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CIELO goals and timeline

M.B. Chadwick

Los Alamos National Laboratory, Los Alamos, NM 87544
mbchadwick@lanl.gov

I shall describe some of the major goals of the CIELO project and identify a timeline for completion of various subtasks. Given the various efforts going on, but the interconnected nature of many of these efforts (for example, criticality testing depends on the inter-related performance of H, O, Fe, U, Pu isotopes) much coordination will be needed. I will identify some of the key tie-points between the various efforts on different isotopes.

Additionally, I shall give a summary of some performance aspects of the CIELO project that we want to see satisfied, for example, related to criticality integral testing.

Status and plans for ^{1}H and ^{16}O evaluations by R-matrix analyses of the *NN* and ^{17}O systems

G.M. Hale, M.W. Paris

T-2, MS B214, Los Alamos National Laboratory, Los Alamos NM 87545, USA
ghale@lanl.gov

A LANL R-matrix analysis of the *NN* system at nucleon energies up to 30 MeV was used to provide the *n-p* (1H) standard cross sections below 20 MeV for the IAEA/ENDF evaluation in 2005. This analysis included data for *p+p* and *n+p* scattering, as well as for *n+p* capture and γ+*d* photo-disintegration. A very good fit (with a reduced chi-squared of 0.83) was obtained to all the experimental data (more than 5000 points) included, with small uncertainties at low energies. A new analysis of the *NN* system is planned for the coming year, extending the energy range to at least 200 MeV. This will be a major undertaking, involving the addition of many new data sets, some of which are in the energy range of the existing analysis. Since the R-matrix parameterization and kinematics used in the EDA code are relativistic, we do not anticipate any problems in principle with extending the range of the analysis to such high energies.

In 2010, a new R-matrix analysis of reactions in the ^{17}O system was performed at energies below 7 MeV, which was intended to update the ^{16}O evaluation for ENDF/B-VII.1. A rather good fit was obtained to most of the nearly 6000 data points included in the analysis. However, since the scale of the ^{16}O(n,α)^{13}C cross section obtained from the analysis disagreed by some 30% with that of recent measurements, it was decided to withhold the new evaluation and return to the previous version (VII.0), despite the fact that the newer evaluation appeared to perform equally well in integral data testing. We plan to continue the analysis started in 2010 with new (n,α) data and with new and/or corrected low-energy n+^{16}O scattering data as determined within the CIELO working group. Special attention will be devoted to understanding how the scale of the (n,α) cross section is determined by the unitary constraints of the R-matrix fitting process. A new prescription for determining the uncertainties of R-matrix parameters will affect the cross-section uncertainties obtained from future analysis work on both systems.

Why the uncertainties from least-squares R-matrix analyses are so small

G.M. Hale

T-2, MS B214, Los Alamos National Laboratory, Los Alamos NM 87545, USA
ghale@lanl.gov

A long-standing puzzle in nuclear data evaluation, especially for the standard cross sections, is that the parameter uncertainties, and thus the propagated cross-section uncertainties, from R-matrix analysis programs such as the Los Alamos Energy Dependent Analysis (EDA) code, have been unreasonably small. This has necessitated scaling up the output uncertainties from the code by large empirical factors. The origin of these factors is now finally understood to result from the fact that the often-used "delta chi-squared equals one" prescription to determine parameter uncertainties is in general not correct. A derivation of the correct prescription will be given, and its implication for previous and future cross-section uncertainties from EDA will be discussed. This correction applies equally well, of course, to any least-squares fitting code that uses the unit delta chi-squared criterion to determine its parameter uncertainties. If time permits, I will describe the rather indirect path by which this new result was reached, because it may have implications for other fitting programs, such as the NonlinearModelFit module in *Mathematica*.

The status of data for ^{16}O and the program of work for CIELO

A.J.M. Plompen

European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, Retieseweg 111, 2440 Geel, Belgium
arjan.plompen@ec.europa.eu

The new CIELO initiative offers an excellent opportunity for a new approach to the evaluation of important nuclides for applications. For ^{16}O a combined effort was started through a more or less informal discussion through the CIELO channel, including on the one hand theoretical tools such as the R-matrix, and on the other hand expert knowledge on nuclear data benchmarks, microscopic data and integral experiments. The present contribution aims at developing a common understanding of the goals and the methods of work for n+^{16}O.
The second part of the contribution is devoted to an overview of the status of data for the total cross section, the $^{16}O(n,\alpha)^{13}C$ reaction and its time-reversed partner the $^{13}C(\alpha,n)^{16}O$ reaction. The aim is to arrive at a common understanding of the value and limitations of the different data sets and of the role they should play in a new evaluation for n+^{16}O.

Low energy scattering and total cross section data

S. Kopecky, A.J.M. Plompen

European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, Retieseweg 111, 2440 Geel, Belgium
stefan.kopecky@ec.europa.eu

As the resources for neutron cross section measurements are limited, new experiments should be designed to precisely address weaknesses in the existing experimental data sets.
To reach this goal it is essential to evaluate all existing data, such as cross section data and coherent scattering length information derived by neutron optical measurement methods.
In this contribution we will compare various measurement methods and discuss their advantages and possible limitations. As the broadest range of experimental results is available for nuclei with a large level spacing, light nuclei (hydrogen, deuterium, oxygen, etc.) or double magic nuclei (^{208}Pb), the discussion will focus on these nuclei.

Estimation of neutron cross-sections for ^{16}O up to 5.2 MeV through R-matrix analysis

S. Kunieda[1), T. Kawano[2), M. Paris[2), G. Hale[2), K. Shibata[1) and T. Fukahori[1)

1) Japan Atomic Energy Agency, Tokai-mura Naka-gun, Ibaraki 319-1195, Japan
2) Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA
kunieda.satoshi@jaea.go.jp

There still remain differences among measured data, which makes the evaluated cross-sections uncertain, and which consequently affects some integral calculation. ^{16}O is one of the important nuclei in the nuclear application, but has those kinds of issues as follows.

1. (n,α) cross sections
There are systematic discrepancies among experimental data including those from the inverse reaction. The differences reach up to about 30%, which makes the evaluated cross sections still uncertain and affects, e.g., burn-up characteristics in the reactor.

2. Total cross section in lower energy range (E_n < 10 keV)
The present evaluation is larger than very accurate experimental data below 10 keV by ~3%, which adversely affect some criticality calculations.

3. Covariance/Uncertainty
There are increasing demands for giving uncertainties in evaluated cross section to estimate the margin of integral calculations. The covariance data are available in ENDF/B-VII.1 and JENDL-4.0 for ^{16}O cross sections. However they are estimated in a simple way inferred only from experimental information.

Purpose of this study is to solve those issues as they are common concerns in the world. The R-matrix analysis is carried out for ^{17}O system to estimate both the total and (n,α) cross sections. Measured data we use are 5 sets of neutron total cross section for ^{16}O and the recent data of $^{13}C(\alpha,n)^{16}O$ reaction cross sections. We present the estimated cross sections and their covariance data which are "physically" constrained by the R-matrix theory. Some issues in the analysis are also discussed.

Status and future plans of $^{16}O(n,\alpha)^{13}C$ reaction cross-section investigation at IPPE

V. Khryachkov, I. Bondarenko, V. Pronyaev, N. Semenova, A. Sergachev, T. Khromyleva

Institute for Physics and Power Engineering, 1, Bondarenko sq., Obninsk, Russia
hva@ippe.ru

In the IPPE the technique based on double ionization chamber and a digital signal processing that allows measuring of the differential cross-sections of the reaction (n,α) for gaseous targets was built up. This method allows us to create a gaseous target with known number of nuclei for investigating element and can effectively suppress the background of various natures. The method of neutron flux monitoring in which the dead time of the monitor channel and the main registration channel are identical was used. At the accelerator EG -1 were performed measurements of $^{16}O(n,\alpha)^{13}C$ reaction cross-sections. For neutron generation the (d,d) reaction on a solid deuterium target was used. The data for the $^{16}O(n,\alpha)^{13}C$ reaction cross-section in the neutron energy range 4.9-7.07 MeV was obtained. It is shown that a direct comparison between experiment and estimations cannot be done due to the fact that the width of the neutron spectrum is comparable to the width of the structures observed in cross-section. We propose a method of convolution of evaluated data with the neutron spectrum that allows us to compare them with each other. For low energy neutrons it was observed a satisfactory agreement between the obtained experimental data and estimations. For high neutron energies the experimental data are significantly higher than estimations. New measurements of the reaction $^{16}O(n,\alpha)^{13}C$ using a different methodology and a wider neutron energy range are planned in IPPE.

Neutron cross sections for oxygen-16

C. Lubitz, P. Romano, T. Trumbull, D. Barry

Knolls Atomic Power Laboratory - Bechtel Marine Propulsion Corporation, P.O. Box 1072, MS 112, Schenectady, New York, U.S.A.
clubitz@nycap.rr.com

The full paper will discuss a possible normalization problem with some experimental total cross sections for oxygen-16 which were subsequently included in most current evaluations. The basis is a hypothesized 3% over-estimate of the *zero-kelvin* thermal scattering cross section, which can propagate through an entire data set into the MeV region. The cause is believed to be that the elastic scattering cross section, which is normally flat at zero-Kelvin below about 2 eV, exhibits a 1/v rise at non-zero temperatures. At room temperature, the increase in a constant cross section due to Doppler broadening at neutron energy E=kT can be represented as 1 + 1/(2A) where A is the atomic weight ratio. For O-16 this factor is 1.0315, an increase of 3.15%. Apparently, some experimentalists may have not accounted for this and erroneously normalized their total cross section measurements to the room-temperature value

The proposed remedy is to renormalize selected experimental data files to five high-precision measurements which do not exhibit the same normalization error. When that is done to the major evaluated data files, the degree of consistency between hitherto divergent datasets is quite high. A new test evaluation was produced by adjusting the parameters in an ORNL evaluation by Sayers *et al.* When the elastic scattering cross section is reduced by 3%, the total cross section is within a few tenths of a percent of the five high-precision values. The ORNL evaluation was chosen because (1) it was uniformly 3% above the high-precision points; (2) its angular distributions agreed with KAPL's work in ENDF/B-VI.8-VII.1; and (3) it has R-Matrix Limited resonance parameters, which are easily checked against other work.

