Memo CP-D/222

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To: Distribution

From: M. Lammer and H.D. Lemmel

Subject: 1. Delayed neutron yields from individual precursors
2. Dictionary update

The EXFOR Manual needs additional information and coding rules for "delayed neutron yields from individual precursors". So far there are only three lines on the second page of the LEXFOR entry "Delayed fission neutrons". In the following, some additional definitions and Dictionary entries are proposed, and a complete revised Lexfor entry for "Delayed fission neutron" is presented.

The new formalism is urgently required for the clean-up of fission yield data, so that we will use the proposed coding in the next TRANS tape unless a counter proposal is received.

1. Delayed neutron yields from individual precursors

Delayed neutron yields can be defined for individual precursors. Similarly to fission product yields, independent and cumulative delayed neutron yields can be defined, depending whether the delayed neutron precursor considered was formed directly from fission, or whether it was also formed via beta decay from its own precursor(s). The corresponding paragraph of the Lexfor entry is proposed to be extended as given below:

Yields of delayed neutrons associated with individual precursors

Data should be coded with the precursor nucleus as an independent variable given under the heading ELEMENT and MASS, usually given with units PC/FIS. (Up to here it is the same as before.)

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a) Independent delayed neutron yield of an individual precursor:

REACTION coding: (....(N,F)ELEM/MASS,DL/IND,NU)

It is the same as the product of the Pn-value and the independent fission yield of the precursor.

b) Cumulative delayed neutron yield of an individual precursor:

REACTION coding: (....(N,F)ELEM/MASS,DL/CUM,NU)

It is the same as the product of the Pn-value and the cumulative fission yield of the precursor.

The new Lexfor entry on delayed fission neutrons is attached. Besides the above proposed addition, it contains some restructuring of the text, however without any change in its contents.

2. Dictionary update

Dictionary 36:

DL/IND,NU (INDEPENDENT DELAYED NEUTRON YIELD FROM AN INDIVIDUAL PRECURSOR)
DL/CUM,NU (CUMULATIVE DELAYED NEUTRON YIELD FROM AN INDIVIDUAL PRECURSOR)

1.) Theory

In certain cases, a fission-product nucleus may decay by beta-decay to excited levels in the daughter nucleus which lie above the neutron binding energy. In this case, a "delayed" neutron may be emitted whose measured half-life is equal to that of the preceding beta-emitter (delayed neutron precursor). These half-lives are of the order of 0.1 to 60 sec, which is large compared to the period of prompt neutron emission (<<4×10^{-14} sec, see Fission Yield).

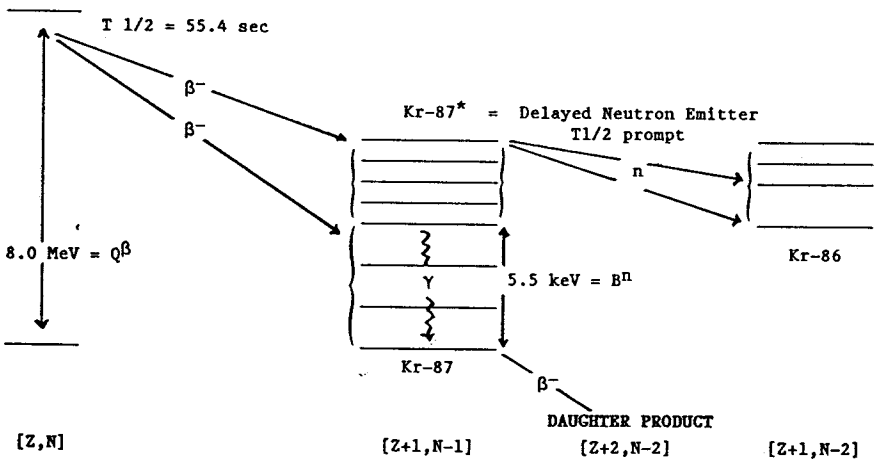

Fig. Schematic representation of Delayed neutron emission

B^n neutron binding energy
Q^β total β^- decay energy

Pn-value

The delayed neutron emission probability (Pn-value) is a decay quantity defined as the fraction of precursor decays leading to delayed neutron emission (decay of Br-87 in the figure above), usually given in percent per decay.

The Pn-value can also be related to the yield data for a given precursor as follows:

$$P_n = \frac{\text{absolute delayed neutron yield}}{\text{precursor fission yield}} \qquad \text{(cumulative or independent)}$$

Sum rule:

Pn + %betas(dn-emitter) = 100 (dn-emitter = Kr-87* in the figure).

