Compilation of Delayed Neutron Data

(V. Semkova, 2012-04-02, extraction from INDC(NDS)-599 with minor modification)

Regarding the characteristics of the delayed neutrons emitted from the fission products, a survey in EXFOR database shows that total average delayed fission neutron yields (nubar) are extensively compiled. Several energy spectra for specific delayed neutron groups are available in EXFOR as well. However, data for delayed-neutron emission probabilities (P_n values) and delayed neutron spectra for individual fission product precursors are rather scarce. This is to a certain extent due to the fact that those data are on the border between reaction data and decay data, and were not considered for the EXFOR compilation with a priority in the past.

Presently, the (β^-,n) branching fractions (P_n values) and emission spectra for delayed fission neutrons are considered within the scope of EXFOR database, and corresponding compilation formats are provided in the EXFOR manuals. In order to respond to the need to include delayed neutron data in a database, the current situation will be assessed at IAEA NDS (number of articles, other available resources, e.g. XUNDL), and a Memo prepared in order to inform the NRDC community (i.e. EXFOR compilers) about this request and the results of the assessment for discussion. A list of relevant articles (17 for the delayed-neutron energy spectra and 34 for the P_n values, see Tables I and II below) identified in relation with the Consultants' Meeting will be included in this NRDC Memo. The references have been selected from M.C. Brady, Ph.D. thesis (Texas A&M, 1989), LA-11534-T, B. Pfeiffer, K.L. Kratz and P. Moller, Prog. Nucl. Energy 41, 39 (2002), and from the presentations of the meeting. The existing entries will be revised in order to ensure consistency in coding in the EXFOR database.

The ZVView retrieval system will be improved to facilitate the search, and visualization of the delayed neutron spectra and emission probabilities will be provided.

Table I. Measurements of Delayed Neutron Spectra.

Author	Reference	Laboratory
Rudstam+	J,NSE,80,238,1982	2SWDSWR
Rudstam+	J,NSE,64,749,1977	2SWDSWR
Kratz+	J,NP,317,335,1979	2GERMNZ
Franz+	J,PRL,333,859,1974	2GERMNZ
Shalev+	J,NP/A,230,153,`974	2SWDSWR
Kratz+	R,INDC(NDS)-107/G,103,1979	2GERMNZ
Batchelor+	J,JNE,3,7,1956	2SWDSWR
Rudstam+	J,NIM,120,333,1974	2SWDSWR
Rudstam+	J,NP/A,235,397,1974	2SWDSWR
Shalev+	J,NP/A, 275,76,1977	2SWDSWR
Greenwood+	J,NSE,91,305,1985	1USABNL
Greenwood+	J,NSE,126,324,1997	1USABNL
Kratz+	J,ZPA,312,33,1983	2GERMNZ
Reeder+	J,NSE,75,140,1980	1USABNW
Franz+	J,NIM,144,253,1977	2GERMNZ
Shalev+	J,PRL,28,697,1972	2SWDSWR
Ohm+	J,NP/A,274,45,1976	2GERMNZ

Table II. Measurements of Delayed Neutron Emission Probabilities.

Author	Reference	Laboratory
Asghar+	J,JIN,37,1563,1975	2FR GRE
Tomlinson+	J,JIN,30,1649,1968	2UK HAR
Tomlinson+	J,JIN,30,1125,1968	2UK HAR
Tomlinson+	J,JIN,33,3609,1971	2UK HAR
Asghar+	J,NP/A,247,359,1975	2FR GRE
Crancon+	J,ZP/A,287,45,1978	2FR GRE
Kratz+	J,JIN,32,3713,1970	2GERMNZ
Schussler+	J,RCA,18,13,1972	
Kratz+	J,JIN,35,1407,1973	2GERMNZ
Kratz+	J,NP/A,229,179,1974	2GERMNZ
Peuser+	J,ZP/A,289,219,1979	2GERMNZ
del Marmol+	J,JIN,32,705,1970	2BLGMOL
del Marmol+	J,RA,16,4,1971	2BLGMOL
Amarel+	J,JIN,31,577,1969	2FR PAR
Roeckl+	J,NP/A,222,621,1974	2ZZZCER
Lund+	J,ZP/A,294,233,1980	2SWDSWR
Aleklett+	J,ZP./A,295,331,1980	2SWDSWR
Ristori+	J,ZP/A,290,311,1979	
Gabelmann+	J,ZPA,308,359,1982	2GERMNZ
Aron+	J,SNP,16,447,1964	
Engler+	J,NP/A,367,29,1981	3ISLSOR
Reeder+	J,PR/C,15,2108,1977	1USABNW
Reeder+	PNL report PNL-SA-8766 (1980)	1USABNW
Reeder+	PNL report PNL-SA-11,100,1983	1USABNW
Reeder+	J,PR/C,31,1029,1985	1USABNW
Reeder+	Proc. Specialists Mtg. on Delay Neutrons, Birmingham, England (1986)	1USABNW
Talbert+	J,PR,177,1805,1969	1USASUI
Ameil+	J,EPJ/A,1,275,1998	2GERGSI
Bernas+	J,NP/A,630,41c,1998	2GERGSI
Doerfler+	J,PR/C,54,2894,1996	2FR GAN
Fedoseyev+	J,Z. PHYS./A,353,9,1995	2ZZZCER
Franchoo+	J,PRL,81,3100,1998	2BLGLVN
Hannawald+	J,PR/C,62,054301,2000	2ZZZCER
Korgul+	J,EPJ/A,3,167,200	2SWDSWR
Kratz+	AIP Conf. Proc., 529,295,2000	2GERMNZ
Mehren+	J,PRL,77,458,1996	2SF JUV
Mueller+	J,PR/C,61,054308,2000	2BLGLVN
Shergur+	J,NP/A,.....2000	2ZZZCER
Solin+	J,PR/C,47,2941,1993	2FR GAN
Wang+	J,PL/B,454,1,1999	2SF JYV
Weissmann	J, PR/C,59,2004,1999	2BLGLVN

Examples of Delayed Neutron Data in the EXFOR Database

Examples of delayed neutron data (see below) which are currently included in the EXFOR database were shown. It appears that some data exist, but the coding of these data needs to be verified; in particular the units specified in the DATA tables.