Critical benchmark results for a modified oxygen-16 evaluation

P. Romano, C. Lubitz, T. Trumbull

Knolls Atomic Power Laboratory – Bechtel Marine Propulsion Corporation, P.O. Box 1072, Schenectady, NY 12301-1072, United States
Paul.Romano.Contractor@unnpp.gov

In this paper, the effect of a reduction in the elastic scattering cross section for oxygen-16 on critical benchmarks is quantified and discussed. This reduction is based on a companion paper where it is hypothesized that current evaluations for oxygen-16 systematically overestimate elastic scattering by about 3% due to a normalization error in various experimental data. Selected critical benchmarks from the leu-comp-therm (LCT) and heu-sol-therm (HST) series of the International Handbook of Evaluated Criticality Safety Benchmark Experiments were calculated using the MC21 Monte Carlo code. The LCT and HST benchmarks were chosen for their sensitivity to the oxygen cross sections and because they have been analyzed in previous studies that highlighted problems with oxygen-16 cross sections. In the absence of any other changes, the 3% reduction in elastic scattering in oxygen-16 resulted in a 320 pcm decrease in k-effective on average for the benchmarks tested. The HST series had a slightly greater sensitivity on average than the LCT series. In particular, the HST-004 benchmark, which contains heavy water, saw an average reduction in k-effective of 650 pcm. The results suggest that correlated changes to the n,α cross section and angular distributions for scattering may be necessary to compensate for the decrease in calculated benchmark k-effective values.

Resonance Evaluations for ^{56}Fe and ^{16}O for the CIELO Project

L. Leal[1)], R. Sayer[1)], A. Kahler[2)], R. MacFarlane[2)], T. Ivanova[3)]

1) Oak Ridge National Laboratory, P. O. Box 2008, Oak Ridge, TN, USA
2) Los Alamos National Laboratory, P. O. Box 1663, Los Alamos, NM, USA
3) Institut de Radioprotection et de Sureté Nucléaire, Fontenay-aux-Roses, Cedex, France
leallc@ornl.gov

The resonance regions for ^{56}Fe and ^{16}O were investigated to address issues regarding calculations of benchmark systems containing these materials. The purpose of this work is to illustrate the status of the resonance evaluations for these isotopes and present, when possible, results of critical benchmark calculations. The new features in the evaluations are:

a) Extension of the resonance energy region into the MeV region;
b) Using the Reich-Moore limited (RML) formalism;
c) Including charged-particle and inelastic channels in the resonance evaluation;
d) Angular representation of the elastic, inelastic and charge particle cross-section data.

The angular representation through resonance parameters may be regarded as an option to replace the existing approach used in the Evaluated Nuclear Data Files (ENDF) that are based on Legendre moments given at a limited number of energies.

Fe-isotopes evaluation within the CIELO project

M. Herman[1),]*A. Trkov*[2)]

1) National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY
2) Jozef Stefan Institute, Ljubljana, Slovenia
mwherman@bnl.gov

The plans for a new set of nuclear data evaluations for the isotopes of iron are outlined. They include a review of existing evaluations, comparison with the available experimental data and discussion of the concerns raised by the applications community. The new evaluations will take advantage of the expanded resources that will become available within the CIELO project. New evaluation will benefit from recent or revised experimental data and more detailed analysis of the uncertainties and correlations among different experiments. The focus will be on ^{56}Fe due to its dominant abundance. Modelling of neutron-induced reactions will exploit recent advances such as: soft-rotor optical model potential, Engelbrecht-Weidenmueller transformation, quantum mechanical treatment of the pre-equilibrium emission (MSD+MSC), and shell-model based microscopic level densities. Particular attention will be dedicated to the cross section fluctuations that in the total cross section persist up to about 10 MeV and to elastic and inelastic angular distributions. The possibility of extending the resonance region beyond the first inelastic threshold will be investigated, including an attempt to derive elastic angular distributions from the resonances. The full covariance matrix will be provided for the resonance region and for all major cross sections in the fast neutron energy range.
In any modern evaluation, the analysis of suitable benchmarks is an integral part of the evaluation process. Since iron is an important structural and shielding material in nuclear applications, a large number of potentially useful integral benchmarks for data validation were identified. In the database of the Radiation shielding and dosimetry experiments database (SINBAD) the recently re-evaluated EURACOS-Fe and ASPIS experiments are not of benchmark quality. However, in the same database, there are several other shielding experiments that include iron, such as the Karlsruhe Iron Sphere, Wuerenlingen Iron Benchmark (PROTEUS), ORNL TSF Iron Broomstick, ORNL TSF Stainless Steel Broomstick, ORNL Neutron Transport Through Iron and SS, University of Illinois Iron Sphere (Cf-252, D-T), University of Tokyo-YAYOI Iron Slab, NAÏADE 1 Iron Benchmark (60cm), Osaka Iron Sphere (OKTAVIAN), FNG-SS Shield, TUD Iron Slab Experiment, IPPE Iron Shells, ORNL 14-MeV Neutron SS/Borated Poly Slab, and many others with iron as a secondary material and need to be checked for applicability.
In addition to the shielding reaction rate and spectra benchmarks, criticality safety benchmarks from the ICSBEP database can provide complementary information on the iron cross sections due to different sensitivity profiles resulting from different neutron spectra, geometrical configurations, amounts of iron present, etc. A lot of benchmarks use iron or steel as a reflector material, steel as cladding, iron as neutron absorbing material, separation material, or shielding material.
Experiments were performed at RPI in which the neutron yields as a function of energy at a number of distinct angles were measured by the time-of-flight technique for a target in a fast broad-spectrum neutron beam. Unfortunately the experimental data have not been released yet.

Review of nuclear data of major actinides and ^{56}Fe in JENDL-4.0

O. Iwamoto, N. Iwamoto

Nuclear Science Engineering Directorate, Japan Atomic Energy Agency,
Tokai-mura, Naka-gun, Ibaraki 319-1195, Japan
iwamoto.osamu@jaea.go.jp

JENDL-4.0 was released in 2010. Most of actinide data were revised from JENDL-3.3 especially at fast energy region using newly developed CCONE code. Fission cross sections of major actinides were determined with the least square method by SOK code taking account of available experimental data. In the resonance region around 1 keV for ^{235}U, capture cross sections was reduced to improve integral benchmark tests. The reduction was confirmed by an experiment of Jandel *et al.* at Los Alamos later. For ^{56}Fe, cross sections of inelastic scattering and angular distributions of elastic scattering were revised from JENDL-3.3. Evaluation methods and comparisons with experimental data and other evaluated data will be reported at the workshop.

Fast neutron induced reactions at the nELBE time-of-flight facility

A.R. Junghans[1)], R. Beyer, Z. Elekes, E. Grosse[1,2)], R. Hannaske[1,2)], T. Kögler[1,2)], R. Massarczyk[1,2)], R. Schwengner[1)], A. Wagner[1)]*

1) Helmholtz-Zentrum Dresden-Rossendorf, Postfach 510119, 01314 Dresden, Germany
2) Technische Universität Dresden, Institut für Kern- und Teilchenphysik, Dresden, Germany
A.Junghans@hzhdr.de

The compact neutron-time-of-flight facility nELBE at the superconducting electron accelerator ELBE of Helmholtz-Zentrum Dresden-Rossendorf has been upgraded. A new enlarged experimental hall with a flight path of up to 10 m and 3 m distance to all walls is available for experiments with a fast neutron beam. The neutron spectrum extends from some tens of keV to about 10 MeV [1]. As the electron bunch length is only a few ps the energy resolution in the MeV range is dominated by the timing resolution of the detectors. nELBE is intended to deliver cross section data of fast neutron nuclear interactions e.g. for the transmutation of nuclear waste and improvement of neutron physical simulations of innovative nuclear systems.

First measurements to characterize the neutron beam and to test the neutron inelastic scattering experiment will be reported. The inelastic scattering of ^{56}Fe was investigated with a double-time-of-flight experiment i.e. the scattered neutron and the de-excitation photon are measured in coincidence using a BaF_2 scintillator and plastic scintillator arrays. Three $LaBr_3$ (3”x3”) scintillators were used to measure the angular distribution of gamma-rays after inelastic scattering.

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Differential cross section measurements at the University of Kentucky – Adventures in analysis

J.R. Vanhoy[1), S.F. Hicks[2), B.R. Champine[3), B.P. Crider[4), E.A. Garza[1), S.L. Henderson[2), S.H. Liu[4), E.E. Peters[4), F.M. Prados-Estévez[4), M.T. McEllistrem[4), T.J. Ross[4), L.C. Sidwell[2), J.L. Steves[1), and S.W. Yates[4)

1) Department of Physics, U.S. Naval Academy, Annapolis, Maryland 21402 USA
2) Department of Physics, University of Dallas, Irving, Texas 75062 USA
3) Department of Physics & Nuclear Engineering, U.S. Military Academy, West Point, New York 10996 USA
4) Departments of Chemistry and Physics & Astronomy, University of Kentucky, Lexington, Kentucky 40506 USA

vanhoy@usna.edu

Elastic and inelastic neutron scattering cross sections are determined at the University of Kentucky Accelerator Laboratory (www.pa.uky.edu/accelerator/) using time-of-flight techniques at incident energies in the fast neutron region. Measurements have been completed for the ^{23}Na(n,n) and ^{23}Na(n,n'γ) reactions and similar measurements are in progress for ^{54}Fe. Commencing in the summer of 2014, measurements will address ^{56}Fe. An overview of the UKAL's facilities and instrumentation will be given, and our measurement and analysis procedures will be outlined. Of particular concern are the portions of the analysis which limit the accuracy of the measurements. We will take a brief look at detector efficiencies derived from the ^{3}H(p,n) cross section, attenuation and multiple scattering corrections, and γ-ray cross-section standardization.

