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Summary Report of the

Workshop on Compilation of Experimental Nuclear Reaction Data for EXFOR Database

IAEA Headquarters, Vienna, Austria

24 – 28 October 2016

Edited by

V. Semkova
Nuclear Data Section, International Atomic Energy Agency, Vienna, Austria

and

A. Bhattacharyya
Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai, India

January 2018

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Abstract

A specialised workshop on Compilation of Experimental Nuclear Reaction Data for EXFOR Database was organised and held at the IAEA Headquarters in Vienna from 24 to 28 October 2016. The workshop covered topics and issues of importance in collection, compilation and dissemination of experimental nuclear reaction data carried out by the International Network of Nuclear Reaction Data Centres. Some recently performed assessments of the EXFOR status and compilation rules for specific type of data were presented. The final conclusions and recommendations were discussed in order to improve quality and consistency of the database. The latest developments in the compilation tools and web retrieval system were demonstrated. Hands-on training in compilation of selected publications was organised. A summary of the presentations and discussions that took place during the workshop is reported here.

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THE INTERNATIONAL NETWORK OF NUCLEAR REACTION DATA CENTRES

National, regional and specialized nuclear reaction data centres, coordinated by the International Atomic Energy Agency, cooperate in the compilation, exchange and dissemination of nuclear reaction data in order to meet the requirements of nuclear data users in all countries. At present, the following data centres participate in the International Network of Nuclear Reaction Data Centres (NRDC):

NNDC	US National Nuclear Data Center, Brookhaven National Laboratory, Upton, USA
NEA DB	OECD NEA Data Bank, Boulogne-Billancourt, France
NDS	IAEA Nuclear Data Section, Vienna, Austria
CJD	Russian Nuclear Data Centre, Institute of Physics and Power Engineering, Obninsk, Russia
CNDC	China Nuclear Data Centre, China Institute of Atomic Energy, Beijing, China
ATOMKI	Charged-Particle Nuclear Reaction Data Group, Institute for Nuclear Research (ATOMKI), Debrecen, Hungary
NDPCI	Nuclear Data Physics Centre of India, Bhabha Atomic Research Centre, Trombay, Mumbai, India
JAEA/NDC	Nuclear Data Center, Japan Atomic Energy Agency, Tokai-mura, Japan
JCPRG	Nuclear Reaction Data Centre, Hokkaido University, Sapporo, Japan
KNDC	Nuclear Data Center, Korea Atomic Energy Research Institute, Daejeon, Republic of Korea
CDFE	Centre for Photonuclear Experiments Data, Moscow State University, Moscow, Russia
CNPD	Centre of Nuclear Physics Data, Institute of Nuclear and Radiation Physics, Russian Federal Nuclear Center –All-Russia Research Institute of Experimental Physics, Sarov, Russia
UkrNDC	Ukrainian Nuclear Data Centre, Institute for Nuclear Research, Kyiv, Ukraine

A detailed description of the objectives of the network and the contributions of each Centre to these activities are given in INDC(NDS)-401 (Rev.6), "International Network of Nuclear Reaction Data Centres".

1. Introduction

The International Atomic Energy Agency organized a four-day specialized workshop on compilation of experimental nuclear reaction data for EXFOR database at IAEA Headquarters, Vienna, Austria from 24 to 28 October 2016. The Workshop was attended by eighteen participants from International Network of Nuclear Reaction Data Centres and three IAEA staff members (Appendix II).

The primary aim of the workshop was to discuss important topics and issues addressed by the International Network of Nuclear Reaction Data Centres in collection, compilation and dissemination of experimental nuclear reaction data. The EXFOR database contains wide range of nuclear quantities for various types of reactions, compiled in its long history, beginning with neutron-induced data and gradually including charged-particle-induced and photonuclear reactions. Maintaining database completeness and consistency of the compilations for the same type of data requires regular reviewed and update of the EXFOR content and compilation rules. Such assessment of the database for thermal neutron scattering data, thermal neutron constants and thick target yields were presented. The presentations covered the underlying theoretical and experimental concepts, EXFOR compilation rules and recommendations promoting best compilation practises. Participants from US National Nuclear Data Centre, Mizoram University (India), National University of Mongolia presented centre's nuclear data compilation activities. Some NRDC centres contribute to the international collaboration by developing various compilation tools and web retrieval systems. Recent progress in software developments was demonstrated. Scientific studies presented by some of the participants provided comprehensive information about the applied experimental and data analysis procedure. The workshop was based on combination of presentations and hands-on training in compilation of selected publications. A summary of the presentations and discussions that took place during the workshop is reported here.

A. Koning, Section Head of the Nuclear Data Section, welcomed the participants, and emphasised that providing a comprehensive, consistent and up-to-data experimental nuclear reaction database to users is of great importance for the development of science and broad range of applications.

Guochang Chen (China Nuclear Data Center) was elected chairperson of the Workshop and Abhijit Bhattacharyya (Bhabba Atomic Research Centre) rapporteur. The agenda was discussed and adopted (see Appendix I).

During the Workshop participants gave presentations, led intensive discussions and took part in hands-on training. The presentations and Working Papers are available at https://www-nds.iaea.org/nrdc/wksp_2016/.

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

2. Presentation summaries

2.1 Summary, conclusions and recommendations of the CM on EXFOR Compilation of Thermal Neutron Scattering Data

V. Semkova

Motivation

The thermal neutron scattering data are important in many fields of science and ever expanding range of applications, such as: neutronics calculations of the various reactor and benchmarks assemblies, neutron dosimetry, radiation protection, boron neutron capture therapy, material science research etc. It is well recognized by the scientific community using simulation codes for the design development of various types of nuclear systems, that the existing thermal neutron scattering evaluations are inadequate for many purposes. This comes primarily from the lack of relevant data for materials and/or conditions of interest, but also from the lack of fidelity of some existing data when applied to some "novel" applications. A NEA/NSC/WPEC Subgroup 42 "Thermal Scattering Kernel S(α,β): Measurement, Evaluation and Application" was established in May 2015 to facilitate the international exchange of information and expertise in thermal scattering data studies. The IAEA Nuclear Data Section is contributing to the new developments following the recommendations put forward at the 30th Meeting of the International Nuclear Data Committee.

A Consultants' Meeting on "Compilation of Thermal Neutron Scattering Data in EXFOR" was organised in 2015 to review the status of EXFOR database for low-energy neutron-induced data, determine the main quantity and corresponding compilation rules, and provide guidelines for compilations. Six participants: Florencia Cantargi and Jose Ignacio Marquez Damian from Centro Atomico Bariloche, David V. Baxter Indiana University, Li (Emily) Liu from Rensselaer Polytechnic Institute, Emmanuel Farhi Institut Laue-Langevin (ILL) and Yoshiaki Kiyanagi from Nagoya University have attended this Meeting. IAEA was represented by N. Otuka, V. Semkova and S. Simakov.

The energies of the thermal neutrons (typically below 0.1 eV) are comparable to the chemical bounding energies and the energies of the thermal motion of the atoms, i.e. the scattering of the slow neutrons depends on the molecular dynamics. Considering the wave nature of the neutron, the associated de Brogline wavelength of the thermal neutrons is comparable with the interatomic spacing in solids and Bragg scattering take place for neutrons with wavelengths that satisfy Bragg's law for the adjacent lattice planes of the sample. Hence, the scattering of the thermal neutron depends not only on neutron-nucleus interaction, but it also depends on the molecular structure, phase, orientation, thermodynamical and other physical properties of the sample.
The variations of the Be-9 total cross section at different sample temperatures are presented on Fig. 1 a): experimental data and ENDF/B-VII evaluation; b): calculations from.

The effect of the sample structure at low incident neutron energies is presented on Fig 2. The total cross-section measurements with single crystal Ge samples (Fig. 2 b) agree well, while the cross-section data in case of the polycrystalline samples (Fig. 2 a) depend on the size of the grains.

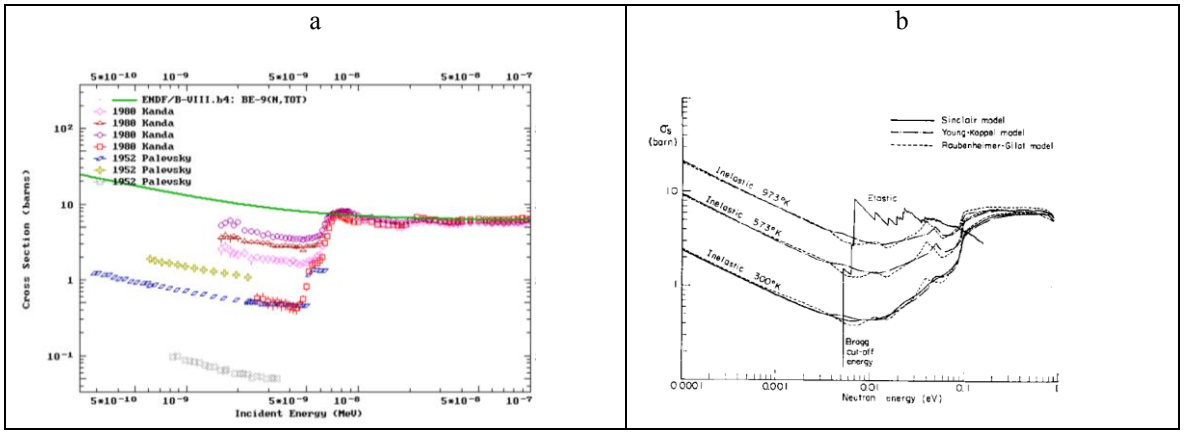


Figure 1. Be-9 total cross section. a): experimental data, b) calculations.

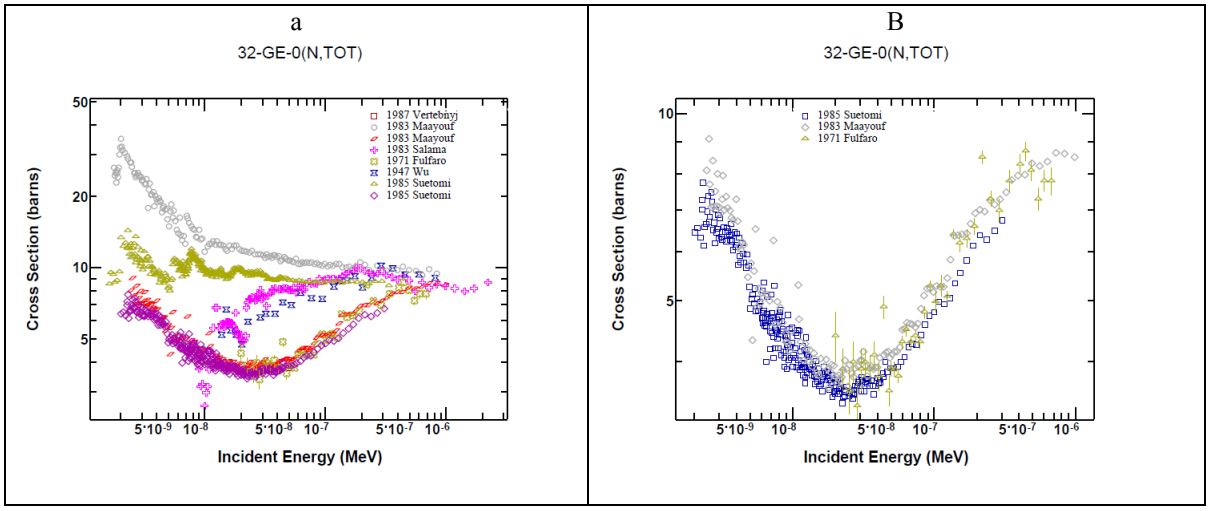
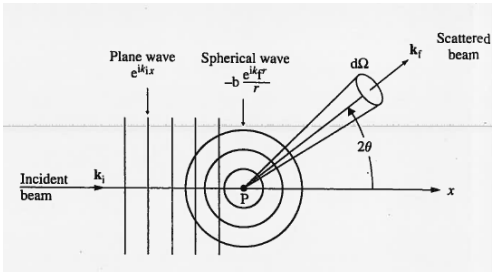


Figure 2. Total neutron-induced cross section for natural Ge: a) all EXFOR data, b) measurements with single crystal Ge sample.

