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INDC International Nuclear Data Committee

Summary Report of the Consultants' Meeting on

EXFOR Data in Resonance Region and Spectrometer Response Function

IAEA Headquarters, Vienna, Austria

8 – 10 October 2013

Prepared by

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December 2013

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ABSTRACT

The Consultants' Meeting “EXFOR Data in Resonance Region and Spectrometer Response Function” was held at the IAEA Headquarters in Vienna from 8 to 10 October 2013. A summary of the presentations and discussions that took place during the meeting is reported here. The participants have agreed on recommendations on data reporting for EXFOR and on the need of documenting spectrometer response functions. Recommendations are given for experimentalists, for compilers, and for evaluators.

December 2013

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1. Introduction

A Consultants' Meeting on "EXFOR Data in Resonance Region and Spectrometer Response Function" was held at IAEA Headquarters, Vienna, Austria from 8 to10 October 2013. Seven consultants Y. Danon, K.H. Guber, F. Gunsing, A. Kimura, G. Noguere, P. Schillebeeckx and G. Žerovnik have attended this meeting. IAEA was represented by N. Otsuka, V. Semkova and S. Simakov. The list of participants and their affiliations are summarised in Appendix VIII.

The Meeting was organized in accordance with recommendations of the Consultants' Meeting on Further Development of EXFOR held from 6 to 9 March 2012 in Vienna (Summary Report INDC(NDS)-0614) to store sufficient information in EXFOR to allow meaningful re-evaluation of experimental data. In particular the importance of response and resolution functions of time-of-flight measurements for a correct analysis of the data was emphasised.

In the welcome address S. Simakov greeted participants of the Consultants Meeting on behalf of the Nuclear Data Section and Section Head, Robin Forrest, who was not able to attend. S. Simakov stressed the importance of collecting the primary observables (time-of-flight distributions for transmission, reaction yield etc.) and detailed information on spectrometers' set-up and response functions. It is especially needed in the resolved resonance energy range, where the experimental resolution broadening often exceeds the natural width of resonances. Up to now regrettably, the EXFOR database does not have such information which makes it difficult to use already available energy or time-of-flight dependent cross section data in further analysis and/or validation. He expressed a hope that experts participating in this meeting can significantly improve this situation by formulating the specific requirements for compilation of such data in EXFOR and by providing documentation of the response functions obtained at their facilities.

The participants elected P. Schillebeeckx as a Chairperson of the meeting and F. Gunsing as a Rapporteur. The agenda was discussed and adopted (see Appendix VII).

During three days participants gave presentations (are available on https://www-nds.iaea.org/index-meeting-crp/CM-RF-2013/) and had intensive discussions. The discussions resulted in the adoption of templates containing all essential experimental information for an analysis of a time-of-flight cross section data (Appendixes I-V) as well as consolidated conclusions and recommendations (see following Section).

The Nuclear Data Section acknowledged all participants for cooperation and contribution to this Meeting.

2. Participants summaries and recommendations

2.1 V. Semkova, IAEA-NDS, Objectives of the meeting

The purpose of the meeting is to discuss the compilation of neutron-induced reaction cross-section data in the resonance energy range in the EXFOR data library. Such data have been extensively compiled in EXFOR due to their importance in many fields of science and applications. However, the database contains mostly resonance parameters obtained after a complex analysis of experimental observables. To provide an optimum use of the results from the measurements in the resonance region it would be advisable to have the experimental observables such as neutron time-of-flight spectra, transmission, reaction yields etc. To properly evaluate the experimental observables from the time-of-flight (TOF) measurements requires knowledge of specific information in order to determine the spectrometers' response function of the particular experiment.

The template that has been developed for the compilation of measurements in the resonance region has proven to be an efficient tool for obtaining the essential experimental information. A review of the template will help to identify additional information that needs to be included in EXFOR files.

Examples of the methods of evaluation of spectrometers' response function applied at the major TOF facilities and the results from the analysis will allow the International Network of Nuclear Reaction Data Centres (NRDC) community to develop a proper format for compilation of observables from the TOF measurements. Compilation of the data in the resonance region according to the new requirements will be applied not only for future measurements but existing entries can also be revised if additional information is provided from experimentalists.

Complementary to the data obtained by conventional time-of-flight method are the results from lead slowing-down spectrometer (LSDS) measurements. Correct interpretation of the LSDS data requires additional information on the spectrometer resolution function as well. A new template for compilation of studies carried out by LSDS also needs to be developed.

The discussions and recommendations from the meeting will be included in a report. All relevant information will be collected and made available to the users through the webpage of the meeting http://www-nds.iaea.org/index-meeting-crp/CM-RF-2013/.

2.2 Y. Danon, RPI, USA - Nuclear Data Measurements at the RPI Gaerttner LINAC Center and EXFOR Reporting

A presentation on EXFOR reporting of resonance region nuclear data measurements at Rensselaer Polytechnic Institute was given. Previous EXFOR entries were usually submitted following a journal or thesis publication. The reported data included raw data such as transmission, capture yield or measured cross sections and also resonance parameters. The presentation included a description of experiments with a lead slowing-down spectrometer, and described the energy resolution and its experimental validation. Examples for previously submitted transmission and capture yield EXFOR entries were discussed. The resolution functions used for analysis of transmission and capture data in different energy regions were described. The resolution functions are implemented in the SAMMY code and were used to extract resonance parameters that were also submitted to EXFOR.

