CHAPTER 7

The Indian Experimental Nuclear Physics data compilation into IAEA-EXFOR database

7.1 Introduction

In the International Nuclear Data Committee (INDC) meeting in 2006 [1], experts recommended that major nuclear data user countries, such as India, China and Russia also contribute to the EXFOR [2] file entries for experimental nuclear data generated in their respective countries. India has become a member of International Network of Nuclear Reaction Data Centres (NRDC) in September 2008 [3]. With the very strong demand and recommendation from INDC, India has considered the classical nuclear data physics activity of EXFOR compilation into IAEA-EXFOR database [4] as an important and major activity of the Nuclear Physics Data Centre of India (NDPCI) [5]. Presently, NDPCI has a responsibility to continue the EXFOR compilation of Indian experimentally measured and published nuclear physics data activity and take up more classical nuclear data physics responsibilities. It has been noted by NDPCI that many of the experiments on neutron induced measurements performed in national laboratories, institutions and in some of the universities in India remain to be coded in EXFOR format submittal to the IAEA-EXFOR database. The identification for coding into EXFOR of all the suitable Indian articles published in the literature has been done by the IAEA-NDS staff.

The EXFOR activity in India got a boost with BARC, Mumbai successfully organizing first EXFOR national training workshops in 2006 sponsored by the DAE-BRNS (Department of Atomic Energy-Board of Research in Nuclear Sciences) In this workshop, more than 40 delegates (experimental nuclear scientists, university faculty, research and postgraduate students) took active part and got a "first time" exposure to a classical nuclear data physics activity of EXFOR compilation culture.

So far four successful workshops on EXFOR have been held: 2006 (Mumbai), 2007 (Mumbai), 2009 (Jaipur) and 2011(Chandigarh). This EXFOR activity represents introduction of a new Experimental Nuclear Physics Database culture in India. The importance of such highly focused training courses on EXFOR is well recognized in the nuclear physics community. The author has attended all four national workshops on EXFOR compilation of Indian nuclear physics data and contributed into IAEA-EXFOR database. In fact, author has worked as trainer in the last two workshops (2009, Jaipur and 2011, Chandigarh) for the M. Sc, M. Phil and Ph. D students to teach them the EXFOR compilation through EXFOR-editor. The author has been continuing EXFOR compilation activity as an important part of his research work since 2006. As of now, the author has contributed more than 30 new EXFOR entries into IAEA-EXFOR database which includes fission yield data measured by Radiochemistry lab, BARC, hybrid surrogate ratio approach {^{233}Pa(n,f)}, fission anisotropy measurement by Nuclear Physics Division, BARC, heavy ion fusion data from Indian universities, Photo-nuclear data from Kharghar, Navi Mumbai and from Pohang, South Korea and many more apart from his own measured data compilation.

The details of new Indian EXFOR entries are, available in "Full EXFOR Compilation Statistics", in the IAEA-NDS site: http://www-nds.iaea.org/exformaster/x4compil/progress India.htm. The EXFOR database is also available in the IAEA-India mirror website: http:/www-nds.indcentre.org.in. An article on the mirror website is available [6]. A schematic of regional IAEA-NDS nuclear data mirror site set-up in India is given below in Fig. 7.1

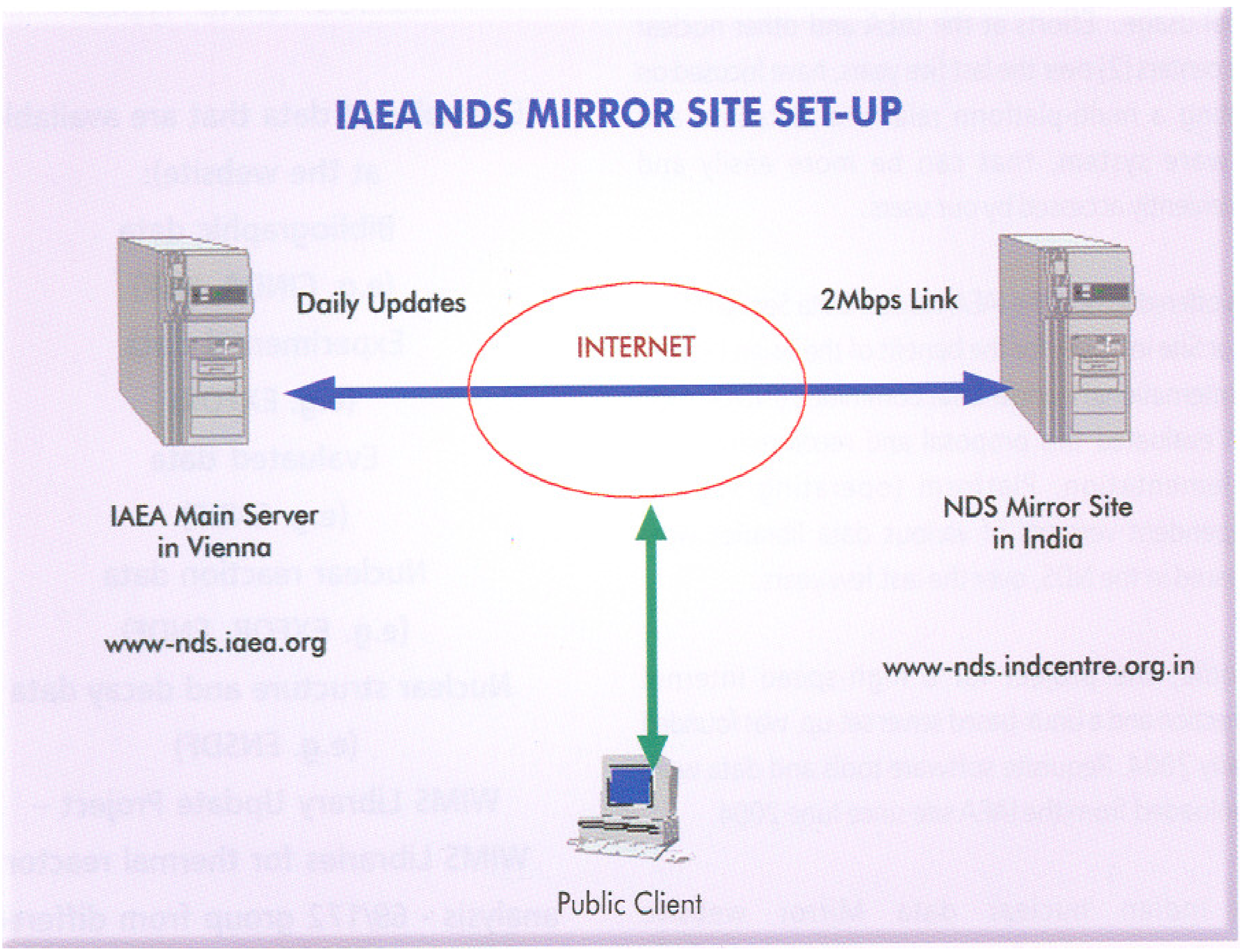


Fig. 7.1 A schematic of regional IAEA-NDS nuclear data mirror site set-up in India.

