Probability for emitting N particles: Proposal for new coding

(O. Schwerer, N. Otsuka, 2012-05-10, CP-C/406)

Currently, probabilities for the emission of a given number of particles are coded with REACTION SF5 = NUM and REACTION SF4 = NPART.
The independent variable PART-OUT is used for the number of outgoing particles.

The quantity is also called multiplicity distribution. It has to be distinguished from multiplicities as quantity (SF6 = MLT), as here the multiplicity is not the result but the independent variable.

As the current practice in compiling such data is not always consistent, and new and more complex cases are being compiled, we propose the following new scheme.

1. All such data must have SF5 = NUM and independent variable PART-OUT.
   (No change from before)

2. SF4 = NPART is cancelled. It is not absolutely necessary to define the quantity but it prevents us from using SF4 for product particles.

3. In SF6, existing codes NU, FY, PY, SIG continue to be used. No new parameter will be needed.

4. With 2 exceptions, all quantities with SF5 = NUM are probabilities normalized to 1, and have therefore dimension NO-DIM.
   The 2 exceptions are:
   - NUM,SIG,(*) given in mb or equivalent units
   - Unnormalized probabilities, to be given with SF8 = REL and ARB-UNITS

This system will allow us to compile more complex cases in a consistent way, while the changes to existing entries will be manageable. When need arises, more quantities in the same style can be added (e.g. NUM,MLT).

Quantities in dictionary 236

Quantity	Type and dimension	Definition	Dimension
NUM,NU	NUP NO	Probability for emission of N (fission) neutrons	Probabilities are normalized, i.e. sum of all probabilities = 1 and units = NO-DIM
PR/NUM,NU	NUP NO	Probability for emission of N prompt neutrons	
NUM,FY and NUM,FY,* (New)	FY NO	Probability for emission of N fission particles *(other than neutrons)*	
NUM,PY	PY NO	Probability for emission of N product particles *(SF3 ≠ F)*	
NUM,SIG,(*) **(new with blank SF7)**	CS B	Cross section for emission of N product particles	Units = mb or equivalent

In case of unnormalized probabilities, SF8 = REL and ARB-UNITS must be used.

Changes in existing entries

Accession no.	REACTION	Change(s) required
14064.002	...(0,F)NPART,NUM,NU	Delete NPART
30367.005-007	...(0,F)NPART,NUM,NU	Delete NPART
30544.002	...(N,F)NPART,PR/NUM,NU	- Delete NPART - Change units to NO-DIM
30609.005-007	...(0,F)NPART,NUM,NU	Delete NPART
41056.003	...(0,F)NPART,PR/NUM,NU	Delete NPART
41425.002-004	...(0,F),PR/NUM,NU	No change needed
41539.003-004	...(0,F)NPART,PR/NUM,NU	Delete NPART
41559.003-004	...(0,F)NPART,PR/NUM,NU	Delete NPART
A0361.002	79-AU-197(92-U-238,X)NPART, NUM,SIG,HF	- Delete NPART - Add keyword MISC-COL (no. of detected events)
O0837.002 O0837.003 O0837.004	..(P,X)NPART,NUM,SIG,**PIP** ..(P,X)NPART,NUM,SIG,**PIN** ..(P,X)NPART,NUM,SIG,P	Change REACTIONs to: (P,X)1-PP-0,NUM,SIG (P,X)1-PN-0,NUM,SIG (P,X)1-H-1,NUM,SIG
O0848.002-008 O0848.009-012	..(P,X)NPART,NUM,SIG,N ..(P,X)NPART,NUM,SIG,N,REL	Change REACTIONs to: (P,X)0-NN-1,NUM,SIG (P,X)0-NN-1,NUM,SIG,REL

Changes in existing entries (continued)

Accession no.	REACTION	Change(s) required
O0953.002-017	..(..,..) NPART,NUM,SIG,N	Change REACTIONs to: (..,..) 0-NN-1,NUM,SIG
O1086.002-004	..(P,X)1-H-1,NUM,PY	- Change units to NO-DIM - Add main reference J,EPJ/A,21,273,2004
O1426.002-011	...(P,X)NPART,NUM,SIG,N	Change REACTIONs to: (..,..) 0-NN-1,NUM,SIG
V0045011-014	(N,F)NPART,PR/NUM,NU,,,EVAL	Delete NPART

New entries (Prelim 1379)