2.3 K. H. Guber, ORNL, USA - Neutron Cross-Section Measurements from ORELA

From 1969 to 2008, the Oak Ridge Electron Linear Accelerator (ORELA) produced numerous neutron-induced cross-section data. ORELA as a high-power white neutron source was ideally suited for experiments to measure neutron fission, total, (n,α), and capture cross sections in the energy range from thermal energies to as high as several MeV. The combination of short primary beam pulse width, small neutron production target and long flight path resulted in excellent time-of-flight resolution in the performed experiments. Thus resonances can be easily resolved and this helps to apply corrections for experimental effects by the data analysis programs, such as sample compositions or impurities and multiple scattering. In order to analyze the resonance data, all facility and experimental related information needs to be included. An important part is the so-called resolution or response function of the facility/experiment. In the case of ORELA experiments the resolution function consists of four parts: the target/moderator assembly, the beam pulse width, and the detector and binning of the data used in the experiment. Depending on the experiment different combinations of these four parts can be used. For example the neutron beam originates either from the tantalum target by itself or from the water moderator part and depending on the neutron energy range of interest a Li-glass or NE110 detector was used, respectively. The two reported detectors were used in transmission experiments but in studies it was found that the combination of water moderator with the Li glass can be used to describe even capture experiments at flight path seven using C_6D_6 detectors.

2.4 F. Gunsing, CEA Saclay, France - Generalities on the Time-of-flight Resolution Function

An outline of the principles of resolution broadening in neutron resonance spectroscopy was presented. The broadening components and the intrinsic widths of resonances are usually non-Gaussian and therefore need be taken into account by a full convolution of the corresponding distributions. In addition the time-of-flight to neutron energy calibration is dependent on the resolution function. Also long tails in the resolution function with an energy-dependent amplitude can introduce an energy-dependent normalization. An example of the several widths involved is shown for ^{232}Th at the n_TOF facility. For this facility results from Monte Carlo simulations of the resolution function are shown. An analytical function, the so-called RPI function, describing the simulations has been parameterized for the n_TOF facility and for the zero degree flight path of GELINA.

2.5 A. Kimura, JAEA, Japan - Neutron Capture Cross Section Measurements at ANNRI in J-PARC

In this presentation, the energy resolution of the pulsed neutron-beam of Accurate Neutron-Nucleus Reaction Measurement Instrument (ANNRI) at the Japan Proton Accelerator Research Complex (J-PARC) and, as examples of the measurements in ANNRI, the neutron capture cross sections measurements for ^{244}Cm and ^{246}Cm were reported.

The energy resolution was obtained by simulation with the Monte-Carlo code PHITS in the energy region from 0.7 meV to 1 MeV. Moreover, measurements have been done in the thermal and epithermal energies. The FWHM values of the time structures by the simulation and measurements are almost consistent. The obtained energy resolution of the pulsed neutron beam from ANNRI was confirmed.

The neutron capture cross sections of ^{244}Cm and ^{246}Cm were measured in the neutron energy range of 1–300 eV at ANNRI. The measured cross sections were obtained by normalizing the relative yields to the values in JENDL-4.0 at the first resonance of ^{240}Pu. The uncertainties of the obtained cross sections were analysed and reported for contributions from several sources. The energy independent uncertainties were 5.5% for ^{244}Cm and 5.9% for ^{246}Cm.

2.6 G. Noguere, CEA Cadarache, France - Analytical Model of the Time Resolution for Neutron Resonance Shape Analysis

The determination of reliable resonance parameters from neutron time-of-flight data requires an accurate description of the time resolution of the facility as a function of neutron energy. The time-of-flight of a neutron has a distribution in time (or equivalently in distance) called the resolution function. Several analytical treatments are available in the shape analysis codes SAMMY, REFIT and CONRAD. The presentation gives a short description of the analytic treatment available in the REFIT code, developed by M. Moxon and currently in use for modeling of the resolution function of the GEel LINear Accelerator GELINA of the Institute for Reference Materials and Measurements (IRMM, Geel, Belgium). Five main processes are taken into account. The channel width (time binning) and the initial burst of neutrons can be expressed in term of time-of-flight uncertainty Δt. The target-moderator assembly, the angle of the flight path with respect to the moderator surface and the detector (in the case of transmission measurements) introduce an uncertainty ΔL on the flight path length L. Parameters of the analytical resolution function are adjusted on probability density functions calculated by Monte-Carlo simulations. The good agreement between the numerical and analytical resolution function is illustrated with iron data measured at the GELINA facility.

2.7 P. Schillebeeckx, EC-JRC-IRMM Response Function of time-of-flight Spectrometers

The basic principles of the time-of-flight technique were explained. For neutron spectroscopy applications the response function of the time-of-flight spectrometer $R(t_m,E_n)$ is required. This response function is the probability that a neutron with energy E_n is observed at a time-of-flight t_m. It depends on different components: the finite duration of the charged particle beam, the neutron transport in the neutron producing target/moderator assembly, the neutron transport in the neutron detector and the time resolution of the detector and electronics. For measurements at a moderated neutron beam the time t_t that the neutron spends in the target/moderator assembly is the dominant contribution. The probability distribution $R(t_t,E)$ of this component strongly depends on the energy of the neutron. Response functions of time-of-flight spectrometers can be more conveniently represented by introducing an equivalent distant defined by $L_t = v\, t_t$, with v the velocity of the neutron. Applying a transformation of variables, results in probability distributions which are less dependent on the neutron energy and more adequate in case interpolations are required. Therefore, it is recommended to store numerical response functions as a function of the equivalent distance.

2.8 P. Schillebeeckx, EC-JRC-IRMM Reporting of Experimental Observables Obtained from Measurements at TOF - Facilities

In this contribution it was stressed that cross sections can only be derived from experimental data by application of a model. In the case of the resonance region, both the resolved and unresolved region, resonance parameters are derived by a least squares adjustment to experimental data. Such an adjustment requires a theoretical estimator of the experimental observable. Its calculation requires a theoretical model that includes both a nuclear reaction formalism (i.e. R-matrix theory) and models to account for various experimental effects such as the response function of the time-of-flight spectrometer, and the sample and detector characteristics. Therefore, to derive accurate nuclear model parameters, i.e. resonance parameters, including reliable covariance information well documented experimental data are required. The documentation includes the full details of the experiment. In addition, the main uncertainty components have to be identified and the correlated and uncorrelated components have to be reported separately, preferably based on the AGS-concept.

