (tritium, helium) are also needed.

For the reprocessing of spent fuel and the management of nuclear waste, one should know the fission product inventory primarily as a source of radiation (heat production and potential hazard to the environment and personnel). Fission yields enter the calculations of fission product inventories and radioactivity (decay heat).

For an accurate evaluation of the fuel and reactor performance burnup calculations are compared with experimentally determined actual spent fuel composition where fission yields play a crucial role. For certain methods, fission products are used as burnup monitors and therefore their fission yields are required with high accuracy for the evaluation of the measurement results.

For transmutation devices envisaged amongst the Gen-IV reactor systems, information about fission yields for minor actinides are of importance.

In the various uses of fission yields, one should distinguish between the ***independent*** yield of a fission product (FP) which is defined as the probability of its formation directly in fission, and the ***cumulative*** yield defined as the probability of its accumulation from fission plus through the decay of its precursor(s) plus and/or minus through delayed neutron emission.

In recent years there has been a renewed interest in fission yields data for the nuclear fuel cycle. With the improved computing power and capabilities, the enhanced predictive power of models, and the improvement of the decay data entering the evaluated libraries, it has been shown that for certain fission yields (independent and/or cumulative), the required accuracies are not met by the existing data. These new findings were the subject of the presentations by the participants and the technical discussions that ensued.

References

[1.1] CRP on “Compilation and evaluation of fission yield nuclear data (1991-1996)’’, IAEA-TECDOC-1168, Dec. 2000.

[1.2] CRP on “Fission Product Yield Data for the Transmutation of Minor Actinide Nuclear Waste (1997-2002)”, STI/PUB/1286, April 2008.

2. Summaries of presentations of participants

2.1. Dynamical approach for low-energy nuclear fission by the Langevin equation and results from surrogate reaction, S.Chiba, Tokyo Institute of Technology

We treat nuclear fission as a fluctuation-dissipation process, and describe fission in terms of a multi-dimensional Langevin equation. We use 3 collective coordinates, the elongation, fragment deformation and mass asymmetry. The potential energy surface is calculated by the Krappe-Nix model for the macroscopic part, and Strutinsky's prescription for the microscopic correction by using the two-center shell model parametrization of the nuclear shape. The transport coefficients are calculated by a macroscopic method, namely, the Werner-Wheeler method [Ref. 3] for the inertial tensor, and the wall-and-window formula for the friction tensor. The calculated mass distributions for the U mass region were shown to reproduce experimental data quite well as can be seen in Fig. 2.1.

Furthermore, we described the current improvements of our method. Firstly, we have introduced a linear response theory with locally-harmonic approximation to calculate the transport coefficients in a microscopic way. In this manner, effects of the shell and pairing interaction to the transport coefficients are included, and a dependence of the results on the nuclear temperature can be obtained. Then, we extended the 3-dimensional calculation to a 3+1-dimensional one in order to obtain the isotope distribution. For this sake, we introduced the charge asymmetry degree-of-freedom simultaneously with the mass asymmetry assuming that a deviation from UCD is relatively slow compared to charge equilibration and an oscillatory process described by the fluctuation-dissipation theorem. Such a modification enables us to derive the dynamical effect of the charge polarization and elongation at pre-scission and scission configurations. The isotope distributions obtained with an improved treatment of the charge polarization reproduce the experimental or evaluated isotope distributions more accurately as shown in Fig. 2.2.

We also presented some of the results from studies of surrogate reactions at JAEA, whereby an ^{18}O beam was used on ^{232}Th, ^{237}Np, ^{238}U and ^{242}Cm targets to measure the mass distributions of several actinides and deduce systematics.

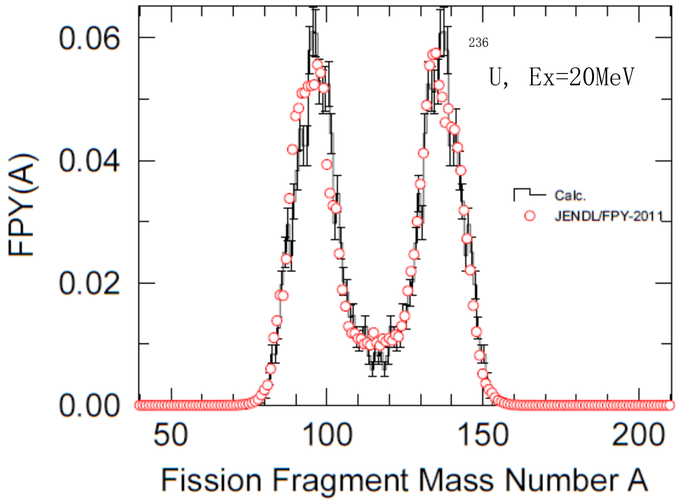

FIG. 2.1. Fission Fragment mass distribution for fission of ^{236}U at Ex=20 MeV.

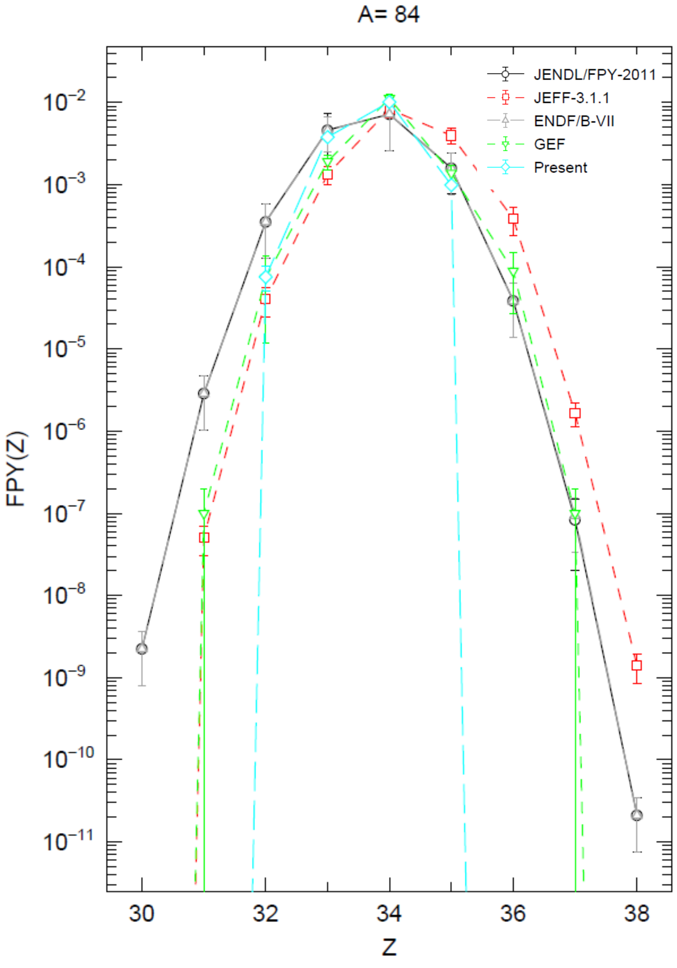

FIG. 2.2. Isotope distribution of the fission product A = 84 yields from the present work (cyan diamonds) are compared with results from JENDL/FPY-2011 (black circles), JEFF-3.1.1 (red squares), ENDF/B-VII (black triangles) and GEF (green upside triangles).

2.2. General description of fission observables: The GEF code[1], K.-H. Schmidt, CENBG

The GEF ('GEneral description of Fission observables') model code [1] describes the observables for spontaneous fission, neutron-induced fission and, more generally, for fission of a compound nucleus

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[1] Supported by the Nuclear-Energy Agency of the OECD.

from any other entrance channel, with given excitation energy and angular momentum. The GEF model is applicable for a wide range of isotopes from $Z = 80$ to $Z = 112$, up to excitation energies of about 100 MeV. Since GEF is based on robust physical ideas it can also give reasonable results for nuclei that are beyond the range of nuclei for which the parameters have been adjusted. The calculated fission barriers, fission probabilities, fission-fragment mass and nuclide distributions, isomeric ratios, total kinetic energies, and prompt-neutron and prompt-gamma multiplicities and energy spectra from the GEF model are generally in good agreement with experimental data and evaluations. GEF covers also cumulative fission-fragment yields, delayed neutrons and gammas. A number of deviations can be explained by deficiencies of the data. For example, the fragment mass distribution of ^{237}Np(n$_{th}$,f) from ENDF/B-VII shows a sizable contribution of a heavier fissioning system, possibly due to a target contamination of 15 ppm of ^{239}Pu(n$_{th}$,f).

The GEF model is based on a general approach to nuclear fission that explains a great part of the complex appearance of fission observables on the basis of fundamental laws of physics and general properties of microscopic systems and mathematical objects. The topographic theorem is used to estimate the fission-barrier heights from theoretical macroscopic saddle-point and ground-state masses and experimental ground-state masses. Motivated by the theoretically predicted early localization of nucleonic wave functions in a necked-in shape, the properties of the relevant fragment shells are extracted. These are used to determine the depths and the widths of the fission valleys corresponding to the different fission channels and to describe the fission-fragment distributions and deformations at scission by a statistical approach. A modified composite nuclear-level-density formula is proposed [2]. It respects some features in the superfluid regime that are in accordance with new experimental findings and with theoretical expectations. These are a constant-temperature behaviour that is consistent with a considerably increased heat capacity and an increased pairing condensation energy that is consistent with the collective enhancement of the level density. The exchange of excitation energy and nucleons between the nascent fragments on the way from saddle to scission is estimated according to statistical mechanics [3,4,5]. As a result, excitation energy and unpaired nucleons are predominantly transferred to the heavy fragment. This description reproduces some rather peculiar observed features of the prompt-neutron multiplicities and of the even-odd effect in fission-fragment Z distributions [6]. In addition, some conventional descriptions are used for calculating pre-equilibrium emission, multi-chance fission and statistical emission of neutrons and gamma radiation from the excited fragments.

The approach reveals a high degree of regularity and provides a considerable insight into the physics of the fission process. Fission observables can be calculated with a precision that complies with the needs for applications in nuclear technology without specific adjustments to measured data of individual systems. Because GEF is a fast code, it is suited for implementation in a wider network calculation. The GEF executable runs out of the box with no need for entering any empirical data. This unique feature is of valuable importance, because the number of systems and energies of potential significance for fundamental and applied science will never be possible to be measured. The GEF model is also suited for examining the consistency of experimental results and for assistance in the evaluation of nuclear data. GEFY tables of independent and cumulative fission yields are provided as well as a set of random files in ENDF-6 format.

Reference

[1] K.-H. Schmidt, B. Jurado, Ch. Amouroux, Ch. Schmitt, Nuclear Data Sheets 131 (2016) 107.
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[6] B. Jurado, K.-H. Schmidt, Phys. G: Nucl. Part. Phys. 42 (2015) 055101.

2.3. Comparing Nuclear Fission Codes: GEF as standalone code vs GEF+TALYS, A. Mattera, Uppsala University

Fission model codes for the calculation of fission observables are essential in producing evaluated nuclear data libraries for fission yields. They are also a way to assist experimental nuclear physicists in data analysis and in the interpretation of their results. Assumptions in the models and tuning of parameters behind the codes provide, in many cases, a good reproduction of experimental data. In this work, we have explored a way of comparing different fission codes in the description of observables that can be fit to experimental data, such as isomeric yield ratios and $\overline{\nu}(A)$ distributions.

The first step in this work was done comparing a standalone version of the GEF code [1] with a combination of GEF and TALYS. In the latter approach, the fragments in their excited states (with mass, and excitation energy distributions obtained from GEF for every fission on an event-by-event basis) were given as input to TALYS [2] that handled the de-excitation. From the output of TALYS, it was then possible to extract measurable quantities (such as ground-state/isomeric-yield distributions, but also total $\overline{\nu}$ and $\overline{\nu}(A)$) that were compared with the same quantities extracted from GEF and with experimental data.

The results of the first comparison, despite proving not conclusive in the case of Isomeric Yield Ratios, show good consistency between how the de-excitation is treated in the two codes. In the case we analyzed ($^{235}U+n_{th}$, $^{239}Pu+n_{th}$ and $^{252}Cf(SF)$), the $\overline{\nu}(A)$ from the two codes agree both in absolute values and in the shape, even though some structures that were observed in GEF - such as a slight enhancement of neutron emission around mass 140 - were not reproduced in TALYS.

The method we are testing is proposed as a way to compare different codes against each other and with data in terms of the fission fragment observables right after scission. This is done by decoupling the de-excitation process, which is handled in an independent and consistent fashion using the models built into TALYS.

The effect on fission observables of different sets of excitation energies calculated using various assumptions and models (e.g. Freya, PbP, …) can then be easily evaluated and is the focus of a more extended study that is being carried out.

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[1] Schmidt, K-H., et al. "General Description of Fission Observables: GEF Model Code." Nuclear Data Sheets 131 (2016): 107-221.

[2] A.J. Koning, S. Hilaire and M.C. Duijvestijn, “TALYS-1.0”, Proceedings of the International Conference on Nuclear Data for Science and Technology, April 22-27, 2007, Nice, France, EDP Sciences (2008): 211-214.

2.4. Fission Yield Activities carried out at CEA-Cadarache, O. Serot, CEA, DEN-Cadarache

In spite of the huge amount of fission yield data available in the evaluated nuclear data libraries, more accurate data are still strongly requested for both nuclear energy applications and for our understanding of the fission process itself. In addition, the variance-covariance matrices are still missing, even in the more recent evaluated files. In this context, two main research activities are carried out at CEA-Cadarache which will be detailed in the present contribution.

The first one is related to the various campaigns of fission yield measurements, performed at the High Flux Reactor of the Institut Laue-Langevin (ILL) in Grenoble (France), in the frame of a collaboration between CEA (Cadarache and Saclay), LPSC (Grenoble, France) and ILL. In the past, the mass spectrometer LOHENGRIN (available at ILL) was coupled to a high resolution ionization chamber in order to investigate isobaric and isotopic yields of fission products in the light mass region. Unfortunately, in the heavy mass region (with nuclear charge higher than 42), such isotopic separation within a mass line is no longer efficient. Therefore, a new experimental setup, based on gamma spectroscopy (for the isotopic identification) was undertaken [1]. In this way, the heavy mass region could be investigated for various thermal neutron induced reactions: $^{233}U(n_{th},f)$ [2,3], $^{235}U(n_{th},f)$ [4], $^{239}Pu(n_{th},f)$ [4,5], $^{241}Pu(n_{th},f)$ [3,4] and $^{241}Am(2n_{th},f)$ [6, 7]. A new procedure for the data analysis has been developed, allowing us to generate for the first time on Lohengrin, the experimental covariance matrix [3, 8], which are very useful for the future evaluations. Results obtained are very encouraging considering how uncertainties have been decreased compared to other experiments and evaluated data, respectively. The symmetric mass region was also studied for $^{233}U(n_{th},f)$ and $^{241}Pu(n_{th},f)$ reactions [8, 9]. This region is challenging due to the low counting rate and also the appearance of contaminant masses. Surprisingly, after removing the contribution of the contaminant masses, a two component structure in the fission fragment kinetic energy distribution was observed, suggesting that the fission process could be modal. Lastly, within our collaboration, a new spectrometer named FIPPS (for FIssion Product Prompt γ-ray), is under development at ILL [10]. FIPPS will consist of an array of γ and neutron detectors placed around the target and coupled with a Fission Fragment (FF) filter. A Gas Filled Magnet (GFM) has been chosen for the FF filter [11]. This new device should allow us to investigate prompt fission γ and neutron characteristics (energy, multiplicity) as a function of the emitter FF properties (nuclear charge, mass, kinetic energy, spin …).

The second activity is dedicated to the calculation of the variance-covariance matrix associated to the JEFF.3.1.1 evaluations [12, 13]. Based on several fission models (Brosa, Wahl and Madland England models), these calculations were performed using the CONRAD code [14], for the most significant fissioning systems for nuclear energy applications (thermal and fast neutron induced reactions). Then, these variance-covariance matrices were propagated to determine the uncertainties relative to nuclear reactor parameters. Examples of decay heat calculations, showing a strong reduction of the uncertainties when covariances are accounted for, will be presented. This part was done in the frame of a collaboration between CEA-Cadarache and the University of Bologna (Italy).

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[3] F. Martin, PhD thesis, University of Grenoble, France, 2013.
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[12] N. Terranova et al., Nucl. Data Sheets 123, 225 (2015),
[13] N. Terranova, PhD thesis, University of Bologna, Italy, 2016.
[14] P. Archier et al., Nucl. Data Sheets 118, 448 (2014).

2.5. A Bayesian Monte Carlo method for fission yield covariance information, D. Rochman, Paul Scherrer Institut

The existing fission yield (FY) libraries such as JEFF-3.2, ENDF/B-VII.1 or JENDL-4.0 contain information of the yields themselves and their uncertainties: for a given fissioning system and for different incident neutron energies, independent and cumulative FY are provided in the form of nominal values and standard deviations. Such information is enough for a large number of simulations, but not for proper uncertainty propagation where the correlation matrix between fission yields is also needed. From the evaluation point of view, full covariance matrices (uncertainties and correlations) can be provided but requires large efforts and time. From the user point of view, such matrices are needed as soon as possible and different institute-based solutions are already under way, leading to a variety of results. This makes the need of covariance matrices from libraries even stronger, in order to avoid unexperienced user's solutions, inevitably leading to very different results and a relatively mistrust in the results.

To help providing correlation matrices for evaluated FY libraries (while keeping the evaluated FY and uncertainties), this work proposes a new method to produce correlation matrices for independent and cumulative fission yields. It is based on a Bayesian method to combine theoretical fission yields with a set of reference data (details can be found in Refs.[1,2]). These two sources of information are merged together using a Monte Carlo process, which leads to a so-called Bayesian Monte Carlo update. The starting point of the method is the GEF code [3] and its model parameters (nominal values and standard deviations). These parameters are sampled and random fission yields are calculated. The sampled fission yields can be represented by averages, standard deviations and correlations between them (together with higher moments of the distributions). Such calculated yields are compared to a reference set (*e.g.* 70 independent FYs with yields higher than 1% from an evaluated library) and simplified chi2 values are calculated for each set. Based on the chi2, weights can be calculated and used to update the probability density functions (pdf) of the GEF parameters. Based on these new parameters, new random fission yields are calculated, together with new weights. This procedure is repeated until convergence of the pdf of the GEF parameters. Finally, the last iteration is used to produce random fission yields, averages, standard deviations and FY correlations. The obtained averages and standard deviations represent a "compromise" between the theoretical information of GEF and the reference yields from the selected library. The final step is to include the calculated correlations between the FY in the reference library. This way, the reference library can be kept *as is* and complemented with a set of FY correlations.

Examples are presented for the independent and cumulative fission yields of four major actinides important for applications in energy production, namely ^{235,238}U, ^{239,241}Pu. The impact of the updated fission yields and their covariances is shown for two distinct applications: PWR UO_2 and MOX assemblies with burn-up up to 40 GWD/tHM and decay heat calculations of a thermal neutron pulse on ^{239}Pu. These results are compared with other existing methods, thus offering a range of solutions for FY evaluators.

References

[1] A.J. Koning, European Physical Journal A 51 (2015) 184.
[2] "A Bayesian Monte Carlo method for fission yield covariance information", D. Rochman *et al.*, accepted for publication in Annals of Nucl. Ene., May 2016.
[3] K.-H. Schmidt *et al.*, Nucl. Data Sheets 131 (2016) 107.

2.6. Fission Product Yields and Related Covariance Data[2], M.T.Pigni, Oak Ridge National Laboratory

A recent implementation of ENDF/B-VII.1 independent fission product yields and nuclear decay data identified inconsistencies in the fission product data caused by the use of updated nuclear schemes in the decay sub-library that are not reflected in fission product yield legacy data. Recent changes in the decay data sub-library, particularly the delayed neutron branching fractions, result in calculated fission product concentrations that are inconsistent with the cumulative fission yields in the library and show large differences with experimental measurements. The evaluation methodology combines a sequential Bayesian method to guarantee consistency between independent and cumulative yields along with the physical constraints on the independent yields [1]. To address these issues, a comprehensive set of updated independent fission product yields was generated for thermal and fission spectrum neutron-induced fission for uranium and plutonium isotopes. To provide a preliminary assessment of the updated fission product yield data consistency, these updated independent fission product yields were utilized to compare the calculated fission product inventories with experimentally measured inventories, with particular attention given to the noble gases. Another important outcome of this work is the development of fission product yield covariance data necessary for fission product uncertainty quantification. This work was motivated to improve the performance of the ENDF/B-VII.1 library for stable and long-lived fission products.

References

[1] M. T. Pigni et al., ''Investigation of Inconsistent ENDF/B-VII.1 Independent and Cumulative Fission Product Yields with Proposed Revisions'', *Nuclear Data Sheets* 123, 231 (2015).

2.7. Fission yields and decay data, M. Fleming, UKAEA

The FISPACT-II capabilities for fission decay heat simulations were summarised with excerpts from the recent benchmark report for pulsed and finite irradiation cases [1]. The new ENDF/B-VIII.1(beta) and JENDL-2015/DDF decay files have been included for new simulations using the same framework. These notably include the addition of new beta intensity evaluations that take into account Total Absorption Gamma-ray Spectroscopy (TAGS) measurements. The modifications have little effect on the total spectroscopic heat values, but as shown in a presentation of A. Sonzogni (see A. Sonzogni's summary and Annex 4), these have a significant effect on the beta and anti-neutrino spectra. Whereas the new JENDL and ENDF/B decay files show broad agreement in average photon and beta energy (EEM/ELP) values, fission yields do not enjoy similar attention and significant differences between the major evaluated libraries exist for many cooling times in all fissile systems. A more modern

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evaluation effort, potentially through international collaboration, was proposed in the discussion to harmonise the differences between the various fission yield files.