The new Indian Exfor entries created by the author have been presented in several national/international workshops [7-11].

7.2 What is EXFOR?

An "EXFOR" is the compilation of published experimental nuclear reaction data for incident neutrons, gammas and charged particles on various targets. Nuclear Data evaluators, applied users and experimentalists widely use this data. There is specific format in which the experimental data is coded into the EXFOR system for ready recovery and comparison with evaluated nuclear data. The nuclear data coded into EXFOR database are the numerical results of individual measurements as reported by the authors. EXFOR is derived from "Exchange Format" – experimental nuclear reaction data compiled regularly through the network of nuclear reaction data centers: (http://www-nds.indcentre.org.in/exfor/). The EXFOR library contains an extensive compilation of experimental nuclear reaction data. Neutron reactions have been compiled systematically since the discovery of the neutron, while charged particles (including reaction of interest to heavy ion fusion research and photon reactions) have been covered less extensively. The EXFOR library contains results of numerical nuclear data evaluators, applied users, experimentalists, and theorists. EXFOR retrievals are available on the web from the sites of the major data centers and CD-ROM.

The EXFOR format allows a large variety of numerical data tables with associated textual information, i.e., bibliographic and descriptive information, to be transmitted in a format:

- that is machine-readable (for checking and processing);
- that can be read easily by nuclear scientists and technologists (for updating, evaluating, etc.).

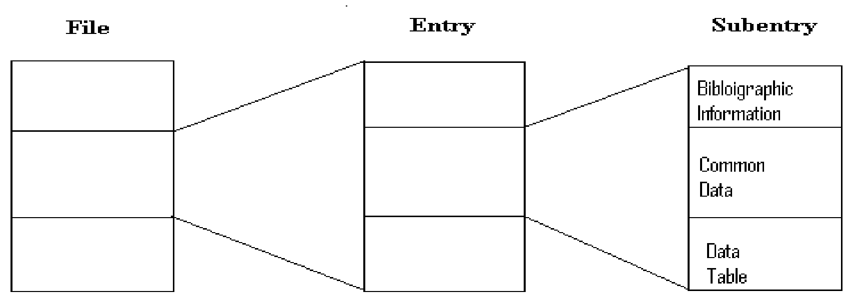
The format was designed for flexibility in order to allow a wide range of data types to be exchanged and stored. A series of keywords and codes have designed to implement this. These keywords and codes are defined in the EXFOR dictionaries.

7.3 Structure of the EXFOR-Exchange Format

The EXFOR format has been designed for flexibility rather than optimization of data processing in order to meet the diverse needs of the nuclear reaction data centers. The EXFOR format is continuously refined and expanded to include new types of data as the need arises. This is accomplished through discussions among the member centers of the NRDC. This section describes the general structure and the format of an EXFOR exchange file. The details of this section have been taken from Ref [12].

7.3.1 Structure of an EXFOR file and Definition of Subentry

An exchange file contains a number of entries. Each entry is divided into a number of subentries. The subentries are composed of bibliographic information and data. The data is further divided into data values that are common throughout the subentry (common data) and a data table. The file may, therefore, be considered to be of following form:



Definition of Subentry

The originating center is responsible for dividing entries into appropriate subentries prior to transmission. This ensures that an entry is divided into subentries in a unique manner, which may be referenced by all centers.

1. A subentry is defined as a data table as a function of one or more independent variables: *i.e.*, *X*, *X′* vs. *Y* with associated errors for *X*, *X′* and *Y* (*e.g.*, *X* = energy; *X′* = angle; *Y* = differential cross section) and any associated variables (*e.g.*, standard).

2. Variables may appear either in the common data portion of a subentry (when uniformly applied to all points), or as a field of the data table (when applied point-wise).

3. For some data, the data table does not have an independent variable *X* but only a function *Y*. (*Examples*: Spontaneous $\bar{\nu}$; resonance energies without resonance parameters)

7.3.2 Identification Files, Entries and Subentries

In order to track, access, and identify data within the EXFOR Exchange System, the following labeling systems have been adopted for files, entries and subentries.

1. An EXFOR Exchange File is labeled using four-character file identification.

2. An entry is labeled using a five-character accession number.

3. A subentry is labeled using an eight-character sub accession number.

Each of these labels includes a center-identification character as the first character in the string. The table on the following page lists the center-identification characters that have been assigned. These characters define both the center at which the information was compiled and the type of data compiled.

Table 7.1 Center Identification Characters

0	Preliminary	For internal center use
1	NNDC (Brookhaven)	Neutron nuclear data
2	NEA-DB (Paris)	Neutron nuclear data
3	NDS (Vienna)	Neutron nuclear data
4	CJD (Obnisk)	Neutron nuclear data

9	NDS (Vienna)	Dictionary transmission
A	CAJaD (Moscow)	Charged-particle nuclear data
B	KaChaPag (Karlsruhe)	Charged-particle nuclear data
C	NNDC (Brookhaven)	Charged-particle nuclear data
D	NDS (Vienna)	Charged-particle nuclear data
E	JCPRG (Sapporo)	Charged-particle nuclear data
F	NPDC (Sarov)	Charged-particle nuclear data
G	NDS (Vienna)	Photonuclear data
H	NNDC (Brookhaven)	Special internal use for relativistic particle reaction data
L	NNDC (Brookhaven)	Photonuclear data
M	CDFE (Moscow)	Photonuclear data
N	NEA-DB (Paris)	Special use for memos only
O	NEA-DB (Paris)	Charged-particle nuclear data
P	NNDC (Brookhaven)	Charged-particle nuclear data from MacGowen file
Q	CJD (Obnisk)	Photonuclear data
R	RIKEN	Charged-particle nuclear data
S	CNDC	Charged-particle nuclear data
T	VNIIEF/NNDC	Charged-particle nuclear data
V	NDS (Vienna)	Special use for selected evaluated neutron data “VIEN” file.

