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Memo CP-D/451

Date: 12 January 2006
To: Distribution
From: O. Schwerer

Subject: **Quantity codes for data in arbitrary units, chain and mass yields (Reply to CP-E/085)**

Items 1) and 2) of CP-E/085

In my opinion, often the quantity code for relative data given in arbitrary units cannot be uniquely determined. E.g., as outlined in CP-E/085, relative data for the production of certain fission products can be coded both as relative fission yields or as relative fission cross sections. This is not (or not only) a question of the EXFOR format but it is an objective fact that such data can be viewed from different sides. We have no general rule for such cases and I doubt that it is possible to make one without creating other inconsistencies. I think the understanding is to code it in a way appearing most reasonable to the compiler, taking into account, among other things, what name the authors of the article use, and, under which quantity the users are more likely to look for the data. I believe, that if many different fission products are measured, this will most often be called fission product yields rather than cross sections.

Concerning PAR vs. DE: Again, this is normally answered by the units. If its "per MeV", than it's DE, otherwise it's PAR. However, for PAR, it's sufficient to have a secondary energy value (sometimes fixed) given as additional independent variable, it does not have to be integrated over a range.
In the case of 14044.002, the actual units given for Fig.2 are "number per unit energy" which points to a single (but not double) differential cross section; since another secondary energy is given as an additional parameter, this is accounted for by PAR.
This was our argument; but again, once the data are coded with ARB-UNITS, it is hard to prove that this is the only correct solution.

Subentry 14044.003 and definition of mass yields

The main point here was that the data originally coded with SF6=DE are a mass spectrum and therefore cannot be coded with DE. Another option would be to code them simply with

….(N,F)MASS,PAR,FY,LF/HF,MXW/REL

but this leads to the conceptual problem that we do not have a fission yield type just PAR,FY. FY always requires a very specific code (more specific than PAR) in SF5, such as : PRE, TER, CHN, IND, CUM, MAS. One reason for this (and for the need of the SF5 code MAS in general) is that MASS in SF4 is not part of the dictionary code (dictionary 36/236 covers only SF5-8 but not SF4). Therefore I have no way of explaining the quantity as mass spectrum in the dictionary (unless we add to it "This quantity always comes with MASS in SF4", which is not in line with the current way the dictionaries work).
Any ideas on better solutions for this problem (without radical changes in the dictionary structure and usage) are very welcome.

The definition of MAS,FY has been proposed earlier for LEXFOR; this and the other types of fission yields can be looked up in the revised LEXFOR page on fission yields which is appended to this memo, and will be included in the upcoming LEXFOR revision. See items 5 and 6 for the definitions of CHN,FY and MAS,FY.

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Appendix *(from next LEXFOR revision)*

Fission Yields

(See also **Fission**).

Theory

The fragments formed at the scission stage by a nucleus undergoing fission are called ***primary, initial,*** or ***pre-neutron emission fragments***.

The ***primary fragments*** repel each other, obtain their full kinetic energy (*e.g.*, 90 MeV), emit prompt neutrons ($<4 \times 10^{-14}$ sec) and gamma rays ($<10^{-11}$ sec), are slowed down in the surrounding medium, and stopped. These fragments are called ***secondary fragments***, *post-neutron-emission fragments,* or *primary fission products* (the emitted γ-rays may cause conversion β's and X-rays).

The ***secondary fragments*** undergo (after .01 sec and more) a series of β-decays forming ***secondary products***, and end up in stable nuclei. For certain products the emission of ***delayed neutrons*** competes with γ de-excitation, both following the β-decay process. In most of these stages ***mass yields*** and ***charge dispersions*** are measured as well as ***energy distributions***.

The terms ***fragments*** and ***products*** are not clearly distinguished. Most frequently the borderline between fragments and products varies, and often the word fragments is used as an overall term, including all stages of decay.