A short overview of the low-energy neutron interactions:

Neutron interaction with a single fixed nucleus: The process that takes place in interaction of slow neutrons with a single fixed nucleus is elastic scattering, e.g. $|\vec{k}_i| = |\vec{k}_f|$, k is the wave vector of a neutron with energy E moving along z-axis. The wave function that describes the process is $\psi(\mathbf{r}) = e^{i\mathbf{kr}} + \frac{e^{i\mathbf{kr}}}{r} f(\mathbf{k})$. The first term represents the incident neutron plane wave and the second term is the spherically scattered wave, where $f(\mathbf{k})$ is the scattering amplitude.



For thermal neutrons (s-wave scattering) the range of nuclear forces is negligible compared with neutron wavelength and the scattering amplitude $(\mathbf{k}) = -b$. The scattering length (b) is in general a complex number. The imaginary part is related to the neutron absorption. The incident flux I_0= neutron density x velocity density of 1 neutron per unit volume throughout

all space $|\psi_i|^2 = 1$, so I_0=v. Respectively for the scattered beam $I_f = |\psi_i|^2$ velocity = $(b^2/r^2)v$ and the number of the scattered neutrons = I_f x $4\pi r^2$. Hence, the scattering cross section $\sigma = \frac{I_f}{I_0} = 4\pi b^2$ and the differential cross section for scattering into the solid angle dΩ $\frac{d\sigma}{d\Omega} = |f(\boldsymbol{\kappa})|^2$. The free nucleus scattering is considered in the center-of-mass system. So, the free atom scattering length is $a = (A/A+1)b$. However, it is conventional to quote the corresponding "bound-atom" values for scattering lengths and cross sections.

The terms scattering length and amplitude are sometimes treated interchangeably. However, the quantity defined in LEXFOR is the thermal-neutron scattering amplitude and the compilers are advised to check the recommended values of the bound coherent scattering length (for example https://www.ncnr.nist.gov/resources/n-lengths/list.html or entry V1002) and compile the amplitude with opposite sign. The review of the coherent scattering amplitudes compiled in EXFOR has shown that in some cases SF3=EL instead of SF3=TSH was used. A list of subentries that have to be corrected is included in Table I.

Neutron interaction with nuclei in a sample: In reality the atoms are not really fixed and are usually combined in molecules, compounds or crystal structures. The energy ($\hbar\omega$) and momentum (Q) transfer are the basic quantities characterising of the thermal neutron scattering. The probability of scattering as a function of the variables Q and ω is a property of the sample and its environment (temperature, pressure, magnetic field, etc.). The energy and momentum transfer are defined by the conservation lows:

$$\hbar\omega = E_i - E_f = \frac{\hbar^2}{2m_n}\left(k_i^2 - k_f^2\right),\ Q^2 = k_i^2 + k_f^2 - 2k_i k_f cos2\theta.$$

The experimental quantity measured in the neutron scattering experiments is the intensity of the neutrons as a function of Q and ω e.c. $I(\vec{Q},\omega)$, which is often called "neutron-scattering law" for the particular sample composition.

The probability of scattering by a potential $V(\vec{r})$ is proportional to $\left|\int e^{i\vec{k_i}\vec{r}}V(\vec{r})e^{i\vec{k_f}\vec{r}}d\vec{r}\right|^2 = \left|\int e^{i\vec{k}\vec{Q}\vec{r}}V(\vec{r})d\vec{r}\right|^2$. The Fermi pseudo-potential for an assemble of nuclei is given by $V(\vec{r}) = \frac{2\pi\hbar^2}{m}\sum_j b_j\delta\left(\vec{r} - \vec{r_j}\right)$ where m is the neutron mass, r_j and b_j are the position and the scattering length of the individual scattering nucleus, $\delta(\vec{r})$ is a Dirac delta function. Although the scattering is described by the characteristics of the system in the initial and the final states without time dependence its evaluation becomes more transparent if we consider the explicit time evolution of particle positions proposed by Van Hove. According to Van Hove formalism $I\left(\vec{Q},\omega\right) = \frac{1}{h}\frac{k_f}{k_i}\sum_{i,j} b_i b_j \int_{-\infty}^{+\infty}\langle e^{-i\vec{Q}\vec{r_i}(0)}e^{i\vec{Q}\vec{r_j}(t)}\rangle\, e^{-i\omega t}dt$, where r_i and r_j are the positions of nucleus i at time zero and position of nucleus j at time t respectively, and the $\langle..\rangle$ indicates a double sum over all positions in the sample. Each scattering nucleus has its own b depending on the specific isotope, nuclear spin, etc. If we substitute the integral by A_{ij} the sum can be averaged over the nuclear spin states of the individual nucleus $\sum_{i,j}\langle b_i b_j\rangle A_{ij} = \sum_{i,j}\langle b\rangle^2 A_{ij} + \sum_i(\langle b^2\rangle - \langle b\rangle^2)A_{ii}$. The first term represent the coherent scattering (elastic and inelastic) of neutron waves from different nuclei. The elastic coherent scattering depends on

the atomic structure of the sample, while the inelastic coherent scattering is associated with the collective motion of the atoms. The second term represents incoherent scattering (elastic and inelastic). The coherent and incoherent scattering lengths can be expressed as $b_{coh} = \langle b \rangle$ and $b_{inc} = \sqrt[2]{\langle b^2 \rangle - \langle b \rangle^2}$, and respectively $\sigma_{coh} = 4\pi\langle b \rangle^2$and $\sigma_{inc} = 4\pi(\langle b^2 \rangle - \langle b \rangle^2)$. The neutron scattering law, respectively the double differential cross section in the time domain can be presented as:

$$\frac{d^2\sigma}{d\Omega dE} = \frac{1}{4\pi}\frac{k_f}{k_i}N\left(\sigma_{coh}S_{coh}(Q,\omega) + \sigma_{inc}S_{inc}(Q,\omega)\right)$$

$S(Q,\omega)$ is the scattering function of the system. It gives probability that the scattering changes the energy of the system by amount of $\hbar\omega$ and its momentum by Q.

Time-of-flight method is usually applied for the differential cross section measurements. The processing of the directly measured quantities to obtain dynamical structure factor and ultimately differential cross section involves a number of approximations and additional theoretical simulations. In reality the experimental equipment provide limited dynamic range, typically up to few 100 mV energy transfers and further extrapolation is needed to obtain 3-10 eV data needed for the nuclear applications.

The thermal scattering is a method applied in a wide range of studies and different types of quantities are utilised depending on the specific application. In some cases directly measured diffractograms *I(θ)* and angle time-of-flight spectrograms *I(θ,t)* or processed data such as generalised density of states (gDOS), dynamical structure factor (*S(q,w)*), or structure factor (*S(q)*) are reported. The so called raw data imply fewer corrections and comprehensive information for the particular experimental conditions needs to be compiled in order such data to be properly processed by users. That is way only deduced nuclear quantities e.g. double differential, differential and total cross sections are appropriate for EXFOR compilation. It was proposed to set up an EXFOR-type database with experimental data that are not within the scope of EXFOR database, but are important input information in thermal scattering kernel S(α,β) evaluations.

The report of the Consultants' Meeting INDC(NDS)-0697 contains: description of the experimental and theoretical methods applied in the low-energy neutron interaction studies, revision of the LEXFOR manual for the thermal-neutron scattering, recommendations for the compilation of various types of thermal scattering data, template for submission of time-of-flight measurements, sample compositions of importance for nuclear data community, etc. The report, the presentations from the participants, some relevant literature, collection of additional data for thermal scattering law evaluation and other information are available at the Meeting webpage: https://www-nds.iaea.org/index-meeting-crp/CM-THSC-2015/.

Regarding EXFOR rules TMP is defined in the dictionaries to indicate the quantity dependence from the sample temperature. As proposed in Memo CP-D/928 SF8=TMP is used when the quantity is temperature dependent and sample temperature is other than the room temperature (~300 K). The sample temperature (TEMP) is required as independent

variable. However, the code TMP is always omitted when THS is coded in SF3. A list of EXFOR entries and corresponding corrections is included in Table 1.

Table 1. List of EXFOR subentries to be corrected.

Author	Reference	Subentry	Current reaction cod	To be corrected to
P.Coppens	ACR/B,25,2442,1969	10343002	1-H-2(N,EL)1-H-2,,AMP	1-H-2(N,THS)1-H-2,,AMP
J.Callerame	PR/C,12,1423,1975	10513002	1-H-1(N,EL)1-H-1,COH,AMP	1-H-1(N,THS)1-H-1,COH,AMP
H.S.Sommers JR	11085002	11085002	2-HE-0(N,TOT),,SIG	2-HE-0(N,TOT),,SIG,,TMP
W,Kanda	NST,12,601,1975	21657003 21657004 21657005	4-BE-9(N,TOT),,SIG	4-BE-9(N,TOT),,SIG,,TMP
H.Palevsky	W,PALEVSKY,52	11204004 11204005	4-BE-9(N,TOT),,SIG	4-BE-9(N,TOT),,SIG,,TMP
O.Aizawa	85SANTA,1,561,85	22007003	14-SI-0(N,TOT),,SIG	14-SI-0(N,TOT),,SIG,,TMP
H.Palevsky	PR,92,202,1953	11714002 11714004	26-FE-0(N,TOT),,SIG	26-FE-0(N,TOT),,SIG,,TMP
E.Suetomi	NST,22,765,1985	22036002 22036003	32-GE-0(N,TOT),BA,SIG	32-GE-0(N,TOT),,SIG
S.Sidhu	PR,156,1225,1967	12617002 12617004	28-NI-61(N,EL)28-NI-61,COH,AMP 28-NI-64(N,EL)28-NI-64,COH,AMP	28-NI-61(N,THS)28-NI-61,COH,AMP 28-NI-64(N,THS)28-NI-64,COH,AMP
W.Milligan	PCJ,57,535,1953	12622002	21-SC-45(N,EL)21-SC-45,COH,AMP	21-SC-45(N,THS)21-SC-45,COH,AMP
L.Winsberg	PR,75,975,1949	12625002 12625003 12625004 12625005 12625006	20-CA-0(N,EL)20-CA-0,COH,AMP 20-CA-0(N,EL)20-CA-0,COH,SIG 22-TI-0(N,EL)22-TI-0,COH,SIG 81-TL-0(N,EL)81-TL-0,COH,SIG 30-ZN-0(N,EL)30-ZN-0,COH,SIG	20-CA-0(N,THS)20-CA-0,COH,AMP 20-CA-0(N,THS)20-CA-0,FA,SIG 22-TI-0(N,THS)22-TI-0,COH,AMP 81-TL-0(N,THS)81-TL-0,COH,AMP 30-ZN-0(N,THS)30-ZN-0,COH,AMP
L.Winsberg	PR,75,975,1949			Add total cross section for compounds
H.R.Child	PR,174,1553,1968	13045002 13045004 13045006 13045008 13045010 13045012	66-DY-160(N,EL)66-DY-160,COH,AMP 66-DY-161(N,EL)66-DY-161,COH,AMP 66-DY-162(N,EL)66-DY-162,COH,AMP 66-DY-163(N,EL)66-DY-163,COH,AMP 66-DY-164(N,EL)66-DY-164,COH,AMP 66-DY-0(N,EL)66-DY-0,COH,AMP	66-DY-160(N,THS)66-DY-160,COH,AMP 66-DY-161(N,THS)66-DY-161,COH,AMP 66-DY-162(N,THS)66-DY-162,COH,AMP 66-DY-163(N,THS)66-DY-163,COH,AMP 66-DY-164(N,THS)66-DY-164,COH,AMP 66-DY-0(N,THS)66-DY-0,COH,AMP
M.Arif	PR/A,35,2810,1987	13118002	92-U-235(N,EL)92-U-235,BA,AMP	92-U-235(N,THS)92-U-235,BA/COH,AMP
Arnold	PR,124,1848,1961	13468002 13468003	48-CD-0(N,EL)48-CD-0,COH,AMP 63-EU-0(N,EL)63-EU-0,COH,AMP	48-CD-0(N,THS)48-CD-0,COH,AMP 63-EU-0(N,THS)63-EU-0,COH,AMP
D.J.Larson	BAP,20,561,1975	13792002	1-H-1(N,EL)1-H-1,COH,AMP	1-H-1(N,THS)1-H-1,COH,AMP
L.Koester	ZP/A,289,399,1979	20857029 20857030 20857031 20857032 20857033 20857034 20857035 20857036	14-SI-0(N,EL),COH,AMP 14-SI-28(N,EL)14-SI-28,COH,AMP 14-SI-29(N,EL)14-SI-29,COH,AMP 14-SI-30(N,EL)14-SI-30,COH,AMP 16-S-0(N,EL),COH,AMP 16-S-32(N,EL)16-S-32,COH,AMP 16-S-33(N,EL)16-S-33,COH,AMP 16-S-34(N,EL)16-S-34,COH,AMP	14-SI-0(N,THS),COH,AMP 14-SI-28(N,THS)14-SI-28,COH,AMP 14-SI-29(N,THS)14-SI-29,COH,AMP 14-SI-30(N,THS)14-SI-30,COH,AMP 16-S-0(N,THS),COH,AMP 16-S-32(N,THS)16-S-32,COH,AMP 16-S-33(N,THS)16-S-33,COH,AMP 16-S-34(N,THS)16-S-34,COH,AMP
A.Abragam	PRL,28,805,1972	20883002	9-F-19(N,EL)9-F-19,,AMP	9-F-19(N,THS)9-F-19,COH,AMP
A.T.Stewart	PR,90,1125,1953	21384002	1-H-1(N,EL)1-H-1,COH,AMP	1-H-1(N,THS)1-H-1,COH,AMP
H.Palevsky *	PR,99,611(B11),1955 *	11782002	6-C-0(N,TOT),,SIG/TMP	6-C-0(N,TOT),,SIG,,TMP
		11782003	12-MG-0(N,TOT),,SIG/TMP	12-MG-0(N,TOT),,SIG,,TMP
		11782004	13-AL-27(N,TOT),,SIG/TMP	13-AL-27(N,TOT),,SIG,,TMP
		11782005	29-CU-0(N,TOT),,SIG/TMP	29-CU-0(N,TOT),,SIG,,TMP
		11782006	40-ZR-0(N,TOT),,SIG/TMP	40-ZR-0(N,TOT),,SIG/TMP
		11782007	82-PB-0(N,TOT),,SIG/TMP	82-PB-0(N,TOT),,SIG,,TMP
H.Palevsky	W,PALEVSKY,54	11355004	50-SN-0(N,TOT),,SIG	50-SN-0(N,TOT),,SIG,,TMP
D.J.Hughes	PR,92,1206,1953	12243005	83-BI-209(N,TOT),,SIG/TMP	83-BI-209(N,TOT),,SIG,,TMP
H.Yan	NIM/B,269,425,2011	14289002	1-H-MTH(N,TOT),,SIG/TMP	1-H-MTH(N,TOT),,SIG,,TMP bulk methane

