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LEXFOR
(EXFOR Compiler's Manual)

Compiled and edited by

Victoria McLane
National Nuclear Data Center
Brookhaven National Laboratory, USA

on behalf of the
Nuclear Data Center Network

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Abstract: EXFOR is the exchange format for the transmission of experimental nuclear reaction data between national and international nuclear data centers for the benefit of nuclear data users in all countries. This report contains the compiler's section of the manual, including physics definitions, background information and practical examples. For a description of the format and coding rules see the EXFOR Systems Manual (IAEA-NDS-207, BNL-NCS-63330).

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"A.B. Author et al.: Data file EXFOR-12345.002 dated 1980-04-05, compare J. Nucl. Phys. 12, 345, (1979). EXFOR data received from the IAEA Nuclear Data Section, Vienna."

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<u>DRAFT</u>

Brookhaven National Laboratory

Upton, NY 11973-5000

DISCLAIMER

LEXFOR

INTRODUCTION

LEXFOR is the compiler's section of the EXFOR Manual. The contents are arranged similar to a lexicon in alphabetical order by subject heading. As distinct from the EXFOR Systems Manual, LEXFOR includes information essential for compilers using EXFOR, that is:

- physical definitions of codes defined in the EXFOR Systems Manual and its dictionaries,

- physical background information required for preparing high-quality EXFOR entries,

- practical examples of how to use the EXFOR system,

- other information that may be helpful to compilers.

The responsibility for updating LEXFOR is outlined in the EXFOR Systems Manual, Appendix P, page P.7.

The LEXFOR subject headings are given at the top of each page. Each subject heading starts with a new page for the sake of easier updating.

Absorption

Definition: Absoprtion is the sum of all energetically possible interactions excluding elastic and inelastic scattering.

REACTION Coding: ABS in REACTION SF3

Sum rules: Absorption = total minus scattering

$\qquad\qquad\qquad$ = nonelastic minus inelastic

For fissile isotopes at thermal energies below reaction (*e.g.*, n,2n) thresholds:

$\qquad\qquad$ Absorption = capture plus fission

Absorption is a ***sum*** cross section. It should only be used where two or more reactions are energetically possible. Where absorption is, throughout an experimental data set, identical with the (n,γ) reaction, it should be coded as (n,γ), see below. (See also **Tautologies**).

Examples:

a.) The frequently so-called "hydrogen absorption cross section" must clearly be coded as (n, γ), because no other neutron-absorbing reaction besides (n, γ) is possible.

b.) The thermal "absorption cross section" for gold may well be coded as (n, γ), since the energetically possible (n,p) and (n,α) cross sections are negligible in comparison with the measurement uncertainty of the (n, γ) cross section.

Capture

Definition: A reaction in which the incident projectile is absorbed by the target nucleus which then emits electromagnetic radiation.

REACTION coding: G in REACTION SF3 (Process)

Alpha

Definition: Alpha is the radiative capture-to-fission cross section ratio, $\sigma_{n,\gamma}/\sigma_{n,f}$.

REACTION coding: `(…(N,ABS),,ALF)`[1]

$\qquad$ at resonance energy: `(…(N,ABS),,ALF,,RES)`

See also **Single-Level Resonance Parameters**.

Disappearance Cross Section

The disappearance or removal[2] cross section is defined in CINDA as the cross section for all neutron-induced process producing no emergent neutron, that is (n,γ) + (n,p) + ... It differs from the absorption cross section in that it does not include (n,2n), (n,np), *etc*.

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[1] The REACTION process code ABS is entered, since capture and fission are considered.

[2] Note other meanings of "removal" in reactor physics and shielding physics.

Activation

Definition: Activation is the production of a radioactive residual nucleus as a result of a reaction, which is determined by measuring a specific decay radiation emitted by the product nucleus.

The activation cross section is usually identified with a specific reaction, and, therefore, the data given should be coded under the appropriate reaction, *e.g.*, (n,γ) or (n,p).

When the radioactive nuclide may be produced by two or more parallel reactions, it may be coded as a production cross section, or as a sum of the possible reactions, whichever is more appropriate. (See also, **Production Cross Sections, Sums**).

Examples:

a.) `((26-FE-58(N,N+P)25-MN-55,,SIG)+(26-FE-58(N,D)25-MN-57,,SIG))`

b.) `(26-FE-0(N,X)25-MN-57,,SIG)`

The code ACTIV (activation) is entered under the information-identifier keyword METHOD.

The decay information used in the analysis of the data given should be specified under the appropriate keywords. (See **Decay Data**).

Compilers should take special care when coding activation cross sections to nuclei that have metastable states to specify what has actually been measured. (See **Isomeric States**).

Analysis

The information-identifier keyword ANALYSIS is used to enter all relevant information on how the experimental results have been analyzed to obtain the values (given under DATA) which actually represent the result of the analysis. In particular, this keyword is used for deduced data such as resonance parameters. If the basic data used for the analysis have also been entered in EXFOR, a cross-reference to those sets should be given in the free text. If important assumptions were made (*e.g.*, negative resonances), these should be specified either directly or by reference. For example, extrapolation and interpolation should be given only with appropriate references. (See also **Assumed Values, Dependent Data**).

The keyword ANALYSIS should not be used for information on any analysis made on the data set to obtain theoretical conclusions.[3]

Resonance parameters require an entry under ANALYSIS explaining how they have been obtained. "Single level" or "multi-level" must be given in coded form. A more precise definition of the analysis in free text is desirable, at least in the form of a cross-reference to the literature in which a description of the analysis can be found.

An energy step used in the analysis may be coded in the data table under the data heading ANAL-STEP.

See also **Corrections** and EXFOR 8.3, ANALYSIS.

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[3] Such information can be noted under the keyword ADD-RES.

Angle

(See also **Correlations, Differential Data**).

Secondary-Particle Angle

The angle of a secondary particle with respect to the incident-projectile beam may be entered either as an angle in degrees (data units ADEG) or as a cosine (data units NO-DIM). An angle given in degrees, minutes, and/or seconds must be entered in two or three fields with the data heading repeated. See EXFOR Manual, page 4.3.

For relativistic data, angular distributions may be given as a function of q, referred to as momentum transfer, which is related to the center-of-mass angle by:

$$q = 2k \sin(\theta/2)$$

where k is center-of-mass momentum of the final system.

The momentum transfer is given in units of inverse length (*e.g.*, 1/fermi). See Kerman [1] for more detail.

Data headings:

ANG	=	angle in lab system
ANG-CM	=	angle in center-of-mass system
COS	=	cosine of angle in lab in system
COS-CM	=	cosine of angle in center-of-mass system
q	=	momentum transfer

and other codes given in Dictionary 24 with the family flag G.

When two or more angles are considered, the data headings ANG1, ANG2, *etc.*, are used. These are entered in the same order as the particles for which the angles are given are entered in the particle considered subfield of the reaction string.

The angle at which the data are normalized, if different from the angle at which the data were measured, or, if given in the COMMON section when the data are measured at more than one angle, may be given under the data heading ANG-NRM.

Angular Error and Resolution

Numerical values for the angular error or resolution may be entered in the COMMON or DATA section using data headings from Dictionary 24 with the family code H, *e.g.*, ANG-RSL, COS-ERR. Further information can be given in free text under the keyword ERR-ANALYS, (See also **Errors, Resolution**).

Reference

[1.] A.K. Kerman, H. McManus, R.M. Thaler, ***Ann. Phys.*** **8**, 551 (1959)

Assumed Values

The data table should give under the data heading DATA (and its derivatives) only values defined by the data specification keyword REACTION. It is, however, often important that numerical values used for the derivation of the results also be entered into the data table in coded form, *i.e.*, values assumed by the author, including values taken from another source.

Reference cross sections used for normalization should be entered under the keyword MONITOR. (See **Standards**).

Decay data should be entered under the keyword DECAY-DATA. (See **Decay Data**).

Assumed values for which a data-heading keyword exists should be coded under that data heading in the COMMON or DATA sections, *e.g.*, spin (SPIN J), resonance energy (EN-RES).

All other assumed values for which a quantity code exists may be entered under the data heading ASSUM in the COMMON or DATA section and defined in the BIB section under the keyword ASSUMED. See EXFOR, Chapter 8, ASSUMED.