A follow-up of, and based on the ‘Bayesian’ total Monte-Carlo (BMC) method of D. Rochman *et al* [2] was presented, where comparisons between GEF [3]-based and evaluated uncertainties were made. Some cautionary remarks on uncorrelated Gaussian sampling of input parameters were made, particularly with highly sensitive parameters such as the Z-distribution controlling parameter hbar omega of charge-polarization oscillations (HOMPOL). A prototyped function for minimisation was used to evolve the calculated independent yield (co-)variances, which underlined the challenge of reproducing the discontinuities in evaluated uncertainties. This remains an open challenge for the BMC method in fission yield uncertainty. A proposal for consistently spliced covariances to accommodate these low-uncertainty nuclides was made. In the discussion, R. Capote suggested that instead of splicing, the low uncertainty nuclides should be used to shape correlated uncertainties – effectively reducing uncertainties through the combination of precision experimental data and the advanced simulation capabilities of GEF. The implementation of a Unified Monte Carlo (UMC) algorithm was proposed.

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[1 M. Fleming and J.-C. Sublet, Validation of FISPACT-II Decay Heat and Inventory Predictions for Fission Events, CCFE-R(15)28, 2015.

[2] D. Rochman, O. Leray, A. Vasiliev, H. Ferroukhi, A. Koning, M. Fleming and J.-C. Sublet, A Bayesian Monte Carlo method for fission yield covariance information, Annals of Nuclear Energy, vol. 95, pp. 125-134, 2016.

[3] K.-H. Schmidt., et al. "General Description of Fission Observables: GEF Model Code." Nuclear Data Sheets 131 (2016), 107-221.

2.8. Fission Yields Relevant to Calculation of Antineutrino Spectra, A.A. Sonzogni, Brookhaven National Laboratory

Following the fission of an actinide nuclide, more than 800 neutron rich fission products are produced, which in their decay to the valley of stability produce electron, antineutrino, neutron and gamma radiation. Due to several conservation rules, the mean energies from these radiation types are correlated.

In February 2016, the Daya Bay collaboration published the measurement of their near detectors antineutrino spectrum, as well as the fission ratios from the reactors that produced this spectrum. A close examination of this spectrum reveals that a) The total number of antineutrinos detected is smaller than the prediction, b) the measured spectrum is also different from the prediction, as it is lower at the peak, and then larger than the prediction at around 5.5 MeV.

The antineutrino spectrum can be calculated as the weighted sum of the spectra produced by the 4 main fuels (^{235}U, ^{239}Pu, ^{238}U and ^{241}Pu) in the reactor, with the fission ratios as the weighting factors. For each fuel, the spectrum can be obtained from two methods, the conversion and the summation method.

The conversion method uses the highly precise electron spectra measured at ILL. This method must have a good estimate of the effective Z as a function of the end point energy as an input parameter in the Fermi function for each virtual branch. The summation method combines fission yield and decay data.

In a recent publication, we have used the summation method to a) decompose the total spectrum into the contributions of each fission product, b) derive a systematic of the energy integrated, Inverse Beta Decay cross section weighted antineutrino spectra. Additionally, we have published an article [1] where we describe that after a critical review of the ENDF/B-VII.1 yields, corrections were introduced that resulted in a much better agreement with the spectra calculated with the JEFF yields.

We have also shown the effect of isomeric ratios in the calculation of decay radiation. Due to differences in angular momentum, the radiation pattern from ground state and isomeric state can be very different.

In the calculation of reactor antineutrino spectra, the contribution from ^{238}U is the least known. We have explored this effect using the GEF code, preliminary results show that contributions from ^{238}U can’t improve the agreement between data and calculations. However, this is a very model dependent result, and precisely measured yields from ^{238}U in the neutron energy range of 0.5-5 MeV are highly desirable.

Reference

[1] A.A. Sonzogni, E.A. McCutchan, T. Johnson, P. Dimitriou, Phys. Rev. Lett. 116, 132502 (2016).

2.9. Study on the mass distribution yield and its energy-dependence for n+U and Pu fission with a semi-empirical model, N. Shu, China Nuclear Data Center

A semi-empirical model is developed for calculating the mass distribution yield and its energy dependence of n+U and Pu fission. The system's potential energy in the model included the liquid drop energy and two shell corrections, corresponding to the SL, SI and SII fission modes. Multi-chance fission (n,nf) and (n,2nf) were also considered. The yield was expressed with a five-Gaussian-like formula with 13 parameters, which were determined by fitting to experimental data.

The results showed the model could describe well the mass distribution with changing incident energy and some of the yield energy-dependences (Y-E) (Fig. 2.3). The correlation coefficient of the covariance of the mass yields and the yield energy-dependence were also presented (Fig. 2.4).

The chain yield of A=144 (n+^{235}U fission) decreases with incident neutron energy, which could be explained by the fact that it was mainly contributed by SII fission, and that SII fission decreases with incident neutron energy. The two waves in the Y-E diagram near 6 and 12 MeV reflect the opening of the (n,nf) and (n,2nf) fission chances (Fig. 2.4).

Some decay branchings to daughter isomers are different between the data used in the fission yield libraries of ENDF/B-VII.1 and JEFF-3.2. So we calculated the branching's based upon ENSDF data and as a next step will check the impact on cumulative fission yields.

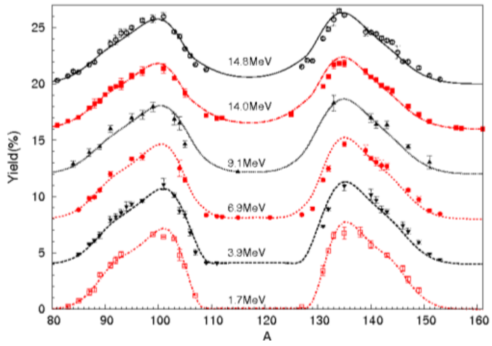

FIG.2.3 n+^{238}U fission yield mass distributions.

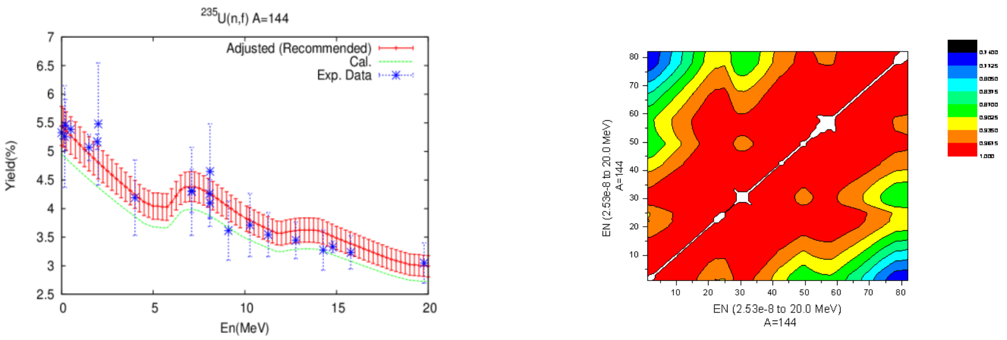

FIG.2.4 Energy-dependence and correlation coefficient of A=144 chain yield from n+^{235}U fission.

2.10. Energy Dependence of Fission Product Yields of ^{235}U, ^{238}U and ^{239}Pu for Incident Neutron Energies between 0.5 and 15 MeV, W. Tornow, Duke University &Triangle Universities Nuclear Laboratory (TUNL)

Accurate information about the energy dependence of neutron-induced Fission Product Yields (FPYs) is sparse, primarily due to the lack of suitable mono-energetic neutron sources. There is a clear need for approved data. To address this issue, a collaboration was formed between LANL, LLNL and TUNL to measure the energy dependence of FPYs for ^{235}U, ^{238}U and ^{239}Pu in the 0.5 to 15 MeV energy range using the activation technique. The experiments are being performed at TUNL using a 10 MV Tandem Van de Graaff accelerator to produce mono-energetic neutrons via the ^{7}Li(p,n)^{7}Be, ^{3}H(p,n)^{3}He, ^{2}H(d,n)^{3}He and ^{3}H(d,n)^{4}He reactions. The measurements utilize dual-fission chambers, each dedicated to one of our three actinide isotopes, with thin (10 – 100 μg/cm^{2}) reference foils of similar material as the thick (100 – 400 mg) activation target, which is located at the center between the individual halves of the dual-fission chamber. This method allows for the accurate determination of the numbers of fissions that occurred in the thick target without requiring the knowledge of the fission cross section and neutron fluence on target. After neutron activation/irradiation for a few days, the thick target is removed from the dual-fission chamber and γ-ray counted using HPGe detectors for a period of 1 to 2 months to determine the yield of various fission products. So far measurements have been performed at incident neutron energies of 0.6, 1.4, 2.4, 3.5, 4.6, 5.5, 7.5, 8.9 and 14.8 MeV. Results are presented for high-yield neutron-induced FPYs at these energies. Special emphasis is given to ^{147}Nd for which the previously deduced energy dependence was confirmed below 2 MeV and for which the discrepancies in the 14 MeV energy range were resolved in favor of the LLNL-83 data. Previous data did not exist for this important isotope between 2 and 14 MeV. Data for 15 high-yield FPYs were recently published by our group [1]. One of our future plans calls for FPY measurements at thermal energies at the MIT research reactor. Due to the higher neutron flux, thinner reference and target foils are required than currently used at TUNL.

We have also started to obtain FPY data for photon-induced fission of ^{235}U, ^{238}U and ^{239}Pu using TUNL's mono-energetic High-Intensity Gamma-ray Source (HIγS). Preliminary results are reported at E_γ=13 MeV. Future measurements will be performed at 8.0 and 10.5 MeV to compare to the energy dependence of neutron-induced FPYs at low neutron energies.

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2.11. Cumulative yields of Bromine, Krypton, Rubidium and Iodine isotopes from fission of ^{233}U, ^{235}U, ^{238}U and ^{239}Pu by neutrons in the energy range from thermal to 5 MeV, V.M. Piksaikin, Institute of Physics and Power Engineering

The data base of fission product yields is of great importance in reactor design and operation, burn-up determination, decay heat calculations and many other related applications. The present method is based on the relationship between the cumulative yield CY(A,Z) of fission product (A,Z), the emission probability of delayed neutrons P_n(A,Z), the total delayed neutron yield ν_d and the relative abundances a(A,Z) of delayed neutrons from precursors (A,Z): $CY(A,Z)\cdot P_n(A,Z)=\nu_d\cdot a(A,Z)$. Improvements owing to the IAEA Coordinated Research Project on the Development of a Reference Database for beta-delayed neutron emission in obtaining a high quality data base of such precursor characteristics as the delayed neutron emission probabilities P_n and their half-lives $T_{1/2}$ as well as a macroscopic data base containing data on the total delayed neutron yields $\nu_d(E_n)$ for a wide range of fissile nuclei and primary neutron energy allows to expand the delayed neutron measurement technique for obtaining the fission product yields for the delayed neutron precursors in fission of heavy nuclei by neutrons. The primary purpose of the present work was to make measurements of the delayed neutron activities (decay curves) in fission of ^{233}U, ^{235}U, ^{238}U and ^{239}Pu by neutrons in the energy range from thermal to 5 MeV and to use this information for obtaining the energy dependence of cumulative yields of bromine ^{87}Br, ^{88}Br, ^{89}Br, ^{91}Br, krypton ^{93}Kr, rubidium ^{94}Rb, ^{95}Rb and iodine ^{137}I, ^{138}I, ^{139}I and ^{140}I isotopes.

The experimental method employed in the measurements is based on a cyclic irradiation of the fissionable samples by neutrons generated in the T(p,n) and D(d,n) reactions at the accelerator target and measurements of the composite decay of the gross neutron activity. Measurements with different irradiation time intervals were foreseen to enhance the contribution of certain delayed neutron groups in the composite delayed neutron decay curve. In the present experiment the irradiation time was 180.06 and 300.06 s. The delayed neutron counting intervals were 424.5 and 724.5 s. The sample delivery time was 150 ms short enough to get information on the relative abundance of delayed neutrons related to the shortest precursor groups.

In processing of the experimental data two 12-group models of the time distribution of the delayed neutron precursors based on the known half-lives of 17 precursors were used. The first model was employed to obtain information on the relative abundances of delayed neutrons related to precursors ^{87}Br, ^{88}Br, ^{89}Br, ^{91}Br, ^{93}Kr, ^{94}Rb, ^{95}Rb and the second one for obtaining the relative abundances of delayed neutrons related to precursors ^{137}I, ^{138}I, ^{139}I, and ^{140}I. The group periods were chosen in a way to properly allocate the appropriate delayed neutron precursors by placing each of them in a separate group. The remained groups were composite, comprising of several delayed neutron precursors with effective periods obtained by an averaging procedure. The analysis of the delayed neutron decay curves was carried out by an iterative least square procedure.

The energy dependences of the cumulative yields of ^{87}Br, ^{88}Br, ^{89}Br, ^{91}Br, ^{93}Kr, ^{94}Rb, ^{95}Rb,^{137}I, ^{138}I, ^{139}I, and ^{140}I precursors were used for the estimation of the most probable charge $Z_p(A)$ in the appropriate isobaric β-decay chains. The obtained results were analyzed in terms of the deviation $\Delta Z_p(A')$ of the most probable charge in the isobaric β-decay chains from the unchanged charge distribution before prompt neutron emission (nuclear charge polarization).

The obtained cumulative yields in the present work of ^{87}Br, ^{88}Br, ^{89}Br, ^{91}Br, ^{93}Kr, ^{94}Rb, ^{95}Rb, ^{137}I, ^{138}I, ^{139}I, and ^{140}I precursors were compared with appropriate data taken from the evaluated nuclear data libraries ENDF/B, JEFF, JENDL and the evaluation by Wahl.

2.12. Fission Research by Uppsala and JRC-IRMM, A. Al-Adili, Uppsala University

The Uppsala group investigates the fission process through various experimental activities; independent fission yields and isomeric ratios at the IGISOL facility [1], fission cross sections at the NFS facility [2] as well as fission-fragment (FF) properties and particle emission at the JRC-IRMM [3]. The latter aims at measuring FF yields, energies and angles, and obtaining information about the prompt neutron emission process. Two different techniques (2E and 2E-2v) are employed using either a Frisch-grid ionization chamber or JRC-IRMM's VERDI spectrometer [4].

This work discusses results on the ^{234}U(n,f) reaction where the FF properties were measured with the ionization chamber, for E_n between 0.2 and 5 MeV [5]. The pre-neutron mass yields, kinetic energies and angular distributions were determined as a function of $E_{n.}$ These data are important for the 2nd chance fission modeling of ^{235}U(n,f). A strong FF angular anisotropy was known in earlier literature and was confirmed in this work. Some new results on the <TKE> in correlation to angle-mass dependencies were also discussed.

A second project concerns measured data of the thermal neutron induced fission of ^{234}U, performed at the ILL reactor in 1999. The data contains a large background ^{235}U(n_{th},f) component due to a small impurity in the target. Preliminary FY results were shown although they do not fully agree with fission-yield and TKE expectations. Some analysis is still needed to get final distributions right [6].

Finally, large efforts are put into investigating the variations in the prompt fission neutron multiplicity as a function of fragment mass and E_n. The goal is to explore the origin of the extra neutrons that are emitted at higher excitation energies, i. e. - to determine from which fragment they are emitted. In an earlier study, we showed that the 2E-method suffers from the need of assuming the neutron multiplicity distribution in order to analyse experimental data. Different assumptions imply significant effects on the data, especially on the product yields [7]. Therefore, the Uppsala group together with the JRC-IRMM colleagues have initiated a series of systematic measurements of the neutron emission using liquid scintillators in conjunction with the ionization chamber. The proof-of-principle was done on ^{252}Cf(sf) and ^{235}U(n_{th},f). The status of the analysis were discussed, where provisional saw-teeth were presented along with a preliminary neutron spectrum [6]. Current plans are to run at E_n= 5 MeV with ^{235}U to investigate the change in neutron saw-tooth shape. Extensive simulations are being performed and benchmarked against dedicated neutron measurements, to optimize the needed shielding to reduce the background neutron contribution. Finally, the VERDI spectrometer will hopefully provide a mean to independently check the obtained results.

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2.13. Correlations of fission yields with prompt neutron emission, F.-J. Hambsch, EC-JRC Dir. G.2 Standards for Nuclear Safety and Safeguards

The investigation of the dynamics of the nuclear fission process has been a standing research topic at the JRC-Institute for Reference Materials and Measurements (JRC-IRMM) during the past decades. Recently several projects have been undertaken of which results have been presented at this meeting. The focus was not only put on fission fragment yields but also on the de-excitation of fission fragments through the emission of prompt neutron and gamma-rays.

To this end new detector systems were developed at JRC-IRMM, e.g. a position sensitive ionisation chamber used in conjunction with the neutron scintillator array SCINTIA [1]. This allows having neutron detectors outside the plane of fission and neutron emission axis. The setup and analysis routines have been tested using the spontaneous fission reaction of ^{252}Cf. Presently, we study fluctuations of fission fragment properties as a function of incident neutron energy in the resolved resonance region using the SCINTIA array at the GELINA white neutron time-of-flight spectrometer of JRC-IRMM. As a preliminary result no strong fluctuations of the prompt neutron number for the strongest resonances in ^{235}U has been observed so far. All the data have been summed up and the so-called saw-tooth shaped mass-dependent neutron multiplicity, ν(A), has been generated. In comparison to literature values a clear difference has been observed, with the new data showing deeper dips in the ν(A) distribution around the doubly magic masses (A ~ 130-132) and at very low masses around A ~ 80. Cross checking with what was available from two of the other references [2, 3] a clearly wider mass and total kinetic energy (TKE) distribution is observed in those experiments. This results in wrong assignments of the respective prompt neutron number. Also for the dependency of the neutron number on TKE, ν(TKE), the present results show a steeper slope compared to literature data, again due to the wider distributions found in literature.

The angular distribution of the prompt fission neutron emission in ^{235}U(n,f) has also been compared to literature data [4, 5]. Here the present data clearly follow closer the Skarsvag data [4] than the Vorobyev data [5].

As a second detector system VERDI (VElocity foR Direct mass Identification), a double velocity - double energy (2E-2v) spectrometer became operational. Also here the system was successfully commissioned with ^{252}Cf(sf) sources. The result shows that for the pre-neutron masses the VERDI detector is superior in mass resolution compared to our twin Frisch grid ionisation chamber. For post-neutron mass distributions still issues related to the Schmitt-calibration need to be solved, hopefully within the coming months. Hence, also the difference of those two mass distributions, being the number of prompt emitted neutrons, is still off compared to other literature data by about 15%. Further improvements are planned to this detector system in terms of adding a 2nd Multi-channel plate detector and improved analysis routines. Finally, VERDI will be the complementary method to assess neutron multiplicity as a function of mass and total kinetic energy. It is planned to use the spectrometer at the upcoming Neutron For Science (NFS) at GANIL, France.

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2.14. Measurements and calculations of fission product yields at LANL, F. Tovesson, Los Alamos National Laboratory (LANL)

New experimental capabilities to measure fission product yields (FPY) from neutron-induced fission have been developed at LANL. A new instrument, SPIDER, employs the 2E-2v method to deduce the mass of fission products and thus enables measurement of the mass chain yields. Spontaneous fission of ^{252}Cf was measured with the instrument as a benchmark, and those results have been published [1]. The SPIDER detector was then commissioned in 2014 at the Los Alamos Neutron Science Center (LANSCE) which has two different spallation neutron targets, one at the Lujan Center and one at the Weapons Neutron Research facility (WNR). The Lujan Center target is moderated and provides an intense thermalized neutron spectrum. The fission product yields from thermal neutron-induced fission of ^{235}U and ^{239}Pu has been measured with SPIDER at the Lujan Center, and preliminary results have been presented.

A larger detector array for fast neutron-induced fission measurements, MegaSPIDER, is currently under construction and uses the same basic techniques and detector components as SPIDER. This instrument will be used for experiments at the un-moderated neutron spallation target at WNR. The MegaSPIDER instrument has an array of 16 individual spectrometers and will cover 1% of the full solid angle around the fissioning target. This is sufficient to measure the energy dependence of fission product yields from 0.5 to 20 MeV.

The energy dependence of FPYs has come under scrutiny by the nuclear data community in recent years, and a detailed re-analysis of previous experimental data for ^{239}Pu resulted in a updated evaluation file for this isotope in ENDF/B-VII in 2011. A semi-empirical model developed by J. Lestone [2] calculates the FPY for different actinides as a function of incident neutron energy, and compares well with previous experimental results. The goal of the experimental program with MegaSPIDER is to provide an independent measurement that can be directly compared to this and other models.

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2.15. Nuclear Structure & Decay Data Needs for Improvement of FY & Capabilities at ANL, F. Kondev, Argonne National Laboratory

Needs for nuclear structure and decay data of relevance to fission product (FP) yields determination were presented. These include ground-state half-life, absolute gamma-ray emission probabilities and excitation energies, half-lives, branching and isomeric ratios for isomeric states. Examples outlining the importance of high-quality evaluated data that are lacking in many general purpose databases were presented. A brief description of the CARIBU facility at ANL was also given. It is capable of providing high purity and intensity beams of FP that can be delivered to various state-of-the-art experimental equipment for further studies of relevance to FPYs. The powerful combination of Penning Trap measurements with gamma-ray spectroscopy techniques was also outlined and several examples from recent studies at ANL were presented.