References:

[1] B. Becker et al., "Data reduction and uncertainty propagation of time-of-flight spectra with AGS", Journal of Instrumentation **7** (2012) P11002

2.9 G. Žerovnik, JSI, Slovenia, Use of the Grenoble Lead Slowing-down Experiment for Cross Section Validation

In principle the lead slowing-down spectrometer can provide experimental information which is complementary to the information obtained from energy dependent cross section data and integral experiments. Measurements of the gamma detector response as a function of time-of-flight, which can be used for capture cross section validation, have been performed at the INS Grenoble. Configuration with no sample (only background) and several configurations including samples have been analyzed using the MCNP5 code. So far, the lead slowing-down spectrometer has been successfully used in the process of Au-197 evaluation for JEFF-3.2 library, where the limit between the resolved and unresolved resonance region has been shifted from 5 keV to 2 keV. Also, the results from the spectrometer have been used for improvement of the Mn-55 evaluation starting from the ENDF/B-VII.0 library.

2.10 N. Otsuka, IAEA-NDS, Time-of-Flight Spectra in EXFOR

The EXFOR Format allows us to compile time-of-flight spectra (e.g., transmission, reaction yield) and quantities derived from the spectra (e.g., resonance parameters, cross sections) in the EXFOR library. These data have been compiled by the International Network of Nuclear Reaction Data Centres (NRDC) according to the geographical responsibility (e.g., compilation of data from LANSCE, ORELA, RPI by NNDC). Though time-of-flight spectra are valuable for future analysis (reanalysis, simultaneous analysis) and compilation of them has been desired for many decades [1,2], there are many EXFOR entries where only resonance parameters are compiled without the corresponding time-of-flight spectra. There could be several reasons, e.g., manpower for preparation of numerical data tables for submission to data centres, potential danger from improper use of data submitted to EXFOR.

Addition of sufficient experimental details to each time-of-flight spectrum is a key for proper use of the data set, and IAEA NDS has developed a template for data submission in collaboration with EC-JRC IRMM, and further improvement of the template in this Consultants’ Meeting is expected. Separation of the uncorrelated uncertainty from the total uncertainty is also essential for proper least-squares analysis of time-of-flight spectra, and experimentalists are encouraged to submit uncorrelated uncertainty separately from the total uncertainty or correlated uncertainty. Compilation of response (resolution) functions R(E,t) is a new issue for NRDC. It is not a trivial issue to include them in the current EXFOR Format, and it would be feasible to start collection of resolution functions submitted by the participants of the Consultant Meeting on the web page of the IAEA NDS (e.g., http://www-nds.iaea.org/index-meeting-crp/CM-RF-2013/).

Fission cross sections measured by lead slowing-down time spectrometers (LSDS) in RPI (USA), KURRI (Japan) and INR (Russia) have been utilized for validation of evaluated data libraries, and they have been compiled in EXFOR. Experimental LSDS cross sections can be utilised only when the resolution functions of the LSDS are available [3], and IAEA NDS is collecting resolution functions to make these EXFOR entries useful for validation.

References:

[1] K.H. Boeckhoff (ed.), Proc. of a Specialists' Meeting on Neutron Data of Structural Materials for Fast Reactors, Geel, Belgium, 5-8 December, 1977, Pergamon Press, Oxford, pp. 789 - 802 (1977).

[2] P. Johnston (ed.), "Summary record of the third meeting of nuclear reaction data centres, Paris, France, 19-23 June 1978", INDC(NDS)-99, OECD Nuclear Energy Agency (1978).

[3] T. Nakagawa, O. Iwamoto, Report JAERI-Data/Code-2002-02, JAERI (2002).

2.11 S.P. Simakov, IAEA-NDS, Response Function of the Fast Neutron Time-of-flight Spectrometer

S. Simakov, NDS/IAEA, has reported the results of investigation of response functions for two fast neutron Time-of-Flight (TOF) spectrometers at Institute for Physics and Power Engineering (IPPE) in Obninsk, Russian Federation. One of them was used to measure the double differential cross section (DDX) for (n,n′) and (n,xn) reactions employing electrostatic tandem accelerator and gaseous tritium target to produce mono energetic neutrons between 4.8 and 8.5 MeV and at 20.1 MeV. Another spectrometer was employed to measure DDX for (n,xn) and (n,n′γ) reactions at 14 MeV incident energy making use of pulsed deuteron klystron accelerator KG-0.3. The latter facility was also utilized for measurement of neutron leakage spectra from spherical assembles with T(d,n) and ^{252}Cf sources. The measured DDX were submitted to EXFOR, whereas the leakage data - to SINBAD.

The most challenging problem related to the resolution function in the TOF spectrometry of the secondary fast neutrons is the separation of the elastic peak, which is extremely large at forward angles. The reported study on spectrometer response functions included the results of measurements of neutron spectra from bare neutron sources and of the shape of elastically scattered neutrons from enriched ^{208}Pb sample. The measurements were supplemented by detailed Monte Carlo simulation of experimental facilities including target assembly, neutron collimator, detector and its shielding. These simulations however failed to fully reproduce the shape of response function. Due to this reason the energy profile measured with bare neutron source or ^{208}Pb sample were recognised as the best approximation for the response function. After separation of elastically scattered neutrons, the DDX for secondary neutron emission spectra were submitted to EXFOR.

For the purpose of validation of evaluated or theoretical data against measured DDX, the excitation cross sections for discrete levels in the reaction residual can be folded with symmetric Gaussian distribution. Its width is calculated from spectrometer time resolution and flight path uncertainty following the standard equations for TOF method. This approximation is valid for studied nuclei because of the relatively large density of exited levels and moderate spectrometer resolution.

3. Summary of the discussions

EXFOR is nowadays well recognized as the centralized database where measured experimental nuclear reaction data should be stored for future use. The numerical data stored in EXFOR are usually not available in the associated reports and papers. The basic measured or pre-processed data for a typical measurement are a set of detector count spectra as a function of time-of-flight. Usually these spectra are then processed in order to obtain a reaction yield (or transmission), which can then be used by a R-matrix analysis code for analysis. Since these quantities are the basis for further analysis it makes sense to report data primarily as two columns with time-of-flight –yield (or transmission) pairs. Typical time-of-flight spectra easily contain a number of channels in the order of several tens of thousands.