BRC neutron evaluations of actinides with the TALYS code

P. Romain, H. Duarte, and B. Morillon

CEA, DAM, DIF, F-91297 Arpajon, France
pascal.romain@cea.fr

Over the last five years, new evaluations of plutonium and uranium have been performed at Bruyères-le-Châtel (BRC) from 1 keV up to 30 MeV. Only nuclear reactions models are used to build these evaluations. Total, shape elastic and direct inelastic cross sections are obtained from coupled channel calculations using a dispersive optical potential (BRC, [1,2,3]) devoted to actinides. All the other cross sections are calculated owing to the Hauser-Feshbach theory (TALYS code [4]) with a pre-equilibrium component when necessary. We take particular care over the fission channel. For uranium isotopes, a triple-humped barrier [3,5] is required in order to reproduce accurately the variations of the experimental fission cross sections. With increasing neutron incident energy, a lot of residual nuclei produced by nucleon emissions lead also to fission. All available experimental data assigned to the various fission mechanisms of the same nucleus are used to define its fission barrier parameters. As a result of this approach, we are now able to provide consistent evaluations for a large series of isotopes. Of course, our new evaluations are tested against integral data.

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Evaluation of neutron induced reactions on U-238 nucleus

R. Capote[1), M. Sin[2), A. Trkov[3), M.W. Herman[4), D. Bernard[5),
G. Noguere[5), A. Daskalakis[6), and Y. Danon[6)

1) International Atomic Energy Agency, NAPC-Nuclear Data Section, P.O.Box 100, Vienna A-1400, Austria
2) Nuclear Physics Department, University of Bucharest, P.O. Box MG-11, RO-2, 70709 Bucharest-Magurele, Romania
3) Jozef Stefan Institute, Jamova cesta 39, SI-1000 Ljubljana, Slovenia
4) National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973, USA
5) SPRC/LEPh, CEA - Cadarache, F-13108 Saint-Paul-Lez-Durance, France
6) Gaerttner LINAC Center, Rensselaer Polytechnic Institute, Troy, NY 12180, USA

r.capotenoy@iaea.org

Advanced modelling of neutron induced reactions on U-238 nucleus using the EMPIRE system is aimed at improving our knowledge of the neutron scattering leading to better nuclear data for nuclear power applications. Capture and fission channels in n + U-238 reaction are well constrained by available experimental data and IAEA neutron standard evaluations allowing to focus on the impact of elastic and inelastic scattering in evaluated cross sections. The reaction model includes - a new rotational-vibrational dispersive optical model potential couplings the low-lying collective bands of vibrational character observed in even-even actinides; - the Engelbrecht-Weidenmüller transformation allowing for inclusion of compound-direct interference effects enhanced by a dispersive treatment of the optical model potential; - and a multi-humped fission barrier with absorption in the secondary well described within the optical model for fission. Impact of the advanced modelling on inelastic scattering cross section and corresponding uncertainties is being assessed both by comparison with selected microscopic experimental data and integral criticality benchmarks including measured reaction rates (e.g. FLAPTOP, JEMIMA, BIGTEN, MASURCA, PROFIL, and PROFIL-2). Additionally, neutron scattering yields on U-238 measured accurately at RPI by the time-of-flight technique at 29, 60, 112 and 153 degrees have been used as a further constraint on the incident energy dependence of elastic and inelastically scattered neutrons. Benchmark calculations provided feedback to improve the reaction modelling. Improvement of scattering cross sections in existing libraries is discussed.

Status of Pu-239 evaluations

T. Kawano, P. Talou

Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA
kawano@lanl.gov

This paper summarizes the current status of nuclear data evaluations for n+Pu-239, as well as U-235 and U-238, since a common nuclear reaction modelling to evaluate the nuclear data is often employed. The nuclear data include fission, capture, scattering cross sections, as well as the prompt fission neutron energy spectrum, which have large sensitivities to the criticality benchmark testing. The evaluated nuclear data files currently available for Pu-239 are compared, and the source of differences in the cross sections is discussed. Some open questions on the statistical model calculations for deformed systems are also given. For the prompt fission neutron spectrum (PFNS) evaluations at Los Alamos, we have been revisiting the PFNS of the neutron-induced fission reaction on Pu-239 for incident neutron energies from thermal up to 20 MeV. Significant efforts have been made in estimating realistic covariance matrices associated with the existing PFNS measurements, as well as to quantify uncertainties expected in the Chi-Nu experiment to be performed at LANSCE. In parallel, Monte Carlo Hauser-Feshbach simulations of the de-excitation of the primary fission fragments in the thermal neutron-induced fission reaction of Pu-239 have been performed and compared with the Los Alamos model predictions and experimental data. Our current status of the PFNS evaluation will be presented as well.

Status of evaluated data for neutron induced reactions on ^{238}U in the resonance region

P. Schillebeeckx[1)], B. Becker[1)], R. Capote[2)], S. Kopecky[1)], H.I. Kim[3)], M. Moxon[4)], V. Pronyaev[5)], and I. Sirakov[6)]

1) European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, Retieseweg 111, 2440 Geel, Belgium
2) International Atomic Energy Agency, NAPC/Nuclear Data Section, Vienna, Austria
3) Nuclear Data Centre, Korea Atomic Energy Research Institute, Daedeok-daero 989-111 Yuseng-gu, 305-353 Daejeon, Republic of Korea
4) Hyde Copse 3, Marcham, United Kingdom
5) Institute of Physics and Power Engineering, Obninsk, Russia
6) Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

peter.schillebeeckx@ec.europa.eu

Some nuclear data of interest for the CIELO project are the cross sections for neutron induced reactions on ^{238}U in the resonance region. In this contribution an overview of experimental data which are reported in the literature is given and independent evaluations for ^{238}U+n in the resonance region are compared. In addition, recent and on-going experiments at the time-of-flight facilities GELINA and n_TOF are discussed together with the status of a new evaluation.

The resolved and average resonance parameters for ^{238}U+n in the main libraries originate from the work of Derrien *et al.* (Conf. Nucl. Data for Sci. and Tech., Santa Fe, 2004). These parameters and resulting cross sections are verified (and adjusted) by comparing experimental and theoretical observables, i.e. transmissions and both capture and fission yields derived from time-of-flight experiments. To calculate the theoretical observables in the resolved resonance region the REFIT code is used. In the unresolved resonance region (URR) the EURACS code developed as part of a collaboration between INRNE and EC-JRC-IRMM is employed. This code has recently been used for an evaluation of cross section data in the URR for ^{197}Au (see contribution of Becker et al.).

At present the parameters in the resolved resonance region up to 500 eV have been verified and re-evaluated. The average resonance parameters for the URR have been validated based on average transmission data obtained at ORELA as well as the average capture cross sections derived from a least-squares adjustment by Pronyaev of experimental data using the GMA code. The latter is the result of an international cooperative effort to improve cross section standards for neutron induced reactions.

Resonance Evaluations of ^{235}U for the CIELO Project

L. Leal[1)], A. Kahler[2)], G. Noguere[3)], O. Bouland[3)], Y. Penneliau[3)]

1) Oak Ridge National Laboratory, P. O. Box 2008, Oak Ridge, TN, USA
2) Los Alamos National Laboratory, P. O. Box 1663, Los Alamos, NM, USA
3) CEA/Cadarache Saint-Paul-Lez-Durance, France
leallc@ornl.gov

The Resonance region of ^{235}U has been investigated to understand issues regarding calculations of benchmark systems in the energy range 100 eV to 1 MeV. The resolved and unresolved resonance regions of ^{235}U are 0.0001 eV to 2.25 keV and 2.25 keV to 25 keV, respectively.
The purpose of this talk is to present a chronological description of the various ^{235}U resonance evaluations that have been produced since the early 1980s (i.e., from ENDF/B-V to the current ENDF/B-VII.1 evaluation). The issues that motivated the ^{235}U resonance re-evaluations and led to several ENDF versions will be emphasized.

An ongoing resonance re-evaluation work, using recent experimental data for ^{235}U, will be presented. An improved set of resonance parameters has been generated up to 2 keV to address the problem of the capture cross-section data in the ENDF/B and JEFF libraries that are overestimated above 100 eV, as identified by WPEC SG29.

A complementary evaluation work has recently been performed in the unresolved resonance range by taking into account the PROFIL experiments. These experiments were carried out in the PHENIX reactor of CEA Marcoule in the 1990s. The Integral Data Assimilation (IDA) procedure of the nuclear data code CONRAD has been used to extract the ^{235}U capture-to-fission ratio in fast neutron energy range. The capture cross section is deduced from the α ratio via the ^{235}U fission cross section recommended by the neutron standard group of the IAEA. Below 2 keV, the derived capture cross section confirms the group-average capture cross-section obtained from the new resonance analysis.

Another issue that has been investigated is the impact of the (n,γf) reactions on the α ratio and more generally on the average capture cross section. Existing cross-section evaluation codes based on the reduced-R-matrix formalism (SAMMY, CONRAD, REFIT) do not incorporate (n,γf) reactions. The magnitude of the (n,γf) cross-section has been calculated using the AVXSF code that uses the Hauser-Feshbach average cross-section formalism. An individual resonance approach has been carried out from extended resolved-resonance parameters including extra (n,γf) widths and established from the experimental investigations available from the literature. The correction of the capture cross-section data from the (n,γf) reaction for ^{235}U is about 1-2%.