2.16. Fission yield studies at IGISOL: current status and aiming for neutron-induced independent fission yields, M. Lantz, Uppsala University

Fission product yields are important observables of the fission process, whose knowledge is of importance both for fundamental physics, such as nuclear astrophysics [1], and in nuclear energy applications [2]. With the Ion Guide Isotope Separator On-Line (IGISOL) technique, developed at University of Jyväskylä since the 1980's, products of nuclear reactions are stopped in a buffer gas and then extracted and separated by mass [3,4]. Earlier versions of the facility used gamma spectroscopy for identification of the nuclides [5]. Later on, the facility was supplemented with the JYFLTRAP double Penning trap [6,7]. The high resolving power of JYFLTRAP enables individual fission products to be separated by mass, making it possible to measure relative independent fission yields. In some cases it is even possible to resolve low-lying isomeric states from the ground state [8], permitting measurements of isomeric yield ratios.

So far independent fission yields from the reactions U(p,f), U(d,f) and Th(p,f), with protons and deuterons in the energy range 20-50 MeV, have been studied using the IGISOL-JYFLTRAP facility, some results are given in [9-11] and references therein. Isomeric yield ratios have been measured for U(p,f) and Th(p,f) but require further studies for more comprehensive comparisons [12,13]. There have also been measurements performed from the reaction U(n,f) using 50 MeV deuterons on ^{13}C as neutron source [14,15].

Recently, a neutron converter target has been developed utilizing the Be(p,xn) reaction, giving a white neutron spectrum up to 30 MeV. The prototype was designed with the ambition of being flexible, easy to install and remove, and provide a high neutron flux on the fissionable target. Simulations of the expected neutron fluxes have been done [16] using the Monte Carlo codes FLUKA [17] and MCNPX [18]. A characterisation of the neutron field from the Be target was performed at the TSL facility in Uppsala by means of two different measurement techniques, time-of-flight measurement and Bonner sphere spectroscopy [19]. Thereafter further characterisation measurements have been performed with a prototype converter at IGISOL [20,21]. The first measurements of neutron-induced fission yields are expected during the fall 2016. It is important to note that the converter gives a white neutron spectrum, but several parameters can be varied, such as incident proton energy, thickness of the Be target, and the insertion of moderating material in between in order to vary the energy distribution. It is also possible to consider thin Li targets, enabling quasi-monoenergetic neutron fields.

In parallel with the development of the neutron converter, studies of the ion guide efficiency have been performed through simulations, in order to investigate the fission product counting efficiency in the reaction chamber. The dependence on mass, charge and energy, as well as the different geometrical parameters, have been studied [22], confirming present assumptions about the ion guide performance and providing guidance for further development. There are also plans for larger ion guides that will increase the efficiency, with the intention of learning from the experiences of the CARIBU gas catcher at Argonne National Laboratory [23].

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2.17. The SOFIA experiment, J. Taieb, CEA-Arpajon

Despite decades of investigations, accurate data on independent yields are still scarce. Even for the most studied reaction, i.e, the thermal-neutron induced fission of Uranium-235, uncertainties associated to the isotopic independent yields are mainly of about 30%. This lack of high-resolution data constitutes an obstacle to the development of precise (semi-)empirical and theoretical models.

Experimental constraints, in usual experiments, where neutrons impinge on an actinide target prevent from measuring unambiguously the mass- and charge-numbers of all fission fragments. Following a pioneering experiment based on the use of the reverse kinematics at relativistic energies in the nineties [1], the SOFIA Collaboration has designed and built an experimental set-up dedicated to the simultaneous measurement of isotopic yields, total kinetic energies and total prompt neutron multiplicities, by fully identifying (in A and Z) both fission fragments in coincidence, for the very first time.

In a set of two experiments which took place in 2012 and 2014, we measured all independent yields from the COULEX-induced fission of three Uranium isotopes ^{234}U, ^{235}U and ^{236}U. The second experiment focused on the COULEX-fission of Uranium-236, which is the surrogate reaction of the neutron-induced fission of ^{235}U at 8.2 MeV neutron energy. The high statistics reached in that experiment allows for a good accuracy, the uncertainty on the element yields being of 0.5% FWHM in the asymmetric fission, as shown in Fig.2.4. The accuracy on the isotopic yields ranges from 2 to 5% as seen in Fig.2.5.

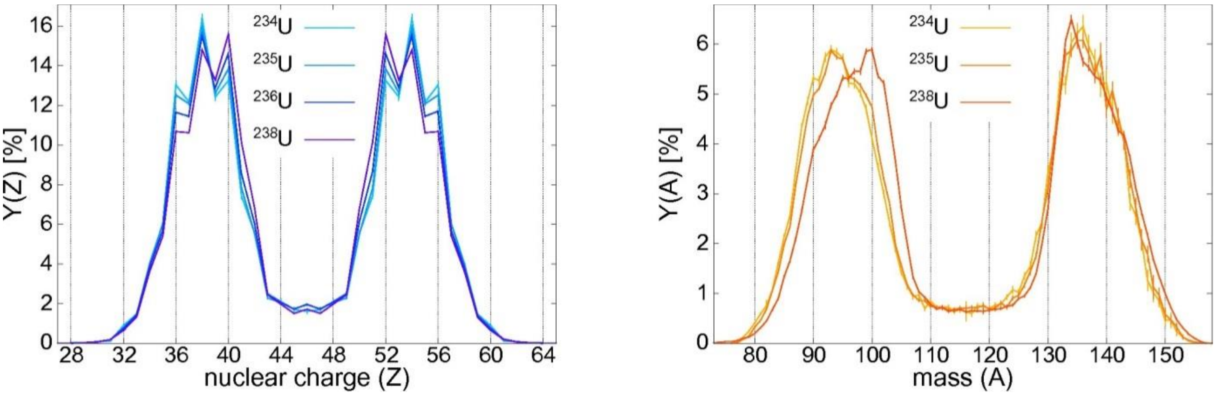

FIG. 2.4 Independent element- and mass-yields for the COULEX fission of four Uranium isotopes. Error bars are included.

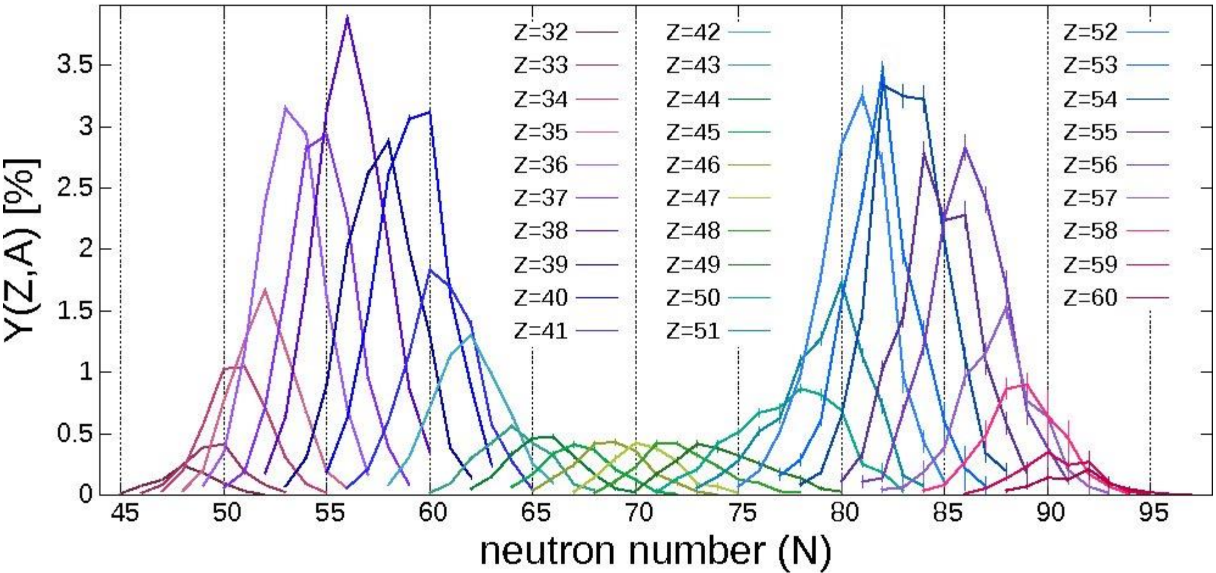

FIG. 2.5 Isotopic yields for the fission of ^{235}U with error bars.

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2.18. Fission yields measurements activities in China, S. Liu, China Nuclear Data Center

In this meeting, some of the fission yield measurement activities of the CNDC in China during the 1990's were presented. The content is separated in two parts, one includes fission yields measurement with radio-chemistry and gamma-ray spectrometry method, the other introduces a new approach for independent yields measurement based on fission products particle identification technique.

Part 1:

In the 1990's, we performed fission yield measurements using gamma-ray spectrometry. We have measured thermal, 3 MeV, 5 MeV, 8 MeV and 14.8 MeV neutron-induced fission of ^{235}U, and ^{238}U and have determined the cumulative yields of ^{95}Zr, ^{99}Mo, ^{140}Ba, ^{147}Nd products. For thermal, 3 MeV, and 14.8 MeV neutron-induced fission of ^{235,238}U, we have also measured the cumulative yields of ^{85m}Kr, ^{87}Kr, ^{88}Kr, and ^{135,138}Xe gas products. For thermal neutron- induced fission of ^{235}U, and ^{239}Pu we have also measured the cumulative yields of the short-lived products ^{88}Rb, ^{95}Y, ^{101}Mo, ^{101}Tc, ^{138g}Cs, ^{142}La.

Part 2:

We are currently testing the E-v method for fission product mass distribution measurements. We want to combine the kinetic energy(E) and velocity(v) of outgoing fission fragments with the goal of achieving a mass resolution better than 1 atomic mass unit (amu) for the light fission products. Our experimental setup consists of detector components for time-of-flight and energy measurements and a flight path vacuum tube. A pair of micro-channel plates for particle time-of-flight measurements were used to determine the particle velocity. The golden silicon surface barrier detectors were used to measure the energy. We were able to achieve the time-of-flight system time resolution of 200ps at FWHM, and the energy resolution of 44 keV FWHM for a 5.48MeV α particle of ^{241}Am. The fission product mass distribution of ^{252}Cf spontaneous fission has been measured. Our preliminary result for the mass resolution was 1.6 amu at the mass about 110.

3. Technical discussion

3.1. Fission yield measurements

Many new measurements of fission yields have been performed in the period lapsing since the last IAEA CRP (1991-1996). In particular, the emergence of new measurement techniques such as inverse kinematics gave the field a boost due to the superior mass and kinetic energy resolution achieved compared to traditional techniques. The application of this technique is however limited to the few experimental facilities in the world where heavy ion beams are available at relativistic (e.g. GSI [3.1.1]) and Coulomb energies (GANIL [3.1.2]), respectively. To date, only high intense radioactive beams up to ^{238}U can be produced at these facilities, therefore, the systems that can be studied are limited. Nevertheless efforts are being made by the international community to extend the GSI facilities to produce heavier radioactive beams such as ^{242}Pu. The incident energy region is also limited, e.g. at GSI the excitation energy is fixed to the giant dipole region of about 14 MeV, which corresponds to about 8 MeV incident neutron energy for neutron-induced fission. At GANIL however, fission yields can be measured as a function of incident particle energy but with inferior mass and charge resolution [3.1.3].

In regards to more traditional methods of measuring neutron-induced fission yields, the techniques that are used have been improved in recent years leading to better resolution and statistics. The implementation of, e.g., the digital technique together with sophisticated digital signal processing routines have led to more precise and reliable fission yield data which have revealed several shortcomings of the previous measurements, e.g., in ^{252}Cf(SF) and ^{235}U(n,f) [3.1.4,3.1.5].

An example of using smaller-scale facilities for fission yield experiments is the facility at the Triangle Universities National Laboratory, where fission yields of ^{235,238}U, ^{239}Pu actinides are measured at different incident neutron energies using dual-fission chambers, each dedicated to one of the three actinide isotopes, with thin (10 – 100 μg/cm^2) reference foils of similar material to a thick (100 – 400 mg) activation target. This method allows for the accurate determination of the numbers of fissions that occurred in the thick target without requiring knowledge of the fission cross section and neutron fluence on target. This method was used to investigate the incident neutron energy dependence of fission yields [3.1.6]. Photo-fission of the same targets is also investigated. Other institutions with similar set-ups and instrumentation could repeat the measurements to verify the results.

Detector systems able to determine both the energies and the velocities of both fragments, the so-called 2E-2v systems, are now under development at different laboratories (e.g. VERDI at JRC-IRMM [3.1.7], SPIDER at LANL [3.1.8], FALSTAFF at CEA [3.1.9], STEFF in the UK [3.1.10]). In the past, a similar instrument at the ILL high flux reactor called COSI-FAN-TUTTE [3.1.11] demonstrated the superior resolution in mass number attained with a time-of-flight resolution of a few 100 ps and an energy resolution of less than 0.5 %. The problem of this earlier detector system [3.1.11] was that it covered a very limited solid angle, where even the non-colinearity of the fission fragment emission due to prompt neutron emission could not be covered adequately and caused problems. The new designs mentioned above strive therefore for much higher solid angle coverage of up to 2% of the full 4π solid angle. The results shown from VERDI and SPIDER are very promising as they significant improvement with respect to previous measurements, nevertheless further effort is required to reach the goals set by the conceptual design of both instruments.

The LOHENGRIN spectrometer at the ILL high flux reactor in Grenoble, France has been traditionally used for fission yield measurements. In recent years the possibilities of the instrument have been extended towards covering also the heavy mass fragment range [3.1.12]. In such a case, isotopic yields are measured using gamma-ray spectroscopy. Since these measurements depend on the knowledge of the decay data, improvements in the evaluated decay data libraries are strongly recommended. These measurements also highlight the inter-connection between fission yields and decay data since one cannot expect to improve the former without simultaneously improving the latter. Further extensions are foreseen for LOHENGRIN to cope with growing demands for higher quality and more precise fission yield data.

Another technique of measuring independent isotopic fission yields is offered by the IGISOL (Ion Guide Isotope Separator On-Line) facility at Jyväskylä University, Finland [3.1.13]. IGISOL is coupled to a Penning Trap and the high mass resolving power even allows for direct measurements of isomeric yield ratios by direct ion counting, thus avoiding problems related to partial lack of knowledge of decay data. So far the facility has been used to study proton-induced fission but development of neutron-fields is currently ongoing [3.1.14].

Apart from the new measurements of fission fragment yields using the new techniques such as ‘fission in inverse kinematics’ and the developed ‘unstopped fission fragments’ methods described above, there exist in the literature many fission yield data obtained with methods that are now considered to be dated, such as radiochemical methods, classical mass spectrometry. These data have been used in the previous evaluations that produced a good part of the fission product yields libraries existing and being used today. All these ‘historical’ data need to be revisited in light of the new measurements and models that have become available in recent years. In this respect, it maybe timely to look into the EXFOR database [3.1.15] and check the completeness with respect to the compilations performed in the two previous IAEA CRPs on fission product yields [1.1,1.2].

In summary there is still a lot of work to do to make the new data available for future evaluations, to further improve the detector systems under development, especially the 2E-2v and those used in inverse kinematics measurements. The results of more elaborated experiments that will provide complete data for every single fission event, including fragment masses, fragment charges, ternary charged particles, number of neutrons and γ rays and corresponding energies, are valuable information for the development and improvement of sound and reliable theoretical models. Although in practice it is not possible to measure fission yields and all the other related observables for the full range of fission systems and fission products needed in detailed reactor calculations due to experimental limitations, new and improved experiments are important to pave the way for precise and reliable fission yield data, if possible as a function of incident particle energy and for as many systems as possible.

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3.2. Model developments and systematics

Models of fission yields are very important for our understanding of the underlying physics of the fission process, but also for practical applications because they are used in evaluations to obtain numerical values where no yields have been measured, or to check and adjust experimental data to the expected distribution of yields.

Several models have been developed worldwide to describe the fission process and its various observables. Despite the progress made in the development of purely theoretical models for the fission process, these are still not sufficiently accurate and reliable or easy to use for applied purposes. The models discussed here are those that are widely used in evaluations of fission yields. They are of empirical nature, based on equations and parameters derived from studies of systematic trends in measured fission observables. As such, they can be classified as follows.

3.2.1. Parametric models of fission-fragment yields

a) Mass distributions

The mass distribution is formulated as the sum of a number of Gaussian distributions, representing the Brosa modes of fission. The parameters of the models are determined for specific fissionable systems. Systematic trends over several systems or as a function of excitation energy are given in several cases. In case of mass distributions after prompt-neutron emission, the mass-dependent neutron multiplicities are considered, for example according to the Wahl systematics (see below).

- Empirical 5-Gaussian systematics for fission-product mass yields by Katakura [3.2.1].
- Empirical systematics by the sum of several Gaussian contributions by Wahl [3.2.2], CYF code.
- Multi-modal parametrization by Gorodisskiy et al. [3.2.3], PYF code [3.2.4].
- Phenomenological model of Yu. V. Kibkalo [3.2.5].

b) Element distribution for a given mass

For specifying the independent yield of a given nuclide, the contributions from the different isobars need to be given. The element distribution for a given mass is well approximated with a Gaussian curve plus even-odd staggering in proton number. By far the most used parametrization for this purpose is the Zp model of Wahl [3.2.6].

3.2.2. Parametric models of mass-dependent prompt-neutron multiplicities

The mass-dependent mean prompt-neutron multiplicities are used to derive post-neutron mass distributions from parametrized pre-neutron mass distributions. The description of pre-neutron mass distributions is simpler, because they are symmetric with respect to mass symmetry. Wahl [3.2.2] has given empirical systematics of the saw-tooth curve for several systems as a function of excitation energy.

3.2.3. Modeling of the de-excitation process of the fragments after scission

There are several models that treat the de-excitation process of the fragments after scission. They normally require the experimental two-dimensional A-TKE distribution as an input, which provides the information on the distribution of the total excitation energy (TXE) over mass. In addition, these models require a prescription for how to divide the TXE between the two fragments. Earlier models only treat the prompt-neutron emission, whereas more recent models also cover the prompt-gamma emission.

One of the first and most widely used descriptions of the prompt-neutron spectrum was introduced by Watt [3.2.7]. He proposed a closed formula, deduced from a Maxwell-type energy spectrum from one or two average fragments and the transformation into the frame of the fissionable system with at least two adjustable parameters: the temperature and the velocity of the average fragment. The ”Los-Alamos model” [3.2.8] extended this approach essentially by the use of a triangular temperature distribution of the fragments to a four-term closed expression for an average light and an average heavy fragment. A similar two fragment model was also used by Kornilov et al. in ref. [3.2.9].

In 1989, Madland et al. [3.2.10] introduced the point-by-point model by considering the emission from all individual fragments, specified by Z and A. This model was further developed by several groups with a varied success in reproducing the measured prompt-neutron spectra for particular fissionable systems with especially adjusted parameters. All models mentioned above are based on empirical data: The Watt model and the Los Alamos model are directly fitted to the measured prompt-neutron spectrum, while the point-by-point model is based on the measured A-TKE distribution. A comprehensive account of these models can be found in [3.2.11].

Codes that cover only neutron emission:

- FINE (by N. Kornilov) [3.2.12]

Codes that cover both prompt-neutron and prompt-gamma emission:

- CGMF code (LANL) [3.2.13]
- FIFRELIN code (CEA-Cadarache) [3.2.14]
- FREYA code (LLNL and LBNL) [3.2.15]

3.2.4. Description of the complete fission process covering the yields and the properties of fission fragments, prompt neutrons and prompt gammas.

There are only few models available that treat the whole fission process covering practically all fission observables.

- Extended Brosa model by M. C. Dujvestijn et al. [3.2.16], incorporated in the TALYS code [3.2.17].
- GEF by K.-H. Schmidt et al. [3.2.18] as a stand-alone version or incorporated in the TALYS code [3.2.17].

The first one is applicable to excitation energies ranging from 15 to 200 MeV, while the second one covers the range from spontaneous fission to the excitation energy of 100 MeV.

The Brosa model implemented in the TALYS code [3.2.17] is based on a macroscopic-microscopic description of the potential energy surface of the fissionable system, and identifies three distinct fission modes leading to three possible distinct fission paths and scission points. These distinct modes lead to distinct mass distribution shapes, one symmetric and two asymmetric ones. The Brosa model as incorporated in TALYS has been used extensively for calculating fission fragment yields at higher energies ranging up to 150 MeV relevant to accelerator-driven applications.

The GEF model [3.2.18] is an alternative approach that has been extensively tested in low energy fission. It is based on several assumptions for (i) the topological properties of continuous functions in multi-dimensional space, (ii) the separability of the influences of fragment shells and macroscopic properties of the compound nucleus, (iii) the properties of a quantum oscillator coupled to the heat bath of the other degrees of freedom and (iv) an early freeze-out of collective motion to consider dynamical effects. The main advantage of this approach is that it produces remarkably accurate fission data for the applied user, without specific adjustments to experimental data of individual systems. It therefore has enhanced predictive power and can be used to provide values for fission yields where no experimental data are available. For more details see K.-H. Schmidt's summary (section 2.2). For the near future a coupling of the output of the GEF code and FIFRELIN is envisaged as FIFRELIN needs input data that so far are taken directly from experiments.