7.4 Quantities in EXFOR and EXFOR retrieval (WWW/ZVView)

There are many nuclear data physics quantities that can be entered in EXFOR database.

- Integral and partial cross sections (incl. excitation functions, spectrum-averaged data, ratios etc.)
- Differential cross sections of many types, including angular distributions and Legendre coefficients, secondary particle spectra etc.
- Resonance parameters
- Fission product yields, Nu-bar, fission quantities
- Product yields and thick target yields
- Reaction rates, resonance integrals

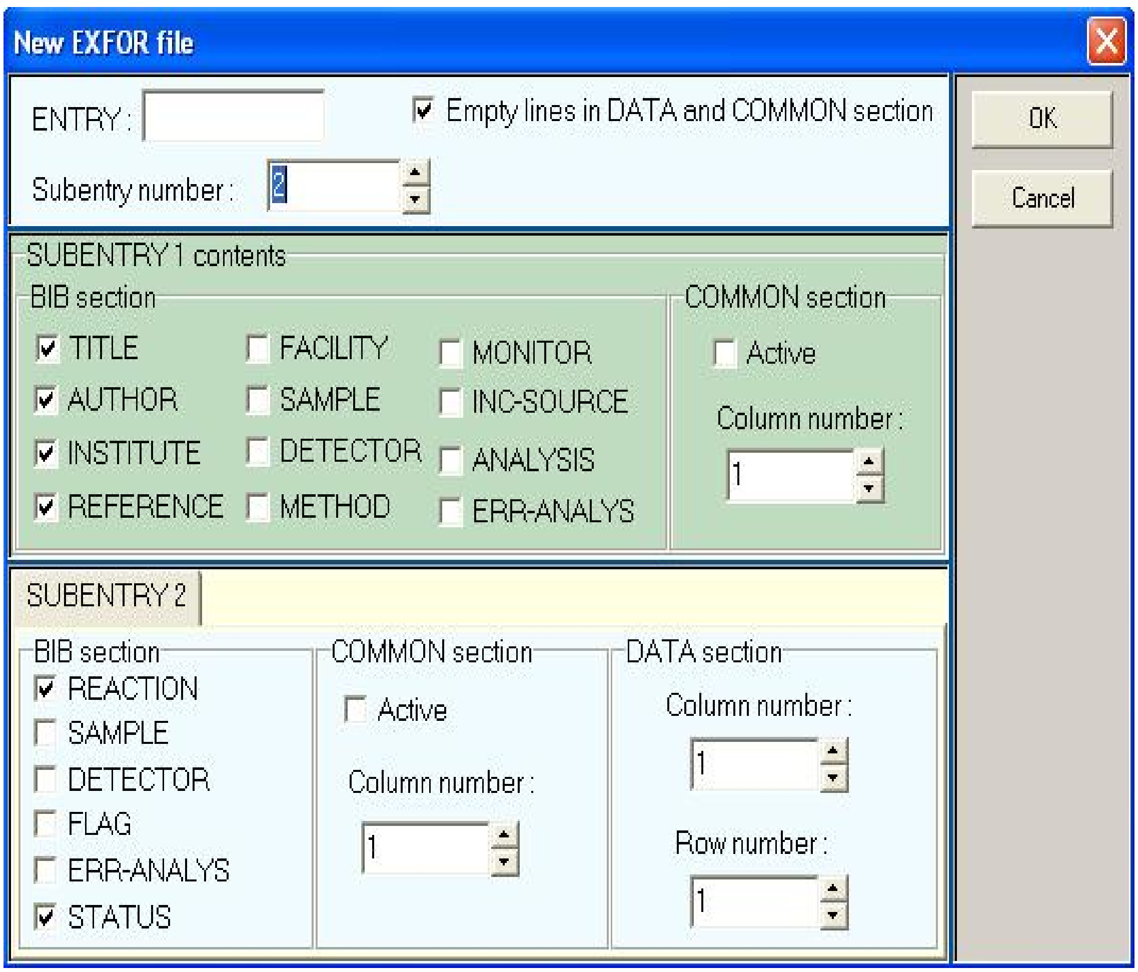


Fig.7. 2 Creation of EXFOR file using EXFOR-Editor

EXFOR retrieval (WWW/ZVView)

The Exfor entries are created using an EXFOR-Editor. A typical view for creation of EXFOR entry using an editor is given in Fig. 7.2. The EXFOR data can easily retrieved through website: http://www-nds.iaea.org/exfor Fig. 7.3 shows the typical example of ^{56}Fe(n,p) cross-section experimental data with ENDF/B-VI evaluation.