Following are some examples of data to be coded using the keyword ASSUMED.

a.) A cross section assumed for one of the elements in a compound to derive the cross section for another.

b.) Cross sections assumed for an isotopes in a natural isotopic mixture to derive a cross section for another isotopes in the mixture.

c.) A resonance width assumed in order to deduce other resonance parameters.

Astrophysical S-factor

(See also **Thermonuclear Reaction Rates)**.

For non-resonant reactions between low-energy charged particles, the steepest dependence of $\sigma(E)$ is contained in the penetration factor for the Coulomb and angular momentum barrier. For incident energies small compared to the height of these barriers, it is convenient to factor out the energy dependence, and an additional factor of 1/E. The cross section can then be written:

in terms of the Coulomb parameter

$$\sigma(E) = \frac{S(E)}{E} \exp(-2\pi\eta)$$

$$\eta = Z_1 Z_2\, e^2 / h v$$

where v = relative velocity
Z_1, Z_2 = charge of incident ion and target, respectively

or in terms of the Gamow energy

$$\sigma(E) = \frac{S(E)}{E} \exp\left[-\beta / \sqrt{E}\right]$$

$$\beta = 0.98948\, Z_1 Z_2 m^{1/2}$$

where E = center-of-mass incident energy (MeV)
Z_1, Z_2 = charge of incident ion and target, respectively
m = reduced mass of system:[4] $m = m_1 m_2 / (m_1 + m_2)$

REACTION Coding: `(.....,SIG,,SFN)`

Units type: E*B(*e.g.*, B*EV).

S-factor as a function of angle.

Occasionally, the S-factor may be given as a function of angle: $S(E,\theta)$.

REACTION coding: `(...DA,,SFC)`
Units type: EDA (*e.g.*, B*MEV/SR)

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[4] The actual mass must be used, not the mass number.

Author

The author(s) of a data set are entered under the information-identifier keyword AUTHOR, all names between one set of parentheses and separated by a comma. The sequence of the names should be the same as in the publication.

See EXFOR Chapter 8, AUTHOR, for coding format.

If a data set has several references with varying co-authors, all co-authors may be entered.[5]

Some East-European authors spell their names, and, in particular, their initials differently depending on whether they publish in their own language or in English. Gyulia (Hungarian) = Julius (English). Hristov (Bulgarian) = Christoph (English). If this is detected, the spelling in the author's own language is preferred.

For the transliteration of Cyrillic names the following list should be used.

А	Б	В	Г	Д	Е	Ё	Ж	З	И	Й	К	Л	М	Н	О	П
A	B	V	G	D	E		Zh	Z	I	Y	K	L	M	N	O	P
Р	С	Т	У	Ф	Х	Ц	Ч	Ш	Щ	Ъ	Ы	Ь	Э	Ю	Я	
R	S	T	U	F	Kh	Ts	Ch	Sh	Shch	'	Y	'	E	Yu	Ya	

This list had been made according to the ISO prescriptions, amended for computer usage with respect to accents, with the exception that different systems are not allowed in parallel (as is the case with the new ISO prescriptions). For instance the earlier transliterations Ju and Ja are allowed in the new ISO as well as Yu and Ya.

This scheme corresponds to the official Russian transliteration scheme with the exception of ′ which is represented as ".

<u>Asian Names</u>: For Asian names the full name may be given with the family name given first:

 Example: Li Xaodong

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[5] NDS will enter all authors.

Average Resonance Parameters

For average resonance parameters, the energy range over which the data were averaged must be specified under the data headings EN-MIN and EN-MAX. When specified, the parameters *l* and J are given under the data headings MOMENTUM L and SPIN J (see under **Quantum Numbers**).

1. **Averaged Widths**: The average of the resonance widths of a specified type in a specified energy range.

    REACTION Coding: quantity modifier AV in SF8

    Example: `(…(N,EL),,WID/RED,,AV)` Averaged reduced neutron width

2. **Average Level-Spacing**: The average energy distance (D) between nearest-neighbor compound-nucleus resonances of total spin J caused by neutrons of orbital angular momentum *l*.

    If the J and l values of the resonance are not determined, then D is understood to indicate the observed level spacing.

    REACTION Coding: Parameter code D in SF6

    Example: `(…(N,0),,D)`

    Authors may apply statistical tests to evaluate the number of missed resonances. This information should be given under ANALYSIS.

3. **Fermi-gas model parameters**: See under **Nuclear Quantities**.

4. **Strength Functions**: The strength function (S) is defined as the ratio of the average reduced neutron width to the average level spacing for compound-nucleus resonances of specified spin J and angular momentum *l*.

    If *l* is known, but J is not known, the strength function given is defined as:

    $$S^l = <g\Gamma^l_n> / (2l+1) D^l$$

    If J and *l* are not known, then S is understood to be the observed strength function.

    REACTION Coding: parameter code STF in SF6

    Example:

    ```
    REACTION      (…(N,EL),,STF)
    ...
    DATA
    EN-MIN        EN-MAX         MOMENTUM L    DATA
    EV            EV             NO-DIM        NO-DIM
    ...           ...            ...           ...
    ENDDATA
    ```

Center-of-Mass System

An indication that data are given in center-of-mass system (CMS) is given within the data headings (not within the quantity codes). All quantities are understood to represent the laboratory system, unless the data headings are modified by -CM, as for example:

EN-CM	=	incident projectile energy in CMS
E-CM	=	energy of outgoing particle in CMS
COS-CM	=	cosine of angle in CMS
NUMBER-CM	=	heading for the coefficient number when the Legendre or cosine fit refers to an angle given in CMS[1]
DATA-CM	=	heading for data which are given in the CMS.

See also others given in Dictionary 24.

The compiler may convert data from the center-of-mass system to the laboratory system, but should document such conversions in free text under the keyword STATUS, or HISTORY.

Note: Only one representation (*i.e.*, either laboratory or center-of-mass) for each parameter may be coded as a variable in the data table. Other representation may be added under the data heading MISC if considered desirable by the compiler. In case of doubt, the laboratory system is preferred.

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[1] Independent of whether the fit has been made to an angular distribution in CMS or whether it has first been made to an angular distribution in the laboratory system and then converted to CMS.

Chemical Compounds

In general, chemical compounds are specified under the keyword REACTION by combining the code CMP with the element number and symbol of its main component, *e.g.*, 26-FE-CMP for iron oxide or any other iron compound. For a small number of materials of particular importance for users of nuclear reaction data, special compound codes are used. These are listed in Dictionary 9. (See also EXFOR Manual, page 6.7).

> *Example*: `1-H-BNZ` for benzene (C_6H_6).

More detailed information on the compound is given under the keyword SAMPLE.

Three rules must be kept in mind:

1) A more specific code has priority over a more general code.

   Examples:

   a) Zirconium hydrides are to be entered as 40-ZR-HYD and not as 1-H-CMP or 40-ZR-CMP.

   b) Water is to be coded as 1-H-WTR and not as 1-H-CMP.

2) For alloys (or other mixtures) the code CMP is combined with the element symbol of the major component, usually the one named first. For chemical compounds the code CMP is combined with the symbol of the primary element, usually the first one of the formula, for example, $CaCO_3$ is coded as 20-CA-CMP, and not 6-C-CMP or 8-O-CMP.

3) If the compiler feels that two possible codes are equally relevant, the reaction combination using the equal sign (tautology) may be used.

   Examples:

   a) Ammonium-hydrocarbon
      `((7-N-AMM,.....)=(1-H-CXX,....))`

   b) Brass, if it contains 50% Cu and 50% Sn
      `((29-CU-CMP,....)=(50-SN-CMP,....))`

Typical data on compounds entered are low-energy data, where chemical or crystalline binding forces affect the neutron cross sections; an example is the total cross section or thermal-scattering data of water. However, thermal scattering data for H_2 must be entered under the isotope 1-H-1, supplemented by an entry under the keyword SAMPLE.

If, for example, the sample is a compound, *e.g.*, PuO_2, and, if the data given refer only to Pu, then the data is entered under Pu.

