# Beta-delayed Neutron Emission Probability and Multiplicity

(V. Semkova, N. Otsuka, 4C-3/396, 2014-04-30)

If the $\beta^-$ decay energy ($Q_\beta$) is larger than the two or more neutron separation energy ($S_{2n,\ 3n...}$) of the product of the decay a process of multiple neutron emission may take place. The following quantities are defined for the cases when $Q_\beta - S_{xn} > 0$ ($x$=1,2,...):

- $P_{xn}$ ($x$=1,2,3): probability to emit x β-delayed neutrons per decay
- $P_n$: probability to emit at least one β-delayed neutron per decay ($P_n = P_{1n}+P_{2n}+P_{3n}+_{...}$)
- $P'_n$: multiplicity of β-delayed neutrons per decay ($P'_n = P_{1n}+2P_{2n}+3P_{3n}+\ldots$)

The current description LEXFOR "Delayed Fission Neutrons" does not distinguish the multiplicity from probability. In the relation with the IAEA CRP on "Development of reference database for beta-delayed neutron emission", we foresee compilation of above three quantities. We propose to keep the current quantity code `,PN` for the multiplicity $P'_n$, and also to add new quantity codes for $P_{xn}$ and $P_n$.

**Dictionary 236 (Quantities)**

`NUM,PN`: probability for emission of N beta-delayed neutrons
`UNW,PN`: probability for emission of at least one beta-delayed neutrons
`,PN`: multiplicity of beta-delayed neutrons ($P'_n = P_{1n}+2P_{2n}+\ldots$)

| Quantity | Reaction Type | Dimension |
|---|---|---|
| NUM,PN | PN | NO |
| UNW,PN | PN | NO |
| ,PN | PN | PN |

There is no consistent nomenclature established in the literature and $P_n$ value is referred in some articles to the β-delayed neutron emission probability and in other articles to the multiplicity. However, the compilers should verify the meaning of the determined quantity. Free text explanation could be useful for users as well. For cases when only 1 beta-delayed neutron emission is feasible $P'_n \equiv P_n$. For consistency of the compilation in such cases ~~`UNW`~~`,PN` coding is proposed.

In order to make each data set searchable not only by the precursor nuclide but also by the decay product, we would like to forbid use of the variable nuclide formalism `ELEM/MASS` in REACTION SF1 and to code the decay product always in REACTION SF4.

Revision to the LEXFOR entry is proposed at the end of this memo.

***Example***

Table 1 of T.Björnstad et al., Delayed neutron emission probabilities of $^{11}$Li**,** Nucl. Phys. A359 (1981) 1

| Quantity | Probability (%) |
|---|---|
| $P_{1n}$ | 85±1 |
| $P_{2n}$ | 4.1±0.4 |
| $P_{3n}$ | 1.9±0.2 |
| $P_n$ | 91±1 |

| | |
|---|---|
| $P'_n$ | 98±1 |

($P_n$ value is not given in this article, but calculated for explanation of the coding rule.)

```
SUBENT       01230002   20140417
BIB
REACTION   (3-LI-11(0,B-),NUM,PN)
STATUS    (TABLE) Text (p6) of Nucl.Phys.A359(1981)1
ENDBIB
NOCOMMON
DATA
PART-OUT   DATA      DATA-ERR
NO-DIM    NO-DIM    NO-DIM
 1.        0.85      0.01
 2.        0.041     0.004
 3.        0.019     0.002
ENDDATA
ENDSUBENT
SUBENT       01230003   20140417
BIB
REACTION   (3-LI-11(0,B-),UNW,PN)
STATUS    (TABLE) Private communication
ENDBIB
NOCOMMON
DATA
DATA      DATA-ERR
NO-DIM    NO-DIM
 0.91      0.01
ENDDATA
ENDSUBENT
SUBENT       01230004   20140417
BIB
REACTION   (3-LI-11(0,B-),,PN)
COMMENT   Average multiplicity of beta-delayed neutron
STATUS    (TABLE) Text (p6) of Nucl.Phys.A359(1981)1
ENDBIB
NOCOMMON
DATA
DATA      DATA-ERR
PC/DECAY  PC/DECAY
 98.       1.
ENDDATA
ENDSUBENT
```

## LEXFOR Entry (Addition and deletion to “Delayed fission neutrons”)

**Delayed-Neutron Emission Multiplicity (<n>)**

**Definition**: Multiplicity of β-delayed neutron per decay

**REACTION Coding**: `(Z-S-A(0,B-)Z′-S′-A′,,PN)`

where `Z-S-A` is the precursor nucleus (i.e., before β-decay)
`Z′-S′-A′` is the decay product nucleus (i.e., after β-decay)

**Units:** a code from Dictionary 25 with dimension PN (*e.g.*, PC/DECAY)

**Delayed-Neutron Emission Probability ($P_n$ value)**

~~**Definition**: Neutron yield per β decay for a given nucleus. This is a decay quantity of the fission product nucleus and is independent of the fissioning target nucleus. It is related to the fission yield by~~

~~$P_n$ = absolute delayed neutron yield / cumulative fission yield~~

~~**REACTION Coding**:~~

~~a. ((Z-S-A(0,B-)Z'-S'-A',,PN) for a single fragment~~

~~where: Z-S-A is the fission product nucleus (precursor nucleus before β decay);~~

~~Z'-S'-A' is the delayed-neutron emitting fission fragment.~~

~~b. (ELEM/MASS(0,B-),,PN) for a series of fragments~~

~~The fission product nucleus is entered as a variable in the data table (see EXFOR Chapter 6: Variable Nucleus).~~

~~**Units**: a code from Dictionary 25 with dimension PN (*e.g.*, PC/DECAY)~~

**Definition**: Probability for emission of at least one β-delayed neutron

**REACTION Coding**: (Z-S-A(0,B-)Z'-S'-A',UNW,PN)

**Units:** a code from Dictionary 25 with dimension NO (*e.g.*, NO-DIM)

**Delayed-Neutron Emission Probability ($P_{Nn}$ value)**

**Definition**: Probability to emit N β-delayed neutrons ($P_{1n}$, $P_{2n}$,…)

**REACTION Coding**: (Z-S-A(0,B-)Z'-S'-A',NUM,PN)

**Units:** a code from Dictionary 25 with dimension NO (*e.g.*, NO-DIM)

The number of emitted neutrons is give under the data heading PART-OUT with units of NO-DIM.

From these definitions $P_n=P_{1n}+P_{2n}+\ldots$ and $\langle n\rangle=P_{1n}+2P_{2n}+\ldots$ Especially $P_n=\langle n\rangle$ only one neutron emission is energetically possible, and ,PN must be always used. Note that some authors use the symbol "$P_n$" not for the probability but for the multiplicity.

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