Earlier entries have been coded in a rather non-standard way, probably prior to the addition of specific delayed neutron coding capabilities, e.g. EXFOR entry 21058, see below under c) P_n values (2nd example).

Currently no individual precursor spectral data are included in the EXFOR database as this was seen as outside the scope of the database; however the database has the capability to store such data. If the community considers it appropriate, these data could be added over time. The correction of exiting entries will also be undertaken.

An example was also given of how spectral data can be plotted through the online tool at the IAEA. See the presentation for details.

A draft entry (from the work of Greenwood and Caffrey, *Nucl. Sci. Eng.* **91** (1985) 305) was prepared in order to demonstrate how such data would be stored in the EXFOR database. This entry (labelled as 77777.txt) is available from the meeting webpage.

Examples of delayed neutron REACTION coding in EXFOR:

a) Nubar (total delayed neutron yield)

```
REACTION (92-U-235(N,F),DL,NU)

ENTRY     12856
SUBENT    12856001
INSTITUTE     (1USABNW)
REFERENCE     (J,PR/C,28,1740,8310)
AUTHOR   P.L.REEDER,R.A.WARNER)
TITLE    DELAYED NEUTRON PRECURSORS AT MASSES
         97-99 AND 146-148
```

b) Nubar (delayed neutron yield) for individual precursors

```
REACTION (92-U-235(N,F)ELEM/MASS,DL,NU,,MXW)

ENTRY     20879
SUBENT    20879001
INSTITUTE     (2GERMNZ)
REFERENCE(J,JIN,39,753,77)
AUTHOR   (W.RUDOLPH,K.L.KRATZ,G.HERRMANN)
TITLE        HALF-LIVES, FISSION YIELDS AND NEUTRON EMISSION
            PROBABILITIES OF NEUTRON RICH ANTIMONY ISOTOPES
```
with the individual precursors specified in the DATA table by their charge (ELEM) and mass (MASS) numbers.

c) P_n values (delayed neutron emission probability, i.e. branching fraction)

```
REACTION (ELEM/MASS(0,B-),,PN)[Note proposal below to include DL]

ENTRY     12946
SUBENT    12946001
INSTITUTE    (1USABNW)
REFERENCE    (C,85SANTA,,(DB01),8505)
AUTHOR    (R.A.WARNER,P.L.REEDER)
TITLE     DELAYED NEUTRON DATA FROM TRISTAN
```

with the individual precursors specified in the DATA table by their charge (ELEM) and mass (MASS) numbers as in the previous example.

PROPOSAL: In order to help users find delayed neutron data more easily and consistently, it is proposed that the DL code will be added into the REACTION string above, to give:

```
REACTION (ELEM/MASS(0,B-),DL,PN)
```

The example below also refers to P_n values, but with a different REACTION coding. Possibly this ENTRY was entered into the EXFOR database prior to the introduction of specific delayed neutron coding capabilities.

```
REACTION((92-U-235(N,F)ELEM/MASS,DL,NU,,MXW)/
        (92-U-235(N,F)ELEM/MASS,IND,FY,,MXW))

ENTRY     21058
SUBENT    21058001
INSTITUTE    (2GERMNZ)
REFERENCE    (J,RCA,25,1,78)
AUTHOR    (K.L.KRATZ)
TITLE     INDEPENDENT FISSION YIELDS AND NEUTRON EMISSION
             PROBABILITIES OF SHORT-LIVED HALOGEN ISOTOPES
```

d) Aggregate delayed neutron energy spectra

REACTION (90-TH-232(N,F),DL,DE,N,FST) INCORRECT CODING!

```
ENTRY     10640
SUBENT    10640001
INSTITUTE    (1USAWAU)
REFERENCE    (J,NSE,62,636,1977)(J,ANS,23,492,197606)
AUTHOR    (G.W.ECCLESTON,G.L.WOODRUFF)
TITLE     Measured Near-Equilibrium Delayed Neutron Spectra
          Produced by Fast-Neutron-Induced Fission of 232Th,
          233U, 235U, 238U, and 239Pu
```

Should be coded as: (90-TH-232(N,F),DL,NU/DE,,FST)

e) Aggregate group delayed neutron energy spectra

```
REACTION (90-TH-232(N,F),DL/GRP,NU/DE,,REL,EVAL)
```

```
ENTRY     V0017
SUBENT    V0017001
INSTITUTE    (3ISLSOR)
REFERENCE    (J,NSE,62,660,197704)
AUTHOR   (D.Saphir, D.Ilberg, S.Shalev, S.Yiftah)
TITLE    Evaluated delayed neutron spectra in reactor calculations
```

f) Individual precursor delayed neutron energy spectra

Currently there are no such data in EXFOR, but they would be coded as:

```
REACTION (92-U-235(N,F)37-RB-93,DL,NU/DE,,FIS)
```

when identified as coming from a fission reaction, or as:

```
REACTION (37-RB-93(0,B-),DL,NU/DE)
```

when no information concerning the formation of the precursor is available, or it is not from a fission event.