The process of the reduction of several independent uncorrelated measured spectra to a single reaction yield (or transmission), introduces off-diagonal covariance elements. The AGS system provides a way to store the full covariance matrix with a limited number of additional columns that can easily be reported.

For the practical use of EXFOR, for inter-data comparisons and for input for some analysis codes, reporting energies is mandatory in the EXFOR format. Therefore, it is convenient to report approximate neutron energies in addition to time-of-flight. The time-of-flight to energy conversion, which cannot be done with a single fixed flight length since it depends also on the energy dependence of the response function (RF), needs in that case to be explained.

Some EXFOR entries report a cross section instead of a yield. The conversion from yield to cross section is only straightforward in case the resolution broadening is neglected and for very thin samples, as for example used in fission experiments which do not suffer from self-shielding and multiple interaction effects. In total up to 18 columns are allowed by the EXFOR format to report a measurement. It is recommended to report additional information like the neutron flux as well.

The response function $R(t_m,E)$ of a time-of-flight facility or slowing-down spectrometer is defined as the response in observed time-of-flight t_m of the spectrometer for a neutron of energy E_n. The distribution in time-of-flight t_m for a given energy E_n can equivalently be expressed in a distribution of time or in distance. Usually the distribution of equivalent distance shows only slow variation as a function of E_n and is therefore preferred for visual representations and in case interpolation is required. For some types of measurements the RF is of great importance for the interpretation of the data in terms of underlying physical quantities. This is especially the case for resolved resonances, where the RF, together with Doppler broadening, alters the intrinsic shape of the resonances, which are described by a set of resonance parameters. The knowledge of the RF is therefore essential for any future exploitation of the data contained in EXFOR. For other types of data, for example fast neutron-cross sections, the RF plays a less important role and where necessary a more approximate modelling is usually sufficient.

The RF is often decomposed in a number of independent contributions:

- the distribution of the pulsed charged particle beam, serving as a start of the time-of-flight measurement
- the neutron producing target and moderator ensemble
- interactions in the sample and detector ensemble
- electronic noise from the signal processing and data acquisition system

- the widths of the data binning.

The analysis code performs the convolution of these components with the intrinsic resonance shape.

The contribution from the target/moderator ensemble, as observed at the position of the sample to be measured, is often common to many experiments. For this reason a centralized repository related to EXFOR is a convenient way to store RFs which can be referred to from EXFOR entries. While a parameterized analytical function may in some cases be an adequate description of a RF, nowadays Monte Carlo simulations can provide the RF in a detailed way. Storage of the RF in numerical form or possibly even as input file for a Monte Carlo description or R-matrix analysis codes would preserve this information in a sustainable way.

The remaining components are usually specific for a typical data set. The distribution of the pulsed charged particle beam may be characterized by a numerical distribution, but often a typical distribution, (Gaussian, uniform, etc.) and a characteristic parameter is sufficient. Electronic jitter is usually negligible but can be easily lumped together into the charged particle beam distribution. In case of a reaction cross section experiment, the contribution due to the sample can be neglected in most cases. The contribution of the detector is important for example for scattering experiments or transmission measurements with a thick in–beam detector. A numerical form or an analytical modelling may be given either in the data entry or in the repository. The broadening contribution due to the binning of the data can be given explicitly in a concise way, even if the data itself contain the binning information as well.

Finally it is important to note that the RF, in particular the target/moderator ensemble, is subject to improvements with the availability of, for example, updated simulations. Therefore any description of the RF is welcome to start with; however a description of the geometry is also important and should be given in separate referenceable documentation.

The participants of the present CM will put efforts in supplying a useful description of the RF of the facilities they use to the repository. They will also encourage the relevant nuclear data communities to use the EXFOR templates for data reporting.

4. List of Recommendations

Several points have come up during the discussions and are summarized here as a list of recommendations.

4.1 Recommendations for NDS of IAEA, NRDC and EXFOR compilers

- Set up and maintain a repository where information on response functions of different facilities can be collected.
- No constraints on the format of response and resolution function should be given, but an implementation in existing codes (e.g., CONRAD, REFIT, SAMMY) could be supplied when possible.
- The repository should foresee support for 2-dimensional histograms to report numerical response functions $R(t_m,E_n)$ (or in equivalent distance) as a function of time-of-flight and real neutron energy.
- NDS should inform the NRDC Network about decisions of the meeting in order to establish rules for compilation of all information relevant to the spectrometers' response function.
- Compilers should send a request to authors to provide information according to the template and include all data in the compilation of the experiment.

4.2 Recommendations for experimentalists

- It is strongly recommended that the data are reported in measured time-of-flight in addition to the required derived neutron energy, and as a measured reaction yield or transmission instead of cross section. The data may also include the region around the gamma-flash, which is valuable experimental information for time calibration purposes and background determination. Since an equivalent neutron energy for a time-of-flight smaller than the one corresponding to the gamma-flash is unphysical and since a numerical value for the energy is mandatory, one could adopt a negative value like -1.0 as an indication.
- If covariances due to data reduction are significant, reporting of additional uncertainty columns allows reconstructing the full covariance matrix, preferably as implemented in AGS.
- A minimum requirement is to distinguish between the total uncertainty and the uncorrelated uncertainty component and report them separately.
- Add the derived neutron energies for EXFOR for use in data set comparisons. Specify how the energy was calculated from the TOF.
- Use the 18 available columns for data reporting to document additional quantities of interest like the used neutron flux distribution and correction factors depending on energy.
- Report the applicable response function to be used with the data. Separate the components of the RF. Mention the experiment-specific components as the contribution of the pulsed charged particle beam, the sample/detector contribution, the binning contribution, in the EXFOR entry for the experiment. Use a reference to the repository for the target/moderator component if it exists, or submit this component for inclusion.
- Use the templates as a guideline for the information to be supplied, and leave fields empty when not appropriate.
- Give feedback to EXFOR when the template is insufficient for the data you want to report.