Results obtained in this work were converted into the ENDF-6 evaluation format and processed by NJOY. The processed library has been used in the TRIPOLI and MCNP Monte-Carlo codes for C/E comparisons for a select set of benchmarks.

New evaluation of the Resolved and Unresolved Resonance Range of Pu-239

G. Noguere[1], L. Leal[2], A. Kahler[2], P. Leconte[1], Y. Penneliau[1] and C. De Saint Jean[1]

1) CEA, DEN Cadarache, F-13108 Saint-Paul-Lez-Durance, France
2) Oak Ridge National Laboratory, P. O. Box 2008, Oak Ridge, TN, USA
Gilles.noguere@cea.fr

The Pu-239 evaluated data file adopted in the JEFF-3.2 library contains the resonance parameters established in the frame of the working group WPEC SG34 of the NEA [1]. Parameters available in the previous library, JEFF-3.1.2, were established by Derrien at the end of the 1980s [2]. At that time, because of the limited capabilities of the computers, the "resolved resonance range" was divided into three sets of resonance parameters covering three joined energy ranges [10^{-5} eV-1 keV], [1 keV- 2 keV] and [2 keV- 2.5 keV] respectively. Arbitrary external levels and background cross sections were needed to create correct interference terms between each energy range. In order to improve the calculations of several integral benchmarks, the neutron cross sections and prompt neutron multiplicities were also updated in the thermal energy range up to 20 eV [3]. The main goal of the working group WPEC/SG34 was to produce a single set of resonance parameters from thermal to 2.5 keV, without background cross section and arbitrary external levels, which takes into account the modifications of the cross sections and neutron multiplicities performed in the low energy range.

The present contribution will summarize the evaluation works performed by the nuclear data groups of ORNL and CEA Cadarache. The resonance parameters were extracted from time-of-flight data with the SAMMY code. The corresponding Resonance Parameter Covariance Matrix was established with the Marginalization technique of the CONRAD code. New calculations of the neutron multiplicity were performed by taking into account the two-step (n,γf) process. For the description of the Unresolved Resonance Range, a preliminary set of average resonance parameters were calculated with the recent URR option implemented in the TALYS code. CEA and ICSBEP benchmarks were used to test the performances of the new Pu-239 evaluation available in the JEFF-3.2 library.

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CIELO related nuclear data measurements at the Gaerttner LINAC Center at RPI

Y. Danon[1)], Z. Blain[1)], A. Daskalakis[1)], B. McDermott[1)], D. Barry[2)], R. Block[2)], T. Donovan[2)], B. Epping[2)], G. Leinweber[2)], M. Rapp[2)]

1) Gaerttner LINAC Center, Rensselaer Polytechnic Institute, 110 8th st., Troy, NY, 12180, USA
2) Bechtel Marine Propulsion Corporation, Knolls Atomic Power Laboratory, P.O. Box 1072, Schenectady, New York 12301, USA

danony@rpi.edu

The Gaerttner LINAC Center at Rensselaer Polytechnic Institute (RPI) has been conducting neutron-induced transmission, scattering, capture and fission measurements on materials that are relevant to the Collaborative International Evaluated Library Organization (CIELO). Fission and capture measurements of U-235 in the resonance region were performed with the RPI multiplicity detector. Grouping the data in the energy range of 1000 eV to 1500 eV supports a capture cross section that is lower than ENDF/B-VII.1 and closer to JENDL 4.0. Neutron scattering measurements have been made with incident energy range from 0.5 MeV to 20 MeV for Fe-56 and U-238. For back angle scattering the new data for U-238 show discrepancies from ENDF/B-VII.1 and are in better agreement with the JENDL 4.0 evaluation. High energy resolution transmission of Fe-56 was measured in the energy range from 0.5 to 20 MeV and shows good agreement with the evaluations and previous measurements with a lower uncertainty above 4 MeV. Measurements of fission fragment mass and energy distributions, and prompt fission neutron energy and multiplicity distributions that are performed at the center can also provide new data for evaluators. Methods and results from these experiments will be discussed.

^{235}U and ^{238}U (n,xn γ) cross-sections

A. Bacquias [1], C. Borcea [3], Ph. Dessagne [1], S. Goriely [5], S. Hilaire [4], M. Kerveno [1], J.C. Drohé [2], A.J. Koning [6], N. Nankov [2], A.L. Negret [3], M. Nyman [2], A. Plompen [2], P. Romain [4], C. Rouki [2], G. Rudolf [1], M. Stanoiu [2], J.C. Thiry [1]

1) Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, CNRS/IN2P3, 23 rue du Loess, 67037 Strasbourg, France
2) Institute for Reference Materials and Measurements, Retieseweg 111, B-2440 Geel, Belgium
3) National Institute of Physics and Nuclear Engineering "Horia Hulubei", IFIN-HH Str. Atomistilor no. 407, P.O.BOX MG-6, Bucharest - Magurele, Romania
4) Commissariat à L'Energie Atomique, DAM, DIF, F-91297 Arpajon, France
5) Institut d'Astronomie et d'Astrophysique, CP-226, Université Libre de Bruxelles, BE-1050 Brussels, Belgium
6) Nuclear Research and Consultancy Group, Westerduinweg 3, P.O. Box 25, NL-1755 ZG Petten, The Netherlands

antoine.bacquias@iphc.cnrs.fr

The (n,n') and (n,2n) processes are very important in the energy domain of fission neutrons, but the cross-sections suffer from large uncertainties, which are not compatible with the objectives of security fixed for future and advanced nuclear reactors. I will remind the target accuracies of such measurements, as defined in the High-Priority List (OECD/NEA). I will present our experimental effort to improve ^{235}U and ^{238}U (n,xn γ) data.

The experiments were performed at the GELINA facility (Belgium), which provides a pulsed (800Hz) neutron beam covering a wide energy spectrum (from few eV to about 20 MeV). Especially designed for such studies, the GRAPHEME set-up consists of four planar HPGe detectors placed around the sample of interest, and one fission chamber for neutron flux determination. We use prompt gamma spectroscopy for the detection of the gamma transitions coming from the deexcitation of the nuclei formed by (n,xn) reactions. Their cross-sections are determined as a function of incident neutron energy, obtained by time-of-flight method. The experimental set-up and the analysis methods will be presented.

After showing the published results on ^{235}U, I will profit from the comparison with TALYS and EMPIRE predictions to engage the discussion on the interpretation of experimental results, especially for ^{238}U. The somewhat recurrent gap between (n,xn γ) measurements and theoretical values will be filled with open questions, giving leads to further experiments and models.

^{238}U radiative capture cross section measurement using C_6D_6 detectors at the n_TOF CERN facility

F. Mingrone[1)], C. Massimi[1)], G. Vannini[1)], F. Gunsing[2)], C. Guerrero[3,4)], T. Wright[5)], E. Berthoumieux[2)], the n_TOF Collaboration[6)]

1) Dipartimento di Fisica e Astronomia - Università di Bologna and Istituto Nazionale di Fisica Nucleare - Sezione di Bologna, viale Berti Pichat 6/2, 40127 Bologna, Italy
2) CEA Saclay - Irfu, Route Nationale, 91400 Gif-sur-Yvette, France
3) CERN, European Organization for Nuclear Research, Route de Meyrin 385, 1217 Meyrin, Switzerland
4) Universidad de Sevilla, avda. Reina Mercedes S/N, 41012 Sevilla, Spain
5) University of Manchester, School of Physics and Astronomy, Oxford Road, Manchester M13 9PL
6) https://ntof-exp.web.cern.ch/ntof-exp/

federica.mingrone@bo.infn.it

Within the present complex framework of new energy sources development, there is an unavoidable need for the knowledge of high precision nuclear data. ^{238}U is a key isotope both for improving security standards of existing Generation III and LW reactors and for the design of new Generation IV reactors. In particular, the present knowledge of the ^{238}U(n,γ) reaction cross section still misses the precision and accuracy required. Despite the availability of a large number of measurements, in fact, inconsistencies are present both in the resolved resonance region up to 25 keV and in the unresolved one. This uncertainty influences both fast and thermal reactor systems, and contributes to the uncertainty on Pu isotope density at the end of fuel cycles.

To solve these inconsistencies, radiative capture cross section on ^{238}U was inserted in the NEA High Priority Request List of most relevant nuclear data requirements. With the Accurate Nuclear Data for nuclear Energy Sustainability (ANDES) project from the European Commission 7th Framework Programme, three measurements have been planned in order to reach the desired accuracy: two at the n_TOF facility at CERN with different experimental setups and one at the EC-JRC-IRMM facility GELINA. Combining together these three independent measurements it should be possible to achieve the goal of a 2% accuracy in the cross section.

Here the ^{238}U(n,γ) cross section measurement performed at the n_TOF CERN facility using two C_6D_6 scintillation detectors is presented. The detection technique used, together with the high purity ^{238}U sample, allows a high precision measurement from epithermal energy up to hundreds of keV, including both the resolved and the unresolved resonance regions. Detector calibrations, background subtraction and n_TOF fluence evaluation have been taken in great account to perform an analysis as precise and accurate as possible. The steps of the analysis will be presented, which had led to the extraction of the experimental yield. In addition, a preliminary discussion on the statistical and systematic errors will be shown.