		14289003	1-H-MTH(N,TOT),,SIG/TMP	1-H-MTH(N,TOT),,SIG,,TMP confined methane
B.M.Rustad	RSI,36,48,1965	12675003	83-BI-209(N,TOT),,SIG	83-BI-209(N,TOT),,SIG,,TMP
F.Lasinger	AKE,12,159,1967	20028002	1-H-CXX(N,TOT),,SIG/TMP,,SPA	1-H-CXX(N,TOT),,SIG,,SPA/TMP
		20028003	1-H-CXX(N,TOT),,SIG/TMP,,SPA	1-H-CXX(N,TOT),,SIG,,SPA/TMP
		20028004	1-H-CXX(N,TOT),,SIG/TMP,,SPA	1-H-CXX(N,TOT),,SIG,,SPA/TMP
		20028005	1-H-PLE(N,TOT),,SIG/TMP,,SPA	1-H-PLE(N,TOT),,SIG,,SPA/TMP
		20028006	1-H-PLE(N,TOT),,SIG/TMP,,SPA	1-H-PLE(N,TOT),,SIG,,SPA/TMP
		20028007	1-H-PLE(N,TOT),,SIG/TMP,,SPA	1-H-PLE(N,TOT),,SIG,,SPA/TMP
S.F.Beshai	AE-222,1966	20161005	90-TH-OXI(N,TOT),,SIG/TMP	90-TH-OXI(N,TOT),,SIG,,TMP
A.Steyerl	EANDC(E)-150S,41,1972	20582002	2(12-MG-0(N,TOT),,SIG/TMP)	2(12-MG-0(N,TOT),,SIG,,TMP)
A.Steyerl	ZP,250,166,1972	21017002	13-AL-27(N,TOT),,SIG/TMP	13-AL-27(N,TOT),,SIG,,TMP
		21017003	13-AL-27(N,TOT),,SIG/TMP	13-AL-27(N,TOT),,SIG,,TMP
		21017008	29-CU-0(N,TOT),,SIG/TMP	29-CU-0(N,TOT),,SIG,,TMP
		21017009	29-CU-0(N,TOT),,SIG/TMP	29-CU-0(N,TOT),,SIG,,TMP
		21017013	79-AU-197(N,TOT),,SIG/TMP	79-AU-197(N,TOT),,SIG,,TMP
A.Steyerl	ZP,267,379,1974	21016003	6-C-0(N,TOT),,SIG/TMP	6-C-0(N,TOT),,SIG,,TMP
B.Broecker	EANDC(E)-66,52,1966	21146002	1-H-1(N,TOT),,SIG	1-H-CXX(N,TOT),,SIG
		21146003	1-H-1(N,TOT),,SIG	1-H-CXX(N,TOT),,SIG
		21146004	1-H-1(N,TOT),,SIG	1-H-CMP(N,TOT),,SIG
		21146005	1-H-1(N,TOT),,SIG	1-H-MHT(N,TOT),,SIG
		21146006	1-H-1(N,TOT),,SIG	1-H-CMP(N,TOT),,SIG
		21146007	1-H-1(N,TOT),,SIG	1-H-PFN (N,TOT),,SIG
		21146008	1-H-1(N,TOT),,SIG	1-H-BNZ (N,TOT),,SIG
		21146009	1-H-1(N,TOT),,SIG	1-H-CMP (N,TOT),,SIG
		21146010	1-H-1(N,TOT),,SIG	1-H-CMP (N,TOT),,SIG
		21146013, 21146016 - 21146020	1-H-1(N,TOT),,SIG/TMP	1-H-1(N,TOT),,SIG,,TMP
A.Gibert	HPA,19,493,1946	21167002	7-N-14(N,THS)7-N-14,BA,SIG/TMP,,MXW	7-N-14(N,THS)7-N-14,BA,SIG,,MXW
		21167003	7-N-14(N,TOT),,SIG/TMP,,MXW	7-N-14(N,TOT),,SIG,,MXW/TMP
A.Gibert	HPA,19,285,1946	21233002	1-H-1(N,TOT),,SIG/TMP,,MXW	1-H-1(N,TOT),,SIG,,MXW/TMP
J.Rossel	HPA,20,105,1947	21234003	1-H-WTR(N,TOT),,SIG/TMP,,MXW	1-H-WTR(N,TOT),,SIG,,MXW/TMP
		21234007	1-H-1(N,THS)1-H-1,,SIG/TMP,,MXW	1-H-CMP(N,THS)1-H-CMP,,SIG,,MXW Delete TEMP
A.Meister	IRMM-R-01-96,1996	22357002 22357003 22357006 22357009	92-U-238(N,TOT),,SIG/TMP,,RAW 92-U-238(N,TOT),,SIG/TMP,,RAW 92-U-238(N,TOT),,SIG/TMP,,RAW 92-U-238(N,TOT),,SIG/TMP,,RAW	92-U-238(N,TOT),,TRN,,TMP 92-U-OXI(N,TOT),,TRN,,TMP 92-U-238(N,TOT),,TRN,,TMP 92-U-OXI(N,TOT),,TRN,,TMP
		22357004 22357005	92-U-238(N,TOT),,SIG/TMP	92-U-238(N,TOT),,SIG,,TMP
K.Knorr	EANDC(E)-066,29,1966	22505003	29-CU-0(N,TOT),,SIG/TMP	29-CU-0(N,TOT),,SIG,,TMP
T.Springer	ZN/A,15,828,1960	22546002	10-NE-0(N,TOT),,SIG/TMP	10-NE-0(N,TOT),,SIG,,TMP
		22546003	18-AR-0(N,TOT),,SIG/TMP	18-AR-0(N,TOT),,SIG,,TMP
M.Dritsa	EANDC(OR)-63L,1967	22613002	2(1-H-WTR(N,TOT),,SIG/TMP)	2(1-H-WTR(N,TOT),,SIG,,TMP)
K.Volev	NIM/B,300,11,2013	23196035	48-CD-0(N,ABS),,SIG/TMP,,,EVAL 48-CD-0(N,TOT),,SIG/TMP,,,EVAL	48-CD-0(N,ABS),,SIG,,TMP,EVAL 48-CD-0(N,TOT),,SIG,,TMP,EVAL
K.Kanda	NSE,60,230,1976	20756003 20756004 20756005	82-PB-0(N,TOT),,SIG	82-PB-0(N,TOT),,SIG,,TMP
L.Q.Amaral	IEA-320,1973	30342002	1-H-CXX(N,THS)1-H-CXX,,SIG/TMP,,FCT	1-H-CXX(N,THS)1-H-CXX,,SIG,,FCT
J.R.Granada	AKE,28,(3),228,1976	30349002	80-HG-0(N,TOT),,SIG/TMP	80-HG-0(N,TOT),,SIG Delete TEMP
F.Kropff Moreno	AKE,31,42,1978	30413002	42-MO-0(N,TOT),,SIG/TMP	42-MO-0(N,TOT),,SIG ; Delete TEMP
F.Kropff	AKE,37,213,1981	30547002	30-ZN-0(N,TOT),,SIG/TMP	30-ZN-0(N,TOT),,SIG Delete TEMP
R.E.Mayer	AKE,39,55,1981	30592002	50-SN-0(N,TOT),,SIG/TMP	50-SN-0(N,TOT),,SIG

M.Adib	INDC(EGY)-3,1982	30636002	92-U-0(N,TOT),,SIG/TMP	92-U-0(N,TOT),,SIG,,TMP
		30636002	92-U-OXI(N,TOT),,SIG/TMP	92-U-OXI(N,TOT),,SIG,,TMP
M.Adib	79KNOX,,101,1979	30776008 30776014 30776015	28-NI-0(N,TOT),,SIG/TMP 4-BE-9(N,TOT),,SIG/TMP 29-CU-0(N,TOT),,SIG/TMP	28-NI-0(N,TOT),,SIG,,TMP 4-BE-9(N,TOT),,SIG,,TMP 29-CU-0(N,TOT),,SIG,,TMP
M.Adib	INDC(EGY)-2,1981	30591002 30591003 30591004	41-NB-93(N,TOT),,SIG/TMP 41-NB-93(N,TOT),,SIG/TMP 41-NB-93(N,TOT),,SIG/TMP	41-NB-93(N,TOT),,SIG 41-NB-93(N,TOT),,SIG,,TMP 41-NB-93(N,TOT),,SIG,,TMP
F.Cantargi	NIM/B,248,340,2006	31578002	1-H-CXX(N,TOT),,SIG/TMP	1-H-CXX(N,TOT),,SIG Delete TEMP
		31578003	1-H-CXX(N,TOT),,SIG/TMP	1-H-CXX(N,TOT),,SIG,,TMP
L.Torres	NIM/B,251,304,2006	31588002	1-H-BNZ(N,TOT),,SIG/TMP	1-H-BNZ(N,TOT),,SIG,,TMP
		31588003	1-H-WTR(N,TOT),,SIG/TMP	1-H-WTR(N,TOT),,SIG,,TMP
L.A.Rodriguez Palomino	NIM/B,267,175,2009	31662002 31662003	1-H-CXX(N,TOT),,SIG/TMP 1-H-ARM(N,TOT),,SIG/TMP	1-H-CXX(N,TOT),,SIG,,TMP 1-H-ARM(N,TOT),,SIG,,TMP