4.3 Recommendations for evaluators

- Be aware that especially for older entries a cross section may be given which in reality is a reaction yield or the natural logarithm of the transmission divided by the areal density.
- Give feedback to EXFOR when errors or inconsistencies are found.

4.4 Templates for data

As a guide for these recommendations, templates for reporting time-of-flight data and for reporting neutron spectrometer response functions are given on the website. These templates are regularly updated to account for user feedback. As an example some templates are given in this document. For data submission to EXFOR, the user is directed to the website for adequate templates.

Remarks to authors:

1. The maximum total number of columns is **18**.
2. Definitions of the 1st to 6th columns are fixed and they are obligatory fields.
3. The 7th to 18th columns may depend on authors, and must be filled by authors.

4. The numerical data must be FORTRAN-readable using a floating-point format (See EXFOR Formats Manual).

   FORTRAN-readable according to a floating-point format means, in detail:

   - A decimal point is always present, even for integers.
   - A decimal number without an exponent can have any position within the 11-character field.
   - No blank is allowed following a sign (+ or -).
   - A plus sign may be omitted, except that of an exponent when there is no E.
     In an exponential notation, the exponent is right adjusted within the 11-character field. The mantissa may have any position. The values are either zero or have absolute values between 1.0000E-38 and 9.999E+38.
   - The following table contains examples of valid entries:

Fixed point numbers with a decimal point	**Floating point numbers with an Exponent**	
0.14	+0.014E+01	1.4-1
0.14	0.0014E+2	1.4E-1
0.14	0.0014E2	1.40 E-01
+0.14	.0014E+2	
-0.14	-0.140E+00	
-.14	-.14E0	

APPENDIX I

Template for Submission of Time-of-Flight Spectra (EXFOR 28881.002)

A. EXPERIMENT DESCRIPTION

1. Main Reference		[1,2]
2. Facility	GELINA	[3]
3. Neutron production		
Neutron production beam	Electron	
Nominal average beam energy	100 MeV	
Nominal average peak current	70 µA	
Repetition rate (pulses per second)	800 Hz	
Pulse width	1 ns	
Primary neutron production target	Mercury cooled depleted uranium	
Target nominal neutron production intensity	3.4 x 10^{13} s^{-1}	
4. Moderator		
Primary neutron source position in moderator	Above and below uranium target	
Moderator material	2 H_2O filled Be-containers around U-target	
Moderator dimensions (internal) (thickness, height×width×depth,…)	2 x (14.6 cm x 21 cm x 3.9 cm)	
Density (moderator material)	1 g/cm^3	
Temperature (K)	Room temperature	
Moderator-room decoupler (Cd, B, …)	None	
5. Other experimental details		
Measurement type	Transmission	
Method (total energy, total absorption, …)	Good transmission geometry	[4]
Flight path length (m) (moderator –detector)	L = 49.3445 m	
Flight path direction	9° with respect to normal of the moderator face viewing the flight path	
Neutron beam dimensions at sample position (mm × mm, diameter in mm, …)	35 mm in diameter	
Neutron beam profile	-	
Overlap suppression (Filter material and thickness, chopper, …)	^{10}B overlap filter (0.008 at/b)	
Other fixed beam filters	Na, Co, Pb (8 mm)	
6. Detector		
Type	Scintillator (NE912)	
Material	Li-glass	
Surface Dimensions (mm × mm. diameter in mm, …)	101.6 mm in diameter	
Thickness (mm)	6.35 mm in thick	
Distance from sample (m)	25 m	
Detector(s) position relative to neutron beam	In the beam	
Detector(s) solid angle	-	
7. Sample		
Type (metal, powder, liquid, crystal)	Metal	
Chemical composition	^{197}Au (100%)	
Sample composition (at/b)	^{197}Au: (1.757 ± 0.004) x 10^{-2} at/b	
Temperature	22° C	
Sample mass (g)	-	
Geometrical shape (cylinder, sphere, …)	Foil	
Surface dimension (mm × mm, diameter in mm, …)	50 mm x 50 mm	
Nominal thickness (mm)	3 mm	
Containment description	None	
Additional comment	Stack of 2 foils and 1 disc	
8. Data Reduction Procedure		[4, 5]
Dead time correction	Done (< factor 1.2)	
Back ground subtraction	Black resonance technique	
Flux determination (reference reaction, …)	-	
Normalization	1.0000 ± 0.0025	
Detector efficiency	-	

Self-shielding	-	
Time-of-flight binning	Zone length bin width 1024 4 ns 1024 2 ns 4096 1 ns 5120 2 ns 5120 4 ns 5120 8 ns 5120 16 ns 5120 32 ns 5120 64 ns 5120 128 ns	
9. Response function		
Initial pulse	Normal distribution, FWHM = 2 ns	
Target / moderator assembly	Numerical distribution from MC simulations entry RF.NNNN1	[6, 7]
Detector	Analytical function defined in REFIT manual entry RF.NNNN2	[8]

B. DATA FORMAT

Column	Content	Unit	Comment
1	Energy	eV	Relativistic relation using a fixed FP length of 49.345 m and average TOF
2	t_l	ns	
3	t_h	ns	
4	T_{exp}		Transmission
5	Total Uncertainty		
6	Uncorrelated uncertainty		Uncorrelated uncertainty due to counting statistics
7	AGS-vector (K)		Background model (u_K/K = 3%)
8	AGS-vector (N)		Normalization (u_N/N = 0.25%)

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APPENDIX II

Template for Submission of Time-of-Flight Spectra (EXFOR 23141.003)

Edited by IAEA Nuclear Data Section (Rev., 11 October 2013)