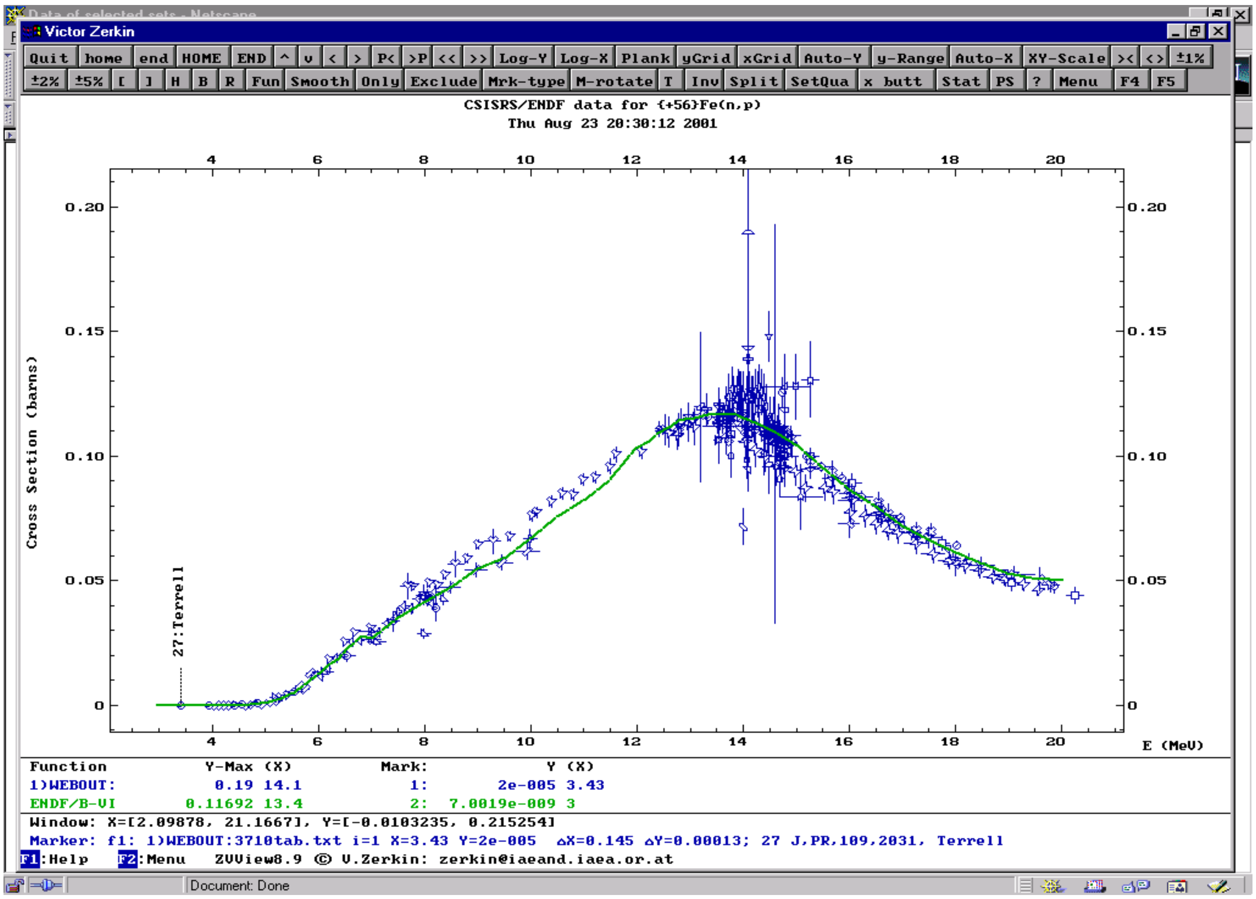


Fig. 7.3 ^{56}Fe(n,p) cross-section experimental data with ENDF/B-VI evaluation

7.5. List of newly created EXFOR entry for the Indian experimentally measured Nuclear Physics data into IAEA-EXFOR database, NDS,

Since 2006, the author has contributed more than 30 new Exfor entries for Indian experimental nuclear physics data into IAEA-EXFOR database. All these new Exfor entries have been duly approved by corresponding authors of the journal paper before its communication to Nuclear Data Section, IAEA. The Table 7.2 presents some of the interesting and newly created Exfor entries by author.

Table 7. 2 Newly created Exfor entries in IAEA-EXFOR database

Sr. No	Entry No.	Title of the Paper	Authors	Reference
1.	33020	Fragment angular momenta in low and medium energy fission of ^{242}Pu	B.S.Tomar et al.,	J,ZP/A,327,225, 1987
2.	33021	Effect of shell closure proximity on fragment angular momenta in ^{241}Pu(n,f)	S.P.Dange et al.,	J,JRN,108,269,1 987
3.	33022	Fission fragment angular momentum in the spontaneous fission of ^{244}Cm	H.Naik, R.J.Singh and R.H.Iyer	J,RCA,92,1,200 4
4.	D6044	Fragment angular momenta in low and medium energy fission of ^{242}Pu	B.S.Tomar et al.,	J,ZP/A,327,225, 1987
5.	D6067	Large pre-equilibrium contribution in A + $^{nat.}$Ni interactions at ~ 8-40 MeV	Abhishek Yadav et al.,	J,PR/C,78,0446 06,2008

6.	33023	Determination of the ^{233}Pa (n,f) reaction cross-section from 11.5 to 16.5 MeV neutron energy by the hybrid surrogate ratio approach	B.K.Nayak et al.,	J,PR/C,78,061602,2008
7.	D6075	Determination of the ^{233}Pa (n,f) reaction cross-section from 11.5 to 16.5 MeV neutron energy by the hybrid surrogate ratio approach	B.K.Nayak et al.,	J,PR/C,78,061602,2008
8	33033	Measurement of the neutron capture cross-section of ^{232}Th using the neutron activation technique	H.Naik, **P. M. Prajapati** et al.,	J,EPJ/A,47,51, 2011
9	33036	^{233}Pa(2nth, f) cross-section determination using a fission track technique	H. Naik, **P. M. Prajapati** et al.,	J,EPJ/A,47,100, 2011
10	G0014	Post-neutron mass yield distribution and Photo-neutron cross-section measurements in ^{209}Bi with 65-MeV	H. Naik et al.,	J,KPS,52,934, 2008
11	33037	Measurement of neutron-induced reaction cross-sections in zirconium isotopes	**P. M. Prajapati,** H. Naik et al.,	J,NSE,171,78 (2012)
12	33040	Measurement neutron capture cross-sections of ^{232}Th at 5.9 MeV and 15.5 MeV	**P. M. Prajapati,** H. Naik et al.,	J,EPJ/A,48, 35,2012

7.5.1 Exfor entries related to the present work

In this section, the detailed Exfor entries have been given which are directly related to the present research work.