14286	**D.L.Bleuel+,J,NIM/A,624,691,2010**	
.002	98-CF-252(0,F)0-G-0,NUM,FY,,REL	Unnormalized over all multiplicity distribution (Fig.6, author's data)
.003	(1) 98-CF-252(0,F)42-MO-106,NUM,FY,G (2) 98-CF-252(0,F)46-PD-108,NUM,FY,G	Normalized multiplicity distributions for 2 identified fission channels (Fig.7, author's data)
.004	98-CF-252(0,F)ELEM/MASS,NUM,FY,G	Normalized multiplicity distribution for channel with 2 identified products defined with ELEM1,2 and MASS1,2 (2n channel, Fig.12, author's data)
.005	98-CF-252(0,F)ELEM/MASS,NUM,FY,G	Normalized multiplicity distribution for channel with 2 other identified products defined with ELEM1,2 and MASS1,2 (4n channel, Fig.12, author's data)
14315	**A.Chyzh+,J,PR/C,85,021601,2012**	
.002	98-CF-252(0,F)0-G-0,PR,FY/DE,,RAW	(Existing quantity) (Fig. 1a, author's data)
.003	98-CF-252(0,F)0-G-0,NUM,FY	Normalized over all multiplicity distribution (Fig. 2a, author's data)

Appendix: Coding examples from new entries 14286 and 14315

1) Entry 14286

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ENTRY            14286
SUBENT        14286001
BIB                  8         21
TITLE       Gamma-ray multiplicity measurement of the spontaneous
            fission of 252Cf in a segmented HPGe/BGO detector
            array
AUTHOR      (D.L.Bleuel,L.A.Bernstein,J.T.Burke,J.Gibelin,
            M.D.Heffner,J.Mintz,E.B.Norman,L.Phair,N.D.Scielzo,
            S.A.Sheets,N.J.Snyderman,M.A.Stoyer,M.Wiedeking)
INSTITUTE   (1USALRL,1USABRK)
REFERENCE   (J,NIM/A,624,691,2010)
SAMPLE      Cf-252 source, 1.5E6 fission/minutes, on a nickel foil
             backing, 90 microg/cm2
METHOD      (COINC) Coincidence of gamma rays from fission
                    fragments
DETECTOR    (HPGE) The experiment was performed using six EURISYS
             high-purity germanium (HPGe) Clover detectors of the
             Livermore-Berkeley Array for Collaborative Experiments
             Each Clover consists of four HPGe crystals in a shared
             cryostat surrounded by 16 SCIONIX bismuth-germanate
             detectors. The system had high degre of segmentation
             with 19 HPGe and 94 BGO  detectors and good solid
             angle coverage.
HISTORY     (20110201) Compiled by S.H.
ENDBIB              21          0
NOCOMMON             0          0
ENDSUBENT           24          0
SUBENT        14286002   20120330
BIB                  3          5
REACTION    (98-CF-252(0,F)0-G-0,NUM,FY,,REL)
            Overall gamma ray multiplicity spectra
ERR-ANALYS  (ERR-S) Statistical uncertainty
STATUS      (TABLE ) Data presented in Fig. 6 of the reference
                     sent by author (D.L.B.)
ENDBIB               5          0
NOCOMMON             0          0
DATA                 3         36
PART-OUT    DATA       ERR-S
NO-DIM      ARB-UNITS  ARB-UNITS
     0.0      292.8E+5   124.8E+2
     1.0      453.2E+6   580.1E+2
     2.0      340.1E+6   340.2E+2
     3.0      190.7E+6   196.4E+2
     4.0      102.3E+6   119.5E+2
etc.
…...
    33.0      437.6E+0   127.4E+0
    34.0      167.0E+0   121.2E+0
    35.0      157.0E+0   111.3E+0
ENDDATA             38          0
ENDSUBENT           48          0
SUBENT        14286003   20120330
BIB                  5         10
REACTION  1(98-CF-252(0,F)42-MO-106,NUM,FY,G)
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          2(98-CF-252(0,F)46-PD-108,NUM,FY,G)
ANALYSIS   Gamma ray multiplicities in both channels are
           normalized to sum to unity.
ERR-ANALYS (ERR-S) Statistical uncertainty