A. EXPERIMENT DESCRIPTION

1. Main Reference		[1]
2. Facility	ANNRI	[2-4]
3. Neutron production		[5]
Neutron production beam	Proton	
Nominal beam energy	3 GeV	
Repetition rate (pulse/sec)		
Pulse width	Two bunches, each with a width of 100 ns, at intervals of 600 ns	[5]
Pulse frequency	25 Hz	
Nominal beam power	120 kW	[4]
Primary neutron production target	Mercury	
Neutron source position in moderator		
4. Moderator		
Material	Para H	
Dimension (thickness, height×width×depth,…)	140 mm thick	
Mass		
Temperature (K)	19.7 K	
Target nominal neutron production intensity (n/sec)	$0.6x10^{8}$(n/sec/cm^{2})@ the moderator surface (120kW).	
Moderator-room decoupler (Cd, B, …)		
5. Other experimental details		
Measurement type	Capture	
Method (total energy, total absorption, …)	Total energy (PHWT)	
Flight path length (m) (moderator – target (detector): face to face distance)	21.502 ± 0.005 m	
Flight path angle with respect to moderator surface	0 deg	
Neutron beam dimensions at sample position (mm × mm, diameter in mm, …)	Diameter of 7 mm	
Neutron beam profile		
Overlap suppression (Filter material and thickness, chopper, …)	Not Used	
Other fixed beam filters	Not Used	
6. Detector		[3]
Type	Ge detectors. (An array consists of 14 Ge crystals and BGO Anti-Compton shield.)	
Material	Ge	
Surface Dimensions (mm × mm. diameter in mm, …)		
Detector(s) angle with respect to neutron beam line		
Detector(s) solid angle		
Thickness (mm)		
Distance from samples (mm)	125 mm	
7. Sample		
Type (metal, powder, liquid, crystal)	curium oxide and aluminium powder mixture	
Chemical composition	CmO_2	
Sample composition (at/b)	^{244}Cm (90.1 mole%), ^{245}Cm (2.71 mole%), ^{246}Cm (7.22 mole%)	
Temperature	Room Temperature	
Sample mass (g)	0.6 mg	
Geometrical shape (cylinder, sphere, …)	cylinder	
Surface dimension (mm × mm, diameter in mm, …)	5 mm in diam	
Nominal thickness (mm)		

Containment description	Sealed in an Al case (9 mm in outer diam., 280 mg, 0.5 mm-thick walls)	
Additional comment		
10. Data Reduction Procedure		
Dead time correction		
Back ground subtraction	^{10}B(n,$\alpha_1\gamma$)	
Flux determination (reference reaction, …)	1.1 eV resonance of Pu-240 (JENDL-4.0).	
Normalization	Assumed as a constant.	
Detector efficiency		
Self-shielding	1 ch, last ch, 1 μsec	
Time-of-flight binning	INDC(NDS)-0647	
(initial channel, final channel, bin width) or		
(number of bins per time or energy decade)		
Additional comment		
8. Response/Resolution function	$\langle E\rangle = (72.3 \langle L\rangle/t)^2$ with $\langle L\rangle$=21.502 m, t in μsec, E in eV.	
Mean energy-time correspondence		
Analytic form	See section A.3.	
Initial pulse	entry RF.NNNN1	
Target / moderator assembly	entry RF.NNNN2	
Detector	5000 log-equidistant bins per energy decade	
Binning		

References

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B. DATA FORMAT

Column	Content		Unit
1	Energy	See Section A.9.	eV
N/A	TOF$_{min}$		ns
N/A	TOF$_{max}$		ns
2	Observable	Capture cross section (yield corrected for self-shielding / area density)	b
3	Uncertainty (1σ)	Total uncertainty	b
4		Unc. due to contribution of capture events by other nuclei (uncorrelated)	b
5		Unc. due to contribution of fission events (uncorrelated)	b
6		Unc. due to counting statistics (uncorrelated)	b
7		Unc. due to corrections of self-shielding and multiple scattering (uncorrelated)	b
8		Other uncertainty (neutron flux, contaminations of scattered events, dead-time correction; partially correlated)	b
Const.		Unc. due to ^{240}Pu abundance (fully correlated)	4.4%
Const.		Unc. due to ^{240}Pu resonance parameter (fully correlated)	2.2%
Const.		Unc. due to difference in efficiency between ^{240}Pu and ^{244}Cm (fully correlated)	2.4%

Additional comments from authors:

- The cross sections were obtained by normalizing the relative cross sections to the values in JENDL-4.0 at the first resonance of ^{240}Pu.

APPENDIX III

Template for Submission Lead Slowing-Down Spectrometers Data (EXFOR 13197.002)

Edited by IAEA Nuclear Data Section (Rev., 11 October 2013)

A. EXPERIMENT DESCRIPTION

1. Main Reference		[1]
2. Facility	RINS	
3. Neutron production		
Neutron production beam	Electron	
Nominal beam energy	55 MeV	
Repetition rate (pulse/sec)	90 pulse/sec	
Pulse width	0.2 µs	
Pulse frequency		
Nominal beam power		
Primary neutron production target	Tantalum	
Neutron source position in moderator	Centre of lead block	
4. Moderator		
Material	Natural Pb (99.99?% pure)	
Dimension (thickness, height×width×depth,…)	180 cm × 180 cm × 180 cm	
Mass	~ 66 metric tons	
Temperature (K)		
Target nominal neutron production intensity (n/sec)		
Moderator-room decoupler (Cd, B, …)	Cd	
5. Other experimental details		
Measurement type	Fission	
Method (total energy, total absorption, …)		
Flight path length (m) (moderator – target (detector): face to face distance)		
Flight path angle with respect to moderator surface		
Neutron beam dimensions at sample position (mm × mm, diameter in mm, …)		
Neutron beam profile		
Overlap suppression (Filter material and thickness, chopper, …)		
Other fixed beam filters		
6. Detector		
Type	Multi-sample hemisphere fission chamber	
Material	Ge	
Surface Dimensions (mm × mm. diameter in mm, …)		
Detector(s) angle with respect to neutron beam line		
Detector(s) solid angle		
Thickness (mm)		
Distance from samples (mm)	In detector	
7. Sample		
Type (metal, powder, liquid, crystal)		
Chemical composition		
Sample composition (at/b)		
Temperature		
Sample mass (g)	3.160 ±0.024 µg	
Geometrical shape (cylinder, sphere, …)		
Surface dimension (mm × mm, diameter in mm, …)		
Nominal thickness (mm)		
Containment description		
Additional comment		
8. Data Reduction Procedure		