Fission fragments are often specified only by their mass, including all Z-numbers, so that the fragment yield remains constant during β decay. Fission products are usually specified by ***Z and A***. A specified fission product is obtained in two ways: either immediately from fission (primary yield) or from the decay of another fission product. Thus, the total amount of a specified fission product varies with time. Very short-lived fission products may, nevertheless, be most important, because some have extremely high capture cross sections (10^6 b). Finally, all decay to stable end products, partially via metastable states. For odd A-numbers, only one stable end product exists that is significantly formed in fission; for even A-numbers, one or two exist.

The sum of the yield for all fission products will, in general, add up to 200%, *i.e.*, 100% for each of the heavy and light product distributions (see example in figure[1]). Since in ternary fission more than two fragments are formed per fission, the yields for all fragments sum up to a bit more than 200%.

For further information, see Pappas [1] and Walker [2].

8 WALSH et al.

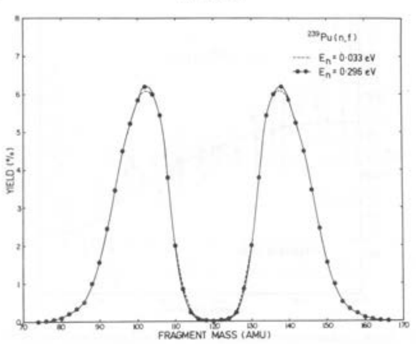

FIG.7. Mass yields for neutron energies 0.033 and 0.296 eV.

[1] Taken from R.L. Walsh et al., **Physics and Chemistry of Fission**, Proceedings of a Symposium, Juelich, 1979 (I.A.E.A., 1980) p.129.

Fission Yields (continued)

Coding:

1. **Absolute Yields**. (Fissions and fission fragments are counted independently.)

REACTION coding: The quantity code `FY` in SF6. The yield type is specified in SF5 (Branch) (see under specific type of yield, following pages).
Units: a code from Dictionary 25 with the dimension FY (*e.g.*, `PC/FIS`).

2. **Relative yields**.

REACTION Coding: same as above with modifier `REL` in SF8
Units: `ARB-UNITS`

However, emission of light particle in ternary fission does not change the sum of yields in the binary fission mass range usually measured, and other mass splits in ternary fission are negligible, therefore, relative yield measurements may be normalized to 200% if the measurement was made for a sufficient large number of fragments. If this is done, the data table may include some values that have not been measured but obtained by interpolation; such values must be labeled by flags.

The fission product considered is coded either in `REACTION` SF4 or as a variable in the data table.

Examples for product nuclei coded within the reaction code:

`(92-U-235(N,F)54-XE-124,IND,FY)` independent yield of the fission product ^{124}Xe

`(92-U-235(N,F)54-XE-133-G,CUM,SIG)` cumulative production cross section for the fission product ^{133g}Xe

for coding product nuclei as variables in the DATA tables:

`(92-U-235(N,F)ELEM/MASS,IND,FY)` independent yield of specified product nuclei which are given in the DATA table under the data headings `ELEMENT`, `MASS`, and `ISOMER` (if applicable).

`(92-U-235(N,F)MASS,CHN,FY)` chain yield of several mass numbers given in the DATA table under the data heading `MASS`.

See **Reaction Product** and EXFOR Manual Chapter 6: Variable Nucleus for details.

Yield data to be compiled in EXFOR

1. **Primary fission-fragment yield**. The primary yield per fission of fission-fragment mass A before prompt neutron emission. It may also be called pre-neutron-emission fragment-mass distribution. In all experimental techniques corrections for some prompt neutrons already emitted cannot be avoided.

Fission Yields (continued)

REACTION coding: Branch code `PRE` in SF5.

Example: `(....(N,F)ELEM/MASS,PRE,FY)`

2. **Secondary fission-fragment yield**. The secondary yield per fission of fission-fragment mass A after prompt-neutron emission, but before β decay and delayed-neutron emission. It may also be called post-neutron-emission fragment-mass distribution.