Comments

Information-Identifier keyword COMMENT

Free text comments may be entered under the keyword COMMENT, such as:

- Miscellaneous information that cannot logically be entered under other available keywords.[2]

- Author's statements about the data, *e.g.*, whether they agree with theory or with other data.

- Compiler's or evaluator's comments (see also CRITIQUE, below).

Any information which does not originate with the author must be clearly labeled, *e.g.*, "Comment by the compiler:", and unambiguously separated from author's comments, for example, by including it between quotation marks.

Information-Identifier Keyword CRITIQUE

The keyword CRITIQUE may be used for free text comments on the quality of the data entered, as given by the compiler or by an evaluator.[3]

The reference from which evaluator's comments are taken should be entered under the keyword REL-REF . (See **Reference**).

Information-Identifier Keyword FLAG

The keyword FLAG is used to link free text comments in the BIB section with specific lines in the DATA section. (See **Flags**).

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[2] Free text comments, related to any other information-identifier keywords do not belong under the keyword COMMENT. They should be entered under the appropriate keyword.

[3] Such comments should be called to the attention of the author, when possible.

Corrections

All relevant information about corrections applied to the measured data to obtain the values given under the heading DATA should be entered as free text information under the information-identifier keyword CORRECTION.

> *Example*: **CORRECTION Corrected for multiple-scattering.**

This may include information on:
- corrections that have been applied
- corrections that have not been applied
  - corrections that are estimated to be negligible.

Corrections that are not mentioned by the author but are regarded by the compiler as relevant, are better entered under COMMENT (see Comments) where they must be clearly labeled as compiler's comments.

Errors contributed by the uncertainties of the corrections are entered under ERR-ANALYS (see **Errors**).

Consideration, depending on the compiler's judgment: In general, the data resulting from the corrections applied by the author are compiled. However, evaluators frequently re-assess old data using improved corrections because they may have better knowledge on the theory of the experiment than that which was available to the author at the time of the experiment. (This may concern items such as spectra shapes, detector-efficiency curves, *etc.*) In such cases, the re-assessed data is useful information to the user of EXFOR data and should, therefore, be compiled. They would be labeled under STATUS as (RNORM).

Compare: **Renormalization** and **Status**.

Correlations

(See also **Secondary Particles**, **Secondary Effective Mass**, and **Secondary Linear Momentum**).

For correlations between outgoing particles, the particles must be specified in REACTION SF 7 (particle considered) if they are not evident from the REACTION string. The codes given in Dictionary 36 may not specify the particles explicitly, but may contain a code giving the form for entering the particles. See EXFOR Chapter 6, Dictionary 36.

Angular Correlation

REACTION Coding: Quantities defining the angular correlation between two or more emitted particles or radiations are coded with the parameter code DA/CRL in SF6 (parameter). The angles given are defined by the particles specified in the REACTION code in either the process field (SF3) or the particle considered field (SF7).

Examples:

```
(…(N,N+P)…,,DA/CRL)                    neutron-proton correlation
(…(P,N+P)2-HE-4,,DA/CRL,N/A)           neutron-alpha correlation
```

The angles are coded in the COMMON or DATA section using the data headings ANG1, ANG2, *etc.*, in the same order in which the particles are specified in the REACTION string, or in SF7 (particle considered).

```
BIB
REACTION
...
ENDBIB
COMMON
ANG1          ANG2
ADEG          ADEG
 90.           0.
ENDCOMMON
EN            DATA          DATA-ERR
…            …            …
ENDDATA
```

Correlated particle pairs

Differential data may be reported for a given pair of secondary particle. The particles must be entered in SF7 in the order in which the processes that apply to each particle are given in SF6.

Example:

```
BIB
REACTION        (…(P,N+P)…,,DA/DA/DE,P,N,P)
…
DATA
ANG1          ANG2          E1
ADEG          ADEG          MEV
…            …            …
```

Covariance

Covariance matrices, if given by the experimentalist, should be included, where possible, either in structured form as free text under the keyword COVARIANCE or, for large matrices, stored on a separate covariance file.

Information-Identifier Keyword COVARIANCE

Only non-zero matrix elements need be given.

Example:

```
COVARIANCE    VALUES  GIVEN  ONLY  FOR  ELEMENTS  BELOW  DIAGONAL  OF  SYMMETRIC
              MATRIX ON SAME ENERGY GRID AS DATA.
              1.0
              0.98        1.0
              0.90        0.97        1.0
              0.70        0.82        0.93        1.0
              0.54        0.68        0.83        0.96        1.0
              0.64        0.75        0.85        0.92        0.95        1.0
```

The code COVAR is used under the keyword COVARIANCE to signal the existence of a separate covariance file for that data set.

    Example:

```
    COVARIANCE   (COVAR)  COMPLETE  COVARIANCE  MATRIX  GIVEN   IN   SEPARATE
                 COVARIANCE FILE.
```

Covariance File

Data is stored in the experimentalists' format with a header record that specifies the data set number to which the matrix belongs, the covariance type, and the format. See EXFOR Manual Appendix B for format.

Example:

```
C10034002    Values given only for elements below diagonal of symmetric
C10034002    matrix on same energy grid as data format.
C10034002    FORMAT(9E5.2)
D10034002    1.0
D10034002    0.98       1.0
D10034002    0.90       0.97       1.0
D10034002    0.70       0.82       0.93       1.0
D10034002    0.54       0.68       0.83       0.96       1.0
D10034002    0.64       0.75       0.85       0.92       0.95       1.0
E10034002
```

Cross sections

For the coding of the reaction, see EXFOR Chapter 7. See Dictionary 36 for a complete list of codes.

For fission cross sections, see **Fission**.

For cross sections leading to isomeric states, see **Isomeric States**.

See also **Independent and cumulative yields** and LEXFOR entries for specific processes.

Cross sections

Cross section data are given as a function of incident projectile energy.

REACTION coding: Process code SIG in SF6.

> *Example:* `(29-CU-63(P,N)30-ZN-63,,SIG)`

Unit type: B, *e.g.*, MB.

Spin-spin cross sections (See also **Polarization**).

Definitions: $\sigma_{SS} = (\sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow})/2$ Spin-spin cross section
$\Delta\sigma = \sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow}$ Difference cross section

where $\sigma_{\uparrow\uparrow}$ = cross section for incident-projectile and target spins parallel
$\sigma_{\uparrow\downarrow}$ = cross section for incident-projectile and target spins anti-parallel

REACTION Coding:

Spin-spin cross section: modifier SS in SF8
> *Example*: `(…(N,TOT),,SIG,,SS)`

Spin-dependent difference cross section: modifier DSP in SF8
> *Example*: `(…(N,TOT),LON,SIG,,DSP)` Total spin difference cross section for pure longitudinal spin states

Cross section integral between specified energy limits

Definition:

$$\int_{E_1}^{E_2} \sigma \; dE$$

REACTION Coding: INT in SF6 (parameter).

Example: `(92-U-235(N,F),,INT)`[4]

Unit type: E*B, *e.g.*, B*EV.

The energy limits are specified under the data-heading keywords EN-MIN and EN-MAX.

Such data may be coded only in the following cases:

1. When the data are normalized by means of an integral cross section over a specified energy range, the integral may be entered under the keyword MONITOR.

2. When the differential data are not available.

3. When the energy ranges given are commonly used for inter-comparison of the data.

Generally, only data integrated by the experimentalist are compiled. Data that were not integrated by the experimentalist, should be entered with a comment clearing stating by whom they integrated.

Compilation of such data is optional.

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[4] This code is not to be used for integral measurements.

Data Type

The last subfield of the REACTION code string (SF9) contains a code to indicate whether the data given are experimental, theoretical, evaluated, *etc*. If the data are experimental this field may be omitted.

Derived Data

Data that are not derived from the experimental data by the most direct method, but are, instead, calculated from other data obtained in the analysis of the experimental data, should be entered using the code DERIV in SF9 (Data type) of the REACTION code string.

Only values derived by the experimentalist from his own data should be entered in this way.

If the data from which the value given is derived are entered in an EXFOR subentry, a cross-reference to that subentry should be entered under the STATUS code DEP, see **Status**.

At present, the following types of derived data may be entered in EXFOR system:

- resonance integrals derived from resonance parameters or energy-dependent cross sections.