Dead time correction	Done	
Back ground subtraction	Spontaneous-fission background, time-independent background	
Flux determination (reference reaction, …)	MCNP simulation validated with ^{235}U(n,f) $\varphi(E)=E^{0.776}\exp[-(0.214/E)^{1/2}]$, E in eV	
Normalization	^{235}U(n,f) with 4% uncertainty	
Detector efficiency	Assumed as a constant of energy	
Self-shielding	Negligible	
Time-of-flight binning (initial channel, final channel, bin width) or (number of bins per time or energy decade)		
Additional comment		
9. Response/Resolution function	INDC(NDS)-0647 p. 20	
Mean energy-time correspondence	$\langle E \rangle = 165000 / (t + 0.3)^2$ with t in μsec, E in eV	
Analytic form	Gaussian, $\Delta E(\mathrm{FWHM})/E=$ $(0.0835+0.128E^{-1}+3.05\times10^{-5}E)^{1/2}$	
Initial pulse		
Target / moderator assembly		
Detector		
Binning		

References

[1] Y. Danon et al., Nucl. Sci. Eng. **109** (1991) 341.

B. DATA FORMAT

Column	**Content**		**Unit**
1	Energy	Mean energy. See section 9.	eV
N/A	TOF$_{min}$		ns
N/A	TOF$_{max}$		ns
2	Observable	LSDS averaged cross section	b
3	Uncertainty (1σ)	Total uncertainty (due to fission counting efficiency, number of atoms in sample, neutron flux normalization, counting statistics)	b
4			%
5			%
6			%
7			%
8			%
Const.			%
Const.			%
Const.			%

Additional comments from authors:

- None

APPENDIX IV

Template for Submission of LSDS Data for Validation

Edited by IAEA Nuclear Data Section (Rev., 11 October 2013)

A. EXPERIMENT DESCRIPTION

1. Main Reference		[1,2]
2. Facility	LSDS at Inst. Sciences Nucléaires Grenoble	[1,2]
3. Neutron production		[1]
Neutron production beam	Deuteron	
Nominal beam energy	250 keV	
Pulse width	1000 ns	[1]
Pulse shape	no data (assumed as uniform)	
Neutron source angular distribution	assumed as isotropic	
Neutron source energy	14.1 MeV	
Neutron source energy width	~ 1 keV	
Neutron source spectrum	assumed as Gaussian	
Primary neutron production target	Tritium	[1]
Neutron source position in moderator	Centre of lead block	
4. Moderator		
Material	Natural lead (99.99% pure)	
Dimension (thickness, height × width × depth,…)	160 cm × 160 cm × 160 cm	[1]
Mass	46.5 metric tons	[1]
Moderator-room decoupler (Cd, B, …)	Cd (0.5 mm thick)	
5. Other experimental details		
Measurement type	capture	
6. Detector		
Type	scintillator	
Material	CeF_3	
Surface Dimensions (mm × mm. diameter in mm, …)	20 mm × 20 mm	
Distance from samples (mm)	Adjacent (~0 mm)	
7. Sample		
Type (metal, powder, liquid, crystal)	metal	
Chemical composition	Elemental Au	
Sample composition (at/b)	100% ^{197}Au (no information on impurities)	
Temperature	Room temperature	
Nominal sample mass (g)	0.965 g	
Geometrical shape (cylinder, sphere, …)	Foil (cuboid)	
Surface dimension (mm × mm, diameter in mm, …)	20 mm × 20 mm	
Thickness (mm)	0.125 mm	
Containment description	Not available	
Additional comment		
8. Data Reduction Procedure		
Dead time correction	Done	
Back ground subtraction	Separately measured and provided for analysis	
Flux determination (reference reaction, …)	Not applied	
Normalization	Beam intensity	
Detector efficiency	Not corrected	
Self-shielding	Not applied	
9. Response/Resolution function		
Mean energy-time correspondence	$E = K / (t + t_0)^2$ $K = 1.65 \times 10^{-11}$ eV s^2 $t_0 = 0$	

References

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[2] L. Perrot, Doctoral thesis, l’Université Joseph Fourier – Grenoble I, 2001 (in French).

B. DATA FORMAT

Column	Content		Unit
N/A	Energy		eV
1	TOF_{min}		μs
2	TOF_{max}		μs
3	Observable	Detector response	cts/s
3	Uncertainty (1σ)	Total experimental uncertainty	cts/s
4		Uncertainty due to normalization	cts/s
Const.			

Additional comments from authors:

- . Constants K and t_0 are approximate! Same values have to be used when transforming measured and calculated TOF response for comparison in the energy scale! Simulation has to be done in time domain!
- More experimental details can be found in the MCNP input. Full MCNP input is available.
- High gamma background – measurement with no sample has to be subtracted.

APPENDIX V

Template for the repository of target/moderator resolution of a facility

Edited by IAEA Nuclear Data Section (Rev., 11 October 2013)

A. RESOLUTION FUNCTION

1. Main Reference		
2. Facility	n_TOF at CERN	
3. Target/moderator setup	Pb spallation target with water cooling	
4. Period of useage	phase I, years 2000-2004	
5. Comments	This RF has been superseded by more precise simulated simulations, entry ZZZ.	
6. Analytical expression	''RPI function'' and energy dependent parameters detailed in reference.	
7. References	SAMMY v8.0 manual, report ORNL/TM-9179/R8, ENDF-364/R2	
8. Implementation in code SAMMY		

```
Below is nTOF resolution function 1 eV - 1 MeV presented as an input for the SAMMY code.

# nTOF resolution function 1 eV - 1 MeV
RPI RESOLUTION FUNCTION parameters follow
TAU  00000         0         0         0         0   -3.7004 -684.3900   -0.5189
TAU
LAMBD00000    3.8457         0         0  502.9930   -0.4155
LAMBD
A1   00000   -0.0381 9.974e-06  -0.01172 0.0001019   0.05009         0         0
A1
EXPON00000         0       1.0         0      -1.0         0
EXPON
A3   00000         0         0         0         0-0.0001689 0.0004254  -0.06043
A3     2
A5                 0         0         0         0 0.0002766         0         0
A5     2
```