High-precision measurement of the $^{238}U(n,\gamma)$ cross section with the Total Absorption Calorimeter (TAC) at n_TOF, CERN

T. Wright[1)], J. Billowes[1)], C. Guerrero[2,3)], D. Cano-Ott[4)], F. Gunsing[5)], C. Massimi[6)], F. Mingrone[6)], E. Berthoumieux[5)], the n_TOF collaboration

1) University of Manchester, School of Physics and Astronomy, Oxford Road, Manchester M13 9PL
2) CERN, European Organization for Nuclear Research, Route de Meyrin 385, 1217 Meyrin, Switzerland
3) Universidad de Sevilla, Spain
4) CIEMAT, Nuclear Innovation Unit, Madrid, Spain
5) CEA Saclay - Irfu, Route Nationale, 91400 Gif-sur-Yvette, France
6) Dipartimento di Fisica e Astronomia - Università di Bologna and Istituto Nazionale di Fisica Nucleare - Sezione di Bologna, viale Berti Pichat 6/2, 40127 Bologna, Italy

tobias.wright@postgrad.manchester.ac.uk

The accuracy of the neutron capture cross section of ^{238}U has limitations in the simulation of present and Gen III+ LWRs and on the Gen IV fast reactors. Sizeable inconsistencies still appear in the epithermal energy region up to 25 keV, as is summarized on the NEA High Priority Request List of measurements.

The Accurate Nuclear Data for nuclear Energy Sustainability – ANDES project from the European Commission 7th Framework Programme aims to achieve the required precision and improve the measurements of the ^{238}U cross section data. The neutron capture cross section has been measured at the n_TOF facility at CERN with two different detector set-ups, and also measurements have been performed at GELINA at IRMM. All these measurements are being analysed in common with the aim of reducing the uncertainty in the cross section down to 2%, leading to the most accurate ^{238}U neutron capture cross section to date.

This contribution focuses specifically on the time-of-flight measurement carried out with the Total Absorption Calorimeter (TAC) at the CERN neutron-spallation source n_TOF. The TAC is an array of 40 BaF_2 scintillators and has a large solid angle coverage, high γ-ray total absorption efficiency, reasonable energy resolution, high segmentation and fast time response. The high purity (>99.99%) ^{238}U sample of 6.002g (53x30mm^2) was produced and characterized for the areal density by the EC-JRC-IRMM.

The final experimental yield in the energy range between 0.3 eV and 10 keV will be presented. This includes the corrections associated to the background subtraction, detection efficiency and pile-up effects. A comparison with the existing evaluated cross sections will also be presented, alongside a comparison with other experimental data. Finally, an overview of the systematic and statistical uncertainties will be given.

Neutron-induced reactions on U and Th – A new approach via AMS

A. Wallner[1),2)], R. Capote Noy[3)], M. Christl[4)], I. Dillmann[5)], L.K. Fifield[1)], F. Käppeler[5)], A. Klix[6)], A. Krása[7)], C. Lederer[2)], J. Lippold[8)], A. Plompen[7)], V. Semkova[3)], M. Srncik[1)], P. Steier[2)], S. Tims[1)], S. Winkler[2)]

1) Department of Nuclear Physics, Australian National University, Canberra, ACT 0200, Australia
2) VERA Laboratory, Faculty of Physics, University of Vienna, Währinger Strasse 17, A-1090, Austria
3) NAPC Nuclear Data Section, International Atomic Energy Agency, 1400 Vienna, Austria
4) Dept. of Physics, Laboratory of Ion Beam Physics, ETH Zurich, Zurich, Switzerland
5) Karlsruhe Institute of Technology (KIT), Campus Nord, Institut für Kernphysik, Karlsruhe, Germany
6) Karlsruhe Institute of Technology (KIT), Institute for Neutron Physics and Reactor Technology, Karlsruhe, Germany
7) European Commission, Joint Research Centre, IRMM, Geel, Belgium
8) Ruprecht-Karls-Univ. Heidelberg, Inst. f. Umweltphysik, Im Neuenheimer Feld 229, 69120 Heidelberg, Germany

anton.wallner@anu.edu.au

Existing data for neutron-induced reactions on U and Th have been measured via detection of the prompt radiation, by the activation technique and by detection of emitted particles. A major difficulty in these experiments is the discrimination against the strong γ-background (e.g. from the competing fission channel) or unfavourable decay schemes. Up to now, no measurements have been performed for such reactions applying accelerator mass spectrometry (AMS) except recent work at the VERA (Vienna Environmental Research Accelerator) laboratory. Recent studies exhibit some discrepancies at keV and MeV energies between major nuclear data libraries for ^{238}U(n,γ), ^{232}Th(n,γ) but also for (n,xn) reactions. A similar difference for the cross section ratio ^{238}U(n,γ)/^{197}Au(n,γ) was found between data based on TOF and prompt γ-detection. Some of those ratio measurements may be biased because of the difficulties in detecting all the gamma rays emitted by the ^{238}U(n,γ) and ^{197}Au(n,γ) reactions. Our method based on direct atom-counting has the advantage that the involved systematic uncertainties are in no way correlated with the uncertainties inherent e.g. to the TOF technique. Therefore, such data provide important and independent information for key reactions of reactor physics.

We have extended our initial (n,γ) measurements on ^{235,238}U to higher neutron energies and to additional reaction channels. Natural uranium and thorium samples were exposed to neutrons of energies between thermal and 23 MeV at various neutron producing facilities. After the activation, the production of longer-lived nuclides was quantified by AMS at three different laboratories. The radionuclides counted via AMS were either the direct product of a reaction or a decay-product of a directly produced short-lived nuclide. A particular feature of the U and Th isotopes are the low (n,2n) and (n,3n) thresholds; even the ^{232}Th(n,4n) reaction could be studied.

Those measurements were only possible through the transnational access activities offered within the framework of EFNUDAT, EUFRAT and ERINDA in Europe. Importantly, such a variety of different neutron facilities in combination with three independent AMS facilities allowed us to study in detail systematic uncertainties. Such an approach will serve as a prime example for further precision experiments. We have finished now all AMS measurements and will present our results for neutron capture, (n,xn) and (n,α) reactions on ^{232}Th as well as ^{235,238}U. In a similar campaign, a series of additional reaction studies via AMS was recently launched including (n,γ), (n,α) and (n,xn) reactions on structural materials like Mn, Fe and Ni.

The FLAP 3.0 optical potential for converged coupled-channels calculations of neutron scattering on actinides

I.J. Thompson, F.S. Dietrich, and W.E. Ormand

Lawrence Livermore National Laboratory L-414, Livermore, CA 94551, USA
I-Thompson@llnl.gov

Coupled-channels calculations for neutron scattering on actinide nuclei have recently been shown to need more excited states for convergence than was previously believed (Dietrich *et al*, Phys. Rev. C85, 044611 (2012)). The poor convergence shows up especially when calculating the total and the compound-nucleus production cross sections below 1 or 2 MeV incident neutron energy. Since it is exactly the compound-nucleus production cross section which gives the transmission coefficients which enter into Hauser-Feshbach models for many applications, we have re-examined the fitting of experimental data in neutron scattering on ^{232}Th and ^{238}U over the energy range 0 to 100 MeV, with special examination of the low-energy details. We find that previous optical potentials of Soukhovitskii and of Dietrich (FLAP2.2) are not sufficiently converged for the present purposes.

In order to have a fitted optical potential that is suitably independent of those two potentials, after some trials we found it satisfactory to use a modified version of the Koning and Delaroche optical potential. That potential was fitted to mainly spherical nuclei of mass numbers below A=209, so the changes are clearly to be expected when that global form is extrapolated up to A=232-242, and also when it becomes a bare potential within a coupled-channels set. Our research shows that changes to the surface imaginary strength and its diffuseness are sufficient to give competitive fits to ^{232}Th and ^{238}U total, elastic and inelastic cross sections. What is most interesting are systematic reductions in the compound-nucleus production cross section compared with Soukhovitskii. This indicates that further work is needed to properly determine the uncertainties of the extracted compound-nucleus production cross sections, and to see exactly how well they are in fact constrained by presently available data.

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A self-consistent coupled-channels method for direct neutron capture on non-spherical nuclei: $^{56}Fe(n,\gamma)^{57}Fe$

I.J. Thompson[1), G. Arbanas[2), J. Escher[1), C. Elster[3), F.M. Nunes[4)

1) Lawrence Livermore National Laboratory L-414, Livermore, CA 94551, USA
2) Reactor and Nuclear Systems Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6171, USA
3) Institute of Nuclear and Particle Physics, and Department of Physics and Astronomy, Ohio University, Athens, OH 45701, USA
4) National Superconducting Cyclotron Laboratory, and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA

I-Thompson@llnl.gov

Models of neutron capture have so far accounted for the effects of non-spherical nuclei either in the incoming wave functions (via non-spherical optical model potentials), *or* in the final bound states (via non-spherical real-potential wells), but not in both. In this contribution, the effects of non-spherical nuclear shapes on computed neutron capture cross sections are accounted for self-consistently in the incoming *and* the final state configurations of the coupled-channels model of nuclear reactions implemented in the FRESCO code.

In the incoming partition we couple the elastic channel with the 2+ excited state at 846 keV in Fe-56, using a deformation parameter of β_2 = 0.24 from the RIPL-3 database value extracted by Raman from the B(E2) decay matrix element. We calculated the cross sections to 20 *p*-wave final bound states with binding energies from 7.65 to 2.61 MeV. The wave functions for the bound states were found using a binding potential that was deformed by the same deformation parameter as for scattering. The overall normalization of the bound states was set using the spectroscopic factors from Sen Gupta *et al.*, Nucl. Phys. A160 (1971) 529. We calculated all the E1 transitions from scattering to bound states. (Further work will be needed to model the E2 transitions since core transitions may then become important.)

We apply this model to neutron capture cross section on Fe-56, which is one of the few nuclides that the CIELO collaboration is focused on initially. We quantify the effect of the non-spherical shape on the computed neutron direct capture cross section on Fe-56 by comparing with the results obtained assuming spherical shape of the Fe-56 nucleus. We show the results for the incoming neutron energies below 20 MeV.