1. Measurement of the neutron capture cross-section of 232-Th using the neutron activation technique.

Ref: J, EPJ/A, 47, 51 (2011)

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TRANS                         20110607                                 10000
ENTRY               33033     20110505                                 33033
SUBENT           33033001     20110505                                 33033
BIB                    13           54                                 33033
TITLE         Measurement of the neutron capture cross-section of      33033
              232-Th using the neutron activation technique            33033
AUTHOR        (H.Naik,P.M.Prajapati,S.V.Surayanarayana,                33033
              K.C.Jagadeesan, S.V.Thakare,D.Raj,V.K.Mulik,             33033
              B.S.Sivashankar,B.K.Nayak, S.C.Sharma,S.Mukherjee,       33033
              Sarbjit Singh,A.Goswami,S.Ganesan, V.K.Manchanda)        33033
INSTITUTE     (3INDTRM,3INDBDA,3INDPOO)                                33033
REFERENCE     (J,EPJ/A,47,51,2011)                                     33033
FACILITY      (VDG,3INDTRM)BARC-TIFR Pelletron facility at TIFR,       33033
              Mumbai                                                   33033
SAMPLE        The samples used for irradiation were natural 232-Th     33033
              metal foil and natural In metal foil, which were         33033
              wrapped separately with 0.025 mm thick aluminum foil     33033
              to prevent contamination from one to the other. The      33033
              size of 232-Th metal foil was 1.0 cm**2 with             33033
              thickness of 29.3 mg/cm**2, whereas indium metal         33033
              foil is also of same size with thickness of 2.6          33033
              mg/cm**2.                                                33033
DETECTOR      (HPGE)The gamma-rays of fission/reaction products        33033
              from the irradiated Th and In samples were counted       33033
              in an energy and efficiency calibrated 80 c.c. HPGe      33033
              detector coupled to a PC-based 4K channel analyzer       33033
METHOD        (ACTIV,GSPEC) The 232Th(n,g) reaction cross-section      33033
              at average neutron energy of 3.7 MeV and 9.85            33033
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            MeV has been determined for the first time          33033
            using activation and off-line gamma-ray             33033
            spectrometric technique.                            33033
INC-SOURCE  (P-LI7)The neutron beam was obtained from the       33033
            7-Li(p,n) reaction by using the proton beam main    33033
            line at 6 m above the analyzing magnet of the       33033
            Pelletron facility to utilize the maximum proton    33033
            current from the accelerator                        33033
ANALYSIS    (AREA) The observed photo-peak activity (Aobs) of   33033
            gamma-lines was obtained using PHAST peak fitting   33033
            programme.The nuclear spectroscopic data used in the 33033
            present work for the calculation of 232-Th(n,g) and 33033
            232-Th(n,2n) reaction cross-sections are taken from 33033
            the refs. [53, 54].                                 33033
ERR-ANALYS  (ERR-T) The uncertainties associated to the         33033
            measured cross-sections come from the combination of 33033
            two experimental data sets. This overall uncertainty 33033
            is the quadratic sum of both statistical and        33033
            systematic errors.                                  33033
(ERR-1)     The systematic errors are due to                    33033
            uncertainties in neutron flux estimation (~4%).     33033
            (ERR-2) The irradiation time (~2%)                  33033
            (ERR-3) The detection efficiency calibration (~3 %) 33033
            (ERR-4) The half-life of the fission products and   33033
                    the gamma-ray abundances (~2%).             33033
            (ERR-SYS)The total sytematic error is about ~6%.    33033
STATUS      (APRVD)Entry approved by Dr. H. Naik                33033
HISTORY     (20110505C)Compiled by Mr. Paresh Prajapati and Dr. S. 33033
            Mukherjee, The M. S. University of Baroda,          33033
            Vadodara - 390 002.                                 33033
ENDBIB              54          0                               33033
COMMON               5          3                               33033
ERR-1       ERR-2       ERR-3       ERR-4       ERR-SYS         33033
PER-CENT    PER-CENT    PER-CENT    PER-CENT    PER-CENT        33033
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4.         2.         3.         2.         6.                     33033
ENDCOMMON           3          0                                   33033
ENDSUBENT          61          0                                   33033
SUBENT        33033002   20110505                                  33033
BIB                 3        176                                   33033
REACTION   (90-TH-232(N,G)90-TH-233,,SIG,,SPA)                     33033
DECAY-DATA (90-TH-233,21.83MIN,DG,86.5,0.027)                      33033
INC-SPECT  Fig .5, Neutron spectrum from the 7-Li(p, n) reaction   33033
            at Ep = 5.6 MeV calculated using the results of        33033
           Meadows and Smith of reference 47 of the paper.         33033
           EN         Neutron Flux                                 33033
           MEV        mb/Sr-MeV                                    33033
           0.1        7.79E-04                                     33033
           0.2        0.0014                                       33033
           0.3        0.00189                                      33033
           0.4        0.00225                                      33033
           0.5        0.0025                                       33033
           0.6        0.00267                                      33033
           0.7        0.00275                                      33033
           0.8        0.00276                                      33033
           0.9        0.00272                                      33033
           1          0.00263                                      33033
           1.1        0.0025                                       33033
           1.2        0.00235                                      33033
           1.3        0.00217                                      33033
           1.4        0.00198                                      33033
           1.5        0.00178                                      33033
           1.6        0.00157                                      33033
           1.7        0.00136                                      33033
           1.8        0.00114                                      33033
           1.9        9.38E-04                                     33033
           2          7.38E-04                                     33033
           2.1        5.46E-04                                     33033
           2.2        3.63E-04                                     33033
           2.3        1.90E-04                                     33033
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2.4	2.04E-10	33033
2.5	8.07E-09	33033
2.6	2.14E-07	33033
2.7	3.82E-06	33033
2.8	4.56E-05	33033
2.9	3.65E-04	33033
3	0.00196	33033
3.1	0.00705	33033
3.2	0.01701	33033
3.3	0.02777	33033
3.4	0.0323	33033
3.5	0.03531	33033
3.6	0.05984	33033
3.7	0.12234	33033
3.8	0.19292	33033
3.9	0.20829	33033
4	0.15118	33033
4.1	0.07358	33033
4.2	0.02401	33033
4.3	0.00525	33033
4.4	7.70E-04	33033
4.5	7.57E-05	33033
4.6	4.98E-06	33033
4.7	2.20E-07	33033
4.8	6.51E-09	33033
4.9	1.29E-10	33033
5	1.72E-12	33033
5.1	1.53E-14	33033
5.2	9.16E-17	33033
5.3	3.67E-19	33033
5.4	9.85E-22	33033
5.5	1.77E-24	33033
5.6	2.14E-27	33033