3.2.5. Isomeric fission yields

Many isomers exist among fission products and are important for the calculation of the decay heat after reactor shutdown. However, measured yields or yield ratios are fairly complete only for thermal fission of ^{235}U. Therefore, models are needed to calculate the partitions of independent fission yields of nuclides among their isomeric states. These models basically use spin distributions of fission fragments and of nuclear levels as fitting parameters.

The most widely used model for isomeric yield ratios is that developed by Madland and England [3.2.19]. However, as it failed to reproduce certain systematic trends derived from some measurements, a new model was developed within the IAEA CRP [1.1] by Rudstam [3.2.20]. Starting from the Madland and England model, Rudstam introduced two distributions with two adjustable parameters, one describing the angular momenta of the fission fragments after neutron evaporation and the other describing the spin distribution of the nuclear levels. The new formula was tested on all the available data at that time, which were limited however to thermal neutron-induced fission of ^{235,233}U and fast fission of ^{238}U.

Since the previous IAEA CRP on low-energy fission product yields [1.1], new measurements of isomeric ratios of fission products have been performed, the most recent being the measurements of isomeric ratios of ^{86}Y, ^{99}Nb and ^{136}I for neutron-induced fission of ^{239}Pu by Bail et al [3.2.21]. These new data including the nuclear structure information available in the Evaluated Nuclear Structure Data File (ENSDF) [3.2.22] need to be reviewed and systematically compared against the predictions of the models of Madland and England [3.2.19] and Rudstam [3.2.20] to provide improved prescriptions for the various applications of fission product yield data such as decay heat or anti-neutrino spectra calculations. Furthermore, methods based on direct ion counting exploiting the high mass-resolving power of Penning traps are a promising way to systematically study isomeric yield ratios without gamma spectroscopy.

An attempt to provide a more realistic isomeric ratio was made by Sonzogni et al in Ref. [3.2.23], by identifying the Yrast band population in even-even nuclides following the spontaneous fission of ^{252}Cf. The survey revealed about 30 cases in the ENSDF database, yielding an average population of 100%, 66%, 41%, 18% and 8% for the Yrast 2+, 4+, 6+, 8+ and 10+ levels, respectively. This distribution was used to obtain g.s. and isomeric independent FYs of ^{96,97,100}Y, ^{100,102,104}Nb, ^{128,130,131}Sn, ^{134}Sb, ^{146}La, ^{148}Pr and $^{152;154}$Pm. The results, combined with updated decay data from ENSDF and recent TAGS measurements, have been shown to have an important effect on the anti-neutrino spectra.

On the other hand, the GEF code also gives a rather good description of the measured isomeric yield ratios (see section IX.C of Ref. [3.2.18]). The procedure used to obtain the isomeric ratios differs substantially from the descriptions of Madland and England and Rudstam. GEF assumes that the angular momentum of the fragments is created by the statistical population of single-particle and collective states according to the fragment temperature at scission. The modification of this initial distribution by prompt-neutron and E1-gamma emission before reaching the Yrast line is considered to be weak and is neglected. Once the Yrast line is reached, the angular momentum is carried away by a cascade of E2 gamma transitions, and a special kind of variable-moment-of-inertia (VMI) model has been developed for modelling the angular-momentum-dependent energy of that line. The population of the states of interest on the Yrast line is calculated with a modified sharp-cut-off model, taking into account the energy difference between the states (see sections III.I and III.J of Ref. [3.2.18] for details).

The new developments in measurements and calculations of isomeric yield ratios clearly need to be compared and analyzed carefully in order to perform reliable evaluations for the applications fields.

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3.3. Fission yield evaluations

At present, all the evaluated libraries used worldwide, such as JEFF-3.3.1, ENDF/B VII, JENDL-4.0, CENDL, BROND, ROSFOND, and TENDL, contain evaluated FPY files. These files include independent and cumulative fission yields as defined in section 1.1, and their uncertainties. An overview of the content of some of these evaluated libraries is given in the tables in Appendices 1 to 4 (only for those libraries for which relevant information was provided). The table contains both neutron induced and spontaneous fission yield data.

Ternary fission is included in ENDF/B, JEFF and JENDL libraries, and is based entirely on experimental systematics.

Based on the information provided to us by the expert evaluators responsible for assembling the different FPY libraries, the current status of the major evaluated FPY libraries can be summarized as follows:

ENDF/B VII.1 [information provided by A. Sonzogni, BNL]:

All of the 132000 yields and their uncertainties included in the ENDF/B VII.1 library (see Appendices 1 and 2 of this report), date back to the evaluations of England and Rider [3.3.1].These evaluations were performed over a period of 10-15 years and incorporated contributions from the IAEA CRP [1.1]. Details can be found in Refs. [3.3.1] and [1.1]. There is only one exception to the above situation, the case of neutron-induced fission of ^{239}Pu, for which the fission yields at energies 500 keV, 2 MeV and 14.7 MeV were re-evaluated in 2010 [3.3.2] to address the discrepancies observed between the experimental FPY data of LANL [3.3.2] and LLNL [3.3.3].

JEFF-3.1.1 [Sec.Note: information provided by R. Mills, NNL, after the meeting]:

The latest JEFF fission product yield library is JEFF-3.1.1 [3.3.4], released in 2009, which is based upon the UK library UKFY3.6 .

The UKFY3.6 library includes 19 nuclides which undergo neutron induced fission and 3 nuclides which undergo spontaneous fission. These being chosen as representing greater than 0.1% of fissions in thermal and fast spectrum reactors with uranium, plutonium or thorium used as fuels. The spontaneous fission nuclides being chosen as those that represent most spontaneous fission in these fuels in the 1 to 100 years after removal of the fuel from a reactor. The fissioning systems and the ranges of their FPs are shown in Appendices 1 and 3 of this report.

The library was generated by analyzing experimental data, using models to fill the gaps, adjusting the resultant independent yields to agree with physical constraints and then generating cumulative yields using the latest JEFF decay data [3.3.4]. The uncertainties on the cumulative yield were based upon the available experimental analysis with additional uncertainty being added for the adjustment away from the experimental values and the large uncertainties on the independent yields.

The UKFY3.6 experimental measurement database contains 11887 absolute measurements of fission product yields, 1352 relative measurements and 1471 ratio-of-ratio measurements. The analysis resulted in 13776 usable absolute measurements that were used to fit the parameters of the five-Gaussian model of the mass distribution, the Wahl Z_p model [3.2.5], and the Madland and England isomeric splitting [3.2.19]. A complete independent yield distribution for each fissionable system was then generated.

The independent yield adjustment procedure was based upon preserving the number of protons and neutrons during fission allowing for neutron emission, and the yields for each complementary element pair. The latest JEFF decay paths [3.3.4] were then used to calculate the cumulative yields, but ignoring any decay with a half-life of greater than 1000 years. The uncertainty of cumulative yields for any nuclide was calculated assuming uncorrelated uncertainties where no experimental data was available. Where experimental cumulative yields were available in a mass chain, the uncertainty was increased by the adjustment of the value of the cumulative yield to the data. Then, the nearby cumulative yield uncertainties were calculated by adding the additional uncertainty of the independent yield in quadrature.

This library was distributed in Feb 2005 for testing. Following a review of available data it was decided that based on new information, not available during the evaluation small revisions were required for thermal neutron fission of ^{235}U for mass chain A=137 and of ^{239}Pu for mass chain A=148. In 2008, it was discovered that the ^{235}U thermal ^{137}I independent yield in UKFY3.6A was inconsistent with the cumulative yield and the value was revised. With these corrections, the library was issued as JEFF-3.1.1 in January 2009.

The complete process is described in JEFF report 20 [3.3.4].

Future developments: A revised library UKFY3.7 is being developed. The UKFY3.7 experimental measurement database contains 12908 absolute measurements of fission product yields, 1441 relative measurements and 1471 ratio-of-ratio measurements. The GEF code [3.2.20] is being used to estimate all unmeasured yields (except for ternary fission) rather than the previous empirical models, but the same procedures and adjustment techniques are being applied. It is also planned to generate independent yield covariance matrices based upon the experimental data and the evaluated cumulative yields. This is planned to be issued as JEFF-3.3 after testing.

Future JEFF evaluations will probably be based upon improvements to the GEF code and using new maximum likelihood methods with the existing and new yield measurement types to generate the best possible yields, uncertainties and covariance matrices.

CENDL [information provided by N. Shu, CNDC]:

A complete FPY library was released as CENDL/FPY in 1987 containing 10 fission reactions on ^{233,235,238}U at thermal, fast and high energies, and on ^{239,241}Pu and ^{232}Th at thermal and fast energies. The library included 1170 independent FPYs and the same number of cumulative FPYs. The CENDL/FPY was in ENDF-5 format, however no publication could be found of this CENDL/FPY-1987. An attempt to update and improve that library was undertaken after 1994 by Liu Tingjin and co-workers who also participated in the IAEA CRP [1.1]. The update was completed in 1998, containing the fissioning systems ^{235,238}U and ^{239}Pu at three energies (see Appendices 1 and 4 of this report). Although these data were not published, the major part of the work was introduced in Refs. [3.3.5, 3.3.6].

At the moment, the CENDL FPY evaluation program is being updated by N. Shu and his coworkers who so far have performed the updates for the independent and cumulative yields of n+^{235,238}U, n+^{239}Pu and the cumulative yields of the n+^{233}U fission during 1999-2016. The plan is to complete the updating and improvement of the CENDL FPY data files by including model calculations of FPYs in the next 2-5 years.

Table 3.1 Ongoing updates to the CENDL FPY evaluated files.

Fissioning Actinides	Author	Ref	Date
235U cumlative yield	Tingjin Liu et al. (not published)		2006
238U ‘’	Yongmei Xu, Nengchuan Shu et al.	thesis	2016
239Pu ‘’	Xiaosong Chen, Nengchuan Shu et al.	thesis	2013
233U ‘’	Liu Lile, Nengchuan Shu et al.	thesis	2014
235U indpendent yield	Nengchuan Shu et al.	[3.3.7]	2006
238U ‘’	Nengchuan Shu et al.		2006
239Pu ‘’	Nengchuan Shu et al.		2006

JENDL/FPY-2011 [Sec. Note: information confirmed by F. Minato, JAEA, after the meeting]:

The latest fission yield data file released by the JENDL group is JENDL FP Fission Yields Data File 2011 [3.3.8] which is compiled with the JENDL FP Decay Data File 2011 (JENDL/FPD-2011) to keep the consistency between the number of nuclides contained in the decay data file and fission yields file. The data files include 31 neutron-induced and 9 spontaneous fission yield files (see Appendix 1 for details). Some anomalies observed in the charge distributions of the FYs of thermal neutron-induced fission on ^{235}U FY for A = 86, 88, 100, 131, were corrected. Specifically, the yields of ^{86}Ge, ^{88}As, ^{100}Rb, ^{131}Cd were found to be larger than those of their neighbours and deviate from an inversed parabolic shape. The same deviations are also found in ENDF/B-VII data because the independent fission yields of JENDL/FPD-2011 are basically taken from ENDF/B-VII. The problem of ^{86}Ge arises from a mis-identification of the measured data seen in Ref. [3.3.1].

The independent fission yields of above 4 nuclides were corrected using the method reported in [3.3.9]. The yields are lowered and seem to be reasonable. Before this correction, the aggregate delayed neutron yield (nubar) calculated with JENDL/FPY-2011 and FPD-2011 was $\bar{\nu}$ = 0.01863, while after this correction it is reduced to $\bar{\nu}$ = 0.01694 and is closer to the experimental value of $\bar{\nu}$ = 0.01585±0.0005.

ROSFOND-2010 [Sec. Note: information provided by G. Manturov, IPPE, after the meeting]:

Independent and cumulative FPYs in the 2010 release of the Russian Federation library are partly based on the evaluations of England and Rider [3.3.1] and partly on the evaluations of Mills for JEFF 3.1.1 [3.3.4] as can be seen in Appendix 1. The Z- and A-ranges are therefore identical to those of ENDF/B VII and JEFF 3.1.1 in Appendices 2 and 3, respectively.

Discussion

It is clear from the status of the FPY libraries and the content of Appendix 1, that all the FPY libraries are dated, some more so than others. Since the previous IAEA CRP in 1996, there has been a lot of progress in experimental techniques and new facilities are now being used to measure FPY with enhanced accuracy and resolution. The new data need to be incorporated in the evaluated libraries. At the same time, decay data that are used in the determination of cumulative fission yields, such as half-lives, branching ratios, isomeric ratios, and beta-delayed neutron emission, have been improved and the decay data libraries have been updated accordingly. Nevertheless, some of the widely used FPY libraries have not been revised to take these developments into account. Other discrepancies that have been observed in ENDFB/VII and JENDL FPY libraries, such as the unreasonably high values of FPYs for certain Ge and As isotopes, have been corrected in the latter library, but not in the former.

Correlations between data and covariance matrices have become more and more important for the analysis of nuclear reactor benchmark measurements and sensitivity studies. In the previous IAEA CRP on fission product yields [1.1], correlations between individual fission yield data from the same experiment and between results from different experiments were introduced in the fission yield evaluations. Methods for constructing covariance matrices of experimental fission yields were proposed, and a computer code was adapted and used for the simultaneous evaluation of correlated data. In spite of this effort, however, the final FPY evaluated libraries did not include covariances between the evaluated values.

Since then, there have been renewed efforts to produce covariance matrices for the experimental FPYs (see summary of O. Serot in Sect. 2.). Furthermore, an OECD/NEA Data Bank activity has been running for the past few years (WPEC—SG 37) on evaluation methodologies for fission product yields and uncertainties [3.3.10]. Alternative methods of calculating covariances for FPYs are currently investigated by applying Total Monte Carlo techniques with the TENDL and GEF FPY libraries.

All the currently pursued approaches need to be considered and compared, and most importantly, an ENDF-6 format needs to be adopted so that the FPY covariances are eventually incorporated in the evaluated libraries. The outcome of OECD/WPEC-SG 37 should therefore be seriously considered in any future coordinated effort to update the fission product yields data libraries.

The concern that was voiced by the majority of participants of this meeting was that, due to a shortfall of evaluators and lack of funding opportunities, the required updates of the fission yield libraries cannot be handled at a national level by the one or two remaining experts. An international cooperation of all the experts around the world would be absolutely necessary. It was suggested that such an international effort could take the form of an IAEA Coordinated Research Project, or alternatively, a project like the Collaborative International Evaluated Library Organisation (CIELO) [3.3.11].

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3.4. Validation

The validation of evaluated data involves using methods that globally test the data against experiments, where the experiments and data calculations depend on a minimum of other nuclear data and mathematical approximations [1.1]. It was generally acknowledged that such global testing procedures should be systematically applied to the existing evaluated FPY libraries but also to those that will be developed in the future.

Two such validations are the calculation of delayed neutron (DN) emission and the calculation of decay heat.

The total delayed neutron emission per fission can be calculated for a fissioning nuclide using the summation method, whereby the total delayed neutron yield is given by the product of the cumulative yield c(A,Z) and the delayed neutron branching fraction P_n, for each fission product (A,Z) summed over all delayed neutron emitting fission products. It is also possible to calculate delayed neutron emission as a function of time (decay curves) following a fission pulse or a period of constant fission rate, by using independent FPYs and decay data within inventory codes. Several tests were performed on total delayed neutron yields and decay curves within an ongoing IAEA CRP [3.4.1] (see V. Piksaikin’s summary), showing that in the cases of ^{235}U, ^{239}Pu, the summation calculations do not depend so much on the P_n data set that was used as on the FPY libraries. In the case of ^{238}U, however, the total DN yields are rather sensitive to both the P_n data and FPYs used. More work is needed to analyze these findings to see whether different FP groups are contributing to the latter fissioning systems and whether their FPY data are reliable. It was also shown that DN data extracted from the decay curves obtained from ENDF/B-VI group parameters, do not agree with the systematics developed for average half-lives $T_{1/2}$ of DN for nuclides in the trans-uranium mass region, mainly due to inconsistencies in the respective FPYs. This testing procedure which is being applied to all fissionable systems available in the evaluated libraries, is continuously showing that there are discrepancies and inconsistencies among the available FPY libraries that warrant attention.

The calculation of decay heat is similar to that of delayed neutrons, as it is based on summation calculations. The only extra data required is the total energy of emitted particles per decay for gamma rays, electron (beta) and heavy particles (alphas and neutrons). This is a very useful test, particularly since accurate measurements of decay heat exist [3.4.2]. A comprehensive study of the sensitivity of decay heat calculations to the decay data and FPYs was performed for a wide range of fuel systems and irradiation times [3.4.3] (see M. Fleming's summary). The results showed invariably a dependence on both the decay data and FPYs in the different libraries which needs further investigation: especially for total decay heat data it is not clear whether FPY or decay data are being validated as both contribute, so it was recommended to analyze the beta and gamma decay heat curves separately.

In recent years, there has been a renewed interest in anti-neutrino spectra for both fundamental physics (sterile neutrinos, reactor anomaly) and applications such as the non-invasive monitoring of reactor operation (see A. Sonzogni's summary). The calculation of anti-neutrino spectra using the summation method is very similar to those of DN emission and decay heat: the total spectra can be decomposed into those of the individual FPs weighted by the corresponding FPY. As for DN emission, anti-neutrino spectra are sensitive to short-lived FPs, however, decay data also need to be controlled as in all the other validation techniques.

Since DN emission and anti-neutrino spectra are sensitive to the same time-group of FPs, if tested in parallel they can help confirm errors or inconsistencies in the FPY libraries for the same group of FPs. Both these calculations have also been shown to depend strongly on the isomeric ratios (e.g. ^{98}Y for DNs, ^{96}Y for anti-neutrinos), therefore they can help test the new branching ratios or systematics..

For anti-neutrino spectra, in particular, the FPYs of ^{238}U need to be studied carefully, to help clarify the observations of an enhancement in the spectra. New measurements of ^{238}U FYs from 1-5 MeV are needed to improve the evaluated data, with a focus on the short-lived FPs. [3.4.4].

Another very important type of validation is based on using integral benchmark data, which are obtained from well-defined benchmark measurements of a fissioning system for which all the parameters (irradiation history, geometry, etc) are well-known. A collection of benchmarks appropriate for validation purposes is available at the OECD/NEA Data Bank SFCOMPO site [3.4.5]. Different groups are performing validations using different codes and methods for treating uncertainties. A useful exercise would be to compare the validations performed by the different groups using the same integral benchmark data but different codes.

In these validations, a correct assessment of the uncertainties requires the use of covariance data. Depending on whether correlations are considered or not, and how they are treated, the total uncertainties in the calculated integral data can be overestimated or underestimated by a significant factor. Although a lot of progress has been made in developing methods of treating correlations between uncertainties [3.3.10], there is still a lot of work to do to incorporate these correlations in the evaluations, and eventually in the ENDF-6 formatted files.

The GEF code is a versatile tool that can provide FPYs and associated data (TKE, neutron multiplicities etc) for any fissioning system, together with an estimate of the uncertainties including covariance matrices. Since it is being considered for replacing other parametric models for calculating FPYs where no experimental data are available in some evaluated libraries, and as it is also being used more and more for testing different validation techniques, it was agreed that a comprehensive comparison between the GEF code FPY results and all the evaluated FPY libraries for all the fissionable systems included in the libraries, is timely. This could be done through an international effort coordinated by the IAEA.

References

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4. Conclusions and recommendations

The Technical Meeting on 'Fission Product Yields: current status and perspectives', held from 23 to 26 May 2016, at the IAEA, Vienna, brought together an international group of experts in the field of fission yield measurements, model development, evaluation and validation. Participants reviewed the status of FPYs in all these individual fields, taking into consideration the existing and emerging requirements for FPY data in applications such as reactor technologies, waste management and safeguards. They unanimously agreed that, although significant progress has been made in measurements, models and validation technique in the past decade, this is not necessarily reflected in the evaluated FPY libraries. A list of concluding remarks and recommendations follows:

- To help establish the framework for continued future co-operation in fission yield evaluations and for communication with experimentalists, theorists, evaluators and validators, technical meetings such as the one just completed should be held on a regular basis (biennial or triennial).

- Continued experimental efforts need to be supported including new approaches like experiments in inverse kinematics, 2E-2v measurements in coincidence with prompt-neutron and prompt-gamma measurements, or direct ion counting of FY with Penning traps, especially for isomeric yield ratios.

- The results of the experimental efforts are also very important for the development of model codes as some of the new experimental approaches (inverse kinematics) cover a large range of actinides and measure a complete set of fission data.

- The uncertainties in the experimental measurements need to be well characterized in order to serve as guidance for model developments and evaluations.

- Experimentalists using the same techniques are encouraged to forge collaborations. Experimentalists are also encouraged to perform systematic studies of the same fissioning system with different measurement techniques to discover and/or quantify systematic uncertainties

- Model development is ongoing with the support from different organizations (e.g. OECD Nuclear Energy Agency). An example is the GEF code which is one of the most promising approaches to generating fission yields for isotopes and elements where measurements are either difficult or impossible to perform. The community should also keep abreast of developments in the purely theoretical approaches including the Time-Dependent Hartree-Fock and Langevin methods.

- Many of the evaluated libraries are rather old and date back to the beginning of the 1990s, therefore there is an urgent need to update both the fission yield libraries and the decay data libraries, and to include covariances, consistently.