- thermal cross sections calculated from resonance parameters.

- angular distributions calculated from fitting coefficients.

- cross-section values (*e.g.*, at 0.0253 eV) derived from a smooth fit to measured points.

Decay Data

Radioactive decay data are not compiled in the EXFOR format except as additional information relevant to the measurement of a reaction quantity.

Information-Identifier Keyword DECAY-DATA.

The following decay data pertinent to the table given in the DATA section, are entered in the coded form:
- decaying nucleus (even if decays from the daughter nucleus are measured)
- half-life (value and unit)
- type of radiation
- energy of radiation in keV,
- abundance of the radiation measured.

These data may be given for more than one decay mode. See EXFOR Chapter 8, DECAY-DATA for coding rules.

Decay data are entered:
- in order to define an isomeric state,
- when used as basic parameters for deducing the data given in the DATA section,

Free text explanation is often desirable, for example, a statement on whether the decay data were obtained from the experiment or quoted from another source. (See also **Flags**).

Where unresolved doublets (or multiples) of γ-rays were used in the publication, the energies of all involved γ-rays, or at least the lowest and the highest energy, should be given, separated by a slash. Thus, two energy values given can mean a doublet or the borders of an energy range containing all (unresolved) γ-rays which were used for the analysis.

Example: DECAY-DATA (*Z-S-A-X*,3.1HR,DG,876./892.,0.80)

> Where 0.80 is the total abundance of the two γ-rays at 876 and 892 keV, or of all γ-rays lying between the limits 876 and 892 keV. For γ-rays, the photon abundance should be given, if known.

Decay data assumed or measured by the author for a reaction used in the experiment as a standard (or monitor) are entered under the information-identifier keyword DECAY-MON. See EXFOR Manual Chapter 8, DECAY-MON, for coding rules.

Only the values used by the author to obtain the data should be entered in coded form. Values assumed by the compiler may be entered in free text only.

Decay Data for Variable Product Nuclei

In the case of variable product nuclei, where the reaction product is defined in the COMMON or DATA section using the data-heading keywords ELEMENT and MASS, the decay data information is coded as strings of information under the keyword DECAY-DATA using the data-heading keyword DECAY-FLAG. These strings may be linked to the relevant nuclei in the data table. In particular, when decay data are given for parent or daughter nuclides of the specified product, the data should be linked in this way. (See EXFOR Chapter 7, Variable Nucleus).

More than one string of decay data information for a specific product may be entered by repeating the decay flag for each string.

Example:

```
DECAY-DATA      ((1.)54-XE-125-G,16,8HR,…)
                ((2.)54-XE-127-M,69.SEC,…)
                ((2.)54-XE-127-G,36.4D,…)
                ((3.)55-CS-127,6.25HR,…)
ENDBIB
NOCOMMON
DATA
```

| ELEMENT	MASS	ISOMER	DECAY-FLAG	DATA
NO-DIM	NO-DIM	NO-DIM	NO-DIM	PC/FIS
54.	125.	0.	1.	…
54.	127.	0.	2.	…
55.	127.		3.	…
…	…	…	…	…

```
ENDDATA
```

Although half-life values are, preferably, coded using the keyword DECAY-DATA, if half-life values are the only type of decay information to be given, they may also be entered as a data field under the data-heading keyword HL. (See **Half Lives**).

Delayed Fission Neutrons

Theory

In certain cases, a fission-product nucleus may decay by β 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 β 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 ($<<4\times10^{-14}$ sec, see **Fission Yield**)

Schematic representation of delayed-neutron emission.
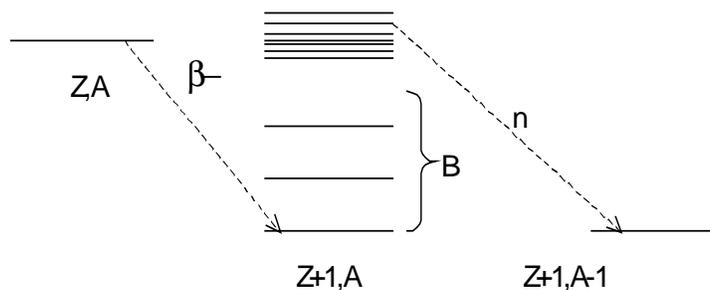
where B = binding energy of the nucleus Z+1,Z

Delayed-neutron groups

Delayed-neutron emission is sometimes 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).

For further detail see Amiel [1], Keepin [2], and Hyde [3].

Definitions and codes of quantities for data to be compiled in the EXFOR System

1. <u>**Total average delayed fission neutron yield**</u>: $(\nu_d = \nu_t - \nu_p)$

    REACTION Coding: NU in SF6 (parameter) and DL in SF5 (Branch)

    a) Absolute delayed neutron yield
    Units: particles (neutrons) per fission (data-unit heading: PART/FIS)[1]
    Example: **(…(N,F),DL,NU)**

    b) Delayed neutron fraction $(\nu_d \,/\, \nu_t)$: coded as a ratio with the units NO-DIM:
    Example: **((…(N,F) ,DL,NU)/(…(N,F),,NU))**

2. <u>**Partial delayed fission neutron yields**</u>

    a. Delayed neutron Groups: coded using the average half-life of the group (HL), the decay constant (DCNST), or the group number (GRP-NUM)[2] as an independent variable.
    - Relative abundance (or relative group yield): coded as the ratio. (The values for the six groups sum up to 1).
    REACTION Coding: **((…(N,F),DL/GRP,NU)/(…(N,F),DL,NU)**
    Units: NO-DIM
    - Absolute group yield:
    REACTION Coding: **(…(N,F),DL/GRP,NU)**
    Units: PC/FIS (neutrons per 100 fissions) or PART/FIS (particles per fission).

    b. Yield of delayed fission neutrons associated with an individual precursor: Coded with the precursor nucleus as an independent variable given under the data headings ELEMENT and MASS, usually with units PC/FIS, as above.

3. <u>**Delayed-Neutron Energy Spectrum for a Given Neutron Group**</u>

    REACTION Coding: **(…(N,F),DL/GRP,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 <u>spontaneous fission</u> enter the fissioning nucleus and code as a nuclear quantity. See **Fission**.

---

[1] Older entries may have used the units NO-DIM.
[2] The group number should only be given if the half-life or decay constant is not given.

4. **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

$$P_n = \frac{absolute\ delayed\ neutron\ yield}{cumulative\ yield}$$

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 7, Variable Nucleus).

Units: PC/DECAY

For delayed neutron emission probabilities see for example, Amarel [4], Tomlinson [5], and Asghar [6].

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.

- The delayed-neutron equilibrium spectrum as found in a steady-state reactor

There are other delayed-neutron quantities that are not properties of the fissioning nucleus but decay properties of the fission-product nucleus which is the "precursor" of the delayed neutron. Quantities in this category that are presently not coded in EXFOR:

- the energy spectrum of the neutrons emitted by a specific precursor.

References

[1.] S. Amiel, *IAEA Panel on Fission-product Nuclear Data*, Bologna, 1973, IAEA report IAEA-169, Vol. II (1973) p. 33

[2.] G.R. Keepin, **Physics of Nuclear Kinetics** (Addison-Wesley, 1965) Chapter 4

[3.] E.K. Hyde, **The Nuclear Properties of Heavy Elements**, Vol. III (Prentice Hall, 1964) p. 261 ff.

[4.] I. Amarel, et.al., *J.Inorg.Nuc.Chem.*, **31**, 577 (1969)

[5.] L. Tomlinson, et.al., *J.Inorg.Nuc.Chem.*, **33**, 3609 (1971)

[6.] M. Asghar, et.al., *Nucl.Phys.A*, **247**, 359 (9175)

Dependent Data

Data that are deduced by a trivial operation from other data sets entered into the EXFOR System should be labeled with the code under the keyword STATUS. Free text under STATUS and/or ANALYSIS should give information as to how the data were deduced. Cross-reference to the EXFOR entries from which the data were deduced must be coded as an eight-digit integer following the code.