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Covariances on ^{239}Pu, ^{238}U and ^{235}U neutron cross sections with the CONRAD code: from physical to integral experiment constraints

C. De Saint Jean, P. Archier, P. Leconte, E. Privas, G. Noguere, O. Litaize

CEA, DEN, DER, SPRC, Cadarache, F-13108 Saint-Paul-lez-Durance, France
cyrille.de-saint-jean@cea.fr

Neutron induced reactions between 0 eV and 20 MeV are based on various physical properties such as nuclear reaction models, microscopic and integral measurements. Most of the time, the evaluation work is done independently between the resolved resonance range and the continuum, giving rise to mismatches for the cross sections, larger uncertainties on boundary and no cross correlation between high energy domain and resonance range. In addition the use of integral experiment is sometimes only related to central values (evaluation is "working fine" on a dedicated set of benchmarks) and reductions of uncertainties are not straightforward on cross sections themselves: "working fine" could be mathematically reflected by a reduced uncertainty.

As the CIELO initiative is to bring experts in each field to propose/discuss these matters, this paper will present several methodologies that may be used to avoid such effects on covariances.

A first idea based on the use of experiments overlapping two energy domains appeared in a near past. It will be reviewed and extended to the use of systematic uncertainties (normalization for example) and for integral experiments as well. In addition, we propose a methodology taking into account physical constraints on an overlapping energy domain where both nuclear reaction models is used (continuity of both cross sections and derivatives for example). The use of Lagrange multiplier (related to these constraints) in a classical generalized least square procedure will be exposed.

Some academic examples will then be presented for both point-wise and multigroup cross sections to present the methodologies. In addition, new results for ^{239}Pu will be presented on resonance range and higher energies to reduce capture and fission cross section uncertainties by using integral experiments (CERES program as well as JEZEBEL experiment).

Evaluation of Prompt Fission Neutron Spectra for major actinides

R. Capote Noy, et al.

IAEA NAPC-Nuclear Data Section, P.O. Box 100, Vienna, Austria
r.capotenoy@iaea.org

Modelling and evaluation methods on prompt fission neutron spectra are reviewed following discussions and results presented at the IAEA CRP meeting on PFNS for major actinides held in October 2013. Current status, challenges and outlook are presented.

Investigation of Prompt Fission Neutron and Gamma Spectra with their covariance matrices. Application to $^{239}Pu+n_{th}$, $^{238}U+n_{1.8MeV}$ and $^{235}U+n_{th}$

O. Litaize, O. Serot, D. Regnier, L. Berge, Y. Peneliau, P. Archier, C. De Saint Jean, G. Noguere

CEA, DEN, DER, SPRC, Cadarache, F-13108 Saint-Paul-lez-Durance, France
olivier.litaize@cea.fr

Prompt fission neutron and gamma spectra as well as multiplicities are important for nuclear heating purpose. A recent tool, FIFRELIN, has been developed at Cadarache for simulating the deexcitation of the fission fragments (FF) in order to generate the quantities mentioned above within a single code. The input data required by the code are the pre-neutron mass and kinetic energy distributions. These distributions come from experiments. Additional models are used to sample the charge, spin and parity of the fragments. The excitation energy sharing between two complementary fragments has been detailed in previous works. When the FF characteristics are sampled (A, Z, KE, J, π) the de-excitation process can start.

The first scheme is based on Weisskopf statistical theory for neutron emission and level density plus strength functions for gamma emission. The neutron emission is performed before the gamma emission (uncoupled scheme).

The second one is a Hauser-Feshbach like scheme based on neutron and gamma transmission coefficients (neutron and gamma emissions are coupled).
The whole simulation allows to estimate fission observables such as prompt fission neutron and gamma spectra as well as multiplicities but also distributions of all fission related quantities. Various thermal, fast and spontaneous fissioning systems have been studied.

In addition, a coupling algorithm between FIFRELIN and the CONRAD nuclear data evaluation code has been initiated in order to generate covariance matrices related to prompt fission spectra.

Characteristics of prompt fission gamma-ray emission – Experimental results and predictions

A. Oberstedt [1], R. Billnert [1,2], S. Oberstedt [2]

1) Fundamental Fysik, Chalmers Tekniska Högskola, 41296 Göteborg, Sweden
2) European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, 2440 Geel, Belgium

andreas.oberstedt@ossolutions.eu

In recent years the measurement of prompt-fission gamma-ray spectra (PFGS) has gained renewed interest. After about forty years since the first (and at the same time last) comprehensive studies on this topic, the development of lanthanide halide scintillation detectors as well as new data acquisition and signal-processing techniques provided appropriate tools to determine PFGS characteristics with unprecedented accuracy. These new experimental efforts were motivated by OECD/NEA requests for new values especially for gamma-ray multiplicities and mean photon energies, in particular for ^{235}U and ^{239}Pu. Both isotopes are considered the most important ones with respect to the modelling of innovative cores for fast Generation-IV reactors.

We present recent experimental results from the reactions ^{235}U(n_{th},f) and ^{241}Pu(n_{th},f) as well as from the spontaneous fission of ^{252}Cf, together with corresponding calculated values, when available. We compare our results with systematics for PFGS characteristics as function of both atomic and mass number of the compound systems, established in 2001 by T.E. Valentine. Although the parameters in that work might need a revision due to the results from recently performed measurements, this systematics may allow estimating gamma-ray multiplicity, mean and total photon energy in cases where target nuclei are not available or accessible for experiments. While this has been done for thermal neutron induced and spontaneous fission, we show how PFGS characteristics may be predicted for fission induced by fast neutrons in the case of ^{238}U.

Characterization of a paraterphenyl neutron detector and preliminary results on ^{238}U(n,f) prompt fission neutron energy spectra at 2, 5.2 and 15 MeV

A. Sardet[1], T. Granier[1], B. Laurent[1], A. Oberstedt[1,2], C. Varignon[1]

1) CEA/DAM Île-de-France, F-91297 Arpajon Cedex, France
2) Fundamental Pysics, Chalmers University of Technology, S-41296 Göteborg, Sweden
alix.sardet@cea.fr

In connection with the international program aiming at improving the adequacy and quality of prompt fission neutron spectra, established in 2009 by the IAEA [1], first measurements on ^{238}U(n,f) were performed at the 4 MV Van de Graaff accelerator facility of the CEA/DAM in Bruyères-le-Châtel. The neutron detector in use consists of a coaxial p-terphenyl scintillator of 7.5 cm diameter and 5.0 cm length. It was previously shown that this kind of detectors exhibits excellent n-γ discrimination properties provided by a pulse shape analysis, a good light yield and neutron efficiency [2,3].

We present results on the characterization of the detector, such as linearity, light output curve and neutron efficiency and show first results from measurements of the reaction ^{238}U(n,f) at 2, 5.2 and 15 MeV neutron energy. The data were acquired using the new digital acquisition system FASTER [4], currently developed by the LPC Caen. We conclude by giving an outlook on upcoming activities, like the analysis of data from an experiment on the neutron induced fission of ^{235}U at 500 keV, carried out at the 7 MV Van de Graaff accelerator facility of the EC-JRC-IRMM in Geel, Belgium.

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Scintillation neutron detector with dynamic threshold

N. Kornilov, T. Massey, S. Grimes

Department of Physics and Astronomy, Ohio University, Athens, OH 45701, USA
kornilov@phy.ohiou.edu

Scintillation neutron detectors are a common tool for neutron spectroscopy. They provide good time resolution, neutron-gamma discrimination and high efficiency of neutron counting. The real open problems connected with application of these detectors are in a high energy range >10MeV. There are no standard neutron spectra known with high accuracy for this energy range. Therefore, traditional methods for experimental investigation of the efficiency function fail for these neutrons. The Monte Carlo simulation cannot provide reasonable accuracy due to unknown characteristics of reactions for α particle production (light output, reaction cross sections). The application of fission chamber with fissile material as a neutron detector did not help to solve the problem.

We may avoid many problems if we use the traditional neutron detector with non-traditional data analysis. Detector should provide the following information: time of flight, pulse height, and pulse shape. All events are collected in list mode. The difference from traditional application is in the analysis of events. We estimated neutron energy E_n from TOF. This is maximal proton energy. On the basis of light output dependence $P(E_n)$ measured for this particular detector, we estimate the pulse height which corresponds to this energy.

We may select angle for proton recoils θ_1 and on the basis of well-known formula calculate proton energy ($E_{p1}=E_n \cos^2\theta_1$) and pulse height $P(E_{p1})$. We will collect only events (after pulse shape identification) belonging to angle interval 0- θ_1. The production cross section for these protons may be calculated without any problems.

In this report we will give main relations, and demonstrate the method for Cf source. Experimental result will be compared with MC simulation.

Consistent data assimilation

M. Herman[1], S. Hoblit[1], G.P.A. Nobre[1], A. Palumbo[1], G. Palmiotti[2], H. Hiruta[2], M. Salvatores[2]

1) National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY
2) Idaho National Laboratory, Idaho Falls, ID
mwherman@bnl.gov

This work is the first attempt to build up a link between the wealth of precise integral experiments and a basic theory of nuclear reactions. Essential ingredients of such a procedure, denominated here as assimilation, are covariances for model parameters and sensitivity matrices. The latter provide direct link between reaction theory and integral experiments. The result is a consistent data assimilation performed directly on the basic nuclear physics parameters that are being used in a variety of nuclear reaction mechanisms. The assimilation procedure should result in more accurate and more reliable evaluated data files of universal validity rather than tailored to a particular application.

This method was tested on ^{235}U and ^{239}Pu with the GODIVA and JEZEBEL experiments. It was found that very small changes in the cross sections were sufficient to reproduce the integral experiments. It is unlikely that differential data alone will ever be able to reach this level of accuracy. However, the differential and integral data when used together in the assimilation exercise can hopefully produce evaluations that reproduce simultaneously both types of the data and satisfy constraints by nuclear reaction theory.