- To be able to provide up-to-date and complete FPY libraries, ENDF-6 formats need to be developed to store new information such as covariances and energy dependencies. Additionally, mass and charge yield data with their uncertainties should be included in the evaluated files. It would also be extremely useful to have total kinetic energy and nubar (fission neutron yields) as a function of mass and charge.

- A lack of funding towards fission yield evaluations has been identified, especially at the national level, leading to a shortfall in available manpower. This could have serious consequences for the timely future releases of evaluated FPY libraries, and the nuclear data libraries at large.
- In relation to this, the experts also expressed concern about the gradual loss of expertise as experienced evaluators have retired without any commensurate replacements due to developments and trends, e.g., in Europe, with regards to nuclear energy production. With the current policies, competence and expertise is being lost, and even though national governments decided to phase out nuclear energy and shutdown reactors, nuclear expertise will still be needed in the decades to come to execute and manage the phase out.
- To reduce the risk associated with the dependence on only few highly specialized evaluators, nuclear data evaluation methods should be standardized to the highest degree possible, and the evaluation process should be transparent, thus ensuring both reproducibility and traceability.
- Dissemination of experimental and evaluated fission product yield data is another important point to be taken seriously by dissemination centers. Existing tools like JANIS (OECD/NEA Data Bank), should be upgraded to facilitate online display and retrieval of FPY data. Participants also expressed the need for improving the retrieval of FPY data from the EXFOR database.
- Validation of evaluated libraries is very important for practical applications, and effort should be made to create an online database of open integral benchmarks, delayed neutron integral data, decay heat data, burn up indicators, post irradiation examinations, anti-neutrino spectra and other integral data that could or should be used to validate evaluated FPY libraries.
- To further enhance progress and developments in fission yields, a more efficient process of sharing information is required, such as providing feedback from sensitivity calculations and validation exercises to the experimentalists so as to guide them to improve their measurements.

  An example is the case of validations using anti-neutrino spectra: current observations of anti-neutrino spectra need further clarification which could be provided by additional improved measurements of fission yields of ^{238}U in the incident neutron energy range of 1 to 5 MeV.

All the above mentioned needs and requirements will not be possible if limited to the nationally coordinated efforts, for the reasons already mentioned. To solve the problem of shrinking manpower and find ways of addressing all the suggested improvements, an international effort is required. The experts acknowledged that in the long term, an international co-operation initiative like the CIELO project would be extremely beneficial to the maintenance of the evaluated FPY libraries. However, as a first step towards updating and improving these libraries, an IAEA Co-ordinated Research Project (CRP) would be the best solution. The focus of this CRP could be on carrying out all the recommended work on the four major actinides (^{235,238}U, ^{239,241}Pu) and ^{252}Cf.

APPENDIX 1: Contents of evaluated FPY libraries, energies, evaluators and date of evaluation.

JEFF-3.1.1				**ENDF/B VII.1**				**JENDL/FPY-2011**			
Neutron Induced Fission Yields				**Neutron Induced Fission Yields**				**Neutron Induced Fission Yields**			
Nucleus	**Authors**	**Year**	**Energies**	**Nucleus**	**Authors**	**Year**	**Energies**	**Nucleus**	**Authors**	**Year**	**Energies**
^{232}Th	R.W.MILLS	Feb-2005	4E5, 1.4E7	^{227}Th	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{227}Th	J.KATAKURA	2012	2.53E-2
^{233}U	R.W.MILLS	Feb-2005	2.53E-2, 4E5, 1.4E7	^{229}Th	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{229}Th	J.KATAKURA	2012	2.53E-2
^{234}U	R.W.MILLS	Feb-2005	4E5	^{232}Th	T.R. ENGLAND, B.F. RIDER	1992	5E5, 1.4E7	^{232}Th	J.KATAKURA	2012	5E5, 1.4E7
^{235}U	R.W.MILLS	Oct-2007	2.53E-2, 4E5, 1.4E7	^{231}Pa	T.R. ENGLAND, B.F. RIDER	1992	5E5	^{231}Pa	J.KATAKURA	2012	5E5
^{236}U	R.W.MILLS	Feb-2005	4E5	^{232}U	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{232}U	J.KATAKURA	2012	2.53E-2
^{238}U	R.W.MILLS	Feb-2005	4E5, 1.4E7	^{233}U	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2, 5E5, 1.4E7	^{233}U	J.KATAKURA	2012	2.53E-2, 5E5, 1.4E7
^{237}Np	R.W.MILLS	Feb-2005	2.53E-2, 4E5	^{234}U	T.R. ENGLAND, B.F. RIDER	1992	5E5, 1.4E7	^{234}U	J.KATAKURA	2012	5E5, 1.4E7
^{238}Np	R.W.MILLS	Feb-2005	2.53E-2, 4E5	^{235}U	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2, 5E5, 1.4E7	^{235}U	J.KATAKURA, F. MINATO, K.OHGAMA	2016	2.53E-2, 5E5, 1.4E7
^{238}Pu	R.W.MILLS	Feb-2005	2.53E-2, 4E5	^{236}U	T.R. ENGLAND, B.F. RIDER	1992	5E5, 1.4E7	^{236}U	J.KATAKURA	2012	5E5, 1.4E7
^{239}Pu	R.W.MILLS	Apr-2005	2.53E-2, 4E5	^{237}U	T.R. ENGLAND, B.F. RIDER	1992	5E5	^{237}U	J.KATAKURA	2012	5E5
^{240}Pu	R.W.MILLS	Feb-2005	4E5	^{238}U	T.R. ENGLAND, B.F. RIDER	1992	5E5, 1.4E7	^{238}U	J.KATAKURA	2012	5E5, 1.4E7
^{241}Pu	R.W.MILLS	Feb-2005	2.53E-2, 4E5	^{237}Np	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2, 5E5, 1.4E7	^{237}Np	J.KATAKURA	2012	2.53E-2, 5E5, 1.4E7
^{242}Pu	R.W.MILLS	Feb-2005	4E5	^{238}Np	T.R. ENGLAND, B.F. RIDER	1992	5E5	^{238}Np	J.KATAKURA	2012	5E5
^{241}Am	R.W.MILLS	Feb-2005	2.53E-2, 4E5	^{238}Pu	T.R. ENGLAND, B.F. RIDER	1992	5E5	^{238}Pu	J.KATAKURA	2012	5E5
^{242m}Am	R.W.MILLS	Feb-2005	2.53E-2, 4E5	^{239}Pu	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{239}Pu	J.KATAKURA	2012	2.53E-2

^{243}Am	R.W.MILLS	Feb-2005	2.53E-2, 4E5	^{239}Pu	M.B. CHADWICK, T. KAWANO	2011	5E5,2E6, 1.4E7	^{239}Pu	J.KATAKURA	2012	5E5,2E6, 1.4E7
^{243}Cm	R.W.MILLS	Feb-2005	2.53E-2, 4E5	^{240}Pu	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2, 5E5, 1.4E7	^{240}Pu	J.KATAKURA	2012	2.53E-2, 5E5, 1.4E7
^{244}Cm	R.W.MILLS	Feb-2005	2.53E-2, 4E5	^{241}Pu	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2, 5E5	^{241}Pu	J.KATAKURA	2012	2.53E-2, 5E5
^{245}Cm	R.W.MILLS	Feb-2005	2.53E-2, 4E5	^{242}Pu	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2, 5E5, 1.4E7	^{242}Pu	J.KATAKURA	2012	2.53E-2, 5E5, 1.4E7
				^{241}Am	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2, 5E5, 1.4E7	^{241}Am	J.KATAKURA	2012	2.53E-2, 5E5, 1.4E7
				^{242m}Am	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{242m}Am	J.KATAKURA	2012	2.53E-2
				^{243}Am	T.R. ENGLAND, B.F. RIDER	1992	5E5	^{243}Am	J.KATAKURA	2012	5E5
				^{242}Cm	T.R. ENGLAND, B.F. RIDER	1992	5E5	^{242}Cm	J.KATAKURA	2012	5E5
				^{243}Cm	T.R. ENGLAND, B.F. RIDER	1992	2.53e-2, 5e5	^{243}Cm	J.KATAKURA	2012	2.53E-2, 5E5
				^{244}Cm	T.R. ENGLAND, B.F. RIDER	1992	5E5	^{244}Cm	J.KATAKURA	2012	5E5
				^{245}Cm	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{245}Cm	J.KATAKURA	2012	2.53E-2
				^{246}Cm	T.R. ENGLAND, B.F. RIDER	1992	5.00E+05	^{246}Cm	J.KATAKURA	2012	5E5
				^{248}Cm	T.R. ENGLAND, B.F. RIDER	1992	5E5	^{248}Cm	J.KATAKURA	2012	5E5
				^{249}Cf	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{249}Cf	J.KATAKURA	2012	2.53E-2
				^{251}Cf	T.R. ENGLAND, B.F. RIDER	1992	2.52E-2	^{251}Cf	J.KATAKURA	2012	2.52E-2
				^{254}Es	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{254}Es	J.KATAKURA	2012	2.53E-2
				^{255}Fm	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{255}Fm	J.KATAKURA	2012	2.53E-2

Spontaneous Fission				**Spontaneous Fission**				**Spontaneous Fission**			
^{242}Cm	R.W.MILLS	Feb-2005		^{238}U	T.R. ENGLAND, B.F. RIDER	1992		^{238}U	J.KATAKURA	2012	
^{244}Cm	R.W.MILLS	Feb-2005		^{244}Cm	T.R. ENGLAND, B.F. RIDER	1992		^{244}Cm	J.KATAKURA	2012	
^{252}Cf	R.W.MILLS	Feb-2005		^{246}Cm	T.R. ENGLAND, B.F. RIDER	1992		^{246}Cm	J.KATAKURA	2012	
				^{248}Cm	T.R. ENGLAND, B.F. RIDER	1992		^{248}Cm	J.KATAKURA	2012	
				^{250}Cf	T.R. ENGLAND, B.F. RIDER	1992		^{250}Cf	J.KATAKURA	2012	
				^{252}Cf	T.R. ENGLAND, B.F. RIDER	1992		^{252}Cf	J.KATAKURA	2012	
				^{253}Es	T.R. ENGLAND, B.F. RIDER	1992		^{253}Es	J.KATAKURA	2012	
				^{254}Fm	T.R. ENGLAND, B.F. RIDER	1992		^{254}Fm	J.KATAKURA	2012	
				^{256}Fm	T.R. ENGLAND, B.F. RIDER	1992		^{256}Fm	J.KATAKURA	2012	

ROSFOND-2010				**CENDL**			
Neutron-induced Fission Yields				**Neutron-induced Fission Yields**			
Nucleus	**Authors**	**Year**	**Energies**	**Nucleus**	**Authors**	**Year**	**Energies**
^{227}Th	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{232}Th	D. WANG	1987	5E5
^{229}Th	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{233}U	D. WANG	1987	2.53E-2
^{230}Th	T.R. ENGLAND, B.F. RIDER	1992	5E5, 1.4E7	^{235}U	T. LIU	1998	2.53E-2, 5E5,1.4E7
^{232}Th	T.R. ENGLAND, B.F. RIDER	1992	5E5, 1.4E7	^{238}U	T. LIU	1998	5E5,1.4E7
^{232}U	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2	^{239}Pu	T. LIU	1998	2.53E-2,5E5
^{233}U	R.W. MILLS	2005	2.53E-2, 4E5, 1.4E7	^{241}Pu	D. WANG	1987	2.53E-2
^{234}U	R.W. MILLS	2005	4E5				
^{235}U	R.W. MILLS	2005	2.53E-2, 4E5, 1.4E7				
^{236}U	R.W. MILLS	2005	4E5				
^{237}U	T.R. ENGLAND, B.F. RIDER	1992	5E5				
^{238}U	T.R. ENGLAND, B.F. RIDER	1992	5E5, 1.4E7				
^{237}Np	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2, 5E5, 1.4E7				
^{238}Np	T.R. ENGLAND, B.F. RIDER	1992	5E5				
^{238}Pu	T.R. ENGLAND, B.F. RIDER	1992	5E5				
^{239}Pu	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2 5E5,1.4E7				
^{240}Pu	R.W. MILLS	2005	4E5,				
^{241}Pu	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2, 5E5				
^{242}Pu	R.W. MILLS	2005	4E5				

^{241}Am	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2, 5E5, 1.4E7					
^{242m}Am	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2					
^{243}Am	T.R. ENGLAND, B.F. RIDER	1992	5E5					
^{242}Cm	T.R. ENGLAND, B.F. RIDER	1992	5E5					
^{243}Cm	T.R. ENGLAND, B.F. RIDER	1992	2.53e-2, 5E5					
^{244}Cm	T.R. ENGLAND, B.F. RIDER	1992	5E5					
^{245}Cm	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2					
^{246}Cm	T.R. ENGLAND, B.F. RIDER	1992	5E5					
^{248}Cm	T.R. ENGLAND, B.F. RIDER	1992	5E5					
^{249}Cf	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2					
^{251}Cf	T.R. ENGLAND, B.F. RIDER	1992	2.52E-2					
^{254}Es	T.R. ENGLAND, B.F. RIDER	1992	2.53E-2					

APPENDIX 2: Z- and A-ranges of FPs for neutron-induced fission of ^{227,229,232}Th, ^{231}Pa, ^{232,233,234}U in ENDF/B VII.1

Z	**A range**					**Z**	**A range**					
	90-Th-227	**90-Th-229**	**90-Th-232**	**90-Th-232**	**91-Pa-231**		**92-U-232**	**92-U-233**	**92-U-233**	**92-U-233**	**92-U-234**	**92-U-234**
	0.0253	**0.0253**	**500000**	**1.40E+07**	**500000**		**0.0253**	**0.0253**	**500000**	**1.40E+07**	**500000**	**1.40E+07**
22			66-66	66-66		23	66-67	66-66	66-66	66-67	66-67	66-67
23			66-69	66-69	66-67	24	66-69	66-69	66-69	66-70	66-69	66-70
24		69-69	66-71	66-72	66-69	25	66-72	66-72	66-72	66-72	66-72	66-72
25	66-68	66-73	66-74	66-74	66-72	26	66-74	66-75	66-75	66-76	66-75	66-75
26	66-71	66-75	66-77	66-77	66-75	27	66-76	66-78	66-77	66-78	66-77	66-78
27	66-77	66-78	66-79	66-79	66-77	28	66-79	66-79	66-79	66-80	66-79	66-80
28	66-79	66-80	66-81	66-82	66-80	29	66-82	66-83	66-82	66-82	66-82	66-82
29	66-81	66-83	66-84	66-84	66-82	30	66-84	67-85	66-85	66-86	66-85	66-86
30	67-85	68-85	68-87	66-87	66-85	31	66-86	69-88	69-87	66-87	68-87	66-87
31	69-87	70-88	70-89	68-89	68-87	32	68-89	71-90	70-90	68-89	70-90	69-89
32	71-90	72-90	72-92	71-92	70-90	33	71-92	73-93	72-92	71-92	73-92	71-92
33	73-92	73-93	75-94	73-94	72-92	34	73-94	75-95	75-95	73-96	75-95	73-96
34	75-95	75-95	77-97	75-97	75-95	35	75-97	77-98	77-97	77-97	77-97	77-97
35	77-97	77-98	79-99	77-100	77-97	36	78-100	79-100	79-100	78-100	79-100	78-100
36	79-98	79-98	81-99	80-103	79-100	37	81-102	83-103	81-102	81-102	81-103	81-102
37	81-105	83-105	83-106	83-105	81-100	38	83-102	84-103	83-103	83-106	84-103	83-106
38	84-107	84-107	86-109	84-108	84-107	39	85-108	87-109	87-109	85-108	87-110	85-109
39	87-109	87-109	88-111	87-111	87-109	40	87-109	88-111	88-111	87-111	88-112	87-111
40	89-111	89-112	91-113	89-113	88-111	41	89-113	91-113	91-113	89-114	91-114	89-114
41	92-113	91-114	93-115	92-116	91-113	42	92-115	93-115	93-115	91-116	93-116	91-117
42	94-115	94-115	96-118	94-119	93-115	43	95-117	97-118	97-118	95-119	97-119	95-119
43	97-118	97-118	98-121	97-122	97-119	44	97-119	98-121	98-120	97-122	98-121	97-122
44	104-121	104-121	106-123	100-125	99-121	45	101-122	101-122	101-122	99-124	101-123	99-125

45	105-121	105-122	107-125	103-128	106-122	46	102-122	109-129	103-129	102-128	109-123	102-128
46	107-123	107-123	109-131	106-131	106-123	47	107-131	109-131	109-131	105-130	109-132	105-130
47	109-131	109-132	111-133	108-133	108-131	48	109-133	111-134	111-134	108-134	111-134	108-134
48	111-133	111-134	113-135	111-136	111-134	49	112-136	113-136	113-136	111-136	113-136	111-136
49	114-135	114-136	115-138	114-137	113-136	50	114-138	115-139	115-138	113-138	116-139	114-138
50	116-138	116-139	118-141	116-140	115-139	51	117-140	118-141	117-141	117-140	118-141	117-140
51	119-141	119-142	121-143	119-143	118-141	52	119-142	120-144	120-143	119-142	120-144	119-143
52	121-143	121-144	123-146	122-145	120-144	53	121-145	128-146	123-146	121-145	123-146	123-145
53	123-146	123-147	130-148	126-147	123-146	54	129-147	128-149	129-148	125-148	130-149	125-148
54	129-147	130-149	131-151	128-150	130-149	55	129-150	131-151	131-151	127-150	131-151	127-150
55	131-151	131-152	133-154	131-152	131-151	56	131-152	132-153	132-153	131-153	133-153	131-153
56	133-153	133-153	135-156	133-155	133-153	57	133-155	135-156	135-156	133-155	135-156	133-155
57	135-155	135-156	137-159	135-158	135-156	58	137-157	137-159	137-157	135-158	137-159	135-158
58	138-155	138-156	140-161	137-159	137-159	59	139-159	140-161	139-161	139-160	140-162	139-160
59	140-157	140-158	142-163	140-163	139-161	60	140-162	142-161	142-161	140-162	142-162	140-162
60	143-159	143-160	145-167	143-166	142-162	61	143-164	145-166	144-163	143-164	145-166	143-165
61	145-161	145-162	148-169	145-168	145-166	62	145-166	147-166	147-165	144-167	147-166	145-167
62	149-163	148-164	150-172	148-171	147-166	63	149-169	151-167	151-167	147-169	151-168	149-171
63	153-165	151-165	153-172	151-172	151-168	64	151-171	153-169	152-169	151-171	153-170	151-171
64	155-167	155-167	157-172	153-172	153-170	65	153-172	156-171	155-171	153-172	156-171	153-172
65	159-168	159-167	160-172	156-172	156-172	66	156-172	159-172	158-172	156-172	159-172	156-172
66	163-170	163-170	163-172	159-172	159-172	67	159-172	163-172	162-172	159-172	162-172	159-172
67	168-171		167-172	163-172	162-172	68	162-172	166-172	166-172	161-172	165-172	162-172
68	163-170		171-172	166-172	165-172	69	165-172	172-172	170-172	165-172	170-172	165-172
69				169-172	168-172	70	168-172			167-172		167-172
70					172-172	71	171-172			171-172		171-172

Z- and A-ranges of FPs for neutron-induced fission of $^{235,236,237, 238}$U, ^{237,238}Np in ENDF/B VII.1

Z	**A ranges**						**Z**	**A ranges**					
	92-U-235	**92-U-235**	**92-U-235**	**92-U-236**	**92-U-236**	**92-U-237**		**92-U-238**	**92-U-238**	**93-Np-237**	**93-Np-237**	**93-Np-237**	**93-Np-238**
	0.0253	**500000**	**1.40E+07**	**500000**	**1.40E+07**	**500000**		**500000**	**1.40E+07**	**0.0253**	**500000**	**1.40E+07**	**500000**
23	66-66	66-67	66-68	66-67	66-68	66-67	22	66-66					
24	66-69	66-69	66-70	66-69	66-70	66-69	23	66-69	66-68		66-66	66-67	66-66
25	66-73	66-73	66-73	66-73	66-73	66-73	24	66-71	66-69	69-69	66-66	66-69	66-69
26	66-75	66-75	66-76	66-75	66-76	66-75	25	66-74	66-73	66-73	66-73	66-73	66-73
27	66-78	66-78	66-78	66-78	66-78	66-79	26	66-77	66-76	66-75	66-75	66-75	66-75
28	66-80	66-81	66-82	66-81	66-82	66-81	27	66-79	66-79	66-78	66-78	66-78	66-78
29	66-83	66-83	66-83	66-83	66-83	66-84	28	66-81	66-82	66-81	66-80	66-80	66-81
30	68-86	67-85	66-86	67-85	66-86	68-86	29	66-84	66-84	66-83	66-83	66-83	66-83
31	70-88	69-88	67-88	69-88	67-88	70-89	30	67-87	66-86	68-85	67-85	66-86	67-85
32	72-91	72-91	69-90	72-91	69-90	72-91	31	69-89	68-89	69-88	70-88	66-88	69-88
33	74-93	74-93	71-93	73-93	72-93	74-94	32	72-92	70-91	72-91	71-90	69-90	72-91
34	76-96	76-96	74-96	75-96	74-96	76-96	33	74-94	72-94	74-93	73-93	71-93	74-93
35	78-98	78-98	77-98	78-99	77-98	78-99	34	77-97	75-96	76-95	75-96	74-96	76-95
36	80-101	80-101	78-100	80-101	79-101	81-102	35	79-100	77-99	78-98	77-98	77-98	78-98
37	83-103	83-104	81-103	83-104	81-103	83-104	36	81-102	79-102	80-101	80-100	79-100	80-101
38	85-104	85-104	83-106	85-104	83-107	85-105	37	83-105	83-104	83-103	83-103	81-102	83-104
39	87-110	87-110	85-109	87-110	87-109	88-111	38	86-105	84-107	85-106	84-105	83-105	85-106
40	89-112	90-112	87-112	89-112	88-112	90-113	39	88-111	87-110	87-106	87-106	87-108	87-106
41	92-114	92-115	90-114	92-115	90-115	93-115	40	90-114	89-113	89-112	89-112	88-111	90-113
42	94-117	95-117	92-117	95-117	93-117	95-118	41	93-116	91-116	92-115	91-114	91-114	92-115
43	97-119	97-119	95-120	97-120	95-120	98-120	42	95-118	94-118	94-117	93-116	93-117	95-117
44	99-121	100-121	97-124	100-121	98-124	100-123	43	98-121	97-121	97-119	97-119	95-119	97-119
45	101-124	103-123	101-125	103-124	101-126	103-124	44	100-123	99-124	99-121	98-121	98-122	100-121
46	109-130	109-130	102-130	110-124	103-130	110-131	45	103-125	102-127	102-123	101-123	101-125	103-123