Example: **STATUS   (DEP,10048007)**

Examples of data which would be labeled as dependent data:

a.) Alpha obtained from the ratio of two independent data sets for fission and capture.

b.) Radiation width obtained from a subtraction of two independent data sets of total width and elastic width.

c.) Legendre- or Cosine-coefficients, when the originally measured differential cross sections are also entered.

d.) If the same data are given in two subentries in different representations, *e.g.*, cross section and cross section times square-foot of energy, one of them should have the status code DEP.

The status code DEP should not be used when some data sets are mutually interdependent, as for example:

- A simultaneous measurement of absorption and capture cross sections, and alpha, where all three interdependent quantities were derived from a common set of raw data. None of these should be labeled with the status code DEP.

Compare: **Interdependent Data** and **Data Type**

Note: Do not confuse the use of the status code DEP with the use of the data type DERIV (derived data), see **Data Type**.

Dependent Variable

The dependent variable is defined under the REACTION code string. The data is given in the data table using the data heading DATA, or its derivatives, see below.

Each line in a data table must contain a value for the dependent variable, *i.e.*, at least one field headed by the data heading DATA, or its derivatives, on each line must contain a value (see examples, below).

For the following derivatives of the heading DATA are used:

DATA-MIN	Lower limit
DATA-MAX	Upper limit
DATA-APRX	Approximate value
DATA-CM	Quantity given in center-of-mass system (see **Center-of-Mass System**).

Examples:

1) The following is a legal data table.

```
DATA
EN              DATA          DATA-MIN
MEV             B             B
1.0             2.22
2.0                           4.
3.0             3.33
ENDDATA
```

2) The following is an illegal data table.

```
DATA
EN              DATA          MONIT
MEV             B             B
1.0             2.22
2.0                           3.
3.0             3.33
ENDDATA
```

For the coding of uncertainties, see **Errors**.

Differential Data

(See also, **Fitting Coefficients**, **Angle).**

The differential data given refers, in general, to the particle defined in the REACTION code string SF3. If it is not evident to which outgoing particle the quantity refers, this is indicated in in SF7 (Particle Considered). See **Particles** for the use of particle considered.

Differential with respect of angle of emitted particle or radiation

1. **Angular distribution** of an emitted particle or radiation.

   REACTION Coding: DA in SF6.

   The angle of the emitted particle or radiation to the incident neutron beam is given as a variable in the COMMON or DATA sections.

   Example: `(...(N,N+P)...,,DA,P)`   angular distribution of protons emitted in the (n,np) reaction

   Unit type: DA (*e.g.*, B/SR)

2. **Relative Angular Distributions** (Modifier codes are given in REACTION SF8).

   a. The shape of the angular distribution given in arbitrary units.
      Modifier: REL
      Units: ARB-UNITS

   b. Ratio to 90°
      Modifier: RSD
      Units: NO-DIM

   c. Ratio to 0°
      Modifier: RS0
      Units: NO-DIM

   d. Ratio to average value from 0° - 180°: $\dfrac{\sigma}{4\pi}$
      Modifier: RS
      Units: NO-DIM

   e. Ratio to the value at another angle: $\dfrac{d\sigma}{d\Omega}(\theta_1)\bigg/\dfrac{d\sigma}{d\Omega}(\theta_2)$

      Code as a ratio using the separator //, see **Ratios**.
      Example: `((...(N,EL)...,,DA)//(...(N,EL)...,,SIG))`
      Units: NO-DIM

   f. Ratios to the integrated cross section: $\dfrac{1}{\sigma}\dfrac{d\sigma}{d\Omega}(\theta)$

      Code as a ratio with the separator /, see **Ratios**.
      Example: `((...(N,EL)...,,DA)/(...(N,EL)...,,SIG))`
      Units: NO-DIM

g.   Ratio to Rutherford scattering
Modifier: RTH
Units: NO-DIM

Differential with respect to energy of emitted particle or radiation

REACTION Coding: DE in SF6 (Parameter)

Unit type: DE (*e.g.*, B/EV)

Example:

`(...(N,INL)...,,DE,,G)`   energy spectrum of gammas from inelastic neutron scattering

Differential with respect to energy and angle of emitted particle or radiation

REACTION Coding: DA/DE in SF6 (Parameter)

Unit type: DAE (*e.g.*, B/SR/MEV)

Example:

`(...(P,INL)...,,DA/DE)`   energy spectrum of inelastically scattered protons as a function of angle

Triple differential data

REACTION Coding: DA/DE/DE or DA/DA/DE in SF6 (Parameter), particles considered ***must be given*** in SF7 for each of the codes in SF6.

Unit type: D3 (*e.g.*, B/SR/MEV2) or D3A (*e.g.*, MB/SR2/MEV)

Examples:

`(...(N,2N+P)...,,DA/DE/DE,N/N/P)` differential cross section with respect to neutron energy and angle, and proton energy

`(...(P,P+A)...,DA/DA/DE,P/A/A)` differential cross section with respect to outgoing proton angle, and alpha energy and angle

Treiman-Yang Angular Distribution

Definition: The angular distribution measured as a function of the angle between two reaction planes for three-particle final states in the anti-laboratory system (i.e., *X* is at rest). That is, for the reaction between particles *X* and *Y* producing particles *a, b, c* (see diagram below), the angle between the planes (*X,a,b*) and (*Y,c*). Data are given in the center-of-mass system. For further detail, see Reference 1.
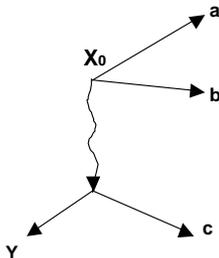
For photonuclear reactions in the center-of-mass system, it is the angle between the (X,a) and (Y,b) or (Y,c) planes, where X is the incident gamma, Y is the target nucleus.
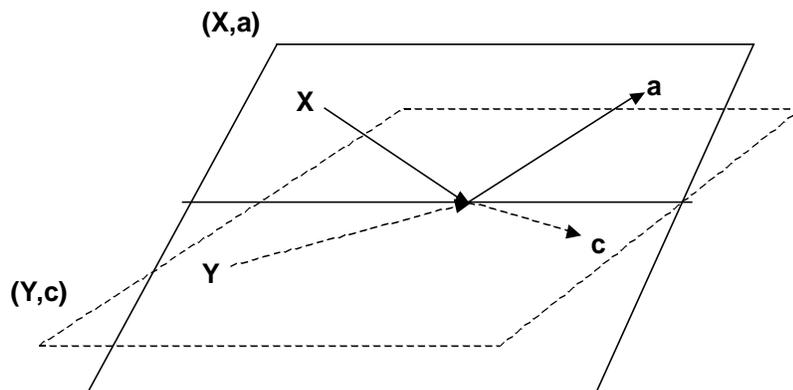
See Shapiro [1] for more information.

REACTION coding: parameter code TYA in SF6.

Example:

```
REACTION   (2-HE-4(G,N+P)1-H-2,,DA/TYA,P)
```
distribution over Treman-Yang angle between (^{4}He,^{2}H) and (γ,p) planes

The reaction planes are defined as:

- Plane 1: defined by target (SF1) and residual nucleus (SF4)

- Plane 2: defined by incident projectile (SF2) and particle designator (SF7)

The data headings ANG-CM and DATA-CM should be used in the data table.

Center-of-Mass vs. Laboratory System

An indication that the differential cross section, the angle, or the energy is given in center-of-mass system is given in the data headings; see **Center-of-mass System**.

References

[1.] I. S. Shapiro et al., ***Nucl.Phys.* 61**, 353 (1965)

Dosimetry Reaction Data

(See also **Standards)**.

A list of the "most-needed" neutron reaction data identification follows.