STATUS     (TABLE) Data presented in fig. 7 of the reference
                   sent by author (D.L.B.)
ENDBIB              10          0
NOCOMMON             0          0
DATA                 4         60
PART-OUT   DATA      1ERR-S     1DATA      2ERR-S     2
NO-DIM     NO-DIM     NO-DIM     NO-DIM     NO-DIM
    1.0      -4.96E-02   2.24E-03   5.64E-01   1.62E-03
    2.0       8.18E-02   2.40E-03   2.65E-01   1.73E-03
    3.0       7.18E-02   1.94E-03   1.17E-01   1.42E-03
    4.0       8.31E-02   1.51E-03   3.05E-02   1.01E-03
    5.0       9.65E-02   1.25E-03   7.59E-03   7.95E-04
    6.0       1.07E-01   1.16E-03   2.24E-03   7.28E-04
 etc.
 ….........
   30.0      -9.78E-06   1.08E-05   1.93E-06   6.97E-06
ENDDATA             62          0
ENDSUBENT           77          0
SUBENT        14286004   20120330
BIB                  5         15
REACTION   (98-CF-252(0,F)ELEM/MASS,NUM,FY,G)
ANALYSIS   Number of emitted neutrons in various fission channels
           was determined from correlated discrete gamma rays of
           fission products
             2n channel  106Mo x 144Ba
             4n channel  106Mo x 142Ba
           Multiplicities in both channels are normalized
           to sum to unity.
           This table contains the gamma ray multiplicity of events
           with 2 neutrons emitted. For the 4n channel see
           subentry 5.
ERR-ANALYS (ERR-S) Statistical uncertainty
STATUS     (TABLE) Data presented in fig. 12 of the reference
                   sent by author (D.L.B.)
ENDBIB              15          0
COMMON
ELEM1      MASS1      ELEM2      MASS2
NO-DIM     NO-DIM     NO-DIM     NO-DIM
  42.          106.       56.        144.
ENDCOMMON
DATA
PART-OUT   DATA       ERR-S
NO-DIM     NO-DIM     NO-DIM
    2.0       1.59E-02   6.31E-03
    3.0       1.20E-02   9.35E-03
    4.0       1.15E-02   1.10E-02
    5.0       6.37E-02   1.20E-02
    6.0       8.74E-02   1.34E-02
etc.
….....
   28.0      -1.80E-03   7.06E-04
   29.0      -2.58E-04   5.16E-04
   30.0       5.16E-04   2.58E-04
ENDDATA             60          0
ENDSUBENT           80          0
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SUBENT        14286005   20120330
BIB                5         15
REACTION   (98-CF-252(0,F)ELEM/MASS,NUM,FY,G)
ANALYSIS   Number of emitted neutrons in various fission channels
           was determined from correlated discrete gamma rays of
           fission products
             2n channel  106Mo x 144Ba
             4n channel  106Mo x 142Ba
           Multiplicities in both channels are normalized
           to sum to unity.
           This table contains the gamma ray multiplicity of events
           with 4 neutrons emitted. For the 2n channel see
           subentry 4.
ERR-ANALYS (ERR-S) Statistical uncertainty
STATUS     (TABLE) Data presented in fig. 12 of the reference
                   sent by author (D.L.B.)
ENDBIB              15         0
COMMON
ELEM1      MASS1      ELEM2      MASS2
NO-DIM     NO-DIM     NO-DIM     NO-DIM
  42.          106.       56.        142.
ENDCOMMON
DATA
PART-OUT   DATA       ERR-S
NO-DIM     NO-DIM     NO-DIM
    2.0       2.06E-02   4.42E-03
    3.0       3.48E-02   6.60E-03
    4.0       2.22E-02   7.63E-03
    5.0       4.79E-02   8.06E-03
    6.0       4.68E-02   9.16E-03
    7.0       5.94E-02   1.04E-02
etc
…...
   28.0       9.37E-04   4.68E-04
   29.0       4.68E-04   3.70E-04
   30.0       1.17E-04   2.62E-04
ENDDATA             60         0
ENDSUBENT           80         0
ENDENTRY
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2) Entry 14315