47	110-131	110-132	106-131	110-133	106-131	111-133	46	105-127	104-130	104-123	104-130	103-128	105-124
48	112-134	112-135	109-134	112-135	109-134	113-135	47	111-133	107-132	112-132	106-132	105-131	112-132
49	115-137	114-137	111-136	115-137	112-136	115-138	48	113-136	110-136	112-134	111-134	109-134	113-135
50	117-139	117-140	114-138	117-140	115-139	117-140	49	115-138	113-137	114-137	113-136	111-136	115-137
51	119-142	119-142	117-141	119-142	117-141	120-143	50	118-141	116-140	117-139	116-139	114-139	117-140
52	122-144	121-145	120-143	122-145	120-144	122-145	51	120-143	119-142	119-142	118-141	117-141	119-142
53	126-147	130-147	123-146	129-147	123-146	130-148	52	123-146	122-145	121-144	120-144	120-144	122-145
54	128-149	130-149	125-148	131-149	125-150	131-150	53	125-148	125-147	129-147	123-146	123-146	129-147
55	131-152	131-152	127-151	132-152	129-151	132-153	54	131-151	127-150	130-149	130-149	125-149	131-149
56	133-153	134-155	131-154	134-155	131-154	134-156	55	132-153	131-152	131-152	131-151	129-151	132-152
57	137-157	137-157	133-155	137-158	133-156	137-158	56	134-156	132-155	133-153	133-153	131-154	134-155
58	138-159	138-159	135-158	138-159	137-159	139-161	57	137-159	135-158	137-157	135-156	135-156	137-158
59	141-162	141-162	139-161	141-163	139-161	142-163	58	139-161	137-160	138-159	137-159	137-158	139-159
60	143-162	143-162	140-163	143-165	141-163	144-166	59	142-164	140-163	141-162	140-162	139-161	141-163
61	146-166	146-167	143-166	146-167	143-167	147-169	60	144-167	143-166	143-165	142-162	141-163	144-165
62	148-166	149-171	145-169	148-171	146-169	149-171	61	147-169	145-169	146-166	145-166	144-166	146-167
63	151-168	151-171	149-171	151-171	149-172	152-171	62	149-172	148-171	148-166	147-166	147-169	149-171
64	154-170	154-171	151-172	154-171	152-172	155-171	63	152-172	151-172	151-168	151-171	149-172	152-171
65	157-172	157-172	153-172	157-172	155-172	158-172	64	155-172	153-172	154-170	152-171	152-172	154-171
66	160-172	160-172	156-172	160-172	157-172	161-172	65	158-172	156-172	157-172	155-172	155-172	157-172
67	165-172	165-172	159-172	164-172	161-172	165-172	66	161-172	159-172	160-172	158-172	157-172	160-172
68	167-172	168-172	162-172	167-172	163-172	168-172	67	165-172	162-172	163-172	162-172	161-172	164-172
69	172-172	172-172	165-172	171-172	166-172		68	168-172	165-172	167-172	165-172	162-172	167-172
70			168-172		169-172		69	171-172	168-172	171-172	169-172	165-172	171-172
71			172-172		172-172		70		172-172		172-172	168-172	
							71					171-172	

Z- and A-ranges of FPs for neutron-induced fission of ^{238,239,240,241}Pu in ENDF/B VII.1

Z	A range					Z	A range				
	94-Pu-238	94-Pu-239	94-Pu-239	94-Pu-239	94-Pu-239		94-Pu-240	94-Pu-240	94-Pu-240	94-Pu-241	94-Pu-241
	500000	0.0253	500000	2000000	1.40E+07		0.0253	500000	1.40E+07	0.0253	500000
23	66-67		66-66	66-66	66-67	23	66-66	66-66	66-67	69-69	66-67
24	66-69	69-69	66-69	66-69	66-70	24	66-69	66-69	66-69	66-72	66-69
25	66-72	66-72	66-72	66-72	66-72	25	66-73	66-73	66-72	66-75	66-73
26	66-75	66-72	66-75	66-75	66-76	26	66-75	66-75	66-76	66-78	66-75
27	66-78	66-77	66-77	66-77	66-78	27	66-78	66-78	66-78	66-79	66-78
28	66-80	66-79	66-79	66-79	66-82	28	66-80	66-80	66-80	66-83	66-81
29	66-83	66-82	66-83	66-83	66-83	29	66-83	66-83	66-83	67-85	66-83
30	66-85	66-85	66-85	66-85	66-86	30	67-85	66-85	66-86	69-88	67-85
31	68-87	68-87	68-87	68-87	66-87	31	69-88	69-88	67-87	71-91	69-88
32	70-90	70-90	70-90	70-90	69-90	32	71-90	71-90	69-90	73-93	71-91
33	72-92	72-92	72-92	72-92	71-92	33	73-93	73-93	71-92	75-96	73-93
34	75-95	75-96	75-95	75-95	73-96	34	75-95	75-95	73-96	78-98	75-96
35	77-98	77-97	77-97	77-97	75-97	35	78-98	77-98	77-97	80-101	78-98
36	79-100	79-100	79-100	79-100	78-100	36	80-100	80-100	78-100	83-104	80-101
37	81-103	81-103	83-103	83-103	81-102	37	83-103	83-103	81-102	85-106	83-103
38	84-105	83-105	84-105	84-105	83-104	38	84-106	84-106	83-105	87-109	85-106
39	87-107	87-108	87-108	87-108	85-107	39	87-108	87-108	85-107	89-109	87-108
40	88-112	88-108	88-108	88-108	87-110	40	89-108	89-108	87-111	92-116	90-109
41	91-113	91-114	91-114	91-114	89-113	41	92-115	91-115	90-114	94-117	92-115
42	93-115	93-116	93-116	93-116	91-116	42	94-117	94-117	92-116	97-120	94-117
43	97-117	97-119	97-119	97-119	95-119	43	97-119	97-119	95-119	99-121	97-120
44	98-119	98-121	98-121	98-121	97-122	44	99-121	99-121	97-124	102-123	99-121
45	101-122	101-122	101-123	101-123	99-124	45	101-123	101-123	99-125	105-124	102-123
46	103-129	103-123	103-123	103-123	101-130	46	104-130	104-130	102-130	107-132	104-124

47	106-132	106-131	106-131	106-131	103-130	47	107-132	107-132	105-131	115-134	107-132
48	112-134	114-134	108-134	108-134	106-134	48	114-134	114-134	107-134	116-137	109-135
49	113-136	114-136	114-136	114-136	109-136	49	115-136	115-136	111-136	117-140	115-137
50	114-138	116-138	116-138	116-138	112-138	50	117-139	117-139	113-138	120-142	117-140
51	117-141	118-141	118-141	118-141	115-140	51	119-142	119-141	117-140	122-145	119-142
52	119-143	120-144	120-143	120-143	118-142	52	121-144	121-144	119-143	129-147	121-145
53	121-146	123-146	123-146	123-146	121-145	53	123-147	123-147	123-145	131-149	129-147
54	129-148	128-148	130-148	130-148	125-148	54	130-149	130-149	125-148	131-152	131-149
55	131-151	131-151	131-151	131-151	127-150	55	131-152	131-152	127-150	133-155	131-152
56	132-153	132-153	132-153	132-153	129-152	56	133-154	133-154	131-154	137-158	133-155
57	135-156	135-156	135-156	135-156	133-154	57	135-157	135-157	133-155	138-159	137-157
58	137-158	137-159	137-159	137-159	135-158	58	137-159	137-159	135-158	141-163	138-159
59	139-161	139-162	139-161	139-161	139-160	59	140-162	140-162	139-160	143-166	141-163
60	142-162	142-163	142-163	142-163	140-162	60	142-165	142-165	140-163	146-169	143-165
61	144-166	144-167	144-167	144-167	141-165	61	145-167	145-167	143-166	149-171	146-168
62	146-169	147-169	147-169	147-169	144-167	62	148-169	148-169	145-168	151-172	148-171
63	149-171	151-171	149-171	149-171	147-169	63	151-171	151-172	147-171	154-172	151-172
64	152-171	152-171	152-171	152-171	149-171	64	153-171	153-172	151-172	157-172	154-172
65	155-172	155-172	155-172	155-172	151-172	65	156-172	156-172	153-172	160-172	156-172
66	157-172	158-172	158-172	158-172	155-172	66	159-172	158-172	155-172	166-172	159-172
67	161-172	161-172	161-172	161-172	159-172	67	162-172	161-172	159-172	168-172	162-172
68	163-172	164-172	164-172	164-172	161-172	68	165-172	165-172	161-172	171-172	165-172
69	167-172	168-172	167-172	167-172	165-172	69	169-172	168-172	165-172		169-172
70	171-172	172-172	170-172	170-172	166-172	70		171-172	167-172		172-172
71					169-172	71			171-172		
72					172-172						

Z- and A-ranges of FPs for neutron-induced fission of ^{242}Pu, ^{241,242,243}Am and ^{242,243,244}Cm in ENDF/B VII.1

Z	**A range**											
	94-Pu-242	**94-Pu-242**	**94-Pu-242**	**95-Am-241**	**95-Am-241**	**95-Am-241**	**95-Am-242**	**95-Am-243**	**96-Cm-242**	**96-Cm-243**	**96-Cm-243**	**96-Cm-244**
	0.0253	**500000**	**1.40E+07**	**0.0253**	**500000**	**1.40E+07**	**0.0253**	**500000**	**500000**	**0.0253**	**500000**	**500000**
23	66-66	66-68	66-68		66-66	66-67	66-67	66-67	66-66	66-67	66-66	66-67
24	66-69	66-71	66-71		66-69	66-70	66-69	66-69	66-69	66-69	66-69	66-69
25	66-73	66-73	66-73	66-72	66-72	66-72	66-72	66-72	66-69	66-72	66-70	66-72
26	66-75	66-75	66-75	66-75	66-73	66-75	66-75	66-75	66-73	66-75	66-73	66-73
27	66-79	66-78	66-79	66-77	66-77	66-77	66-77	66-78	66-76	66-77	66-77	66-77
28	66-81	66-81	66-82	66-79	66-79	66-80	66-79	66-80	66-79	66-80	66-79	66-79
29	66-84	66-84	66-84	66-82	66-82	66-82	66-83	66-83	66-82	66-82	66-82	66-82
30	68-86	67-86	67-86	67-85	66-85	66-86	66-85	66-86	66-84	66-85	66-84	66-85
31	70-89	69-89	69-89	69-88	68-87	66-87	68-88	68-88	67-86	68-88	67-87	67-87
32	72-91	71-91	71-91	71-90	70-90	68-90	70-90	70-90	69-89	70-90	69-89	70-90
33	74-94	74-94	73-93	73-92	72-92	71-92	72-93	73-93	72-91	72-93	71-92	72-92
34	76-96	76-96	76-96	75-95	74-94	73-96	75-95	75-96	74-94	74-96	74-94	74-95
35	78-99	78-99	77-98	77-97	77-97	75-97	77-98	77-98	77-96	77-97	77-97	77-97
36	81-101	80-101	79-101	79-100	79-100	77-100	79-100	79-100	78-100	78-100	78-100	79-100
37	83-104	83-104	83-104	83-102	81-102	81-102	83-103	81-103	81-101	81-102	81-102	81-102
38	85-107	85-106	84-106	84-105	84-105	83-104	84-105	84-105	83-104	83-104	83-104	83-105
39	88-109	88-109	87-109	87-107	87-107	85-107	87-108	87-108	85-106	87-107	85-106	87-107
40	90-109	90-109	89-109	89-110	88-110	87-110	89-110	88-110	87-110	88-110	88-109	88-110
41	92-116	92-116	91-116	91-110	91-110	89-114	91-110	91-111	89-111	91-111	90-111	90-112
42	95-118	95-118	93-118	93-117	93-117	91-117	94-117	93-118	91-111	93-111	92-112	93-112
43	97-120	97-120	97-120	97-119	95-119	95-119	97-119	95-120	95-118	97-118	95-119	95-119
44	100-123	99-123	98-122	98-121	98-121	97-122	99-121	98-122	97-120	98-120	97-120	98-120
45	103-124	102-124	101-123	101-122	101-122	99-124	101-123	101-123	99-121	101-121	99-122	101-122
46	105-124	105-124	103-130	103-129	103-122	101-128	103-123	103-130	101-121	102-129	102-122	102-129

47	108-133	107-133	106-132	106-131	106-131	103-130	106-132	106-132	105-130	105-131	105-131	105-131
48	116-135	115-135	109-134	108-134	108-134	106-134	108-134	108-134	106-134	107-134	107-134	107-134
49	116-137	115-137	116-137	116-136	116-136	109-136	116-136	111-136	109-136	109-136	109-136	111-136
50	118-140	117-140	117-139	117-138	116-138	112-138	117-139	117-139	111-138	118-138	112-138	112-138
51	120-143	120-142	119-142	119-141	118-141	117-140	119-141	119-141	118-139	118-141	119-140	118-141
52	122-145	122-145	120-144	121-143	120-143	119-142	121-144	121-144	119-142	120-143	120-143	120-143
53	130-148	130-147	123-147	123-146	128-146	121-145	123-146	123-146	121-144	121-146	121-145	121-146
54	131-150	131-150	130-150	129-149	130-148	125-148	130-149	130-148	129-148	129-148	129-148	129-148
55	132-153	131-152	131-151	131-151	131-151	127-150	131-151	131-151	129-150	129-151	129-150	129-150
56	134-155	133-155	132-154	132-153	132-153	129-152	132-154	132-154	131-152	131-154	131-152	132-153
57	137-158	137-158	135-157	135-156	135-156	133-154	135-156	135-156	133-154	135-156	133-155	135-155
58	138-160	138-159	137-159	137-159	137-158	135-158	137-159	137-159	135-157	137-158	135-157	137-158
59	141-163	141-163	139-162	139-161	139-161	139-160	139-162	139-161	139-159	139-161	139-160	139-161
60	144-166	143-166	141-165	142-162	141-162	140-163	142-163	141-163	140-162	141-163	140-162	141-163
61	146-168	146-168	144-167	144-166	144-166	141-165	145-167	144-167	143-164	143-166	143-164	143-166
62	149-171	148-171	147-169	147-169	146-169	144-167	147-169	146-169	144-166	146-167	145-167	146-167
63	151-172	151-172	149-172	151-169	149-171	147-170	151-172	149-172	147-168	149-171	149-169	149-171
64	154-172	154-172	152-172	152-170	152-171	149-172	152-172	151-172	149-170	151-172	151-171	151-172
65	157-172	156-172	155-172	155-172	155-172	151-172	155-172	155-172	153-172	155-172	153-172	155-172
66	160-172	159-172	157-172	158-172	157-172	155-172	158-172	157-172	155-172	156-172	156-172	156-172
67	163-172	162-172	161-172	161-172	161-172	159-172	161-172	161-172	159-172	159-172	159-172	159-172
68	166-172	166-172	163-172	164-172	163-172	161-172	164-172	163-172	161-172	162-172	161-172	162-172
69	170-172	169-172	166-172	167-172	166-172	165-172	167-172	166-172	165-172	165-172	165-172	165-172
70		172-172	170-172	171-172	170-172	166-172	170-172	170-172	167-172	168-172	167-172	168-172
71						169-172			171-172	171-172	171-172	171-172
72						171-172						

Z- and A-ranges of FPs for neutron-induced fission of ^{245,246,248}Cm, ^{249,251}Cf, ^{254}Es, and ^{255}Fm in ENDF/B VII.1

Z	**A range**						
	96-Cm-245	**96-Cm-246**	**96-Cm-248**	**98-Cf-249**	**98-Cf-251**	**99-Es-254**	**100-Fm-255**
	0.0253	**500000**	**500000**	**0.0253**	**0.0252**	**0.0253**	**0.0253**
23	66-67	66-67	66-68		66-67		66-66
24	66-69	66-69	66-71		66-69		66-69
25	66-72	66-73	66-73	66-69	66-72	66-68	66-72
26	66-75	66-75	66-75	66-73	66-75	66-75	66-72
27	66-78	66-78	66-79	66-76	66-78	66-78	66-77
28	66-80	66-80	66-81	66-79	66-80	66-79	66-79
29	66-83	66-83	66-84	66-82	66-83	66-83	66-81
30	66-86	66-86	67-87	66-84	66-85	67-85	66-85
31	68-88	68-88	69-89	66-87	67-88	69-88	67-87
32	70-91	70-91	71-92	68-90	70-91	72-91	70-90
33	73-93	73-93	73-94	71-92	72-93	74-94	72-92
34	75-96	75-96	76-97	73-96	75-96	76-96	75-95
35	77-98	77-98	78-99	75-97	77-98	78-99	77-97
36	79-100	79-101	80-102	77-100	79-101	81-101	80-100
37	83-103	83-103	83-104	79-102	83-103	83-103	83-103
38	84-105	84-106	85-107	83-105	84-106	85-106	84-105
39	87-108	87-108	88-109	85-107	87-108	87-108	87-108
40	89-110	89-110	90-112	87-110	89-110	90-111	89-110
41	92-112	91-113	93-114	89-112	91-113	92-113	92-113
42	94-113	94-113	95-114	92-116	94-116	94-116	94-115
43	97-120	97-120	97-121	95-120	97-118	97-118	97-118
44	99-121	99-122	100-123	97-122	99-118	99-121	99-120
45	101-123	101-123	102-124	99-124	101-120	101-121	101-122
46	103-130	104-130	105-131	102-126	103-130	104-123	104-123

47	106-132	106-132	107-133	105-130	106-132	106-132	106-132
48	108-134	109-134	110-135	107-134	108-135	108-135	109-135
49	111-136	111-137	112-138	109-136	111-137	111-137	111-137
50	113-139	113-139	121-140	112-138	113-139	114-139	114-139
51	119-141	120-142	121-143	115-140	117-142	117-142	117-142
52	121-144	121-144	123-145	121-143	118-144	118-144	119-144
53	123-147	123-147	130-148	123-145	129-147	121-147	123-146
54	130-149	130-149	131-150	125-148	130-150	131-150	130-149
55	131-152	131-152	131-153	127-150	131-152	131-152	131-152
56	132-154	133-154	134-155	131-154	133-154	133-154	133-154
57	135-156	135-157	137-158	133-156	135-157	135-157	137-157
58	137-159	137-159	138-160	135-158	137-159	137-160	138-159
59	139-162	139-162	141-163	139-161	140-162	140-162	140-162
60	142-164	142-164	143-166	140-164	142-165	142-165	143-165
61	145-167	145-167	146-168	143-166	145-167	145-167	145-167
62	147-169	147-169	148-171	145-169	147-169	147-169	148-169
63	151-172	151-172	151-172	147-172	151-172	151-172	151-172
64	152-172	152-172	153-172	151-172	152-172	152-172	153-172
65	155-172	155-172	156-172	153-172	155-172	155-172	156-172
66	158-172	158-172	159-172	155-172	158-172	157-172	158-172
67	161-172	161-172	162-172	159-172	161-172	161-172	161-172
68	163-172	163-172	165-172	161-172	163-172	163-172	164-172
69	166-172	166-172	168-172	165-172	166-172	166-172	167-172
70	170-172	169-172	171-172	167-172	169-172	170-172	170-172
71				171-172	172-172		

Z- and A-ranges of FPs for spontaneous fission of ^{238}U, ^{244,246,248}Cm, ^{250,252}Cf, ^{253}Es, and ^{254,256}Fm in ENDF/B VII.1