Basic considerations on the proper evaluation method

H. Leeb, G. Schnabel, Th. Srdinko

Atominstitut, Technische Universität Wien, Wiedner Hauptstrasse 8-10, 1040 Vienna, Austria
leeb@kph.tuwien.ac.at

Evaluated nuclear data libraries are an essential prerequisite for the construction and development of novel nuclear technologies, health and safety measures in various industrial fields and applications of radiotherapy. Recent developments and applications demand for an extension of the energy range and the inclusion of reliable uncertainty information in the nuclear data libraries. Existing nuclear data libraries are extensively benchmarked and proved in the energy range up to about 20 MeV, which is relevant for conventional nuclear reactors. In this region a great wealth of experimental data of high quality is available and the evaluation by statistical means is the proper method to provide reliable data sets and associated uncertainties. The extension of the energy range is not straightforward because of the scarcity of experimental data at higher energies. Thus one has to develop a novel evaluation technique which heavily relies on nuclear models. At present there is no unique procedure available how to perform evaluations in the extended energy range. In this contribution we start from the basic requests on a nuclear data evaluation technique to provide our best knowledge of the reaction observables and their uncertainties. Based on the concepts of Bayesian statistics, we show on specific examples the influence of the a-priori knowledge on the mean values of the final evaluation. Especially the meaning of the covariance matrices is considered, which may differ in different models even if for equal mean values. Hence, even very good description of observables may not suffice for a reliable covariance matrix. Summarizing our considerations we conclude that the extension to energy regions with scarce experimental data represents a challenge for nuclear theory to provide proper nuclear models. Furthermore also some additional consent on the uncertainty information is required. Both aspects underline the importance of the proposed project CIELO.

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Data mining the EXFOR database

D. Brown, M.W. Herman, J. Hirdt

National Nuclear Data Center, Brookhaven National Laboratory, Brookhaven, USA
dbrown@bnl.gov

The EXFOR database contains the largest collection of experimental nuclear reaction data available as well as this data's bibliographic information and experimental details. We created an undirected graph from the EXFOR datasets with graph nodes representing single observables and graph links representing the connections of various types between these observables. This graph is an abstract representation of the connections in EXFOR, similar to graphs of social networks, authorship networks, etc. Analyzing this abstract graph, we are able to address very specific questions such as 1) what observables are being used as reference measurements by the experimental community? 2) are these observables given the attention needed by various standards organizations? 3) are there classes of observables that are not connected to these reference measurements? In addressing these questions, we propose several (mostly cross section) observables that should be evaluated and made into reaction reference standards.

Evaluation of neutron induced reaction cross sections for ^{197}Au in the resonance region

B. Becker[1)], R. Capote[2)], E. Dupont[3)], S. Kopecky[1)], C. Lampoudis[1)], R. Massarczyk[4)], C. Massimi[1,5)], M. Moxon[6)], V. Pronyaev[7)], P. Schillebeeckx[1)], I. Sirakov[8)], A. Trkov[9)], R. Wynants[1)] and G. Žerovnik[1,9)]

1) European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, Retieseweg 111, 2440 Geel, Belgium
2) International Atomic Energy Agency, NAPC/Nuclear Data Section, Vienna, Austria
3) OECD Nuclear Energy Agency, 12 Bd des Iles, 92130 Issy-les-Moulineaux, France
4) Helmholtz-Zentrum Dresden-Rossendorf, Postfach 510119, 01314 Dresden, Germany
5) University of Bologna and sezione INFN of Bologna, Via Irnerio 46, Bologna, 40126, Italy
6) Hyde Copse 3, Marcham, United Kingdom
7) Institute of Physics and Power Engineering, Obninsk, Russia
8) Institute for Nuclear Research and Nuclear Energy, BG-1784 Sofia, Bulgaria
9) Jožef Stefan Institute, Jamova cesta 39, 1000 Ljubljana, Slovenia
bjorn.becker@ec.europa.eu

A new evaluation of cross sections for neutron induced reactions on ^{197}Au in the energy region below 100 keV has been carried out at EC-JRC-IRMM. This evaluation is a result of an international cooperative effort to improve cross section standards by a subgroup formed by the Working Party on International Evaluation Cooperation of the Nuclear Energy Agency Nuclear Science Committee and a Coordinated Research Project organized by the International Atomic Energy Agency. In this contribution, the full methodology of the evaluation will be discussed. This is in particular important for the CIELO project as the same procedures will be used for the evaluation of the ^{238}U cross sections.

In the resolved resonance region the latest independent evaluation coming from the ENDF project was used as a starting file. Adjustments of this file were made using high resolution transmission and capture cross section measurements that have been carried out at the GELINA time-of-flight facility of EC-JRC-IRMM.

In the unresolved resonance region (URR), the average partial cross sections have been expressed in terms of neutron strength functions and transmission coefficients by applying the Hauser-Feshbach statistical reaction theory including width fluctuations. The results of dispersive coupled channel optical model (DCCOM) calculations were then used to verify the energy dependence of the neutron strength functions and the scattering radius. Average energy independent parameters were derived from a least square fit of well documented experimental data. In addition, a smooth transition between the URR and the fast energy region was made.

The evaluated file has been processed with the latest updates of NJOY.99 to test their format and application consistency as well as to produce a continuous-energy data library for use in Monte Carlo neutron transport codes. Simulations of lead slowing-down experiments and thick sample time-of-flight measurements were then used to validate the results.

Resonance parameters from neutron induced total and capture cross section measurements on ^{241}Am at GELINA

S. Kopecky[1), B. Becker[1),O. Bouland[2), F. Gunsing[3), G. Noguere[2), A.J.M. Plompen[1), C. Sage[1), C. Lampoudis[1), and P. Schillebeeckx[1)

1) European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, Retieseweg 111, 2440 Geel, Belgium
2) CEA-Cadarache, DEN, F-13108 Saint-Paul-lez-Durance, France
3) CEA-Saclay, Irfu/SPhN, F-91191, Gif-sur-Yvette, France
stefan.kopecky@ec.europa.eu

Resonance parameters for neutron induced reactions on ^{241}Am below 110 eV have been determined. The parameters result from a resonance shape analysis of transmission and capture data measured at the time-of-flight facility GELINA, with the accelerator operating at a 50 Hz repetition rate. The transmission experiments were carried out at a 25 m station using a Li-glass scintillator. The capture experiments were performed at a 12.5 m station using a pair of C_6D_6 detectors. The capture data were normalized by using resonance parameters derived from the transmission measurements.
The neutron widths obtained in this work are approximately 22% larger than the values included in the evaluated data libraries. Also the thermal capture cross section is larger than most of the recommended values. However, the presented resonance parameters are consistent with results of both integral experiments and of the experimentally determined resonance integrals.

Measurement of the ^{241}Am capture cross section at the n_TOF facility at CERN

E. Mendoza[1), D. Cano-Ott[1), C. Guerrero[2) and the n_TOF collaboration

1) Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), 28040, Madrid, Spain.
2) European Organization for Nuclear Research (CERN), CH-1211 Geneva 23, Switzerland.
emilio.mendoza@ciemat.es

The ^{241}Am neutron capture cross section was measured at the n_TOF facility at CERN during the 2010 campaign, using two different experimental setups: a BaF_2 Total Absorption Calorimeter (TAC) and a pair of C_6D_6 detectors. Both measurements are part of the European Commission 7th Framework Programme ANDES project, and in both cases the same ^{241}Am sample were used. We will present the experimental capture yield obtained with the TAC, together with a preliminary resonance analysis.

Fission cross sections measured at n_TOF with PPACs

C. Paradela[1), L. Audouin[2), E. Leal-Cidoncha[1), L.S. Leong[2), I Duran[1), D. Tarrío[1), L. Tassan-Got[2), on behalf of the n_TOF Collaboration

1) Universidad de Santiago de Compostela, Facultad de Física, Santiago de Compostela, Spain
2) Centre National de la Recherche Scientifique/IN2P3 – Université Paris-Sud – IPN, Orsay, France

carlos.paradela@usc.es

During last years several experimental campaigns have been developed at the CERN-n_TOF facility to investigate, by using PPAC detectors, the neutron-induced fission reactions of different isotopes, namely ^{234}U, ^{232}Th, ^{237}Np, ^{233}U, ^{nat}Pb and ^{209}Bi [1,2,3]. In all the measurements, samples of ^{235}U and ^{238}U were included as references to obtain relative cross sections. Furthermore, two different setup configurations have been used: the first setup with the PPACs perpendicular to the beam direction and the second one with the detectors tilted 45º, in order to cover the full emission angle of the fission fragments.

In this work, we review the impact of the fission cross sections measured at the n_TOF facility, with particular emphasis on the ratio between ^{238}U and ^{235}U, measured up to 1 GeV for the first time.

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Measurement of the neutron-induced fission cross section of ^{240,242}Pu

P. Salvador-Castiñeira[1, 2], F.-J. Hambsch[1], T. Brys[1], S. Oberstedt[1], C. Pretel[2], M. Vidali[1]

1) European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, Retieseweg 111, 2440 Geel, Belgium
2) Institute of Energy Technologies, Technical University of Catalonia, Av. Diagonal 647, 08028 Barcelona, Spain

paula.salvador-castineira@ec.europa.eu

For a sustainable nuclear energy supply a combination of present light water reactors, future advanced fast reactors and waste minimization in closed fuel cycles with partitioning and transmutation is needed. This is the view of the Strategic Research Agenda of the European Technological Platform for a Sustainable Nuclear Energy (SNETP). In order to implement these novel nuclear systems and their respective fuel cycles it is necessary to improve the accuracy of nuclear data, to reduce systematic uncertainties and to validate related nuclear models. Within the project ANDES (Accurate Nuclear Data for nuclear Energy Sustainability) a European wide effort has been started to measure reaction cross sections identified as being crucial for the development of innovative reactor concepts [1].