2.2. Monoenergetic fast neutrons: powerful tool for nuclear and material studies

P. Prajapati

Tandetron Accelerator with terminal voltage of 2 MV, designed by the High Voltage Engineering Europa B. V was delivered at Piestany in November 2015. It is under Commissioning test. It is capable of deliver protons or deuterons beam with energy from 100 keV up to 4 MeV. It can also accelerate the alpha particle beam up to 6 MeV. Nuclear reaction $^{2}D(d,n)^{3}He$ will be mainly used for neutron production within the frame of current project at Piestany. The employment of gas cell appears to be most optimal, since it provides sufficient yield of neutrons. The state of art D_2 gas target has been designed for neutron production after critically examining gas target facilities at ATOMKI, Debrecen [1] and PTB, Braunschweig [2]. The simulation of neutron production from gas target has been carried out by DROSG [3] code. The simulated results indicate that maximum 7 MeV neutrons can be produced with deuteron beam energy of 4 MeV with 1 μA current. The simulations predict neutron fluence of the order of 10^6 n/sec. Neutron shielding and safety calculations have been performed by MCNP code [4]. The calculations show that the neutron and photon dose calculations for 7 MeV neutrons with fluence of 1x106 n/sec outside the hall is under the limit of Radiological limits (i.e. 1 mSv/y) given by International organizations such as IAEA, Eurotom and ICRP. Further, it is planned to measure $^{20}Ne(\alpha,\gamma)^{24}Mg$ cross-section at stellar energies. It is end point helium burning reaction for the stellar Nucleosynthesis. SRIM-TRIM [5] calculations have been performed for the neon target preparation. 500 kV ion implanter facility at Slovak University of Technology at Tranava will be used for neon target preparation.

References:

1. L.Olah et al, Nucl. Inst. Meth. Phys.Res. A 404, (1998) 373-380
2. S. Cabral et al., Nucl.Sci.Eng. 106, (1990) 308-317
3. M.Drosg, DROSG-2000, Codes and database for 59 neutron source reactions, documented in the IAEA report IAEA report IAEA-NDS-87 Rev. 9 (May 2005)
4. X-5 Monte Carlo Team, "MCNP - Version 5, Vol. I: Overview and Theory", LA-UR-03-1987 (2003)
5. SRIM – The Stopping and Range of Ions in Matter", J. F. Ziegler, J. P. Biersack and M. D. Ziegler, Ion Implantation Press (2008)

2.3 ND compilation activities at the NNDC

B. Pritychenko

A short review of compilation activities at NNDC has been presented. The compilations and the corresponding Nuclear Science References (NSR) and Exchange Format (EXFOR) databases provide a middle layer in between research activities and nuclear structure, decay and reaction evaluators and evaluated databases. The important features of the compilation operations are broad coverage, speed and direct contacts with the data users. The additional details on compilations and statistics are shown below.

NSR Compilations in FY 2016

NSR team: 1.5 NNDC, 2 contractors and 1 IAEA collaborator.

Our goal is to provide the coverage for current publications; however, due to many historical and technical reasons a substantial number of articles were missed in the past and we are proactively recovering these references.

Our major requirement is speed, prompt creation of entries for ENSDF.

NSR Quality Assurance: Manager + Users + Evaluators + Compilers inputs. We do not have a bug database, we just fix bugs immediately.

Direct communication with Phys. Rev. C: ~15% of authors submit keywords to NSR.

NSR database is updated 2-3 times a week (Most frequently-updated nuclear physics database).

More NSR statistics

NSR References:
- 3263 new article entries, total NSR: 222684 (~10 times bigger than EXFOR)
- 859 modified (bug fixes) article entries
- 1856 keyworded article abstracts

NSR Dictionary updates:
- 1750 new authors, total NSR: 96685
- 7 new journals, total NSR: 516
- 225 new reactions, total NSR: 7904
- 408 new nuclides, total NSR: 6415

NSR Database updates: 117 in FY 2016

NSR Web retrievals: 442175

EXFOR Compilations in FY 2016

The NNDC is a member of Nuclear Reaction Data Centers (NRDC) network that is responsible for the compilation of nuclear reaction data sets from the U.S. and Canada (Area #1). The USA and Canada are the largest data producers and the relative geographical areas contributions are shown below.

Area 1: USA/Canada – 37.16%,

Area 2: Europe – 34.79%,

Area 3: Asia/Africa/Australia/LA – 13.35%,

Area 4: Former SU/RF – 14.70%.

NNDC compilations of EXFOR entries (experiments): 126, corrected entries: 122.

A substantial number of charged particle and photonuclear experiments are still missing in EXFOR, some existing compilations are incomplete due to many reasons. We continue to address these issues.

Data recovery mission at Oak Ridge lab in March of 2015: Many thanks to M. Dunn and K. Guber. All recovered data sets have been compiled and submitted to the EXFOR database.
NNDC compilations challenged the status quo with EXFOR editor on the number of subentries and compilation size.

We are involved in a strong nuclear data dissemination effort. EXFOR Web application was upgraded in collaboration with the IAEA.

We would like to update the database at least once a month, as soon as the IAEA would release an update.

A few words on Oak Ridge National Laboratory library recovery mission
NSR like ENSDF has been started at Oak Ridge National laboratory and transferred to Brookhaven in 1980.

Oak Ridge library had many unique and valuable publications that of importance for ENSDF evaluations.

In May of 2016, NSR technical staff member Joann Totans travelled to Oak Ridge and recovered the unique publications: 35 boxes of reports, private communications and theses that have been published prior to 1980. Oak Ridge employee C. Nasaraja has helped Joann.

These publications have been shipped to NNDC, and J. Totans is presently processing them as time permits.

We are planning to add these publications to a common PDF database. V. Zerkin (IAEA) is working with J. Totans.

Finally, NNDC has been providing a complete bibliographical coverage of nuclear science and the compilation of experimental nuclear reaction results for the area #1. We also invest resources in the original data and references recovery. This work has been performed by a dedicated team that includes 2 NNDC staff members (Pritychenko, Totans), 4 contractors (Singh, Betak, Hlavac, Schwerer) and 1 IAEA collaborator (Zerkin).

2.4 Nuclear Data Activities at Mizoram University

B. Lalremruata

The nuclear data activities at Department of Physics, Mizoram University are reported which are divided into three categories: 1. EXFOR compilation activities, 2. Development of ^{7}Li(p,n)^{7}Be neutron spectrum code below 3-body break up threshold, 3. Measurements of neutron capture cross sections on 70Zn at <En> =0.96 and 1.69 MeV.

There are 8 new EXFOR entries made in the year 2016 by Nuclear Data Physics Center of India(NDPCI) in which Dr. B. Lalremruata acts as EXFOR coordinator. In India, article compilation into EXFOR is done as a regular activity by regular Indian compilers from Universities and Research Centres. NDPCI also organized EXFOR workshop biennially. It is also observed that EXFOR entries prepared by regular activity contributes almost ~50% of all Indian EXFOR entries since 2012; and the total entries made under the Nuclear Data Physics Centre of India (NDPCI) are 338 till date. Six NDPCI EXFOR workshops have been conducted at various universities and research institutes since 2016. The 7th workshop will be held at North Eastern Hill University from 6-10th March 2017. Although there have been many EXFOR workshop activities organized under the NDPCI, there are new participants in every workshops, yet no regular compilers are generated so far. Regular compilations are done by Universities with funds given by BRNS through NDPCI but no official coordinator for long term basis is assigned. NDPCI needs to engage at least one regular compiler on a permanent basis in its headquarter at BARC to coordinate and perform regular compilation. Without it, regular compilation activity will not last long.

We have performed an experiment at the Folded Tandem Ion Accelerator (FOTIA) Facility, BARC, Mumbai for measuring ^{70}Zn(n,g)^{71}Zn^{m} cross section at proton energies 2.25, 2.60, 2.80 and 3.50 MeV using ^{7}Li(p,n)^{7}Be reaction as neutron source. Due to continuous proton beam structure, we have to rely on calculated neutron energy spectrum. Also, subtractions of the (p,n1) neutron contributions are an essential part in experimental determination of neutron-induced reaction cross section. Therefore, we developed a new deterministic code EPEN-Energy of Proton Energy of Neutron. Our formalism is very similar to that of Lee and Zhou except that-

i) Kinematic equations are written in terms of ^{7}Li mass rather than ^{7}Be because of its better accuracy.

ii) Differences in selection of "±" as their selection criteria always yield a dip ~30keV.

For a given proton energy, the double differential cross sections at various neutron energies (in step of 1 keV) and neutron emission angles (in 1 degree step) are integrated over the angular range corresponding to the initial proton energy range and also covered by the neutron activation sample. The integration can be written as

$$\frac{dY(E_n)}{dE_n} = \int d\Omega \frac{d^2Y(\theta, E_n)}{dE_n d\Omega} w_1(\theta)\, w_2\left(E_p(\theta, E_n)\right) \quad , \qquad (1)$$

The predicted neutron spectra near threshold were validated by experimental neutron spectra. Our neutron spectra were compared with those predicted by PINO and SimLiT. At E_p=2.8 and 3.5 MeV, our neutron spectra agree perfectly with those predicted by SimLiT, but PINO shows much narrower (p,n_1) energy spectrum near the upper boundary of the (p,n_1) energy

spectra predicted by EPEN and SimLiT. 3. The (p,n_0) neutron spectra of EPEN and SimLiT show excellent agreement with PINO if the proton beam energy spread is negligible. EPEN output can be used as an input to the Monte Carlo particle transport codes (e.g., MCNP, GEANT, PHITS) to describe more complicated neutron source systems as done by Friedman et al. for SimLiT+GEANT.

The measurement of neutron capture cross sections on ^{70}Zn at $<E_n>$ = 0.96 and 1.69 MeV is also discussed. The neutron capture cross sections of zinc isotopes are important both for reactor applications as well as for nuclear astrophysics. This neutron capture reaction is also a candidate of dosimetry reactions to study deviation of the epithermal reactor neutron spectrum from 1/E distribution. No experimental results exist between the upper boundary of the resolved resonance region and 10 MeV. Moreover, large discrepancies are observed between TENDL-2014, JENDL-4.0 and EAF-2010. Therefore, the cross section of this reaction has been measured for the first time in the MeV region.

The protons at 2.80 MeV and 3.50 MeV after passing through a beam collimator (0.5 cm in diameter) bombarded a 2.0-mg/cm2 (37.4 μm) thick natural lithium target. The proton beam energy spread is ±0.02 MeV. A 0.25-mm thick tantalum foil was used as a proton beam stopper. The proton beam current during irradiation varied from 50 to 100 nA. The beam diameter on the lithium target was about 5 mm. The neutron flux was monitored online by a NE213 neutron detector at zero degree and at 1 m distance from the lithium target. The neutron flux energy spectra was calculated by EPEN at the two proton energies in the present experimental configuration, and it is 0.96 and 1.69 MeV for E_p=2.80 and 3.50 MeV, respectively. The decay data adopted in the present work is taken from the ENSDF library.