Z	**A range**								
	92-U-238	**96-Cm-244**	**96-Cm-246**	**96-Cm-248**	**98-Cf-250**	**98-Cf-252**	**99-Es-253**	**100-Fm-254**	**100-Fm-256**
23		66-67	66-67	66-68	66-66	66-67	66-66	66-66	66-66
24		66-69	66-69	66-69	66-69	66-71	66-69	66-67	66-69
25	66-67	66-72	66-72	66-73	66-72	66-73	66-72	66-70	66-72
26	66-75	66-73	66-75	66-75	66-74	66-75	66-74	66-73	66-74
27	66-79	66-77	66-77	66-78	66-77	66-78	66-77	66-75	66-77
28	66-81	66-79	66-79	66-80	66-79	66-81	66-80	66-79	66-79
29	68-84	66-81	66-83	66-83	66-82	66-83	66-82	66-81	66-82
30	70-87	66-84	66-85	66-85	66-85	67-86	66-85	66-84	66-85
31	72-89	67-87	67-88	68-88	66-87	69-88	66-87	66-87	66-87
32	74-92	70-90	70-90	70-91	69-90	72-91	68-90	68-89	69-90
33	76-94	72-92	72-93	72-93	71-93	73-93	71-92	71-92	71-92
34	78-97	75-95	75-95	75-96	74-95	76-96	73-96	73-94	73-96
35	80-100	77-97	77-98	77-98	77-98	78-99	77-97	77-97	77-97
36	82-102	79-100	80-100	80-101	79-100	80-101	78-100	78-100	78-100
37	84-105	81-102	83-103	83-104	81-103	83-103	81-102	81-102	81-102
38	86-105	84-105	84-105	84-106	84-105	85-106	83-104	83-104	83-105
39	89-111	87-107	87-108	87-109	87-107	87-108	85-107	85-106	85-107
40	91-113	88-110	89-110	89-111	89-110	89-110	88-110	87-110	88-110
41	94-115	91-112	92-113	92-113	91-112	91-112	90-112	90-111	90-112
42	96-118	93-112	94-113	94-114	93-114	94-115	93-114	92-114	93-116
43	99-120	97-119	97-120	97-121	97-116	97-119	95-117	95-116	95-117
44	102-123	98-121	99-121	99-122	98-117	99-124	97-120	97-119	97-120
45	104-125	101-121	101-122	102-123	101-123	101-125	101-124	99-121	101-122
46	110-125	103-129	104-130	104-124	103-123	104-126	102-130	102-121	102-130
47	112-133	106-131	106-132	107-133	105-131	106-132	105-131	105-131	105-132

48	114-135	108-134	109-134	109-135	108-134	108-134	107-134	106-134	107-134
49	116-139	111-136	111-136	111-137	111-136	111-137	109-136	109-136	111-136
50	118-141	119-139	119-139	114-140	112-139	113-139	111-138	111-138	112-138
51	121-144	120-141	120-142	121-142	115-141	118-142	115-140	113-140	115-141
52	124-146	121-144	122-144	123-145	117-144	124-144	117-143	115-142	117-143
53	131-149	128-146	123-146	130-147	123-146	125-147	128-146	121-145	121-146
54	132-151	129-148	130-149	131-150	130-149	125-150	130-148	129-148	130-148
55	133-154	131-151	131-151	131-152	131-151	132-151	131-151	129-150	131-151
56	135-156	132-153	133-154	133-155	132-153	133-154	131-154	131-153	132-154
57	138-159	135-156	135-157	137-157	135-156	135-156	135-156	133-155	135-155
58	141-162	137-159	137-159	138-159	137-158	137-159	137-158	135-158	137-158
59	143-162	140-161	140-162	140-163	139-161	139-161	139-161	139-160	139-161
60	146-166	142-163	142-163	143-165	142-163	142-164	140-164	140-162	141-163
61	148-166	145-166	145-167	145-168	144-166	144-167	143-165	143-165	143-166
62	151-166	147-169	147-169	148-171	147-169	147-169	145-168	145-167	146-168
63	154-168	151-172	151-172	151-172	149-171	149-172	149-171	147-169	149-171
64	158-170	152-172	153-172	153-172	152-172	152-172	151-172	151-172	151-172
65	162-171	155-172	155-172	156-172	155-172	155-172	153-172	153-172	153-172
66	166-172	158-172	158-172	159-172	157-172	157-172	156-172	155-172	155-172
67	171-172	161-172	161-172	161-172	161-172	159-172	159-172	159-172	159-172
68		163-172	164-172	164-172	162-172	162-172	161-172	161-172	161-172
69		166-172	167-172	167-172	165-172	165-172	165-172	165-172	165-172
70		169-172	170-172	170-172	168-172	168-172	166-172	166-172	167-172
71		172-172			171-172	171-172	169-172	169-172	171-172
72							172-172	172-172	172-172

APPENDIX 3: Z- and A-ranges of FPs from n-induced fission of ^{232}Th, ^{233,234,235,236,238}U in JEFF-3.1.1.

Z	**A ranges**											
	90-Th-232	**90-Th-232**	**92-U-233**	**92-U-233**	**92-U-233**	**92-U-234**	**92-U-235**	**92-U-235**	**92-U-235**	**92-U-236**	**92-U-238**	**92-U-238**
	400000	**1.40E+07**	**0.0253**	**400000**	**1.40E+07**	**400000**	**0.0253**	**400000**	**1.40E+07**	**400000**	**400000**	**1.40E+07**
1	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3
2	3-4	3-4	3-8	3-4	3-4	3-4	3-6	3-4	3-4	3-4	3-4	3-4
3			6-9				6-9					
4			8-10				8-12					
							9-12					
							12-15					
							15-15					
							21-21					
20					50-52							
21					50-57							54-56
22		56-60			50-61							54-61
23		56-65			51-64				53-57			54-65
24		56-67			52-67				53-63	62-63	61-65	54-67
25	64-69	56-69	63-66	63-67	55-69	61-68	64-67		54-67	62-69	61-69	55-69
26	64-72	56-72	62-71	62-72	56-72	61-72	64-72	63-70	55-71	62-72	61-72	56-72
27	64-75	59-75	62-75	62-75	59-75	61-75	64-75	63-74	57-75	62-75	61-75	59-75
28	64-78	61-78	62-78	62-78	60-78	61-78	64-78	63-77	58-78	62-78	61-78	61-78
29	65-80	63-80	63-80	63-80	63-80	63-80	65-80	63-80	61-80	63-80	63-80	63-80
30	66-83	66-83	66-83	66-83	64-83	66-83	66-83	66-83	63-83	66-83	66-83	66-83
31	69-86	69-86	69-86	69-86	69-86	69-86	69-86	69-86	65-86	69-86	69-86	69-86
32	72-89	70-89	70-89	70-89	70-89	70-89	72-89	70-89	67-89	72-89	72-89	70-89

33	75-92	75-92	73-92	74-91	73-91	74-92	75-92	75-91	70-92	75-92	75-92	75-92
34	76-94	76-94	74-94	74-94	74-93	74-94	76-94	76-94	72-94	76-94	76-94	76-94
35	79-97	79-97	77-97	78-96	78-96	79-97	79-97	79-97	75-97	79-97	79-97	79-97
36	80-100	80-100	79-99	80-99	80-98	80-99	80-100	80-99	78-100	80-100	80-100	80-100
37	84-101	84-102	82-102	83-101	83-101	83-102	83-102	83-102	80-102	84-102	84-102	84-102
38	84-105	84-105	84-104	84-104	84-103	84-104	84-104	84-104	83-105	84-105	86-105	86-105
39	89-108	89-108	86-108	87-108	87-107	88-108	88-108	88-108	85-108	88-108	89-108	89-108
40	90-110	90-110	89-110	90-109	89-109	90-110	90-110	90-110	88-110	90-110	90-110	90-110
41	94-113	93-112	91-111	92-111	92-110	93-112	93-112	93-112	91-112	93-113	94-113	93-112
42	95-115	95-115	94-114	94-114	94-113	94-114	94-114	95-114	93-115	95-115	95-115	95-115
43	99-118	99-118	96-117	97-117	97-116	97-117	98-117	99-117	96-118	98-118	99-118	98-118
44	99-120	99-120	99-119	99-119	99-118	99-119	99-119	99-119	99-120	99-120	99-120	99-120
45	103-122	103-122	102-121	102-121	102-121	103-122	103-122	103-122	102-122	103-122	103-122	103-122
46	105-124	105-124	102-124	104-124	104-124	104-124	104-124	104-124	104-124	104-124	104-124	104-124
47	109-130	109-130	109-130	109-130	108-129	109-130	109-130	109-130	108-130	109-130	109-130	109-130
48	111-132	110-132	110-132	110-132	108-131	110-132	111-132	111-132	108-132	111-132	111-132	110-132
49	113-135	113-135	113-135	113-135	112-134	113-135	113-135	113-135	111-135	113-135	113-135	113-135
50	115-137	114-137	114-137	114-137	112-136	114-137	115-137	115-137	112-137	115-137	115-137	114-137
51	121-139	119-139	119-139	119-139	117-138	119-139	120-139	121-139	117-139	120-139	121-139	120-139
52	122-142	122-142	121-142	121-142	119-141	122-142	122-142	122-142	119-142	122-142	122-142	122-142
53	126-144	125-144	124-144	124-144	122-143	124-144	125-144	125-144	122-144	125-144	127-144	126-144
54	130-147	126-147	126-147	128-147	126-145	129-147	126-147	126-147	125-147	126-147	130-147	126-147
55	133-151	132-150	130-150	131-149	130-147	131-150	132-150	132-150	128-151	132-151	133-151	132-150
56	134-153	134-153	132-152	132-151	132-150	132-152	134-153	134-152	130-153	134-153	134-153	134-152
57	138-155	137-155	135-154	135-153	134-152	136-154	137-155	137-155	134-155	137-155	138-155	137-155

58	140-157	139-157	137-157	138-156	136-154	138-156	139-157	139-157	136-157	139-157	140-157	139-157
59	141-159	141-159	140-159	140-158	139-157	141-158	141-159	141-159	139-159	141-159	141-159	141-159
60	143-161	142-161	142-161	142-160	141-159	142-160	142-161	142-161	142-161	142-161	143-161	142-161
61	147-163	147-163	145-162	145-162	144-161	146-162	147-163	147-163	145-163	147-163	147-163	146-163
62	147-165	147-165	146-164	146-164	146-164	146-164	147-165	147-165	146-165	147-165	147-165	147-165
63	151-166	151-167	151-166	151-166	149-166	151-166	151-166	151-167	151-167	151-167	151-167	151-167
64	154-167	154-169	152-167	152-167	150-168	152-168	152-168	154-169	152-169	154-169	154-169	152-169
65	159-167	158-171	157-168	156-169	154-170	157-169	158-169	159-170	157-171	159-171	159-171	157-171
66	161-167	160-172	158-169	158-170	157-173	158-170	160-170	160-171	158-173	160-172	160-173	158-173
67	165-167	165-173	164-169	163-170	160-175	164-171	165-170	165-171	164-175	165-173	165-175	163-175
68	166-167	166-174	166-169	164-170	163-177	166-171	166-170	166-171	166-177	166-173	166-175	164-177
69		169-174	169-169	169-169	166-178	169-171	169-169	169-171	169-179	169-173	169-175	169-179
70		171-174			169-180	171-171		171-171	171-180	171-173	171-175	170-181
71					172-181				175-180		175-175	175-181
72					175-182				177-180			177-181
73					180-183							181-181
74					182-183							

Z and A-ranges of FPs from n-induced fission of ^{237,238}Np, ^{238,239,240,241,242}Pu in JEFF-3.1.1.

Z	A ranges											
	93-Np-237	**93-Np-237**	**93-Np-238**	**93-Np-238**	**94-Pu-238**	**94-Pu-238**	**94-Pu-239**	**94-Pu-239**	**94-Pu-240**	**94-Pu-241**	**94-Pu-241**	**94-Pu-242**
	0.0253	**400000**	**0.0253**	**400000**	**0.0253**	**400000**	**0.0253**	**400000**	**400000**	**0.0253**	**400000**	**400000**
1	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3
2	3-4	3-4	3-4	3-4	3-4	3-4	3-8	3-4	3-4	3-4	3-4	3-4
3							6-9					
4							6-12					
5							11-12					
6							8-14					
23											58-61	57-62
24	62-62	59-65	60-64	60-65	60-63	60-64	59-63	58-65	59-64	58-64	58-65	57-66
25	61-67	59-69	60-68	60-69	60-67	60-68	59-67	58-68	59-68	58-68	58-69	57-69
26	61-72	59-72	60-72	60-72	60-71	60-71	59-71	58-72	59-72	58-72	58-72	57-72
27	61-75	59-75	61-75	61-75	61-74	61-75	59-75	59-75	59-75	59-75	59-75	59-75
28	61-78	61-78	61-78	61-78	61-77	61-78	61-78	61-78	61-78	61-78	61-78	61-78
29	63-80	63-80	63-80	63-80	63-80	63-80	63-80	63-80	63-80	63-80	63-80	63-80
30	66-83	66-83	66-83	66-83	66-83	66-83	66-83	66-83	66-83	66-83	66-83	66-83
31	69-86	69-86	69-86	69-86	69-85	69-86	69-86	69-86	69-86	69-86	69-86	69-86
32	70-89	70-89	70-89	70-89	70-88	70-89	70-89	70-89	70-89	70-89	70-89	72-89
33	74-91	74-92	74-92	75-92	74-91	74-91	74-91	74-91	75-92	75-92	75-92	75-92
34	74-94	74-94	76-94	76-94	74-93	74-94	74-94	74-94	76-94	76-94	76-94	76-94
35	79-97	79-97	79-97	79-97	78-96	78-96	78-97	79-96	79-97	79-97	79-97	79-97
36	80-99	80-100	80-100	80-100	80-98	80-99	80-99	80-99	80-100	80-100	80-100	80-100
37	83-102	83-102	83-102	83-102	83-101	83-101	82-102	83-102	83-102	83-102	84-102	84-102

38	84-104	84-105	84-105	84-105	84-104	84-104	84-104	84-104	84-105	84-105	84-105	86-105
39	87-106	88-107	88-107	88-107	87-106	87-106	87-107	88-106	88-107	88-107	88-107	89-108
40	90-110	90-110	90-110	90-110	89-108	89-108	89-110	90-109	90-109	90-109	90-109	90-110
41	92-112	93-112	93-113	93-112	92-112	92-112	92-112	92-112	93-113	93-113	93-113	93-113
42	94-114	94-114	94-115	94-115	94-114	94-113	94-115	94-114	94-115	94-115	94-115	95-115
43	97-117	97-117	98-117	98-117	97-116	97-116	96-117	97-117	98-117	98-118	98-117	98-118
44	99-119	99-119	99-120	99-120	99-119	99-119	99-120	99-120	99-120	99-120	99-120	99-120
45	102-122	103-122	103-122	103-122	102-121	102-121	102-122	102-122	103-122	103-122	103-122	103-122
46	104-124	104-124	104-124	104-124	102-124	102-124	102-124	104-124	104-124	104-124	104-124	104-124
47	109-130	109-130	109-130	109-130	107-130	107-129	107-130	107-130	108-130	108-130	108-130	108-130
48	110-132	110-132	111-132	111-132	108-132	108-132	108-132	108-132	108-132	108-132	108-132	110-132
49	113-135	113-135	113-135	113-135	113-135	113-134	113-135	113-135	113-135	113-135	113-135	113-135
50	115-137	114-137	115-137	115-137	114-137	114-137	114-137	114-137	115-137	115-137	115-137	115-137
51	120-139	120-139	121-139	120-139	119-139	119-139	119-139	120-139	120-139	121-139	121-139	121-139
52	122-142	122-142	122-142	122-142	121-142	121-141	121-142	122-142	122-142	122-142	122-142	122-142
53	125-144	125-144	125-144	125-144	124-144	124-144	124-144	124-144	125-144	125-144	125-144	126-144
54	129-147	128-147	126-147	126-147	128-146	128-146	126-147	128-147	128-147	126-147	126-147	126-147
55	132-150	131-150	132-150	132-150	131-149	131-148	131-150	131-149	131-150	132-151	132-150	132-151
56	132-152	132-152	134-153	134-153	132-151	132-151	132-152	132-151	132-152	134-153	134-153	134-153
57	136-155	136-154	137-155	136-155	135-153	135-153	135-155	135-154	136-154	137-155	136-155	137-155
58	138-157	138-157	139-157	139-157	137-156	137-155	138-157	138-156	138-157	139-157	139-157	139-157
59	141-159	141-159	141-159	141-159	140-158	140-158	140-159	140-158	141-159	141-159	141-159	141-159
60	142-161	142-161	142-161	142-161	142-160	142-160	142-161	142-161	142-161	142-161	142-161	142-161
61	146-163	146-163	147-163	146-163	145-162	145-162	145-163	145-163	146-163	147-163	146-163	147-163
62	146-165	146-165	147-165	147-165	146-165	146-164	146-165	146-165	146-165	147-165	147-165	147-165

63	151-167	151-167	151-167	151-167	150-167	150-166	151-167	150-167	151-167	151-167	151-167	151-167
64	152-169	152-169	152-169	152-169	152-169	150-168	152-169	152-169	152-169	152-169	152-169	152-169
65	157-171	157-171	158-171	157-171	156-170	155-170	156-171	156-171	156-171	158-171	157-171	158-171
66	158-172	158-173	158-173	158-173	158-172	158-172	158-173	158-173	158-173	158-173	158-173	158-173
67	164-173	163-174	164-175	164-175	162-174	161-173	162-175	162-175	162-175	163-175	163-175	164-175
68	164-174	164-175	166-176	164-176	164-175	164-175	164-176	164-176	164-177	164-177	164-177	164-177
69	169-174	169-176	169-177	169-177	169-176	168-176	169-177	168-178	169-179	169-179	169-179	169-179
70	171-174	171-176	171-177	171-177	170-177	170-177	170-178	170-179	170-180	170-181	170-181	171-181
71		175-175	175-177	175-177	175-177	175-177	175-178	175-179	175-180	175-182	175-181	175-182
72			177-177	177-177	177-177	177-177	177-178	177-179	177-180	177-182	177-181	177-182
73										181-181	181-181	181-181

Z- and A-ranges of FPs from n-induced fission of ^{241,242m,243}Am, ^{243,244,245}Cm in JEFF-3.1.1.

Z	A ranges											
	95-Am-241	**95-Am-241**	**95-Am-242M**	**95-Am-242M**	**95-Am-243**	**95-Am-243**	**96-Cm-243**	**96-Cm-243**	**96-Cm-244**	**96-Cm-244**	**96-Cm-245**	**96-Cm-245**
	0.0253	**400000**	**0.0253**	**400000**	**0.0253**	**400000**	**0.0253**	**400000**	**0.0253**	**400000**	**0.0253**	**400000**
1	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3
2	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4
22												56-56
23		56-61	58-60	57-60	57-61	57-61	57-59	57-60	56-60	56-61	55-61	56-62
24	58-64	56-65	57-64	57-65	57-65	57-65	57-64	57-64	56-64	56-65	55-65	56-65
25	58-68	56-69	57-68	57-68	57-68	57-69	57-67	57-68	56-68	56-68	55-68	56-69
26	58-71	56-72	57-72	57-72	57-72	57-72	57-71	57-71	56-71	56-72	56-71	56-72
27	59-74	59-75	59-75	59-75	59-75	59-75	59-74	59-74	59-74	59-75	59-75	59-75
28	61-77	61-78	61-78	61-78	61-78	61-78	61-77	61-78	61-77	61-78	61-78	61-78
29	63-80	63-80	63-80	63-80	63-80	63-80	63-80	63-80	63-80	63-80	63-80	63-80
30	66-83	66-83	66-83	66-83	66-83	66-83	66-83	66-83	66-83	66-83	66-83	66-83
31	69-86	69-86	69-86	69-86	69-86	69-86	69-85	69-86	69-86	69-86	69-86	69-86
32	70-88	70-89	70-88	70-89	70-89	70-89	70-88	70-88	70-88	70-88	70-88	70-89
33	74-91	74-91	74-91	74-91	74-91	75-92	74-90	74-91	74-91	74-91	74-91	74-91
34	74-93	74-94	74-94	76-94	76-94	76-94	74-93	74-93	74-93	74-94	74-93	76-94
35	78-96	78-96	78-96	79-96	79-97	79-97	78-95	78-96	78-96	79-96	79-96	79-96
36	80-99	80-99	80-99	80-99	80-99	80-99	80-98	80-98	80-98	80-99	80-99	80-99
37	83-101	83-101	83-101	83-102	83-102	83-102	83-101	83-101	83-101	83-101	83-101	83-102
38	84-104	84-104	84-104	84-104	84-104	84-105	84-103	84-104	84-104	84-104	84-104	84-104
39	87-106	87-106	87-106	88-107	88-107	88-107	87-106	87-106	87-106	87-106	87-106	88-107
40	89-108	90-108	90-108	90-109	90-109	90-109	89-108	89-108	89-108	90-108	90-108	90-109