Fig. 6,Extrapolated neutron spectrum in 7Li(p, n) 33033
reaction at Ep = 12 MeV obtained from the neutron 33033

spectrum at Ep = 10 MeV of reference 46 of the paper. 33033

EN	Neutron Flux	33033
MEV	mb/Sr-MeV	33033
5.228	4.41928	33033
5.278	5.04291	33033
5.328	6.01152	33033
5.378	7.55317	33033
5.428	9.6155	33033
5.478	11.48641	33033
5.528	12.35986	33033
5.578	11.64606	33033
5.628	9.29659	33033
5.678	5.64977	33033
5.728	2.69334	33033
5.778	1.59589	33033
5.828	1.61459	33033
5.878	1.86877	33033
5.928	1.64885	33033
5.978	1.21338	33033
6.028	1.02771	33033
6.078	1.01758	33033
6.128	0.98905	33033
6.178	0.90555	33033
6.228	0.81651	33033
6.278	0.76498	33033
6.328	0.74102	33033
6.378	0.71093	33033
6.428	0.66059	33033
6.478	0.62557	33033
6.528	0.62654	33033
6.578	0.62931	33033
6.628	0.59609	33033
6.678	0.53383	33033
6.728	0.47473	33033
6.778	0.44115	33033

6.828	0.42253	33033
6.878	0.40167	33033
6.928	0.37026	33033
6.978	0.34264	33033
7.028	0.32534	33033
7.078	0.31659	33033
7.128	0.31049	33033
7.178	0.29162	33033
7.228	0.2498	33033
7.278	0.21012	33033
7.328	0.20051	33033
7.378	0.20467	33033
7.428	0.19287	33033
7.478	0.15854	33033
7.528	0.12748	33033
7.578	0.12762	33033
7.628	0.15781	33033
7.678	0.16381	33033
7.728	0.13334	33033
7.778	0.09563	33033
7.828	0.06795	33033
7.878	0.04929	33033
7.928	0.03749	33033
7.978	0.03106	33033
8.028	0.02881	33033
8.078	0.02955	33033
8.128	0.0322	33033
8.178	0.03599	33033
8.228	0.04029	33033
8.278	0.0443	33033
8.328	0.04673	33033
8.378	0.04623	33033
8.428	0.04142	33033
8.478	0.03094	33033
8.528	0.01527	33033

8.578	0.01137	33033
8.628	0.0303	33033
8.678	0.05288	33033
8.778	0.05851	33033
8.828	0.04877	33033
8.878	0.03774	33033
8.928	0.02765	33033
8.978	0.01968	33033
9.028	0.01494	33033
9.078	0.01457	33033
9.128	0.0197	33033
9.178	0.03147	33033
9.228	0.05186	33033
9.278	0.08576	33033
9.328	0.12897	33033
9.378	0.15814	33033
9.428	0.14774	33033
9.478	0.13522	33033
9.528	0.45942	33033
9.578	1.48469	33033
9.628	2.91008	33033
9.678	4.57921	33033
9.728	6.12017	33033
9.778	6.45023	33033
9.828	5.31394	33033
9.878	3.47149	33033
9.928	2.39912	33033
9.978	2.85879	33033
10.028	2.529	33033
10.078	5.1848	33033
10.128	12.08801	33033
10.178	13.36977	33033
10.228	11.93188	33033
10.278	9.48661	33033
10.328	6.7653	33033