A ^{152}Eu point source ($T_{1/2}$ = 13.517 years) of known activity (A_0 = 7582.5 Bq on 1st Oct. 1999) was used for determination of the absolute photo peak efficiency of the HPGe detector at various characteristic γ energies of the point source. The detection efficiency for the point source placed at a distance of 1 cm from the detector εp was determined by

$$\varepsilon_p = C\, K_c / (A_0\, e^{-\lambda t}\, \Delta t\, I_\gamma), \quad (2)$$

In order to correct the measured efficiency for the coincidence summing effect, the correction factor Kc was calculated using the Monte Carlo simulation code EFFTRAN. Since the calibration of the HPGe detector was carried out with the point source while the activated foil stack has finite area (1 cm × 1 cm), the efficiency for the point source geometry ε_p was transferred by EFFTRAN to the efficiency for the foil stack geometry ε. In order to obtain the detector efficiencies at the characteristic γ energies of the ^{70}Zn^m (E_{Zn}=386.28 keV) and ^{198}Au (E_{Au}=411.802 keV), the point-wise efficiencies were interpolated through the following fitting function:

$$\varepsilon(E) = \varepsilon_0 \exp(-E/E_0) + \varepsilon_c, \quad (3)$$

The covariance between two interpolated efficiencies ε_{Zn} and ε_{Au} are obtained following the prescription by Mannhart:

$$\begin{aligned} \mathrm{cov}(\varepsilon_{Zn}, \varepsilon_{Au}) = {} & \exp[-(E_{Zn}+E_{Au})/E_0]\,(\Delta\varepsilon_0)^2 + (\varepsilon_0^2 E_{Zn} E_{Au}/E_0^4) \exp[-(E_{Zn}+E_{Au})/E_0]\,(\Delta E_0)^2 + \\ & (\Delta\varepsilon_c)^2 + \varepsilon_0\,[(E_{Zn}+E_{Au})/E_0^2] \exp[-(E_{Zn}+E_{Au})/E_0]\,\mathrm{cov}(E_0, \varepsilon_c) + [\exp(-E_{Zn}/E_0) \\ & + \exp(-E_{Au}/E_0)]\,\mathrm{cov}(\varepsilon_0, \varepsilon_c) + [(\varepsilon_0 E_{Zn}/E_0^2) \exp(-E_{Zn}/E_0) + (\varepsilon_0 E_{Au}/E_0^2) \\ & \exp(-E_{Au}/E_0)]\,\mathrm{cov}(\varepsilon_0, E_0), \quad (4) \end{aligned}$$

$$\text{with } (\Delta\varepsilon_{Zn})^2 = \mathrm{var}(\varepsilon_{Zn}) \text{ and } (\Delta\varepsilon_{Au})^2 = \mathrm{var}(\varepsilon_{Au}), \quad (5)$$

This is further propagated to the uncertainty in the detector efficiency ratio

$$\eta = \varepsilon_{Zn}/\varepsilon_{Au}, \quad (6)$$

$$(\Delta \eta/\eta)^2 = (\Delta\varepsilon_{Zn}/\varepsilon_{Zn})^2 + (\Delta\varepsilon_{Au}/\varepsilon_{Au})^2 - 2\ \mathrm{cov}\ (\varepsilon_{Zn},\varepsilon_{Au})/(\varepsilon_{Zn},\varepsilon_{Au}), \quad (7)$$

and we finally obtain $\eta = 1.06459 \pm 0.00274$.

The measured $^{70}Zn(n,\gamma)^{71}Zn^m$ cross section $<\sigma_{Zn}{}^m>_{exp}$ was derived with the $^{197}Au(n,\gamma)^{198}Au$ reference cross section $<\sigma_{Au}>$ by

$$<\sigma_{Zn}{}^m>_{exp} = <\sigma_{Au}>(A_{Zn}/A_{Au})\ [(a_{Au}N_{Au}I_{Au}\varepsilon_{Au}f_{Au})/(a_{Zn}N_{Zn}I_{Zn}\varepsilon_{Zn}f_{Zn})]\ (C_{Zn}/C_{Au}), \quad (8)$$

The reference cross section $<\sigma_{Au}>$ was obtained by folding the IAEA Neutron Cross-Section Standards $\sigma_{Au}(E)$ with the neutron flux energy spectrum $\varphi_0(E)$ obtained by EPEN:

$$<\sigma_{Au}> = \int\varphi_0(E)\ \sigma_{Au}(E)\ dE\ /\int\varphi_0(E)\ dE, \quad (9)$$

The uncertainty in $<\sigma_{Au}>$ due to the uncertainty in the IAEA Neutron Cross-Section Standards was obtained by

$$(\Delta<\sigma_{Au}>)^2 = \Sigma_i\ [\Phi_i^2\ \mathrm{var}\ (<\sigma_i>)]\ /\ (\Sigma_i\ \Phi_i)^2 + 2\ \Sigma_{i>j}\ [\Phi_i\ \Phi_j\ \mathrm{cov}\ (<\sigma_i>\ <\sigma_j>)]\ /\ (\Sigma_i\ \Phi_i)^2, \quad (10)$$

The correction factor C_x in Eq. (6) is decomposed to

$$C_x = C_{x,fluc}\cdot C_{x,low}\cdot C_{x,scat}\cdot C_{x,attn.}, \quad (11)$$

where x = Zn or Au.

The correction factor for the effect of the fluctuation of neutron flux due to proton current fluctuation during the irradiation was taken into consideration was obtained by

$$C_{x,fluc} = <\Phi_m>[1-\exp(-\lambda_x t_1)]\ /\ [\Sigma_{i=1,n}\ \Phi_{m,i}\ [1 - \exp(-\lambda_x \Delta t_1)]\exp\ [-\lambda_x(t_1 - i\Delta t_1)]], \quad (12)$$

where $\Phi_{m,i}$ is the neutron flux measured by the NE213 monitor detector during the i-th time interval (i=1,n), $\Delta t_1 = t_1/n$ (i.e., 30 min) and $<\Phi_m> = \Sigma_{i=1,n}\ \Phi_{m,i}\ /\ n$

The (p,n_1) low energy neutron background was subtracted by the correction factor

$$C_{x,low} = 1 - \int\varphi_1(E)\ \sigma_x(E)\ dE\ /\ \int\varphi(E)\ \sigma_x(E)\ dE, \quad (13)$$

Correction factors for the scattered neutron background C_{scat} originating from elastic, inelastic and multiple scattering in the foil stack and surrounding materials were evaluated by PHITS (Particle and Heavy Ion Transport code System) Ver 2.840.

Gamma spectrometric analysis requires correction for the self-attenuation effect due to the interactions of the γ-rays with the foil stack given by

$$C_{attn}^{-1} = [(1/x_1)\int_0^{x1}\exp(-\mu_{m,1}\rho_1 x)\ dx]\cdot\Pi_{i=2,n}\ \exp(-\mu_{m,i}\rho_i x_i)$$
$$= [[1 - \exp(-\mu_{m,1}\rho_1 x_1)]\ /(\mu_{m,1}\rho_1 x_1)]\cdot\Pi_{i=2,n}\ \exp(-\mu_{m,i}\rho_i x_i) \quad (14)$$

A comparison of the present measured spectrum averaged cross sections was made with the cross sections for mono energetic neutrons predicted by TALYS-1.6 with various level density models. In order to estimate the $^{70}Zn(n,\gamma)^{71}Zn^{g+m}$ cross sections from the measured $^{70}Zn(n,\gamma)^{71}Zn^m$ cross sections, the measured cross sections $<\sigma_{Zn}{}^m>_{exp}$ were multiplied by the isomeric ratios $<\sigma_{Zn}{}^{g+m}>_{TENDL}/<\sigma_{Zn}{}^m>_{TENDL}$ evaluated in TENDL-2015 folded by the $^7Li(p,n_0)$ neutron spectra. The ratios obtained are 1.6698 and 1.6823 at 0.96 and 1.69 MeV respectively.

2.5 Contribution to EXFOR compilation from Mongolia and nuclear physics activity at the Nuclear Research Center, National University of Mongolia

M. Odsuren

M. Odsuren presented contribution t from Mongolia o EXFOR data library and nuclear physics activity at the Nuclear Research Center (NRC), National University of Mongolia. Her presentation focused on the research and compilation activities of the NRC, it can be classified into two main parts: such as contribution to compilation from Mongolia and brief introduction of the NRC. Regarding compilation activities, Mongolia-IAEA collaboration was established in 2014 for EXFOR compilation of heavy-ion induced reaction data measured in West European countries. The NRC consists of four units, namely, Nuclear Data Section, Section of Nuclear Analytical Method, Section of Nuclear Energy and Technology and Department of Nuclear Physics and Technology (education). The nuclear facilities and instruments which are located at the NRC were presented as well. In addition, she reported recent research achievement of the Nuclear Data Section regarding experimental study of fast neutron induced (n,a), (n,p) reactions, systematical analysis of fast neutron induced (n,a) and (n,p) reaction cross sections. New methods for photo-activation analysis and theoretical study of light nuclei cluster structure have been developed.

2.6 Compilation of thermal neutron cross sections and resonance integrals measured by Cd ratio method

V. Semkova

The EXFOR completeness checking for articles cited in the Atlas of Neutron Resonance by S. Mughabghab was proposed at the NRDC Meeting 2013. Considering the large number of references an initial selection of articles reporting experimental cross sections or resonance integrals (3144 articles) was performed at IAEA-NDS by N. Otsuka and responsibilities were assign to NNDC, NEA DB, NDS and CJD for further assessment.

In connection with the assessment of the existing entries and compilation of the missing publications a brief overview the specific information that has to be provided in resonance integral compilations was given order to ensure consistency in the EXFOR database.

The addition to the information given in the LEXFOR manual, compilation of the normalization data of the resonance integral measurements obtained by the Cd ratio method was discussed. The resonance integral is determined by the following formula:

$$I_0(\alpha)_S = I_0(\alpha)_{Rf}\frac{\sigma_{0,S}}{\sigma_{0,Rf}}\frac{(R-1)_{Rf}}{(R-1)_S}\left(\frac{G_{epi}}{G_{th}}\right)_{Rf}\left(\frac{G_{th}}{G_{epi}}\right)_S$$

where "Rf" stands for reference and "S" for sample. Although monitors with well know thermal cross section and resonance integral are used for normalization, it is recommended to compile those data as well as thermal cross section for the studied reaction (included in the formula as well) under ASSMED. In this method first the thermal fluence Φ_0 is determined from the measured specific activities of the bare and Cd-cover samples and the thermal cross section of the monitor and after that the epithermal fluence Φ_e is calculated from the thermal flux and the **ratio** of the thermal cross section to the resonance integral for the monitor, namely:

$$\phi_0 = \frac{R-F_{Cd}R_{Cd}}{g\sigma_0 G_{th}} \quad \phi_e = \frac{\phi_0}{(R-F_{Cd})}\frac{g\sigma_0}{\mathrm{I}_0(\alpha)}\frac{G_{th}}{G_{epi}},$$

So, the resonance integral is proportional to the combination of those nuclear quantities.

In addition when the in the cadmium ratio method is applied the thermal cross section and the ratio of the thermal cross section to the resonance integral are determined simultaneously from the two irradiations with and without Cd-cover.

2.7 Some Remarks on Compilation of Thermal Neutron Constants

N. Otsuka

Cross sections for thermal (2200 m/s) neutrons are fundamental neutron-induced reaction data, which have been evaluated at the IAEA since the pioneering works by Westcott [1], Hanna [2] and Lemmel [3, 4]. In a typical evaluation of the thermal neutron constants (TNC) within the current IAEA Neutron Standards [5], 25 constants (elastic, fission and capture cross sections, absorption and fission g-factors, and total fission neutron multiplicities of ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu at the thermal energy as well as ^{252}Cf spontaneous total fission neutron multiplicity) measured both in differential (mono-energetic) and integral (broad spectrum) experiments are included in a simultaneous generalized least-squares analysis by the GMA code [5]. Recent TNC evaluations for update of the IAEA Neutron Standard are based on the comprehensive work by Axton [6–8]. However, Axton's experimental database (Table 1 of [8]) contains many data not available in the EXFOR library [9]. We have reviewed Axton's experimental database to identify the data missing EXFOR and possible experimental corrections.