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ENTRY            14315   20120229
SUBENT        14315001   20120229
BIB                10         36
TITLE      Evidence for the stochastic aspect of prompt gamma
           emission in spontaneous fission
AUTHOR     (A.Chyzh,C.Y.Wu,E.Kwan,R.A.Henderson,J.M.Gostic,
           T.A.Bredeweg,R.C.Haight,A.C.Hayes-Sterbenz,M.Jandel,
           J.M.O'Donnell,J.L.Ullmann)
INSTITUTE  (1USALRL,1USALAS)
REFERENCE  (J,PR/C,85,021601,2012)
DETECTOR   (PPAC) 252Cf source covered with aluminized mylar
           served as a cathode. The two anodes, made of the same
           thickness aluminized mylar sheet, were placed on both
           sides of the cathode at a distance of 3 mm and
           electrically connected. The PPAC was operated with
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            isobutane gas at the 4.00 torr pressure stabilized by
            a feedback loop of constant gas flow. It has
            efficiency of 82% for the detection of fission
            fragments
            (BAF2) Gamma ray energy and multiplicity was measured
            with a 4pi g-ray calorimeter DANCE made of 160 BaF2
            crystals; each crystal has equal solid- angle
            coverage.Beside capture studies,DANCE can be used for
            the precision measurement of the E-gamma and M-gamma
            distributions as well as the total gamma-ray energy
METHOD      (COINC) Coincidence between fission fragments
            detected by avalanche counter and DANCE detectors was
            required to identify prompt gamma rays fromfission
SAMPLE      A 252Cf source with a strength 0.15 mu-Ci was
            prepared by stippling the material on a 3 mu-m thick
            titanium foil, and then covered by a 1.4 mu-m thick
            aluminized mylar to serve as a cathode.
ANALYSIS    Data were obtained by unfolding of raw data. Response
            matrices for gamma energy as well as gamma
            multiplicity were calculated using GEANT4. The
            unfolding was done using both the iterative Bayesian
            and singular value decomposition (SVD) methods.
ERR-ANALYS (DATA-ERR) No information given
HISTORY     (20120229C) Compiled by S.H.
ENDBIB               36          0
NOCOMMON              0          0
ENDSUBENT            39          0
….....
….....
SUBENT         14315003   20120229
BIB                   2          7
REACTION  1(98-CF-252(0,F)0-G-0,NUM,FY,,RAW) Original exper.data
          2(98-CF-252(0,F)0-G-0,NUM,FY)  Multiplicity distribution
             based on unfolded spectra using SVD method
          3(98-CF-252(0,F)0-G-0,NUM,FY) Multiplicity distribution
             based on unfolded spectra using Bayesian approach
STATUS      (TABLE) Data presented in fig. 2a of the reference
                    sent by author (A.Ch.)
ENDBIB                7          0
COMMON                1          3
E-ERR
MEV
0.1
ENDCOMMON             3          0
DATA                  7         20
PART-OUT   DATA      1DATA-ERR  1DATA      2DATA-ERR  2DATA      3
DATA-ERR  3
NO-DIM     NO-DIM     NO-DIM     NO-DIM     NO-DIM     NO-DIM
NO-DIM
        1.0   4.55E-03   3.73E-05

        2.0   3.83E-02   1.08E-04   2.09E-02   1.93E-04   1.94E-02
   1.07E-04
        3.0   7.85E-02   1.55E-04   4.44E-02   2.15E-04   4.39E-02
   1.52E-04
        4.0   1.22E-01   1.93E-04   7.05E-02   2.86E-04   7.11E-02
   1.86E-04
        5.0   1.52E-01   2.16E-04   9.39E-02   3.38E-04   9.56E-02
   2.12E-04
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        6.0   1.62E-01   2.22E-04   1.10E-01   3.69E-04   1.13E-01
   2.30E-04
        7.0   1.47E-01   2.12E-04   1.18E-01   3.93E-04   1.19E-01
   2.43E-04
        8.0   1.17E-01   1.89E-04   1.15E-01   4.13E-04   1.16E-01
   2.53E-04
        9.0   8.15E-02   1.58E-04   1.05E-01   4.28E-04   1.05E-01
   2.62E-04
       10.0   4.97E-02   1.23E-04   9.00E-02   4.35E-04   8.87E-02
   2.74E-04
       11.0   2.68E-02   9.04E-05   7.23E-02   4.40E-04   7.09E-02
   2.87E-04
       12.0   1.26E-02   6.19E-05   5.47E-02   4.46E-04   5.35E-02
   3.04E-04
       13.0   5.25E-03   4.00E-05   3.89E-02   4.50E-04   3.80E-02
   3.24E-04
       14.0   1.91E-03   2.41E-05   2.59E-02   4.58E-04   2.56E-02
   3.49E-04
       15.0   6.15E-04   1.37E-05   1.63E-02   4.86E-04   1.64E-02
   3.84E-04
       16.0   1.70E-04   7.20E-06   9.71E-03   5.36E-04   1.01E-02
   4.44E-04
       17.0   4.36E-05   3.65E-06   5.70E-03   5.84E-04   6.22E-03
   5.31E-04
       18.0   1.22E-05   1.93E-06   3.57E-03   6.30E-04   3.96E-03
   6.34E-04
       19.0   2.44E-06   8.63E-07   2.65E-03   9.99E-04   2.68E-03
   9.54E-04
       20.0   3.05E-07   3.05E-07   2.37E-03   2.48E-03   1.87E-03
   1.87E-03
ENDDATA            44          0
ENDSUBENT          60          0
ENDENTRY            3          0
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