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           10.378     4.03077                                    33033
           10.428     1.17284                                    33033
           10.478     0.06397                                    33033
           10.528     -0.03379                                   33033
           10.578     0.05033                                    33033
           10.628     0.02146                                    33033
ENDBIB             176          0                                33033
NOCOMMON             0          0                                33033
DATA                 4          2                                33033
EN         EN-ERR     DATA       ERR-T                           33033
MEV        MEV        MB         MB                              33033
        3.7        0.3      16.18       0.87                     33033
       9.85       0.38       2.18       0.12                     33033
ENDDATA              4          0                                33033
ENDSUBENT          185          0                                33033
SUBENT        33033003   20110505                                33033
BIB                  4         24                                33033
REACTION   (90-TH-232(N,G)90-TH-233,,SIG)                        33033
DECAY-DATA (90-TH-233,21.83MIN,DG,86.5,0.027)                    33033
STATUS     (TABLE)Data taken from the Table.1 and 2              33033
           (DEP,33033002)spectrum averaged cross-section         33033
CORRECTION It can be seen from figs. 5 and 6 that the            33033
           contribution to the neutron flux from the tail        33033
           region is 4 % and 49 % at the proton energy of 5.6    33033
           MeV and 12.0 MeV, respectively. In view of this, the  33033
           contribution from the tail region to the 232-Th(n,g)  33033
           reaction has been estimated using the ENDF/B-VII,     33033
           JENDL-4.0 and JEFF-3.1 by folding the cross-sections  33033
           with neutron flux distributions of figs. 5 and 6.The  33033
           contributions 232-Th(n, g) to the reaction from the   33033
           above evaluation at Ep = 5.6 MeV are 5.34, 5.57 and   33033
           5.03 mb from ENDF/B-VII, JENDL-4.0 and JEFF-3.1       33033
           respectively. Similarly at Ep = 12 MeV, 232-Th(n, g)  33033
           the reaction cross-sections from the above evaluation 33033
           are 0.798 and 0.876mb from ENDF/B-VII and JENDL-4.0.The33033
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           actual value of the 232-Th(n, g) reaction cross-section33033
           due to the neutrons from the main peak of the n0 and n133033
           groups of the neutron spectrum is obtained after       33033
           subtracting the average cross-section due to neutrons  33033
           from the tail region from the before-mentioned         33033
           experimental data.                                     33033
ENDBIB              24          0                                 33033
NOCOMMON             0          0                                 33033
DATA                 4          2                                 33033
EN         EN-ERR     DATA       ERR-T                            33033
MEV        MEV        MB         MB                               33033
        3.7        0.3      10.9         0.9                      33033
       9.85       0.38       1.35       0.12                      33033
ENDDATA              4          0                                 33033
ENDSUBENT           33          0                                 33033
SUBENT        33033004   20110505                                 33033
BIB                  3          3                                 33033
REACTION   (90-TH-232(N,2N)90-TH-231,,SIG)                        33033
DECAY-DATA (90-TH-231,25.52HR,DG,84.2,0.066)                      33033
STATUS     (TABLE)Data taken from the Table.1 and 2               33033
ENDBIB               3          0                                 33033
NOCOMMON             0          0                                 33033
DATA                 4          1                                 33033
EN         EN-ERR     DATA       ERR-T                            33033
MEV        MEV        MB         MB                               33033
       9.85       0.38      1722.        76.                      33033
ENDDATA              3          0                                 33033
ENDSUBENT           11          0                                 33033
ENDENTRY             4          0
ENDTRANS             1          0
```

2. ^{233}Pa(2n$_{th}$, f) cross-section determination using a fission track technique.

Ref: J, EPJ/A, 47, 100 (2011)

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TRANS                   20110807                                10000
ENTRY              33036   20110807                             33036
SUBENT          33036001   20110807                             33036
BIB                   12         51                             33036
TITLE       233Pa(2nth, f) CROSS-SECTION DETERMINATION USING A   33036
            FISSION TRACK  TECHNIQUE                            33036
AUTHOR      (H.Naik,P.M.Prajapati,S.V.Suryanarayana,P.N.Pathak,  33036
            D.R.Prabhu,V.Chavan,D.Raj,P.C.Kalsi,A.Goswami)      33036
INSTITUTE   (3INDTRM)                                           33036
REFERENCE   (J,EPJ/A,47,100,2011)                               33036
FACILITY    (REAC,3INDTRM)                                      33036
SAMPLE      About 6 g of thorium nitrate salt was wrapped with   33036
            0.025 mm thick  aluminum foil and doubly sealed with 33036
            alkathene.5.2 ng of separated  233-Pa in the form of 33036
            nitrate was dried on a 0.025 mm thick aluminum  foil. 33036
            Dried 233-Pa(NO3)3 was covered with a 0.0075 mm thick 33036
            Lexan foil  of size 1.5 cm x 1.5 cm.                33036
DETECTOR    (HPGE,TRD)The Purity and amount of the 233-Pa was    33036
            ascertained by a  gamma-ray spectrometric technique  33036
            using an energy and efficiency  calibrated 80 cm3 HPGe 33036
            detector coupled to a PC-based 4K channel            33036
            analyzer.The gamma-ray counting of the irradiated gold 33036
            target (flux  monitor) was also done for the 411.8 keV 33036
            gamma-line of 198-Au using  same 80 cm3 HPGe detector  33036
            coupled to the PC-based 4K-channel  analyzer.The     33036
            counting of fission tracks in lexan foil within a few  33036
            fields i.e. fraction of the total area was done by   33036
            visual inspection  under the microscope.             33036
METHOD      (ACTIV,RCHEM,GSPEC) 233-Pa was prepared from         33036
            activation of 232-Th  followed by beta decay.        33036
            Di-isobutyl carbinol (DIBC), procured from  Aldrich,  33036
            USA, was used as an extractant for the radiochemical  33036
            separation of 233-Pa and quantitative stripping was   33036
```

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           achieved by 0.1 N  HCl.                             33036
ANALYSIS   (AREA)The amount of 233-Pa was estimated using      33036
           gamma-ray (311.9 keV) spectrometric  technique  and 33036
           decay equation. The neutron flux was estimated from 33036
           the  peak area of the 411.8 keV of the flux monitor 33036
           198-Au. The fission track in the lexan was counted  33036
           manually using  optical microscope. The             33036
           233-Pa(2nth,f)fission  cross-section was calculated 33036
           from the fission track using tack density  equation. 33036
ERR-ANALYS (DATA-ERR) The visual counting of the fission track by 33036
           microscope can  cause a systematic error of about 1%. 33036
           The error in 233-Pa(2nth,f)  fission cross-section is 33036
           due to replicate measurements, which is about  1.2%. 33036
           Other systematic errors are due to neutron          33036
           flux (0.5%),  irradiation time (0.2%) and visual    33036
           counting of the fission track under  microscope (1%), 33036
           which was mentioned before. Thus, the total systematic 33036
            error is around 1.8%.                              33036
HISTORY    (20081111C) Compiled by Dr. H. Naik, Radiochemistry 33036
           Divison of B.A.R.C, Mumbai and Mr. Paresh Prajapati 33036
           of The M.S. University of Baroda, Vadodara          33036
STATUS     (APRVD) Entry approved by Dr. H. Naik               33036
ENDBIB             51          0                               33036
COMMON              1          3                               33036
EN-DUMMY                                                       33036
EV                                                             33036
0.0253                                                         33036
ENDCOMMON           3          0                               33036
ENDSUBENT          58          0                               33036
SUBENT       33036002   20110807                               33036
BIB                 1          1                               33036
REACTION   (91-PA-234(N,F),,SIG)                               33036
ENDBIB              1          0                               33036
NOCOMMON            0          0                               33036
DATA                3          1                               33036
```