The review reveals that the same quantity is often not reported by the experimentalist (e.g., absolute cross section in the literature converted to the cross section ratio by Axton, 2200 m/s cross section in the literature converted to the Maxwellian spectrum averaged cross section by Axton, prompt fission neutron multiplicity in the literature converted to the total fission neutron multiplicity by Axton). There are also many cases where the original value is corrected with a newer reference value by Axton (e.g., half-life adopted in sample mass determination, average fission neutron energy for fission neutron detector efficiency calibration). Such values corrected or derived from the literature values are often taken by Axton from Sjöstrand and Story [10], Lemmel [3] and Divadeenam [11] as noted by Axton in Appendix 4 of Ref. [7]. They are not for EXFOR compilation, but we plan to keep them in the "EXFOR Data Correction System" (a complement to the EXFOR database maintained by IAEA NDS) as they could be useful to trace corrections done by the experts.

The final report of our review will be published separately [12].

References

[1] C.H. Westcott et al., At. Energy Rev. **3**, (2), 3 (1965).
[2] G.C. Hanna et al., At. Energy Rev. **7**, (4), 3 (1969).
[3] H.D. Lemmel et al., INDC(NDS)-132 (1975).
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[5] A.D. Carlson et al., Nucl. Data Sheets **110**, 3215 (2009).
[6] E.J. Axton, EUR 8805 EN (1984).
[7] E.J. Axton, IAEA-TECDOC-335, 214 (1985).
[8] E.J. Axton, GE/PH/01/86 (1986).
[9] N. Otuka et al., Nucl. Data Sheet **120**, 272 (2014).
[10] N.G. Sjöstrand et al., AEEW-M 125 (1961).
[11] M. Divadeenam et al., Ann. Nucl. Energy **11**, 375 (1984).
[12] N. Otuka et al., to be published in EPJ Web of Conf. (Proceedings of the International Conference on Nuclear Data for Science and Technology, 11-16 Sept. 2016, Bruges, Belgium).

2.8 InpGraph: Quick start tutorial

S. Taova

New version of the digitizing program InpGraph was presented two years ago (in autumn 2014). Our experience of program usage showed that it is very flexible and friendly.

You may start data processing from any point you want: from setting information on axes or entering the number of entry and additional variables.

A project is created to keep all information about your digitizing procedure.

To provide further promotion of InpGraph and to involve new users to the process of data digitizing a shot instruction – a kind of "Quick start" for our program was prepared. It looks as a set of graphic images followed the commands.

The idea is to start the work with the program without any preliminary preparation, without any knowledge about this procedure.

STEP 1 - Launch InpGraph
STEP 2 - Load Image
STEP 3 - Define Entry number and additional variables
STEP 4 - Define Axes
STEP 5 - Digitize curve
STEP 6 - Compile Exfor File

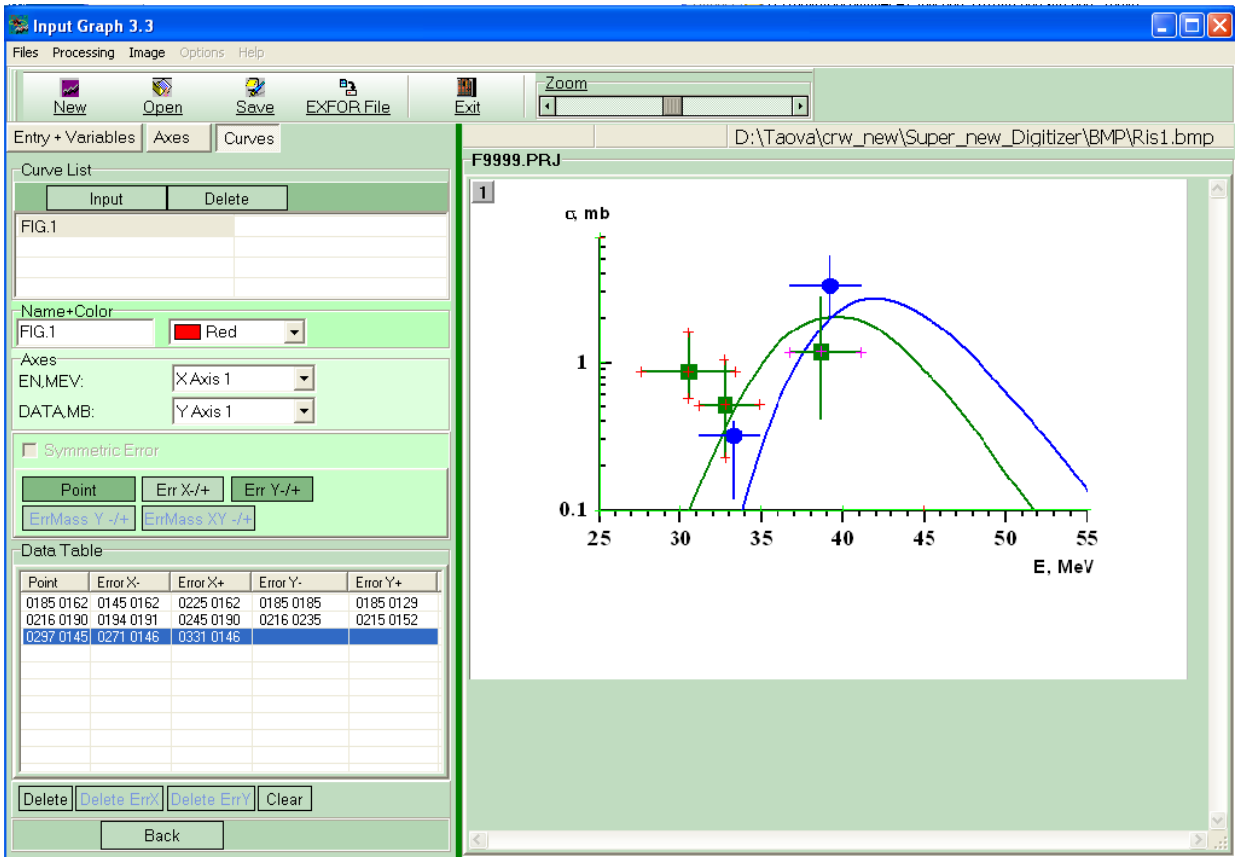
A small booklet was designed for distribution.

As for advanced users a new possibility of entering the asymmetrical error was proposed.

Additional optional button appeared on the page "Curves": Symmetric Error.

Symmetric Error is used as default.

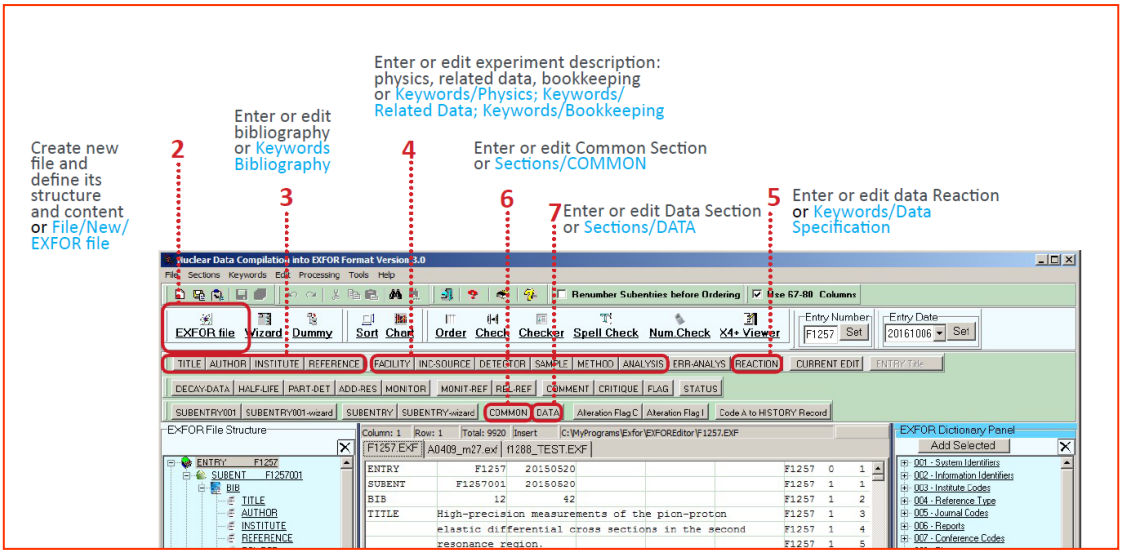
If there is no mark in the field Symmetric Error, it means that asymmetrical error will be introduced.



2.9 EXFOR-Editor: Quick Start Tutorial and Some Useful Feature, G. Pikulina

The Quick Start Tutorial of the EXFOR-Editor was presented. This is a small guide to the compilation tool to simplify the start for the beginners.

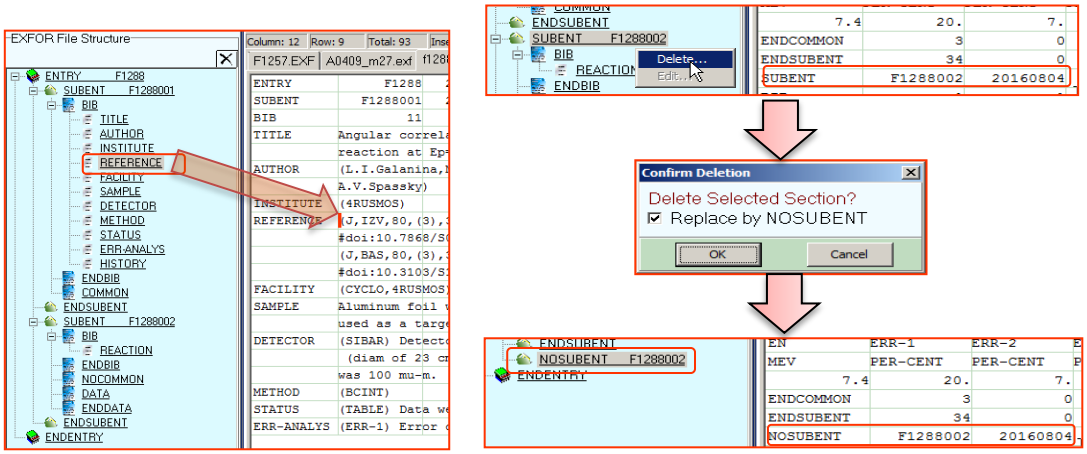
The algorithm of EXFOR file compiling is presented as a set of simple steps that are necessary for getting an EXFOR file. Most of the actions for EXFOR file processing are available from the main window of the EXFOR-Editor.



Some comments on the EXFOR-Editor for advanced users were also presented.

Possibilities of the EXFOR file and Dictionaries tree structure were demonstrated.

The use of buttons **Alternation Flag C**, **Alternation Flag I**, **Code A to History** is described.



The order of automatically changing the number and data of the ENTRY is shown.

The initial steps of the EXFOR file creation and editing were demonstrating during the EXFOR-Editor training.

2.10 Practice of Data Table mode usage

S. Selyankina

Data Table Mode functionalities have been demonstrated. It was shown with an example of author's numerical data from "Izvestiya Rossiiskoi Akademii Nauk, Ser.Fiz., Angular correlations in the 27Al(p,ag)24Mg reaction at Ep=7.4 MeV", L.I. Galanina et al. In this article differential cross-sections for ground and first excited states of residual nuclei have been published. For numerical author's data several procedures were provided. They were pasting data from external file, inserting of new column, setting of constant value, sorting of data, setting precision for data. Data Chart option for plotting of inserted data was shown. It was developed for checking of the correctness of data. Complete entering of numerical data in the same Data Table Mode of Exfor-Editor was provided. Several data sets for the training of Data Table Mode were prepared. One of the examples was demonstrated for colleagues step by step. Some examples were offered for participants of the workshop on the training course.