REACTION coding: Branch code `SEC` in SF5.

Example: `(....(N,F)MASS,SEC,FY)`

3. **Independent fission-product yield**. The direct or independent yield per fission of a *primary fission product* specified by Z and A; *i.e.*, after prompt neutron emission, but before β decay and delayed-neutron emission, including only the direct yield and not the yield obtained from decay of other fission products.

REACTION coding: Branch code `IND` in SF5.

Example: `(…(N,F)ELEM/MASS,IND,FY)`

Sum rule: The secondary yield is equal to the sum, over all Z (for one A) of the independent yields.

Experimental data for independent yields of the product Z,A include yields from the delayed-neutron emission of the product Z,A + 1 or from the beta decay of the product Z-1,A, if separation times are not short against the relevant decay times. Corrections are required and should be mentioned under the keyword `CORRECTION`. Fragment-mass yields are not affected by beta decay but only by delayed-neutron emission.

4. **Cumulative fission-product yield**: the cumulative yield per fission of a *secondary fission product* specified by Z and A, *i.e.*, after prompt-neutron emission, and including the independent yield plus the yield from decay of other fission products.

REACTION coding: Branch code `CUM` in SF5.

Example: `(…(N,F)ELEM/MASS,CUM,FY)`

Sum rule: `CUM,FY` for the β-decaying product Z-1,A + `IND,FY` for product Z,A = `CUM,FY` for product Z,A, if the products Z-1,A and Z,A+1 are not delayed-neutron emitters.

The following events may add to the cumulative yield of the fission-product Z,A in its ground state:

- independent yield from fission
  - β decay from product Z-1,A in ground state
  - β decay from product Z-1,A in a metastable state
  - delayed-neutron emission from product Z,A + 1
  - internal transition from a metastable state of product Z,A

Fission Yields (continued)

In addition, the product Z,A may be formed from neutron capture in the product Z,A-1; this product is not included in the "cumulative yield".

The cumulative yield is often given for an isomeric state of a fission-product Z,A; the isomer is entered in EXFOR as a separate data field, see EXFOR Manual Chapter 6: Variable Nucleus.

5. **Total chain yield**. The total chain yield per fission of fission-fragment mass A is the sum of the cumulative yields of all stable fission products having the same mass A. When only one stable fission product per mass A exists, the total chain yield for mass A is identical with the cumulative yield of the stable end product Z,A.

REACTION coding: Branch code `CHN` in SF5.

Example: `(…(N,F)MASS,CHN,FY)`

6. **Total mass yield** The total mass yield per fission of fragment mass A is the sum of the independent yields of all fission products with the mass A.

REACTION coding: Branch code `MAS` in SF5.

Example: `(…(N,F)MASS,MAS,FY)`

7. **Fractional yields** The distribution of charge Z within a given fragment mass chain A is called ***charge dispersion***. It can empirically be approximated by a Gaussian distribution with a ***most probable charge*** Z_p (see following).

The fractional independent yield of a fission product (after prompt neutron emission) is given by:

$$P(Z) = (c\pi)^{-1/2} \exp\left[-(Z-Z_p)^2/c\right]$$

whereas the fractional cumulative yield is given by

$$\sum_{n=0}^{Z} P_n = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{Z+1/2} e^{\left[\frac{-(n-Z_p)^2}{2\sigma^2}\right]} dn$$

The parameters c and σ are widths of the distributions related by:

$$c \approx 2\left(\sigma^2 + 1/12\right)$$

For charge dispersion, fractional yields are defined only as ratios to total chain yield.

For further information, see Wahl [3].

REACTION coding: coded as an explicit ratio, and followed by the keyword `RESULT`.

In all cases, the data are entered as ratios with values from 0 to 1 and data units `NO-DIM`.