Activation Reactions (for use with neutron threshold detectors)

3-LI-6(N,X)2-HE-4
5-B-10(N,X)2-HE-4
7-N-14(N,P)6-C-14
9-F-19(N,2N)9-F-18
11-NA-23(N,G)11-NA-24
11-NA-23(N,2N)11-NA-22
12-MG-24(N,P)11-NA-24
13-AL-27(N,A)11-NA-24
13-AL-27(N,P)12-MG-27
15-P-31(N,P)14-SI-31
16-S-32(N,P)15-P-32
21-SC-45(N,G)21-SC-46
21-SC-45(N,2N)21-SC-44
21-SC-45(N,2N)21-SC-44-M
22-TI-46(N,P)21-SC-46
22-TI-47(N,N+P)21-SC-46
22-TI-47(N,D)21-SC-46
22-TI-47(N,P)21-SC-47
22-TI-47(N,P)21-SC-47
22-TI-48(N,P)21-SC-48
22-TI-48(N,N+P)21-SC-47
25-MN-55(N,2N)25-MN-54
25-MN-55(N,G)25-MN-56
26-FE-54(N,P)25-MN-54
26-FE-54(N,A)24-CR-51
26-FE-56(N,P)25-MN-56
26-FE-58(N,G)26-FE-59
27-CO-59(N,P)26-FE-59
27-CO-59(N,A)25-MN-56
27-CO-59(N,2N)27-CO-58
27-CO-59(N,G)27-CO-60

28-NI-58(N,P)27-CO-58
28-NI-58(N,2N)28-NI-57 → 27-CO-57
28-NI-60(N,P)27-CO-60
29-CU-63(N,A)27-CO-60
29-CU-63(N,2N)29-CU-62
29-CU-63(N,G)29-CU-64
29-CU-65(N,2N)29-CU-64
30-ZN-64(N,P)29-CU-64
30-ZN-64(N,2N)30-ZN-63
40-ZR-90(N,P)39-Y-90
40-ZR-90(N,2N)40-ZR-89
41-NB-93(N,INL)41-NB-93-M
41-NB-93(N,2N)41-NB-92-M
42-MO-98(N,G)42-MO-99 → 43-TC-99-M
45-RH-103(N,INL)45-RH-103-M
47-AG-109(N,G)47-AG-110-M
49-IN-115(N,INL)49-IN-115-M
49-IN-115(N,G)49-IN-116-M
53-I-127(N,2N)53-I-126
73-TA-181(N,G)73-TA-182
74-W-186(N,G)74-W-187
79-AU-197(N,G)79-AU-198
79-AU-197(N,2N)79-AU-196
79-AU-197(N,3N)79-AU-195
79-AU-197(N,4N)79-AU-194
80-HG-199(N,INL)80-HG-199-M
90-TH-232(N,2N)90-TH-231
90-TH-232(N,G)90-TH-232 → 91-PA-233
92-U-238(N,G)92-U-239 → 93-NP-237

Fission Reactions

90-TH-232(N,F)
92-U-235(N,F)
92-U-238(N,F)

93-NP-237(N,F)
94-PU-239(N,F)
95-AM-241(N,F)

Elements

Naturally occurring elements are, in general, entered with A=0. However, for monoisotopic elements, the atomic weight of the naturally occurring isotope is used. A list of monoisotopic elements follows.

4-BE-9	27-CO-59	59-PR-141
9-F-19	33-AS-75	65-TB-159
11-NA-23	39-Y-89	67-HO-165
13-AL-27	41-NB-93	69-TM-169
15-P-31	45-RH-103	79-AU-197
21-SC-45	53-I-127	83-BI-209
25-MN-55	55-CS-133	90-TH-232

Nearly monoisotopic elements may be entered with the A (mass number) of their main isotope only in cases where there is no noticeable influence from trace isotope on the data presented, *e.g.*, most total and elastic scattering cross sections. Special care should be taken with the capture cross section. Partial cross section leading to levels in one of the trace isotopes should always be coded under that isotope.

Following is a list of nearly monoisotopic elements:

1-H-1	8-O-16
2-HE-4	23-V-51
6-C-12	57-LA-139
7-N-14	73-TA-181

Note: Elements which do not occur naturally must be entered with the isotope number:

43-TC	91-PO
61-PM	93 Z
$84 \leq Z \leq 89$	

Superheavy elements which do not have an element symbol are coded using an * for the element symbol (*e.g.*, 107-*-270). See Dictionary 8.

See also **Target Nucleus**.

Errors

(See also **Covariance**).

Information-Identifier keyword ERR-ANALYS

Free text explanation of the error sources and of the numerical uncertainties values is given under the keyword ERR-ANALYS. In order to link the explanations to the numerical data, the relevant data headings are given in parentheses, starting in column 12, and are followed by free text; when only one data error is given, the data heading need not be given (see EXFOR Manual Chapter 8, ERR-ANALYS). Free text should contain a statement of the error type included in the quoted uncertainties, and also those error types that are not included.

The numerical uncertainty values quoted in the COMMON or DATA section are usually relevant only in conjunction with an appropriate entry under ERR-ANALYS, explaining the type of uncertainty and percentage of contributing uncertainties. Therefore, the compiler should be careful to define the information given. The following aspects are required for a precise definition of the uncertainty:

1. **error-type**, such as:
   - statistical or random uncertainty (uncorrelated)
   - systematic uncertainties (may be correlated)
     sample related: mass, geometric effects, multiple scattering, self-absorption.
     detector related: efficiency, calibration
     normalization: monitor cross section, flux determination

2. **total error or partial error**, for example, the statistical uncertainty, which is most often a partial along with other uncertainties, may be the total uncertainty if other sources of uncertainty are negligible.

3. **shape of error function**, such as:
   Gaussian, symmetric
   triangular, symmetric
   unsymmetric, for example 8.5+0.5/-0.2

4. **error measure**, such as:
   - standard deviation = half-width at half-maximum of Gaussian error distribution function
                = 2/3 probablity that the true value is within error bars
   - confidence limits: when errors are given as confidence limits various definitions exist, for example, 95% probability, which corresponds to approximately two standard deviations.
   - errors supposed not to exceed: approx. 100% probability value is within error bars.

5. **error correlations**: within systematic uncertainties and with other quantities measured in same experiment; see also **Interdependent Data**.

Energy Uncertainties[1]

Numerical values for the uncertainty in a monochromatic incident-neutron energy or of the mean energy in an incident-neutron spectrum may be entered in the COMMON or DATA section using data headings from Dictionary 24 with the family code b, *e.g.*, EN-ERR. Further information can be given in free text under the information-identifier keyword ERR-ANALYS.

Data Uncertainties

Information on the uncertainties associated with the data compiled is entered in one of two ways depending on whether a complete analysis of the uncertainties has been done.

Detailed analysis of the uncertainties <u>has not been done</u> or the compiler does not have enough information to know if a complete annalysis has been done.

The uncertaintiies should be entered in one of the following ways:

1. in the COMMON or DATA section under the data heading DATA-ERR with an explanation in free text under ERR-ANALYS. If two or more errors of different types are given referring to the same data, data headings of the type DATA-ERR1 and DATA-ERR2 are used. Unsymmetric errors are identified using the data headings +DATA-ERR and -DATA-ERR.

2. as free text information under ERR-ANALYS.

Detailed and complete analysis of the uncertainties has been done.

The detailed error formats are used:

1. The numerical values for the uncertainties are entered in the COMMON or DATA section under the data headings ERR-S (statistical or uncorrelated), ERR-T (total), ERR-1, *etc* (systematic or correlated), (see Dictionary 24). The definition of the different systematic uncertainties is given in free text comments under ERR-ANALYS. Constant systematic uncertainties may, alternately, be entered in free text under ERR-ANALYS.

2. Only uncertainties that are one standard deviation (or the equivalent for systematic uncertainty) are entered in this format. If the author gives 2- or 3-sigma uncertainties, they should be converted to 1-sigma uncertainties. Other types off uncertainty information may be entered in free text.

3. The correlation factor for the systematic uncertainties is coded under ERR-ANALYS following the data-heading code, if known.

See example, following page.

Emphasis should be given to the compilation of detailed information on the uncertainties for experimental data on neutron cross sections for standards (see **Standards**) and dosimetry reactions (see **Dosimetry Reaction Data**). When the required error information for these data is not given in the literature, every effort should be made to obtain it from the experimentalists.