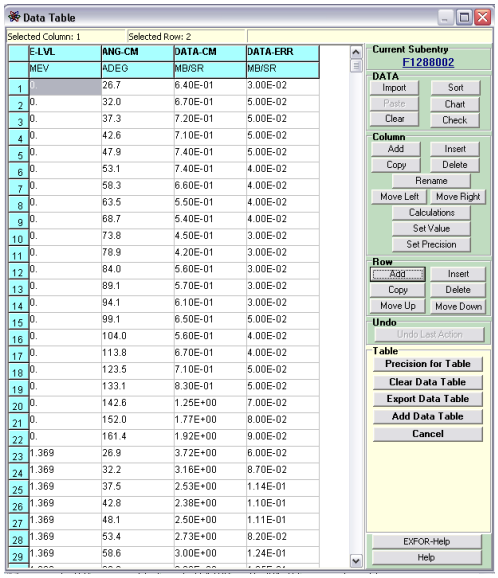


Fig. A resulting table after providing data procedures by usage of Data Table Mode.

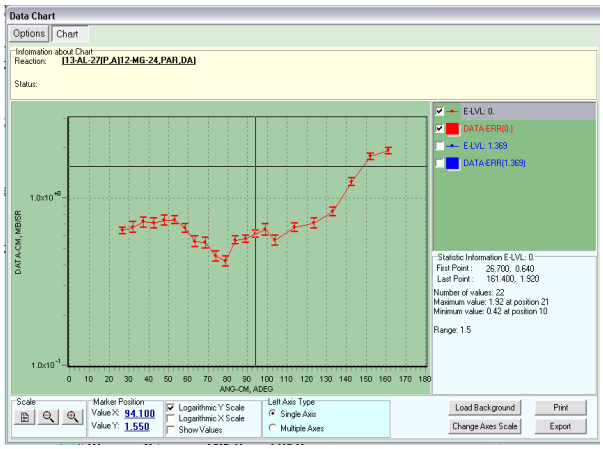


Fig. A curve plotted by use of Data Chart option.

2.11 Calculation of catalytic nuclear reactions induced by reactor neutrons and its applications

N. Kenzhebayev

Neutron catalysis based on the reaction of four neutrons capture by catalyst nucleus (X^A), followed by (release) the collapse of the alpha particle and two electrons and two electron antineutrinos with the restoration of the initial nucleus (cyclic reaction – four of neutron capture, two beta decay and alpha decay). For a series of core-catalyst can consistently capturing neutrons, beta testing decay, turning into the intermediate nucleus.

Po^{210} might produce two isotopes Pb^{206} and Po^{211} by *alfa decay* and *(n,g)*, so sum of their reaction rates R_2 and R_3 will give total equilibrium reaction rate *R*.

The main objectives usage of neutron catalytic chain are:

- to use catalytic material as thermal neutron reflector in reactor core;
- to take out an additional energy from material.

The main results were related with nuclide density and heat density changes during the irradiation time. All results were obtained at the different neutron flux level between 10^{13} – 10^{18} 1/cm^{2}s. To calculate the nuclide densities and heat densities the burn-up equation was used:

$$\frac{dN_i}{dt} = -\lambda_i N_i(t) - \sigma_i \phi N_i(t) + \sum_{j\neq i} \lambda_j P_{j\to i} N_j(t) + \sum_{j\neq i} \sigma_j \phi Q_{j\to i} N_j(t), \quad (1)$$

Total heat generated by decay *H(t)* is also written as:

$$H(t) = \sum_i E_i \lambda_i N_i(t) + \sum_i E_i' \phi \sigma_i N_i(t), \quad (2)$$

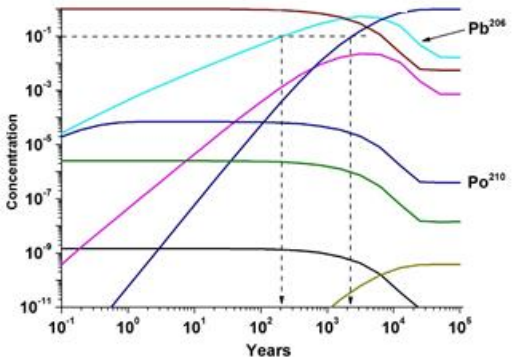
where E_i is the emitted energy by a decay of nuclide *i*.

Solution to equation (1) can be written in matrix form:

$$\mathbf{N}(t) = \mathbf{N}(0)\exp(\mathbf{A}t), \quad (3)$$

where *exp(At)* is the matrix exponential.

As initial number densities (when *t=0*) of composition the *natural lead* was used, because natural lead have four isotopes $Pb^{204}, Pb^{206}, Pb^{207}, Pb^{208}$ which are presented in equilibrium state of catalytic material. The following figure shows the time period of densities change from natural lead to equilibrium state irradiated at 10^{14} *1/cm^{3}s* neutron flux:



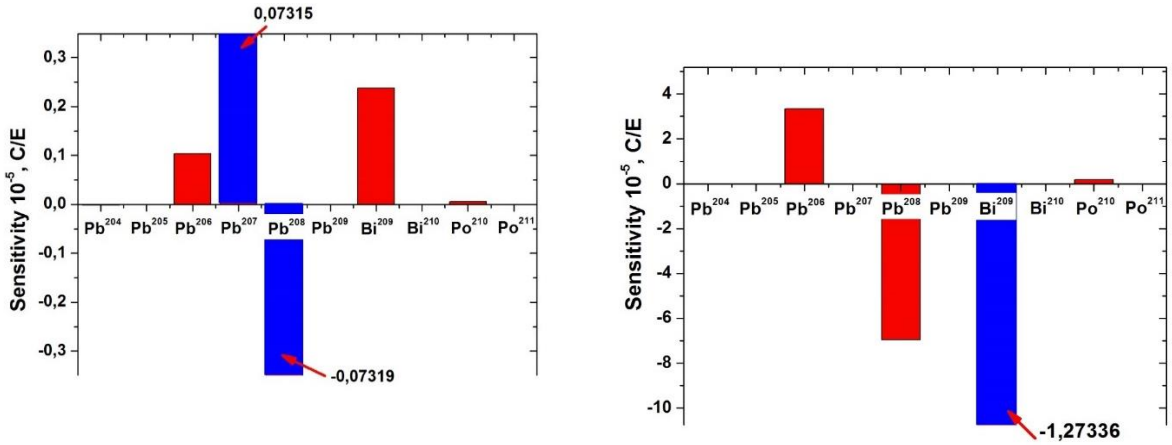
The time period decreases exponentially in high neutron flux levels. If one considers the normal neutron flux in typical reactor core, then the time needed to reach the equilibrium state will be too long (above 10,000 years).

To calculate the heat density, the natural lead was also used as initial number density. The material produces energy from three decays (*alfa, beta and gamma*).

Also the sensitivity of nuclide concentrations to nuclear data were also calculated in the present work. The sensitivity is defined as[1]:

$$S^i = \frac{dN_i(T)}{N_i(T)} \Big/ \frac{d\sigma}{\sigma} = \frac{\sigma}{N_i(T)} \cdot \frac{dN_i(T)}{d\sigma}, \quad (4)$$

Sensitivity analysis of nuclear data can show which nuclear data are important to results. The following figure shows sensitivities of the Pb^{208} and Bi^{209} nuclide concentrations to the *(n,g)* cross section data:



Reference

1. Go Chiba et.al, "Sensitivity Analysis of Fission Product Concentrations for Light Water Reactor Burned Fuel", *Journal of Nuclear Science and Technology*, Vol.47, No.7, p.652-660 (2010)

2.12 Light Web-based EXFOR and ENSDF editors. Status and perspectives

V. Zerkin

Recent developments in the database retrieval systems (2016):

EXFOR:

- PDF files of INDC Reports: open for public access (Access Level=0)
- Input of the users' experimental data to be processed on Web
  - – enter without password, but with "human" control
  - – upload own data without knowledge of EXFOR format
  - – goal: using web exfor tools, such as: constructing covariance matrix, calculating inverse reaction cross sections, etc.
- Links to secondary publications: Web, NSR, PDF

ENDF:

- New and updated libraries:
  - – JENDL-4.0u2 /upd:20160106/ Japanese evaluated nuclear data library
  - – IBA-EVAL: Differential data for ion beam analysis, 2013
  - – JENDL-4.0/HE 2015 (neutrons, protons up to 200 MeV)
  - – JENDL-3.2 Japanese evaluated nuclear data library, 1994

CINDA:

- Links to PDF files

News in the Web tools (2016)

1. login:
   - "human" checking without password system
2. x4data: */uploading user's experimental data/*
   - released for public with "human" checking
3. myplot: */uploading user's data to web-zvview/*
   - password protection replaced by "human" checking
4. myEnsdf:
   - added two checking codes from PNPI
   - added two ENSDF viewers and editor
   - dual entrance
5. myEndf:
   - upgraded GRUCON-D to version: 20-Jun-2016
   - updated to the latest version: CHECKR, FIZCON, INTER, PSYCHE, STANEF

Recent developments in the Web Mirror-sites

New Mirror-site in Russia:

http://www-nds.atomstandard.ru/ (Sept. 2016)

Now EXFOR Web system is available on:

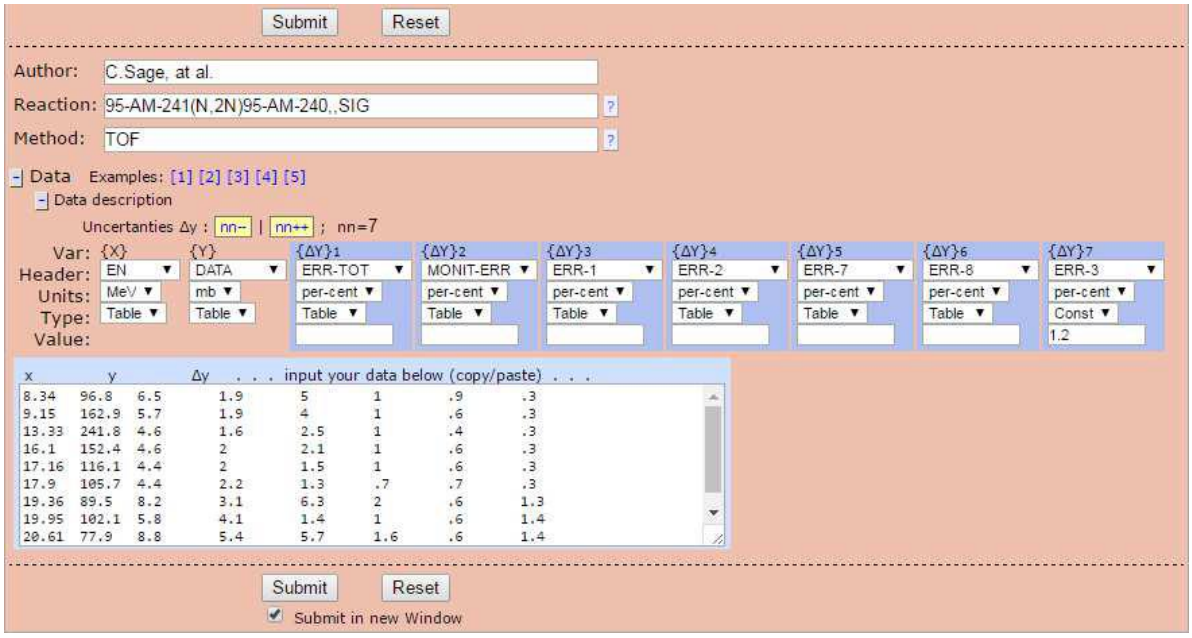
- IAEA-NDS https://www-nds.iaea.org/exfor/
- NNDC, USA http://www.nndc.bnl.gov/exfor/
- BARC, India http://www-nds.indcentre.org.in/exfor/
- CNDC, China http://www-nds.ciae.ac.cn/exfor/
- "Atomstandart", Russia http://www-nds.atomstandard.ru/exfor/

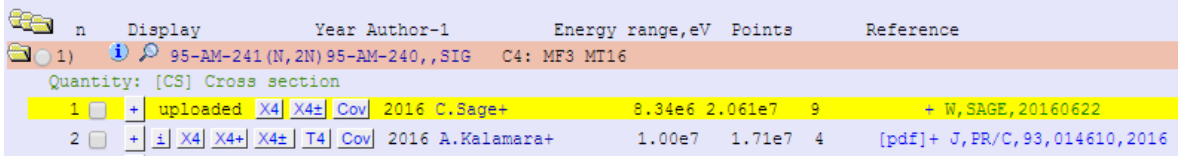
Limitations of EXFOR system on Mirror-sites:

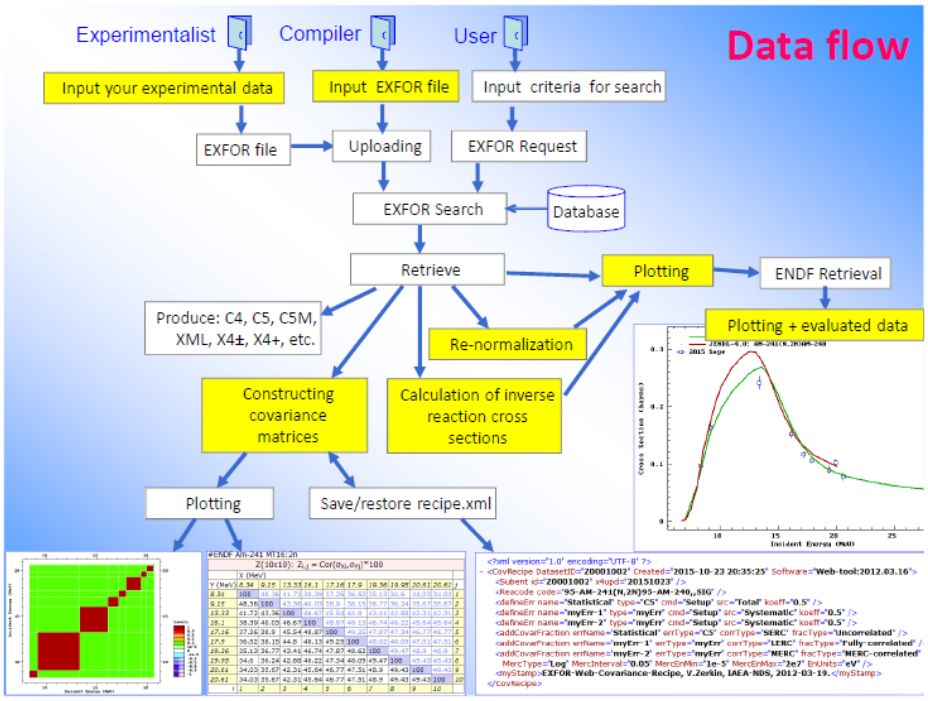
- No archival EXFOR Entries
- No links to PDF's
- No PDF's

Recent developments in the login system

1. We check only that user is "human" (to stop hackers using robots)
   - /x4data/ Uploading experimental data
   - /myplot/ Upload data and plot
   - myEnsdf login modes: Guest and Evaluator
   - common Login system - ?
2. Uploading experimental data http://www-nds.iaea.org/exfor/x4data.htm



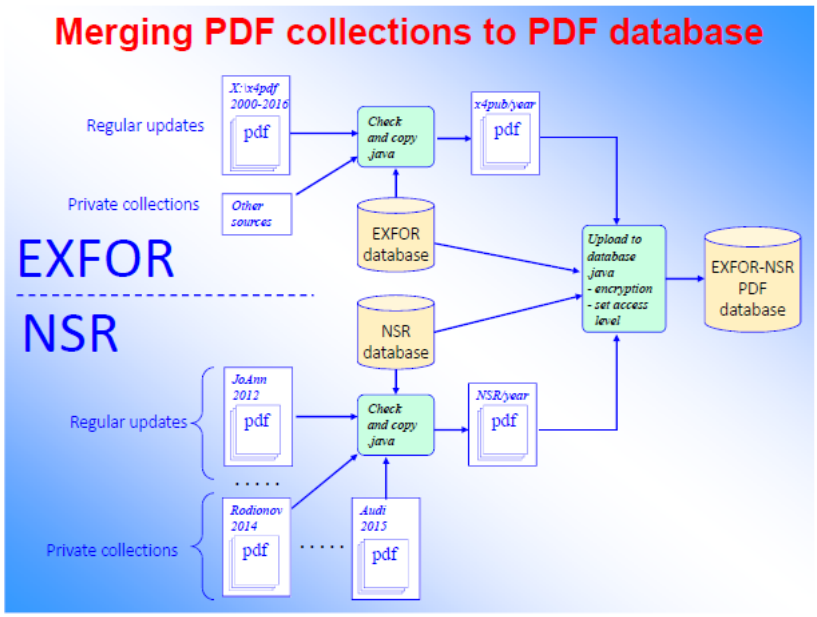




Access to EXFOR-NSR PDF database

PDF Statistics (2016-10-22)

	No. of references	No. of PDF files
EXFOR	34772	26537 (76%)
NSR	222219	44796 (20%)
Joined	237403	54810



Web-based EXFOR and ENSDF editors. Status and perspectives.

Concept

- Basic nuclear data formats (EXFOR, ENSDF, ENDF) are implemented as 80 columns formatted text files. From another hand, structure of information has hierarchical logic.
- Nowadays hierarchical documents allow advanced interpretation in modern forms of information systems (e.g. using XML language, graphical presentations, etc.).
- EXFOR and ENSDF files are presented by Web-viewers as an interactive graph-tree (iTree).
- X4± and ensdf± are extended with edit-mode (top-menu, commands on nodes, editing data using dictionaries and help system, running checking and utility codes, save file original format, undo and other operations)

EXFOR and ENSDF Editors Projects

EXFOR Editor, 2010-2015

- Web-viewer X4± presents information from EXFOR file as an interactive tree with interpreting codes and data according to EXFOR rules and dictionaries, using also information from NSR database and other sources.
- Web editor built on top of X4± Web-viewer: nodes of the tree are extended with commands for editing.
- Editing is implemented via pop-up windows.

ENSDF Editor, 2015-2016

- ENSDF file is presented as hierarchical document (ensdf±) - interactive tree (graph) with possibility to open/collapse branches and with commands associated with the nodes.
- User can remove/add/edit nodes, call checking and utility codes, do other useful operations.
- Editing is implemented via pop-up windows and internal frames.
- The Editor is called from MyEnsdf Web tool for ENSDF evaluators.
- Using AJAX technology sharing software infrastructure with Light EXFOR Editor.

Concluding remarks

- The Web editors are still “experimental projects”
- There are still “technological questions”
- Clear outline of the tasks (and users) is needed
- Demand?

2.13 Nuclear fusion reaction measurements at LUNA for nuclear astrophysics

M.P.Takacs

The nuclear fusion reactions important for the big bang and stellar nucleosynthesis typically take place at energies, which are way bellow the Coulomb barrier. Therefore, these reactions can only proceed via quantum tunneling, which makes their cross sections incredibly small at these astrophysically relevant energies – representing a great challenge for the experimentalist.

The expected signal from these reactions is usually buried under a several orders of magnitude higher background caused by cosmic rays and natural radioactivity in the detector – a real "needle in the haystack" situation. A possible solution to this problem was first pioneered by the Laboratory for Underground Nuclear Astrophysics (LUNA) located under the peaks of the Gran Sasso Mountain in Italy.

The deep underground location (1400 m overburden of rocks) provides a very effective shielding against the cosmic rays: the muon-induced background is 6 orders of magnitude lower than on the surface, and the neutron background is reduced 3 orders of magnitude. The sensitivity granted by this uniquely low background, combined with a compact 400kV electrostatic accelerator and high efficiency detection systems led to successful study of many astrophysically important reactions in the past 25 years of LUNA.

Within the frame of this talk, the importance of a precise knowledge on the resonant capture reactions was emphasized in the determination of the thermonuclear reaction rate. A general overview was provided on the experimental study of narrow resonances by introducing the definition of the resonances strength $\omega\gamma$ and its derivation from the experimental yield *Y*:

$$\omega\gamma = \frac{2}{\lambda_r^2}\,\varepsilon_r Y$$

where λ_r and ε_r are the de Broglie wavelength and the stopping power evaluated at the energy of the resonance E_r. As a practical example, the latest results from the ongoing study of the low energy resonances in the $^{22}\mathrm{Ne}(p,\gamma)^{23}\mathrm{Na}$ reaction at LUNA was reported.

3. Summary of discussions

The workshop was organized to facilitate the International Network of Nuclear Reaction Data Centres activities in collection, compilation and dissemination of experimental nuclear reaction data. Maintaining the database completeness and consistency requires regular reviewed and update of the EXFOR content and compilation rules. Recently such assessment of the database for thermal neutron scattering data, thermal neutron constants and thick target yields were performed. The conclusions, recommendations and list of actions were presented during the Workshop. The participants from US National Nuclear Data Centre, Mizoram University (India), National University of Mongolia presented centre's nuclear data compilation and research activities. Some NRDC centres contribute to the international collaboration by developing various compilation tools and web retrieval systems. Recent progress in software developments was demonstrated. Scientific studies presented by some of the participants provided comprehensive information about the applied experimental and data analysis procedure. Several selected publications were compiled during the Workshop.

Workshop on
EXFOR Compilation
24-28 October 2016, Vienna, Austria

Meeting Room: **VIC M0E79**

AGENDA

(Time including discussions)

Monday, 24 October 2016

9:30 – 12:30

1.1	Welcome address	10 min	A. Koning
1.2	Self-introduction	15 min	All
1.3	Selection of **Chairperson and Rapporteur** Approval of Agenda	5 min	
1.4	Announcement	5 min	A. Oechs
1.5	Objectives of the workshop	10 min	V. Semkova
1.6	Summary, conclusions and recommendations of the CM on EXFOR Compilation of Thermal Neutron Scattering Data	120 min	V. Semkova

12:30 – 14:00 Lunch break

14:00 – 18:00

1.7	Monoenergetic fast neutrons: powerful tool for nuclear and material studies.	45 min	P. Prajapati
1.8	Summary, conclusions and recommendations of the CM on EXFOR Compilation of Thermal Neutron Scattering Data	60 min	V. Semkova
1.9	ND compilation activities at the NNDC	45 min	B. Pritychenko
1.10	Nuclear Data Activities at Mizoram University	45 min	B. Lalremruata
1.11	Contribution to compilation from Mongolia and nuclear physics activity at the Nuclear Research Center, National University of Mongolia	45 min	M. Odsuren

Tuesday, 25 October 2016

9:00 – 13:00

2.1	Compilation of thermal neutron cross sections and resonance integrals	60 min	V. Semkova
2.2	Some remarks on compilation of thermal neutron constants	45 min	N. Otsuka
2.3	InpGraph: Quick start tutorial	30 min	S. Taova

2.4	Exfor-Editor: Quick start tutorial	30 min	G. Pikulina
2.5	Practice of Data Table mode usage	30 min	S. Selyankina

13:00 – 14:00 Lunch break

14:00 – 18:00

2.6	Compilation exercises of thermal neutron cross sections and resonance integrals.	120 min	All
2.7	InpGraph and EXFOR-Editor training	120 min	All

Thursday, 27 October 2016

9:00 – 13:00

3.1	Compilation of D-BE neutron spectra for SPA reactions.	30 min	V. Semkova
3.2	Calculation of catalytic nuclear reactions induced by reactor neutrons and its applications	40 min	N. Kenzhebayev
3.3	Comments on thick target yield measurements and compilation	45 min	S.Takacs
3.3	Comments on InpGraph digitizer	30 min	M.Mikhailiukova
3.4	Light Web-based EXFOR and ENSDF editors. Status and perspectives.	60 min	V. Zerkin

13:00 – 14:00 Lunch break

14:00 – 18:00

3.4	Nuclear fusion reaction measurements at LUNA for nuclear astrophysics	60 min	M. Takacs
3.5	Digitization software GDgraph	60 min	G. Chen
3.6	Compilation of charged-particle induced data	180 min	All

Friday, 28 October 2016

9:00 –

4.1	Review of the compilation exercises.
4.2	Discussions.
4.3	Closing of the meeting

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Atoms for Peace

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