Resolution functions for the lead slowing-down spectrometers (E in eV). $\varphi(E)$ = LN and TN are for lognormal and truncated normal distribution (See also Ref. [1])

EXFOR	Target	Ref.	E_{min}	E_{max}	$\Delta E_{FWHM}/E$	$\varphi(E)$	Plot
12788.002	^{244}Cm	[2]	1.4-1	8.0+4	$(0.0746+0.130E^{-1}+2.52\times10^{-5}E)^{1/2}$	?	RPI1
12788.003	^{246}Cm	[2]	1.4-1	8.0+4			
12788.004	^{248}Cm	[2]	1.4-1	8.0+4			
12991.002	^{242}Cm	[3]	1.1-1	9.8+4			
12991.004	^{238}Pu	[3]	1.0-1	9.8+4			
13197.002	^{247}Cm	[4]	1.2-1	9.8+4	$(0.0835+0.128E^{-1}+3.05\times10^{-5}E)^{1/2}$	?	RPI2
22422.005	^{243}Am	[6]	5.6-2	7.9+3	$0.162899E^{-1/2}+0.352787+7.599\times10^{-5}E$ Note that a factor E is missing in p101 of [1] (informed by T. Nakagawa in 10 Dec. 2012).	?	KUR1
22479.002	^{241}Am	[7]	9.5-2	1.1+4			
22644.003	^{242m}Am	[8]	2.8-2	1.3+4			
22647.003	^{231}Pa	[9]	8.9-2	1.3+4			
22647.004	^{229}Th	[9]	1.3-2	1.0+4			
22731.002	^{237}Np	[10]	1.1+0	4.6+3			
22858.003	^{237}Np	[11]	1.5-1	1.3+3			
23186.002	^{237}Np	[12]	1.0-1	2.2+3	$(0.111+0.214E^{-1}+0.003\,E^{1/2})^{1/2}$ Fitting performed by K. Hirose to Table 3 (exp. data) of [5].	LN	KUR2
23186.003	^{242m}Am	[12]	1.0-1	2.2+3			
23186.004	^{245}Cm	[12]	1.0-1	2.2+3			
41503.003	^{236}U	[13]	1.1+0	1.9+4	$(0.30^2+3\times10^{-5}\,E+0.025/E)^{1/2}$	TN	INR1
41523.002	^{242m}Am	[14]	2.9-2	2.1+4	$2.345(0.132^2+7.5\times10^{-5}\,E+0.044/E)^{1/2}$ These parameters were determined for ^{235}U and ^{239}Pu [15]. No detailed analysis was done for ^{242m}Am and ^{245}Cm.		INR2
41523.004	^{245}Cm	[14]	2.8-2	2.1+4			
41524.002	^{244}Cm	[16]	7.4-2	2.3+4	$(0.308^2+1.1\times10^{-4}\,E+0.24/E)^{1/2}$		INR3
41578.002	^{243}Am	[17]	3.0-1	8.7+3	$(0.33^2+1.1\times10^{-4}\,E+0.178/E)^{1/2}$		INR4
41532.002	^{243}Cm	[18]	3.1-2	1.4+4	The parameters were not determined.		
41533.002	^{246}Cm	[19]	1.4-1	2.1+4	$(0.32^2+1.1\times10^{-4}\,E+0.178/E)^{1/2}$ These parameters are given in [20].		INR5
41533.007	^{247}Cm	[19]	3.0-2	2.0+4			
41533.008	^{248}Cm	[19]	1.2-1	2.1+4			

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Consultants' Meeting on

"**EXFOR data in resonance region and spectrometer's response function**"

8-10 October 2013

VIC, Room M0E59, IAEA Headquarters, Vienna, Austria

AGENDA

Tuesday, 8 October 2013

09:30 -10:45	**Opening Session** Welcome address **(Stanislav Simakov)** Self-introduction of **Participants** Election of **Chairperson and Rapporteur** Approval of Agenda Administrative Announcements **(Alexander Oechs)** Objectives of the Meeting (**Valentina Semkova)**

Presentations
(presentations' time include questions and discussion)

11:00-11:30	**Naohiko Otsuka, IAEA-NDS** "Time-of-flight spectra in EXFOR"
11:30 -12:00	**Peter Schillebeeckx, IRMM** "Introduction on response function for TOF-measurements"
12:00 -12:30	**Peter Schillebeeckx, IRMM** "Reporting of experimental observables obtained from TOF-facilities"
12:30 -14:00	Lunch break
14:00 -15:00	**Frank Gunsing, CEA** "Generalities on the time-of-flight resolution function"
15:00 -16:00	**Yaron Danon, RPI** "Nuclear Data Measurements at the RPI Gaerttner LINAC Center and EXFOR reporting"
16:30 -17:30	**Atsushi Kimura, JAEA** "Neutron capture cross section measurements at ANNRI in J-PARC"

Wednesday, 9 October 2013

9:00 -10:00	**Klaus H. Guber, ORNL** “Neutron Cross Section Measurements at ORELA”
10:30 – 11:30	**Gilles Noguere, CEA** “Analytic model of the time resolution for the Neutron Resonance Shape Analysis”
11:30 – 12:30	**Gašper Žerovnik, JSI** “Use of the Grenoble lead slowing-down experiment for cross section validation”
12:30 -14:00	Lunch break
14:00 -15:00	**Stanislav Simakov, IAEA-NDS** “Response function of the fast neutron time-of-flight spectrometer”
15:00 – 17:30	Discussions and drafting of Conclusions & Recommendations
19:00 -	Social event

Thursday, 10 October 2013

09:00 – 12:30	Discussions and Drafting of Conclusions & Recommendations
12:30 -14:00	Lunch break
14:00 -	**Final Remarks and End of the Meeting**.

IAEA
International Atomic Energy Agency
Atoms for Peace

Consultants Meeting on EXFOR Data in Resonance Region and Spectrometer's Response Function

8-10 October 2013

M-0E 59, Vienna, Austria

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