```
EN          DATA        DATA-ERR                                        33036
EV          B           B                                               33036
0.0253      4834.       57.                                             33036
ENDDATA               3          0                                      33036
ENDSUBENT             9          0                                      33036
ENDENTRY              2          0
ENDTRANS              1          0
```

3. **Determination of the 233-Pa (n,f) reaction cross-section from 11.5 to 16.5 MeV neutron energy by the hybrid surrogate ratio approach.**

Ref: J, PR/C, 78, 061602 (2008)

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TRANS                     20090804                                      33023
ENTRY            33023    20090803                                      33023
SUBENT        33023001    20090803                                      33023
BIB                 14          63                                      33023
TITLE       Determination of the 233-Pa (n, f) reaction cross           33023
            section from 11.5 to 16.5 MeV neutron energy by the         33023
            hybrid surrogate ratio approach                             33023
AUTHOR      (B.K.Nayak, A.Saxena, D.C.Biswas, E.T.Mirgule,              33023
            B.V.John, S.Santra, R.P.Vind, R.K.Choudhury,                33023
            S.Ganesan)                                                  33023
INSTITUTE   (3INDTRM)                                                   33023
REFERENCE   (J,PR/C,78,061602,2008)                                     33023
FACILITY    (VDGT,3INDTAT)                                              33023
SAMPLE      A self-supporting thorium target of thickness 2.0           33023
            Mg/cm**2 was bombarded with a 6-Li beam.                    33023
DETECTOR    (SOLST,SISD) a solid state delta E - E telescope of         33023
            thickness 150.0 micro millimeter to 1.0 millimeter was      33023
            kept at 90 degree with respect to the beam direction        33023
            around the transfer grazing angle to identify the           33023
            projectile-like-fragments (PLF). A 16 strip solid           33023
            state detector (each strip of size 2.0 X 64.0 mm) was       33023
            placed at a back angle covering the laboratory angular      33023
            range of 141-158 degree to detect fission fragments in      33023
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           coincidence with PLFs.                                33023
METHOD     (EDE) The proton, deuteron, triton, alpha and 6-Li    33023
           particles are uniquely identified by plotting delta   33023
           E against the delta E + E. This plot was transformed  33023
           to create an effective particle identification versus 33023
           energy plot.                                          33023
INC-SOURCE A self-supporting thorium was bombarded with 6-Li     33023
           beam of energy 38.0 MeV from a 14 MV Pelletron        33023
           accelerator at Mumbai.                                33023
ANALYSIS   (SURGT) The 234-Pa and 236-U compound systems have    33023
           been populated at overlapping excitation energies in  33023
           the same experiment through 232-Th (6-Li,A) 234-Pa and 33023
           232-Th (6-Li,D) 236-U transfer channels at E (lab) = 3833023
           MeV, and the absolute surrogate method is used to     33023
           determine fission decay probabilities of the above    33023
           compound nuclei by dividing the number of PLF-fission 33023
           coincidences by the associated PLF-singles data. The  33023
           experimental values of fission decay probability      33023
           ratios of 234-Pa and 236-U compound nuclei at the same 33023
           excitation energies have been used to deduce the 233-Pa33023
            (n,f) cross-section using a surrogate ratio approach. 33023
ERR-ANALYS (ERR-S) The uncertainties shown in the measured cross 33023
           section is due to the statistics of coincidence       33023
           counts in each energy beam.                           33023
HISTORY    (20090803C)Compiled by Mr.Paresh Prajapati of The     33023
           M. S. University of Baroda and Dr. S. Ganesan of      33023
           Reactor Physics Design Division, B.A.R.C, Mumbai.     33023
COMMENT    A new hybrid surrogate ratio approach has been        33023
           employed to determine neutron-induced fission cross   33023
           sections of 233-Pa in the energy range of 11.5 to     33023
            16.5 MeV for the first time. The 233-Pa              33023
         (n,f) cross sections are deduced from the measured      33023
           fission decay probabilities ratios of 234-Pa and      33023
           236-U compound nuclei using the surrogate ratio       33023
           method. The 233-Pa (n,f) cross section data from the  33023
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           present experiment along with the data from the        33023
           literature, covering the neutron energy range of 1.0   33023
           to 16.5 MeV have been compared with the predictions    33023
           of statistical model code EMPIRE-2.19. While the       33023
           present data are consistent with the model             33023
           predictions, there is a discrepancy between the        33023
           earliear experiment data and EMPIRE-2.19 predictions   33023
           in the neutron energy range of 7.0 to 10.0 MeV.        33023
STATUS     (APRVD)Entry approved by Dr. B. K. Nayak               33023
ENDBIB             63          0                                  33023
NOCOMMON            0          0                                  33023
ENDSUBENT          66          0                                  33023
SUBENT       33023002   20090803                                  33023
BIB                 4         10                                  33023
REACTION  1((91-PA-233(N,F),,SIG)/(92-U-235(N,F),,SIG))           33023
          2(91-PA-233(N,F),,SIG)                                  33023
MONITOR    ((MONIT)92-U-235(N,F),,SIG) ENDF-B/VII                 33023
STATUS     (TABLE) Data has been provided by author in the        33023
           tabulated form                                         33023
           (DEP,D6075002) 232Th(6Li,a)234Pa/232Th(6Li,d)236U data 33023
COMMENT    The excitation energy was scaled down to the           33023
           equivalent neutron energy range of 11.5-16.5 MeV by    33023
           subtracting the neutron separation energy of 233-Pa    33023
           (Sn = 5.45 MeV)                                        33023
ENDBIB             10          0                                  33023
COMMON              1          3                                  33023
EN                                                                33023
MEV                                                               33023
38.0                                                              33023
ENDCOMMON           3          0                                  33023
DATA                6          6                                  33023
EN         DATA       1ERR-S     1DATA      2ERR-S     2MONIT     33023
MEV        NO-DIM      NO-DIM     MB         MB         B         33023
11.4991    0.50184    0.028      0.8832     0.076      1.703      33023
12.5000    0.51408    0.027      0.8754     0.076      1.799      33023
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13.5080    0.49964    0.021      0.8986     0.066      1.988      33023
14.5120    0.49964    0.021      0.9444     0.071      2.091      33023
15.5163    0.52743    0.026      1.1347     0.077      2.151      33023
16.5710    0.68700    0.049      1.4780     0.1        2.122      33023
ENDDATA              8          0                                 33023
ENDSUBENT           27          0                                 33023
ENDENTRY             2          0
ENDTRANS             1          0
```

7.6 Summary and Conclusions

In brief, an EXFOR is the library and format for the collection, storage and retrieval of experimental nuclear reaction data. The library is the product of a worldwide co-operation, namely the international Network of Nuclear Reaction Data Centers (NRDC) which is co-ordinated by IAEA Nuclear Data Section (NDS). The basic unit of EXFOR is an ‘entry’, which corresponds to one experiment which is usually described in one or more bibliographic references (journal articles, laboratory reports, conference proceedings etc.). All types of microscopic cross-sections and related data (e.g. Integral and partial cross-sections, excitation functions, spectrum averaged data, ratios, differential cross-sections, resonance parameters, fission product yields, reaction rate and resonance integrals etc.) have been included in Exfor database. The NDPCI has considered the classical nuclear data physics activity of EXFOR compilation into IAEA-EXFOR database as an important and major activity. The author has contributed more than 30 new Indian Exfor entries in IAEA-EXFOR database since 2006 as required by NDS, IAEA. The IAEA-EXFOR nuclear data compilation of the Indian experimental nuclear physics data will be continued in future as an important task of NDPCI.

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