---

[1] The terms error and resolution are often misused in the literature. Distinguish between them where possible. See **Resolution.**

Example of coding for detailed analysis of uncertainties:

```
BIB
REACTION      ((29-CU-63(N,A)27-CO-60,,SIG)/(92-U-238(N,F),,SIG))
ERR-ANALYS    Uncertainty in neutron energy about 10 keV.
(ERR-T)
(ERR-S)

              Sources of Systematic Uncertainties

              (ERR-1,1.0) Gamma-ray detection efficiency.
              (ERR-2,0.0) Irradiation geometry.
              (ERR-3,1.0) Uranium deposit, mass, and isotopic contect
              (ERR-4,1.0) Correction for the neutron absorption in Cu sample
              (ERR-5,0.5) Neutron source characteristics.
COVARIANCE    Only above diagonal elements of symetric matrix are given in % on
              same energy grid as data.
                   100       17       19        29       23       14        13
                            100       37        39       45       28        28
                                     100        42       48       29        26
                                       1       100       50       31        30
                                                         100       35        30
                                                                  100        22
                                                                            100
ENDBIB
COMMON
ERR-1         ERR-5
PER-CENT      PER-CENT
 1.5          1.5
ENDCOMMON
DATA
EN            EN-RSL-HW  DATA        ERR-T     ERR-S     ERR-2
ERR-3         ERR-4
MEV           MEV        NO-DIM      PER-CENT  PER-CENT  PER-CENT
PER-CENT      PER-CENT
 3.800        0.081      2.42   -04  13        12.       3.3
 1.0          1.8
 3.800        0.082      1.84    04  22        21.       2.6
 1.0          1.8
 4.065        0.041      5.142  -04  6.5       4.7       2.0
 1.0          1.8
 4.361        0.041      9.769  -04  5.7       3.8       2.0
 1.0          1.8
 4.656        0.042      1.475  -03  5.6       3.6       2.0
 1.0          1.8
 4.954        0.043      2.409  -03  5.0       2.4       2.0
 1.0          1.9
 5.268        0.045      3.912  -03  8.7       7.5       1.7
 1.3          1.9
ENDDATA
```

Interdependent Data

Data that have been measured by the same technique, have certain systematic error sources in common and are, therefore, interdependent; their errors are correlated.

Examples:

$\bar{\nu}$ for ^{233}U and ^{235}U, both measured in the same manganese bath.

Absorption, $\bar{\nu}$, and α all obtained simultaneously in the same experiment

Error correlations must be carefully considered by evaluators. Therefore, the compiler should attempt to enter all required information on common error sources and cross-references between interdependent data sets or subentries. This is particularly worthwhile in the case of private communications; in other cases, evaluators might rather use published references.

Other Uncertainties: For uncertainty in mean secondary energy, see **Secondary Particles**. For uncertainty in mean angle, see **Angle**. See index for information on other uncertainties.

Fission

(See also **Fission Yields, Fission-Neutron Spectra, Delayed Fission Neutrons**).

Theory: The following definition applies in the low energy region and is based on currently accepted models.

Fission can occur either spontaneously, or by the capture of an incident particle. In spontaneous fission, a nucleus exists in a highly excited and deformed state. In the case of capture, a particle is absorbed forming a highly excited nucleus which then undergoes deformation. If the nucleus is excited with sufficient energy such that the electrostatic repulsion will be greater than the surface forces holding the nucleus together, it may undergo scission.

At the scission stage the nucleus generally divides into two deformed and excited fission fragments having a mass greater than the mass of the incident projectile but not less than 7. This process is called **Binary Fission**.

Much less frequently, the nucleus divides into three fragments, where the size of the third fragment varies between a 'scission neutron' and a fragment similar in size to other two fragments. This process is called **Ternary Fission**.

For further detail see Hyde [1] and Feather [2].

Compare: **Reaction Mechanism.**

REACTION Coding: The fission process is coded using the process code F in SF3.

   Example: `(…(N,F),,SIG)` Neutron fission cross section

Special rules apply for the coding of the **Reaction Product** (see EXFOR Manual page 7.4).

Spontaneous Fission is specified by coding 0 in reaction SF2 (incident projectile).

   Example: `(98-CF-252(0,F),,NU)` Spontaneous fission for ^{252}Cf

Fission Fragments. For quantities related to the bulk of heavy or light fission products, the codes HF (heavy fragment) and LF (light fragment) are used in reaction SF7 (particle considered).

   Example: `(…(N,F),,AKE,HF)` Average kinetic energy of heavy fragments

Fission Asymmetry. In the case of binary fission where the fission nucleus divides with high probability into two unequal fragments, the ratio of the mean mass of the heavier fission fragment to that of the light fission fragment is called the fission asymmetry.

See also **Fission Yields**.

REACTION Coding: `((…(N,F),,AP,HF)/(…(N,F),,AP,LF))`
Ternary Fission

REACTION Coding: TER in SF5 (branch).

Example:

    `(…(N,F),TER,SIG)` Ternary fission cross section

    `(…(N,F),TER,DA,LCP)` Angular distribution of light charged particle in ternary fission[1]

Frequently, the ternary fission is further specified by the accompanying light particle, *e.g.*, α-particle accompanied ternary fission. Such information should be coded by specifying the light particle in reaction SF4.

Example: `(N,F)2-HE-4,TER,SIG)`   Cross section for -accompanied ternary fission

The **ratio of binary to ternary fission** may be coded using the codes bin and TER in reaction SF5 (branch) and the code RAT in SF6 (data type).

Example: `(…(N,F),BIN/TER,SIG/RAT)`

Partial fission cross sections

The fission cross section is a sum cross section, for example:

    (n,f) = direct fission[2] + (n,n'f) + (n,2nf) + …

the partial fission cross sections are coded under the keyword REACTION as follows:

    (n,n'f)   `(N,N+F),SEQ,SIG`
    (n,2nf)   `(N,2N+F),SEQ,SIG`
    (n, f)   `(N,G+F),SEQ,SIG`

References

[1.] E.K. Hyde, ***The Nuclear Properties of Heavy Elements***, Vol. III (Prentice Hall, 1964).

[2.] N. Feather, *Ternary Fission,* ***Physics and Chemistry of Fission***, Vienna, 1969 (I.A.E.A., 1969) p. 83.

---

[1] This is a partial cross section for those ternary fissions accompanied by the light charged particle specified.
[2] For the coding of a *direct fission cross section*, a new branch code (*e.g.*, DIR) could be introduced for SFF5 as soon as such a case occurs and is to be coded in EXFOR.

Fission-Neutron Spectra

(See also **Delayed Fission Neutrons**).

Theory

Fission-neutron spectrum data are fitted either to a Maxwellian, a Watt, or a Madland-Nix spectrum or to one of several other defined spectra.[3]

The **Maxwellian spectrum**[4] has the shape:

$$N(E) = \sqrt{E} e^{-\frac{E}{T}}$$

where   E is the energy of the fission neutron
        T is the spectrum temperature given in MeV.

Also often given are the average kinetic energy $\overline{E}$ and the most probable energy E_p which are defined as:

$$\overline{E} = \frac{3T}{2}$$

$$E_p = \frac{T}{2} = \frac{\overline{E}}{3}$$

The **Watt spectrum**[5] is based on the assumption that fragments emit neutrons with a Maxwellian spectrum in the center-of-mass system. The shape of the Watt spectrum is:

$$N(E) \approx e^{-\frac{E}{T}} \sinh\left(\frac{2}{T}\sqrt{EE_f}\right)$$

where   T is the spectrum temperature given in MeV but deviating from the temperature
        defined in the Maxwellian fit;
        E_f is a theoretical *fragment kinetic energy per nucleon*.

The average kinetic energy E is defined as: . $\overline{E} = E_f + \frac{3T}{2}$

The **Madland-Nix spectrum**[6] has the shape

$$N(E) \approx \frac{1}{2}\left[fn(E, E_{HF}) + fn(E, E_{LF})\right]$$

where   E is the energy of the fission neutron
        E_{HF} and E_{LF} are the average kinetic energy per nucleon of the heavy and light
        fragments

The numerical value of $\overline{E}$ should be approximately the same disregarding the spectrum shape to which the data were fitted.

---

[3] The Maxwellian and Watt spectra are considered as only rough approximations; a ***Double Watt Spectrum*** is preferred. The ^{252}Cf spectrum, which is more accuratelt known, suggests that none of the presently-used fits is sufficient.
[4] See Terrell [1].
[5] See Watt [3].
[6] See Madland [4].