41	92-110	92-110	92-111	92-111	93-111	93-111	92-110	92-110	92-110	92-110	92-110	93-111
42	94-114	94-114	94-115	94-115	94-115	94-115	94-112	94-112	94-113	94-113	94-113	94-113
43	97-116	97-116	97-117	97-117	97-118	98-118	96-117	97-117	97-117	97-117	97-118	97-118
44	99-119	99-119	99-120	99-120	99-120	99-120	99-119	99-119	99-120	99-119	99-120	99-120
45	102-121	102-121	102-122	102-122	102-122	103-122	101-122	102-122	102-122	102-122	102-122	102-122
46	102-124	102-124	104-124	104-124	104-124	104-124	102-124	102-124	102-124	104-124	102-124	104-124
47	107-130	107-130	107-130	107-130	107-130	108-130	106-130	106-129	107-130	107-130	107-130	107-130
48	108-132	108-132	108-132	108-132	108-132	108-132	108-132	108-132	108-132	108-132	108-132	108-132
49	113-135	113-134	113-135	113-135	113-135	113-135	111-134	111-134	111-135	111-134	111-135	112-135
50	114-137	114-137	115-137	114-137	115-137	115-137	112-136	112-136	112-137	112-137	112-137	112-137
51	120-139	119-139	120-139	120-139	120-139	120-139	119-139	119-138	119-139	119-139	120-139	120-139
52	122-142	122-141	122-142	122-142	122-142	122-142	122-141	122-141	122-142	122-141	122-142	122-142
53	124-144	124-144	124-144	124-144	125-144	125-144	123-144	123-143	124-144	124-144	125-144	125-144
54	128-147	128-146	128-147	128-147	126-147	126-147	128-146	128-146	128-147	128-146	128-147	128-147
55	131-149	131-149	131-149	131-149	132-150	132-150	131-148	130-148	131-149	131-149	131-149	131-149
56	132-151	132-151	132-152	132-151	134-152	132-152	132-151	132-150	132-151	132-151	132-152	132-151
57	135-154	135-153	136-154	135-154	136-155	136-154	135-153	134-153	135-154	135-153	136-154	135-154
58	138-156	137-156	138-157	138-156	139-157	138-157	137-155	137-155	138-156	137-156	138-156	138-156
59	140-158	140-158	141-159	140-158	141-159	141-159	139-158	139-157	140-158	140-158	140-159	140-159
60	142-161	142-160	142-161	142-161	142-161	142-161	142-160	142-160	142-161	142-160	142-161	142-161
61	145-163	145-163	146-163	145-163	146-163	146-163	145-162	144-162	145-163	145-163	145-163	145-163
62	146-165	146-165	146-165	146-165	146-165	146-165	146-165	146-164	146-165	146-165	146-165	146-165
63	150-167	150-167	151-167	150-167	151-167	151-167	150-167	149-167	150-167	150-167	150-167	150-167
64	152-169	150-169	152-169	152-169	152-169	152-169	150-169	150-169	150-169	150-169	152-169	152-169
65	155-171	155-171	156-171	156-171	157-171	156-171	155-171	154-171	155-171	155-171	156-171	155-171

66	158-173	158-173	158-173	158-173	158-173	158-173	158-173	157-173	158-173	158-173	158-173	158-173
67	161-175	161-175	162-175	161-175	163-175	162-175	160-175	160-175	161-175	161-175	161-175	161-175
68	164-177	163-177	164-177	164-177	164-177	164-177	163-177	163-177	164-177	163-177	164-177	164-177
69	168-179	167-179	168-179	168-179	169-179	168-179	166-179	166-179	167-179	166-179	167-179	167-179
70	170-180	170-181	170-181	170-181	170-181	170-181	170-181	169-180	170-181	170-181	170-181	170-181
71	175-181	173-182	175-182	175-182	175-183	175-183	173-182	172-182	173-183	173-183	174-184	174-184
72	176-181	176-183	176-182	176-182	176-184	176-184	176-183	176-183	176-185	176-184	176-187	176-187
73	181-181	181-183	181-181	181-181	181-184	181-184	181-184	181-184	181-185	180-185	181-187	181-187
74		182-183			182-184	182-184	182-184	182-184	182-185	182-185	182-187	182-187
75									185-185	185-185	185-187	185-187

Z- and A-ranges of FPs from spontaneous fission of ^{242,244}Cm, and ^{252}Cf in JEFF-3.1.1.

Z	**A ranges**			**Z**	**A ranges**			**Z**	**A ranges**			**Z**	**A ranges**		
	96-Cm-242	**96-Cm-244**	**98-Cf-252**		**96-Cm-242**	**96-Cm-244**	**98-Cf-252**		**96-Cm-242**	**96-Cm-244**	**98-Cf-252**		**96-Cm-242**	**96-Cm-244**	**98-Cf-252**
1	1-3	1-3	1-3	31	69-85	69-85	69-86	50	112-136	112-137	112-137	69	166-178	167-179	167-179
2	3-4	3-4	3-8	32	70-87	70-88	70-88	51	119-138	120-139	118-139	70	169-179	170-181	170-181
3			6-8	33	73-90	74-91	75-91	52	121-141	122-142	125-142	71	173-181	174-183	174-184
23		57-59		34	74-93	74-93	76-94	53	123-143	124-144	127-144	72	176-181	176-184	176-187
24	58-63	57-64	59-64	35	78-95	78-96	79-96	54	127-145	128-146	130-147	73	181-181	181-184	180-189
25	58-67	57-68	59-68	36	80-98	80-98	80-99	55	130-148	131-149	132-150	74		182-184	182-189
26	58-70	57-71	59-71	37	82-100	83-101	83-102	56	130-150	132-151	134-152	75			185-189
27	59-73	59-74	59-75	38	84-103	84-104	84-104	57	134-152	135-154	136-155	76			188-189
28	61-77	61-77	61-78	39	87-105	87-106	88-107	58	136-155	137-156	138-157				
29	63-79	63-80	63-80	40	89-108	90-108	90-109	59	139-157	140-158	141-159				
30	66-82	66-83	66-83	41	91-110	92-111	93-111	60	141-159	142-161	142-161				

				42	94-112	94-113	94-114	61	144-162	145-163	146-163				
				43	96-116	97-117	97-117	62	146-164	146-165	146-165				
				44	99-118	99-119	99-120	63	149-166	150-167	151-167				
				45	101-121	102-122	102-120	64	150-168	150-169	152-169				
				46	102-123	102-124	104-124	65	154-170	155-171	156-171				
				47	106-128	107-130	107-130	66	157-172	158-173	158-173				
				48	108-131	108-132	108-132	67	160-174	161-175	162-175				
				49	111-133	111-134	112-135	68	163-176	164-177	164-177				

APPENDIX 4: Z- and A- ranges of FPs from n-induced of ^{235,238}U,^{239}Pu updated in CENDL-1998

Z	**A ranges**							
	92-U-235	**92-U-235**	**92-U-235**	**92-U-238**	**92-U-238**	**94-Pu-239**	**94-Pu-239**	**94-Pu-239**
	0.0253	**500000**	**1.40E+07**	**500000**	**1.40E+07**	**0.0253**	**500000**	**1.40E+07**
22				66-66	66-66			
23	66-68	66-68	66-68	66-69	66-69	66-67	66-67	66-67
24	66-70	66-70	66-70	66-71	66-71	66-70	66-70	66-70
25	66-73	66-73	66-73	66-74	66-74	66-72	66-72	66-72
26	66-76	66-76	66-76	66-77	66-77	66-76	66-76	66-76
27	66-78	66-78	66-78	66-79	66-79	66-78	66-78	66-78
28	66-82	66-82	66-82	66-82	66-82	66-82	66-82	66-82
29	66-83	66-83	66-83	66-84	66-84	66-82	66-83	66-83
30	66-86	66-86	66-86	66-87	66-87	66-86	66-86	66-86
31	66-88	66-88	66-88	66-89	66-89	66-87	66-87	66-87
32	66-91	66-91	66-91	66-92	66-92	66-90	66-90	66-90
33	69-93	69-93	69-93	69-94	69-94	69-92	69-92	69-92
34	72-96	72-96	72-96	72-97	72-97	72-96	72-96	72-96
35	75-98	75-98	75-98	75-100	75-100	75-97	75-97	75-97
36	77-101	77-101	77-101	77-102	77-102	77-100	77-100	77-100
37	79-103	79-104	79-103	79-105	79-105	79-103	79-103	79-103
38	83-108	83-108	83-108	83-109	83-109	83-105	83-105	83-105
39	85-110	85-110	85-110	85-111	85-111	85-108	85-108	85-108
40	87-112	87-112	87-112	87-114	87-114	87-112	87-112	87-112
41	89-115	89-115	89-115	89-116	89-116	89-114	89-114	89-114

42	90-117	90-117	90-117	90-118	90-118	90-116	90-116	90-116
43	93-120	93-120	93-120	93-121	93-121	93-119	93-119	93-119
44	95-124	95-124	95-124	95-124	95-124	95-124	95-124	95-124
45	99-125	99-125	99-125	99-127	99-127	99-124	99-124	99-124
46	99-130	99-130	99-130	99-131	99-131	99-130	99-130	99-130
47	103-131	103-132	103-131	103-133	103-133	103-131	103-131	103-131
48	105-136	105-136	105-136	105-136	105-136	105-136	105-136	105-136
49	107-137	107-137	107-137	107-138	107-138	107-136	107-136	107-136
50	111-140	111-140	111-140	111-141	111-141	111-138	111-138	111-138
51	113-142	113-142	113-142	113-143	113-143	113-141	113-141	113-141
52	115-145	115-145	115-145	115-146	115-146	115-144	115-144	115-144
53	121-147	121-147	121-147	121-148	121-148	121-146	121-146	121-146
54	124-150	124-150	124-150	124-151	124-151	124-150	124-150	124-150
55	127-152	127-152	127-152	127-153	127-153	127-151	127-151	127-151
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57	133-157	133-157	133-157	133-159	133-159	133-156	133-156	133-156
58	135-160	135-160	135-160	135-161	135-161	135-160	135-160	135-160
59	139-162	139-162	139-162	139-164	139-164	139-162	139-162	139-162
60	140-164	140-164	140-164	140-167	140-167	140-164	140-164	140-164
61	141-167	141-167	141-167	141-169	141-169	141-167	141-167	141-167
62	143-171	143-171	143-171	143-172	143-172	143-170	143-170	143-170
63	147-170	147-171	147-171	147-172	147-172	147-171	147-171	147-171
64	147-172	147-172	147-172	147-172	147-172	147-172	147-172	147-172
65	151-172	151-172	151-172	151-172	151-172	151-172	151-172	151-172
66	155-172	155-172	155-172	155-172	155-172	155-172	155-172	155-172

67	159-172	159-172	159-172	159-172	159-172	159-172	159-172	159-172
68	161-172	161-172	161-172	161-172	161-172	161-172	161-172	161-172
69	165-172	165-172	165-172	165-172	165-172	165-172	165-172	165-172
70	166-172	166-172	166-172	166-172	166-172	166-172	166-172	166-172
71	169-172	169-172	169-172	169-172	169-172	169-172	169-172	169-172
72	171-172	171-172	171-172	171-172	171-172	171-172	171-172	171-172

Z- and A- ranges of FPs from n-induced of ^{232}Th, ^{235,238}U, ^{239,241}Pu in CENDL-1987

Z	**A ranges**									
	90-Th-232	**92-U-233**	**92-U-235**	**92-U-235**	**92-U-235**	**92-U-238**	**92-U-238**	**94-Pu-239**	**94-Pu-239**	**94-Pu-241**
	500000	**0.0253**	**0.0253**	**500000**	**1.4E+07**	**500000**	**1.4E+07**	**0.0253**	**500000**	**0.0253**
24	66-70	66-70	66-70	66-70	66-70	66-70	66-70	66-70	66-70	66-70
25	66-71	66-71	66-71	66-71	66-71	66-71	66-71	66-71	66-71	66-71
26	66-76	66-76	66-76	66-76	66-76	66-76	66-76	66-76	66-76	66-76
27	66-76	66-76	66-76	66-76	66-76	66-76	66-76	66-76	66-76	66-76
28	66-82	66-82	66-82	66-82	66-82	66-82	66-82	66-82	66-82	66-82
29	66-82	66-82	66-82	66-82	66-82	66-82	66-82	66-82	66-82	66-82
30	66-86	66-86	66-86	66-86	66-86	66-86	66-86	66-86	66-86	66-86
31	66-86	66-86	66-86	66-86	66-86	66-86	66-86	66-86	66-86	66-86
32	66-88	66-88	66-88	66-88	66-88	66-88	66-88	66-88	66-88	66-88
33	69-89	69-89	69-89	69-89	69-89	69-89	69-89	69-89	69-89	69-89
34	72-96	72-96	72-96	72-96	72-96	72-96	72-96	72-96	72-96	72-96
35	75-96	75-96	75-96	75-96	75-96	75-96	75-96	75-96	75-96	75-96

36	77-100	77-100	77-100	77-100	77-100	77-100	77-100	77-100	77-100	77-100
37	79-103	79-103	79-103	79-103	79-103	79-103	79-103	79-103	79-103	79-103
38	83-105	83-105	83-105	83-105	83-105	83-105	83-105	83-105	83-105	83-105
39	85-107	85-107	85-107	85-107	85-107	85-107	85-107	85-107	85-107	85-107
40	87-110	87-110	87-110	87-110	87-110	87-110	87-110	87-110	87-110	87-110
41	89-112	89-112	89-112	89-112	89-112	89-112	89-112	89-112	89-112	89-112
42	90-116	90-116	90-116	90-116	90-116	90-116	90-116	90-116	90-116	90-116
43	93-118	93-118	93-118	93-118	93-118	93-118	93-118	93-118	93-118	93-118
44	95-124	95-124	95-124	95-124	95-124	95-124	95-124	95-124	95-124	95-124
45	99-124	99-124	99-124	99-124	99-124	99-124	99-124	99-124	99-124	99-124
46	99-130	99-130	99-130	99-130	99-130	99-130	99-130	99-130	99-130	99-130
47	103-130	103-130	103-130	103-130	103-130	103-130	103-130	103-130	103-130	103-130
48	105-136	105-136	105-136	105-136	105-136	105-136	105-136	105-136	105-136	105-136
49	107-136	107-136	107-136	107-136	107-136	107-136	107-136	107-136	107-136	107-136
50	111-138	111-138	111-138	111-138	111-138	111-138	111-138	111-138	111-138	111-138
51	113-139	113-139	113-139	113-139	113-139	113-139	113-139	113-139	113-139	113-139
52	115-142	115-142	115-142	115-142	115-142	115-142	115-142	115-142	115-142	115-142
53	121-142	121-142	121-142	121-142	121-142	121-142	121-142	121-142	121-142	121-142
54	125-150	125-150	125-150	125-150	125-150	125-150	125-150	125-150	125-150	125-150
55	127-150	127-150	127-150	127-150	127-150	127-150	127-150	127-150	127-150	127-150
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59	139-160	139-160	139-160	139-160	139-160	139-160	139-160	139-160	139-160	139-160
60	140-164	140-164	140-164	140-164	140-164	140-164	140-164	140-164	140-164	140-164

61	141-165	141-165	141-165	141-165	141-165	141-165	141-165	141-165	141-165	141-165
62	143-170	143-170	143-170	143-170	143-170	143-170	143-170	143-170	143-170	143-170
63	147-170	147-170	147-170	147-170	147-170	147-170	147-170	147-170	147-170	147-170
64	147-172	147-172	147-172	147-172	147-172	147-172	147-172	147-172	147-172	147-172
65	151-172	151-172	151-172	151-172	151-172	151-172	151-172	151-172	151-172	151-172
66	155-172	155-172	155-172	155-172	155-172	155-172	155-172	155-172	155-172	155-172
67	159-172	159-172	159-172	159-172	159-172	159-172	159-172	159-172	159-172	159-172
68	161-172	161-172	161-172	161-172	161-172	161-172	161-172	161-172	161-172	161-172
69	165-172	165-172	165-172	165-172	165-172	165-172	165-172	165-172	165-172	165-172
70	166-172	166-172	166-172	166-172	166-172	166-172	166-172	166-172	166-172	166-172

ANNEX 1

Technical Meeting on
"Fission Yields: current status and perspective in measurements, theory and evaluations"
IAEA, Vienna, Austria
23-26 May 2016

Meeting Room VIC C0225 A

ADOPTED AGENDA

Monday, 23 May

08:30 – 09:30 **Registration (IAEA Registration Desk, Gate 1)**

09:30 – 10:00 **Opening Session**

Welcoming address (Arjan Koning, NDS Section Head)
Goals of meeting (P. (Vivian) Dimitriou, Scientific Secretary)
Administrative matters
Election of Chairman and Rapporteur
Adoption of the Agenda

10:00 – 18:00 **Presentations by participants (40 min each)**

1) *Dynamical approach for low-energy nuclear fission by Langevin equation and results from the surrogate reaction*, S. Chiba, Tokyo Inst. Of Technology
2) *General description of fission observables: the GEF code*, K-H. Schmidt, CENBG
3) *Validating nuclear fission codes*, A. Mattera, Uppsala Univ.

--------------------------*Lunch Break*-----------------------------

4) *Fission Yield Activities at the CEA-Cadarache (France)*, O. Serot, CEA-Cadarache
5) *A Bayesian Monte Carlo method for fission yield covariance information*, D. Rochman, PSI
6) *Fission Product Yields and Related Covariance Data*, M. Pigni, ORNL
7) *UKAEA work in fission yields and decay data*, M. Fleming, UKAEA
8) *Fission Yields Relevant to the Calculation of Antineutrino Spectra*, A. Sonzogni, BNL
9) *Semi-empirical study on the yield mass distribution for the n+^{238}U fission*, N-C. Shu, CNDC

12:00 – 13:30 Lunch break

Tuesday, 24 May

09:00 – 18:00 **Presentations by participants (cont'd - 40 min each)**

10) *Energy Dependence of Fission Product Yields from ^{235}U, ^{238}U and ^{239}Pu for Incident Energies between 0.5 and 15 MeV*, W. Tornow, Duke Univ.-TUNL

11) *Neutron-induced fission studies at IGISOL – current status of measurements of independent fission yields*, M. Lantz, Uppsala Univ.
12) *Studies on Fission with Aladin*, J. Taieb, CEA-Arpajon
13) *Cumulative yields of Br, Kr, Ru, and I isotopes from fission of ^{233,235,238}U and ^{239}Pu by neutrons in the energy range from thermal to 5 MeV*, V. Piksaikin, IPPE

--------------------------*Lunch Break*-----------------------------

14) *Fission Research by Uppsala and IRMM*, A. Al-Adili, Uppsala Univ.
15) *Correlations of fission yields with prompt neutron emission,* F.-J. Hambsch, EC-JRC Dir. G.2 Standards for Nuclear Safety, Security and Safeguards
16) *Measurements and calculations of fission product yields at LANL*, F. Tovesson, LANL
17) *The fission yields measurements activities in China*, S. Liu, CNDC
18) *Decay Data Needs for Improvement of Fission Yields & Capabilities at ANL*, F. Kondev, ANL
19) *Fission Product Yields needs for beta-delayed neutron applications,* P. Dimitriou, IAEA

12:00 – 13:30 Lunch break

Wednesday, 25 May

09:00 – 18:00 **Round Table Discussion: tentative**

- Short-term/Long-term needs for:
    - Measurements – repeat measurements to provide experimental covariances
    - Theory, Codes
    - Evaluation
    - Covariances – necessity of evaluated covariances
- Validation calculations: decay heat, anti-neutrino, beta-delayed neutrons: test impact of FY and covariances
- Emphasis on burn-up indicators
- How to proceed? (WPEC/SG-37 status; future project, coordination etc)

12:00 – 13:30 Lunch break

Thursday, 26 May

09:00 – 13:00 **Round Table cont'd - Drafting of the Summary Report**

Closing of the Meeting

ANNEX 2

Technical Meeting on

“Fission Yields: current status and perspective in measurements, theory and evaluations”

IAEA, Vienna, Austria
23-26 May 2016

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ANNEX 3

Technical Meeting on

"Fission Yields: current status and perspective in measurements, theory and evaluations"

IAEA, Vienna, Austria
23-26 May 2016

LINKS TO ONLINE PRESENTATIONS

#	Author	Title	Link
1	D. Rochman	Bayesian Monte Carlo method for fission yield covariances	PDF
2	S. Chiba	Dynamical approach for low energy nuclear fission by Langevin equation and results from the surrogate reaction	PDF
3	M. Fleming	UK Atomic Energy Authority work in fission yields and decay data	PDF
4	A. Mattera	Validating Nuclear Fission Codes:a comparison between GEF as standalone code and GEF+TALYS	PDF
5	M.T. Pigni	Fission Product Yields and Related Covariance Data	PDF
6	K.-H. Schmidt	General description of fission observables: The GEF code	PDF
7	N.-C. Shu	Study on the mass distribution and yield energy-dependence for n+U and Pu fissions with semi-empirical model	PDF
8	A.A. Sonzogni	Fission Yields Relevant to the Calculation of Antineutrino Spectra	PDF
9	A. Al-Adili	Fission Research by Uppsala and IRMM	PDF
10	F. Kondev	Nuclear Structure & Decay Data Needs for Improvement of FY & Capabilities at ANL	PDF
11	S. Liu	The fission yield measurement activities in China	PDF
12	F.J. Hambsch	Correlations of fission yields with prompt neutron emission	PDF
13	M. Lantz	Neutron-induced fission studies at IGISOL - current status of measurements of independent fission yields	PDF
14	V.M. Piksaikin	Cumulative yields of Bromine, Krypton, Rubidium and Iodine isotopes from fission of ^{233}U, ^{235}U, ^{238}U and ^{239}Pu by neutrons in the energy range from thermal to 5 MeV	PDF
15	O. Serot	Fission Yield Activities carried out at CEA-Cadarache (France)	PDF
16	F. Tovesson	Measurements and calculations of fission product yields LANL	PDF
17	A.A. Sonzogni	Fission Yields Relevant to the Calculation of Antineutrino Spectra	PDF
18	W. Tornow	Energy Dependence of Fission Product Yields from ^{235}U, ^{238}U and ^{239}Pu for Incident Neutron Energies between 0.5 and 15 MeV	PDF

ANNEX 4

Technical Meeting on
“Fission Yields: current status and perspective in measurements, theory and evaluations”

IAEA, Vienna, Austria
23-26 May 2016

PHOTO

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