Fission Yields (continued)

Examples:

a.) `REACTION    ((92-U-235(N,F)ELEM/MASS,IND,FY)/`
`            (92-U-235(N,F)MASS,CHN,FY))`
`RESULT      (FRIND)`

b.) `REACTION    ((92-U-235(N,F)ELEM/MASS,CUM,FY)/`
`            (92-U-235(N,F)MASS,CHN,FY))`
`RESULT      (FRCUM)`

8. **Most probable charge**. The most probable initial charge Z_p for a given mass chain.

REACTION Coding: the process code `ZP` in SF6

Example: `(…(N,F)MASS,,ZP)`

Note: The Gaussian width parameter is assumed to be approximately constant for all A chains, as given by Wahl, *et al*. Therefore Z_p has sometimes been determined from a single fractional yield measurement. However, there is evidence for a variation of c and σ with mass A, and they may be determined together with Z_p. Therefore, the Gaussian width parameter used should be explained (value or reference).

9. **Most Probable Mass**. The most probable mass A_p is the mean mass for a given element.

REACTION Coding: `AP` in SF6

Example: `(…(N,F)ELEM,,AP)`

10. **Charge yields**. The charge yield (or elemental yield) is defined as the sum of the independent yields for all products with a specified Z.

Definition: Charge distribution (primary charge function) is defined as the distribution of primary charge about Z_p as a function of primary mass.

This quantity is deduced, either from other quantities (charge dispersion, mass distribution), or from instrumental measurements of fragment mass (kinetic energy) and X-rays; both methods involving uncertain corrections for prompt-neutron emission.

REACTION Coding: Branch code `CHG` in SF5.

Example: `(……(N,F)ELEM,CHG,FY)`

10. **R-values**. An R-value is a ratio of measurement results for 2 different energies or energy spectra (one of which is considered to be a monitor reaction), each of which is relative to the same standard reaction.

REACTION Coding: coded as an explicit ratio, followed by an entry under `RESULT` with the code `RVAL`.

Example:

```
REACTION  (((92-U-238(N,F)ELEM/MASS,CUM,FY,,FIS)/
          (92-U-238(N,F)42-MO-99,CUM,FY,,FIS))//
          ((92-U-238(N,F)ELEM/MASS,CUM,FY,,MXW))
          (92-U-238(N,F)42-MO-99,CUM,FY,,MXW)))
RESULT    (RVAL)
```

Fission Yields (continued)

Yields of correlated fragment pairs

The Z and A of the correlated pair are entered under the field headings `ELEM1`, `MASS1`, and `ELEM2`, `MASS2`.

1. **Yields of correlated fragment pairs**.

REACTION coding:: Process code `FY/CRL` in SF6.

Example:

```
BIB
REACTION     (…(N,F)ELEM/MASS,IND,FY/CRL)
…
ENDBIB
COMMON
ELEM1        ELEM2
NO-DIM       NO-DIM
 56.          42.
ENDCOMMON
DATA
MASS1        MASS2        DATA
NO-DIM       NO-DIM       PC/FIS
138.         104.         …
138.         105.         …
…            …            …
ENDDATA
```

2. **Kinetic energy of correlated fragment pair**.

The total kinetic energy of the fragment pair is given.

REACTION coding: Process code `KE/CRL` in SF6.

References

[1.] A. C. Pappas, J. Alstad, and E. Hagebo, *Mass, Energy, and Charge Distribution in Fission*, ***Physics and Chemistry of Fission***, Symposium, Vienna, 1969 (I.A.E.A., 1969), p. 669

[2.] W. H. Walker, *Status of fission product yield data for thermal reactors*, ***Fission-product Nuclear Data***, IAEA Panel, Bologna, 1973, report IAEA-169, Vol. I, (1974) p. 285

[3.] A.C. Wahl, et al., *Nuclear Charge Distribution in Low-Energy Fission*, ***Phys. Rev.*** **126**, 1112 (1962)