The present work contributes to the improvement of the neutron-induced fission cross section of ^{240,242}Pu isotopes. These fission cross sections have been identified in a sensitivity analysis of many cross sections as being of highest priority for fast reactors. Target accuracies are very stringent and are required to be in the 1-3% range for ^{240}Pu and 3-5% for ^{242}Pu compared to current accuracies of about 6% and 20%, respectively. At JRC-IRMM, high quality ^{240,242}Pu targets have been prepared and shipped to the different partners in ANDES involved in these measurements. At the Van de Graaff accelerator of the JRC-IRMM several measurements have been performed to determine the fission cross section of ^{240,242}Pu relative to ^{237}Np and ^{238}U. A Frisch-grid ionisation chamber and a digital data acquisition system were used. Since also the non-negligible contribution from spontaneous fission (SF) for both isotopes has to be properly taken into account this quantity has been remeasured. Both SF half-lives were determined with a total uncertainty lower than 1.5%, showing an increase of around 2% for ^{240}Pu compared to the reference value published in Ref. [2]. The measured SF half-life of ^{242}Pu is in agreement with the value from the same reference. So far cross sections for both isotopes have been determined up to 3 MeV showing some discrepancies (around 12%) to the ENDF/B-VII evaluation mainly for ^{242}Pu around 1.1 MeV, where the evaluation shows a resonance like structure not observed in the present work

The analysis procedure and the involved corrections of the acquired data will be presented together with the preliminary results obtained so far.

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Sensitivity analysis of the nuclear data for MYRRHA reactor modelling

A. Stankovskiy[1), G. Van den Eynde[1), C.J. Diez[2), O. Cabellos[2)]

1) Institute of Advanced Nuclear Systems, SCK•CEN, Boeretang 200, 2400 Mol, Belgium
2) Dpto. de Ingeníeria Nuclear, Universidad Politécnica de Madrid, 28006 Madrid, Spain
alexey.stankovskiy@sckcen.be

The detailed sensitivity analysis of effective neutron multiplication factor to the change of nuclear data evaluation has been performed for the neutronic model of MYRRHA fast spectrum facility being designed at SCK•CEN. It allowed creating the priority list of the nuclides for further deeper analysis. It has been shown that the test version of JEFF-3.2 library gives closer results to ENDF/B-VII.1 than JEFF-3.1.2. With this tendency of new library releases to converge, however, the open issue remains to assess the uncertainties on the cross sections and fission multiplicities. A thorough k_{eff} sensitivity analysis has been performed for two nuclides from the MYRRHA nuclear data priority list: ^{56}Fe and ^{238}Pu. The calculated sensitivity profiles for ^{56}Fe allowed determining that the most important are the elastic scattering and neutron capture cross sections. Further analysis of the ENDF/B-VII.1 and JEFF-3.1.2 evaluations for these reactions has shown that different definitions of resonances and usage or not of the background cross sections lead to the differences reflected in the sensitivity profiles. The fission cross section has been found the most influencing for MYRRHA criticality calculations. Further analysis has shown that the unresolved resonance parameters are responsible for the differences in neutron fission cross section evaluations in nuclear data files for ^{238}Pu.
In the framework of CHANDA FP7 project the sensitivity analysis will be continued for other nuclides in this priority list and will be extended to other reactor safety parameters (such as reactivity coefficients, effective delayed neutron fraction, neutron generation time, etc.). This study will be completed by the uncertainty analysis based on the sensitivity profiles.

Fission yield covariance generation and uncertainty propagation through fission pulse decay heat calculation

L. Fiorito[1,2], C.J. Diez[3], O. Cabellos[3,4], A.Stankovskiy[1], G. Van den Eynde[1], P.E. Labeau[2]

1) SCK•CEN Belgian Nuclear Research Centre, Boeretang 200, 2400 Mol, Belgium
2) ULB Universite Libre de Bruxelles, Avenue Franklin Roosevelt 50, 1050 Bruxelles, Belgium
3) Dpto. De Ingenieria Nuclear, Escuela Tecnica Superior de Ingenieros Industriales, Universidad Politecnica de Madrid UPM, Jose Gutierrez Abascal 2, 28006 Madrid, Spain
4) Instituto de Fusion Nuclear, Escuela Tecnica Superior de Ingenieros Industriales, Universidad Politecnica de Madrid UPM, Jose Gutierrez Abascal 2, 28006 Madrid, Spain

lfiorito@sckcen.be

Fission product yields are fundamental parameters in burnup/activation calculations and the impact of their uncertainties has been widely studied in the past. Evaluations of these uncertainties have been released, although they are still incomplete. Therefore, the nuclear community expressed the need of full fission yield covariance matrices to be able to produce inventory calculation results that takes into account the complete uncertainty data.

State-of-the-art fission yield data and methodologies for fission yield covariance generation are researched in this work. Covariance matrices are generated and compared to the original data stored in the library. Then, the paper focuses on the effect of fission yield covariance information on Fission Pulse Decay Heat results for thermal fission of U-235. Calculations are carried out using different libraries and codes (ACAB and ALEPH-2) after introducing the new covariance values. Results are compared with those obtained with the uncertainty data currently provided by the libraries. The Uncertainty Quantification is performed first with Monte Carlo sampling and then compared with linear perturbation. Indeed, correlations between fission yields strongly affect the statistics of decay heat. Eventually, a sensitivity analysis of fission product yields to Fission Pulse Decay Heat is accomplished in order to provide a full set of the most sensitive nuclides for such a calculation.

Effect of fission yield libraries on the irradiated fuel composition in Monte Carlo depletion calculations

E. Mitenkova, N. Novikov

Nuclear Safety Institute of Russian Academy of Sciences, B. Tulskaya 52, Moscow, 115119, Russia
mit@ibrae.ac.ru

Precision calculations of irradiated fuel composition are particularly important when assessing the radiation characteristics of spent fuel. Fission Product Yields (FPY) are among the most important nuclear data in burnup calculations especially in accurate calculations by Monte Carlo depletion codes.
The different (U-Pu) fuel compositions are considered for next generation of sodium fast breeder reactors. The effect of Fission Yield Libraries on irradiated fuel composition is studied in MONTEBURNS–MCNP5–ORIGEN2 calculations of fast reactors. Fission Yield libraries are compiled for sodium fast reactor with MOX fuel, using ENDF/B-VII.0, original library FY_Koldobsky (FY_KL) and GEFY 3.3 as source data files.

In ENDF/B source files the yields of fission products are traditionally presented for the thermal point 0.0253 eV, "average" point 0.4 MeV (or 0.5 MeV) and high energy point 14 MeV. The FPY three-group energy grid representation causes the ambiguous compilation of FPY libraries for the meaningful energy range of fast reactors. The modern versions of FY_KL, GEFY, TENDL contain data for more detailed grids in intermediate and fast energy ranges. The FY_KL includes FPY data in the fast energy range: 1, 2.5, 5, 7.5, and 10 MeV, GEFY 3.3 – for 1 - 20 MeV in increments of 1 MeV.

This paper contains the comparative results of irradiated fuel composition analysis when using various Fission Yield libraries. Study of irradiated fuel demonstrates the discrepancies in accumulated concentrations of important fission products such as Nd, Kr, Xe, some long-lived isotopes, etc.

Comparative sensitivity study of some criticality safety benchmark experiments using JEFF-3.1.2, JEFF-3.2T and ENDF/B-VII.1

T. Kooyman[1,2], N. Messaoudi[1]

1) SCK-CEN, Boeretang 200, BE-2400 Mol, Belgium
2) Magistère de physique fondamentale, Université Paris Sud, Batiment 470, 3ème étage, Campus d'Orsay, 91400 Orsay, France
timothee.kooyman@u-psud.fr

A sensitivity study on a set of evaluated criticality benchmarks with two versions of the JEFF nuclear data library, namely JEFF-3.1.2 and JEFF-3.2T, and ENDF/B-VII.1 was performed using MNCP(X) 2.6.0. As these benchmarks serve to estimate the Upper Safety Limit for criticality risk analysis at SCK•CEN the sensitivity of their results to nuclear data is an important parameter to asses. Several nuclides were identified as being responsible for a noticeable change in the effective multiplication factor k_{eff}: ^{235}U, ^{239}Pu, ^{240}Pu, ^{54}Fe, ^{56}Fe, ^{57}Fe and ^{208}Pb. A high sensitivity was found to the fission cross section of all the fissile material in the study. Additionally, a smaller sensitivity to capture cross section of ^{235}U and ^{240}Pu was also found. Sensitivity to the scattering law for non-fissile material was postulated. The biggest change in the k_{eff} due to non-fissile material was due to ^{208}Pb evaluation (±700pcm), followed by ^{56}Fe (±360pcm) for both versions of the JEFF library. Changes due to 235U (± 300pcm) and Pu isotopes (±120pcm for ^{239}Pu and ±80pcm for ^{240}Pu) were found only with JEFF3.1.2. ^{238}U was found to have no effect on the k_{eff}. Significant improvements were identified between the two versions of the JEFF library. No more differences were found between the JEFF-3.2T and the ENDF/B-VII.1 calculations involving ^{235}U or Pu.

JEFF evaluations: Status, development plans, and expectations from the CIELO initiative

R. Jacqmin

CEA, Commissariat à l'Energie Atomique, DEN, Reactor and Fuel Cycle Physics, Cadarache Bat.230, F-13108 Saint-Paul-lez-Durance, France.
robert.jacqmin@cea.fr

The JEFF development plans beyond the soon-to-be-released JEFF-3.2 file are discussed. Lessons learned from past evaluation and validation efforts are presented, as well as users' requests. These lessons and requests raise difficult issues regarding the improvements of JEFF-3 evaluations, including feasibility issues. The JEFF project contributes to the CIELO initiative with a double expectation: (i) building a consensus among experts on the quality of evaluated files corresponding to six selected "well-known" nuclides, and (ii) agreeing on best practices and on a realistic course of action for reconciling differences and improving the data.