Delayed neutron groups

Delayed neutron emission is usually represented by 6 delayed neutron groups, distinguished by their half-lives. Each group is associated with, perhaps, several different precursor nuclides with similar half-life values (approximately 55 sec, 22 sec, 6 sec, 2 sec, 0.5 sec and 0.2 sec).

Literature:

S. Amiel, Fission Product Nuclear Data, Vol. II, p. 33 (1973).
G.R. Keepin, Physics of Nuclear Kinetics (1965).
E.K. Hyde, The Nuclear Properties of Heavy Elements, Vol. III (1964).
Amarel et al., J.Inorg.Nuc.Chem., 31, 577 (1969)
Tomlinson et al., J.Inorg.Nuc.Chem., 33, 3609 (1971)
Asghar et al., Nucl.Phys.A, 247, 359 (1975)

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Delayed Fission Neutrons (page 2)

2.) Definition and codes of quantities for data to be compiled in EXFOR

Total average delayed fission neutron yield ($\bar{\nu}_d = \bar{\nu}_t - \bar{\nu}_p$)

Coding:

- Absolute delayed neutron yield: (.....(N,F),DL,NU)
  Units: neutrons per fission (entered as NO-DIM)
- Delayed neutron fraction ($\bar{\nu}_d/\bar{\nu}_t$) - coded as a ratio with the units NO-DIM:

  ((.....(N,F),DL,NU)/(....(N,F),,NU))

Partial delayed fission neutron yields

There are two main types of measurements:

Delayed neutron groups

REACTION Coding: (....(N,F),DL/PAR,NU)

Data should be coded using the average half-life of the group as an independent variable (with data heading HL which need not be explained in the BIB section).

- Relative abundance (or relative group yield) - coded as ratio with units NO-DIM. The values for the goups sum up to 1.
- Absolute group yield-coded with units PC/FIS (neutrons per 100 fissions) or NO-DIM (neutrons per fission).

Yields of delayed neutrons associated with individual precursors

Data should be coded with the precursor nucleus as an independent variable given under the data headings ELEMENT and MASS, usually with units PC/FIS.

a) **Independent delayed neutron yield** of an individual precursor:

REACTION coding: (....(N,F)ELEM/MASS,DL/IND,NU)

It is the same as the product of the Pn-value and the independent fission yield of the precursor.

b) **Cumulative delayed neutron yield** of an individual precursor:

REACTION coding: (....(N,F)ELEM/MASS,DL/CUM,NU)

It is the the same as the product of the Pn-value and the cumulative fission yield of the precursor.

Delayed-neutron energy spectrum for a given neutron group

REACTION coding: (.....(N,F),DL/PAR,DE,N)

Data are coded using the average half-life of the neutron group and the delayed neutron energy or energy range as independent variables.

The data may be given:

a) in percent - the data unit PC/FIS is used
b) as a relative measurement - the quantity modifier REL and data units ARB-UNITS are used.

For the preceding quantities the nucleus to be entered is the target nucleus before the absorption of the incident particle.

For the spontaneous fission enter the fissioning nucleus in the "target" field and replace the reaction (N,F) by (0,F).

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Delayed Fission Neutrons (page 3)

Delayed neutron emission probability (Pn-value)

Definition: Neutron yield per beta decay for a given precursor nucleus.

Reaction coding: (Z-S-A(0,B-)Z'-S'-A,,PN)

Units: either PC/DECAY
or NO-DIM if given as a fraction.

The precursor nucleus Z-S-A before beta-decay is coded in the target field. The neutron-emitting daughter nucleus Z'-S'-A is coded in the reaction-product field.

If P_n values are given for a series of delayed-neutron emitting fission fragments ("precursor nuclei"), the formalism of the the "Variable Product Nucleus" is extended to the target nucleus field SF1 in the following formalism:

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

with the "precursor nuclei" specified in the DATA table under the headings ELEMENT and MASS. In this case the Reaction Product is not coded.

3.) Data not presently compiled in EXFOR

The energy spectrum of all delayed neutrons together is time dependent, due to the contributions from the different half-life groups. This is presently not coded in EXFOR.

The delayed-neutron equilibrium spectrum as found in a steady-state reactor is presently not coded in EXFOR.

There are other delayed-neutron quantities which are not properties of the fissioning nucleus but decay properties of the fission-product nucleus which is the "precursor" of the delayed neutron. Although such quantities are closely related to the quantities given above, they are presently not coded in EXFOR, except for the delayed neutron emission probability (see above). - The energy spectrum of the neutrons emitted by a specific precursor is presently not coded in EXFOR.