Fission spectrum average cross sections are defined as:

$$\sigma = \frac{\int \sigma(E)N(E)\sqrt{E}\,dE}{\int N(E)\sqrt{E}\,dE}$$

Data to be compiled in EXFOR

It is most important to compile ***point data*** of the energy distribution of fission neutrons, however, it is also desirable to compile mean-energy values because they are rather independent of the spectrum shape assumed and frequently needed for measurement analysis (detector response, *etc.*).

1. **Energy spectra of fission neutrons**
    In the literature, these data are usually called X(E). Data are usually given in arbitrary units, which requires the REL modifier in the reaction code. In the normalized form ,

    $$\int X(E)\,dE = 1$$

    Data have the units of a reciprocal energy.

    The data are functions of the outgoing-neutron energy (E), and incident-projectile energy (EN).

    Examples:

`(…(N,F),PR,DE,N)`	Energy spectrum of prompt fission neutrons
`(…(N,F),DL,DE,N)`	Energy spectrum of delayed neutrons
`(…(N,F),DL/PAR,DE,N)`	Energy spectrum for a specific delayed-neutron group

2. **Fitting parameters of fission-neutron spectra**
    Since the average kinetic energy E is the only quantity which is comparable in all fits, EXFOR entries should be made for this quantity.

    Example:

`(…(N,F),PR,AKE,N)`	Average kinetic energy of prompt neutrons

    Details of the fit and of the spectrum shape assumed should be given under the keyword ANALYSIS.

3. **Fission-neutron spectrum averaged cross sections** are entered with the modifier FIS.

    It must be evident in the EXFOR entry whether the data were:
    *   measured directly. The method should be specified under the keyword METHOD. The kind of spectrum and the nuclide and incident-projectile energy from which the fission-neutron spectrum is produced should be specified under the keyword INC-SPECT.
    *   calculated by integrating a measured cross-section curve over an assumed fission-neutron spectrum. This is specified using the code DERIV in REACTION SF9. An entry should also be made under ANALYSIS. It is essential to give the assumed spectrum type and its parameters, as well as how the fit was made (*e.g.*, in a N(E)-versus-E scale or in a N(E)/E-versus-$E^{1/2}$ scale.

See **Spectrum Average** for specification of incident spectrum.

References

[1.] J. Terrrell, *Fission Neutron Spectra and Nuclear Temperature*, **Phys. Rev.** **113**, 527 (1959).

[2.] A. B. Smith, *Fission Neutron Spectra: Perspectivew and Suggestions **Prompt Fission Neutron Spectra***, Proc. Consultants' Meeting, Vienna, 1971 (I.A.E.A., 1972) p. 3.

[3.] B. E. Watt, **Phys. Rev. 87**, 1037 (1952).

[4.] D. G. Madland and J. R. Nix, **Nucl. Sci. Eng., 81**, 213 (1982).

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 ($<4\ 10^{-14}$ sec) and gamma rays (<10-11 sec), are slowed down in the surrounding medium, and stopped. These fragments are called secondary, final, post-neutron-emission fragments, or primary fission products (the emitted γ-rays may cause conversion β's and X-rays).

The primary products 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 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 border-line 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). 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.

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

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: Percent per fission (unit code: PC/FIS).

2. **Relative yields**.

   REACTION Coding: modifier REL in SF8

   Units: ARB-UNITS

The sum of the yield for all fission products will, in general, add up to 200%, *i.e.*, 100% for each of the two fragments formed. 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%. 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)`   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,,FY)`   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, page 7.8 (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.

    REACTION coding:SF5 Code: PRE

      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: SF5 Code: SEC

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

3. **<u>Independent fission-product yield</u>**.   The direct or independent yield per fission of a primary fission product specified by Z and A, 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**: SF5 Code: ind
>
> > *Example*:   `(…(N,F)ELEM/MASS,IND,FY)`
>
> *Sum rule*: The independent yield is equal to the sum, over all Z (for one A) of the secondary yield.

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. **<u>Cumulative fission-product yield</u>**: the cumulative yield per fission of a fission product specified by Z and A, after prompt-neutron emission, including the independent yield plus the yield from decay of other fission products.

> **REACTION coding**: SF5 Code: cum
>
> > *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

In addition, the product Z,A may be formed from neutron capture in the product Z,A-1, which is <u>not included</u> 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, page 7.8.

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: SF8 Code: CHN

Example: (…(N,F)MASS,CHN,FY)

6. 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

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

by:
whereas the fractional cumulative yield is given by
The parameters c and σ are widths of the distributions related by:

$$\sum_{n=0}^{Z} P_n = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{Z+1/2} e^{\left[\frac{-(n-Z_p)^2}{2\sigma^2}\right]} dn$$
$$c \approx 2\left(\sigma^2 + 1/12\right)$$

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.

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)
```

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

REACTION Coding: 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).

8. **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)`

9. **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. As this quantity is mainly of interest for studies of the fission process, but not in applied fields, no codes are proposed.

   REACTION Coding: CHG in SF5.

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

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**, Symp., 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)

Fitting Coefficients

Coefficients obtained from a fit to a differential cross section may be coded into EXFOR by entering the type of expansion used to fit the data in REACTION SF8 and specifying the representation used.

The data for a given energy is entered with the coefficient number given under the data heading number or number-cm (compare **Center-of-Mass System**).

Where the first coefficient (l=0) is either unity or another constant,, it need not be coded in the data table.

Where the first coefficient is identical to the cross section, it should be coded as a separate subentry. Each subentry should have a cross-reference under STATUS to the other subentry, using the code COREL.

Example:
```
STATUS    (COREL,10234002) ZEROTH ORDER COEFFICIENT * 4PI
              GIVEN AS ELASTIC SCATTERING CROSS SECTION
```

Note: If the directly measured differential cross sections are also coded in EXFOR, the fitting coefficients need not be compiled. If compiled, the coefficients should be marked as dependent data under status, with a cross-reference to the subentry number of the cross section from which they were derived.

Expansions to be coded into EXFOR

The following pages contain examples of data to be coded in EXFOR. For a complete list of the fitting coefficient codes, see Dictionary 36.

1. **Cosine Coefficients**

Definition: Coefficients obtained by fitting a differential cross section using an equation containing a sum in powers of cosine.

REACTION Coding: COS in SF8 plus a code indicating the representation used.

Representations:

DA,,COS   = a_l (unit type DA, *e.g.*, B/SR) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = a_0 + \sum_{l=1}^{n} a_l(E)\cos^l\theta$$

DA,,COS/RS = a_l (units NO-DIM) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{\sigma}{4\pi}\left[1 + \sum_{l=1}^{n} a_l(E)\cos^l\theta\right]$$

DA,,COS/Rl = a_l (units NO-DIM) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{d\sigma}{d\Omega}(E,\theta_0)\sum_{l=1}^{n} a_l(E)\cos^l\theta$$

DA,,COS/1K2 = a_l (units NO-DIM) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{1}{k^2}\sum_{l=0}^{n} a_l(E)\cos^l\theta \quad k = wavenumber$$

2. Legendre Coefficients

Definition: Coefficients obtained by fitting a differential cross section using an equation containing a sum of Legendre polynomials.

REACTION Coding: LEG in SF8 plus a code indicating the exact representation used.

Representations:

DA,,LEG = a_l (unit type DA, *e.g.*, B/SR) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = a_0 + \sum_{l=1}^{n} a_l(E)P_l(\cos\theta)$$

DA,,LEG/RS = W_l (units NO-DIM) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{\sigma}{4\pi}\left[1 + \sum_{l=1}^{n} W_l(E)P_l(\cos\theta)\right]$$

DA,,LEG/RSL = B_l (units NO-DIM) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{\sigma}{4\pi}\left[1 + \sum_{l=1}^{n} (2l+1)B_l P_l(\cos\theta)\right]$$

DA,,LEG/2L2 = a_l (unit type DA, *e.g.*, B/SR) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{1}{2}\sum_{l=0}^{n} (2l+1)a_l(E)P_l(\cos\theta)$$

DA,,LEG/L4P = a_l (unit type DA, *e.g.*, B/SR) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{1}{4\pi}\sum_{l=0}^{n} (2l+1)a_l(E)P_l(\cos\theta)$$

DA,,LEG/1K2 = a_l (units NO-DIM) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{1}{k^2} + \sum_{l=0}^{n} a_l(E)P_l(\cos\theta) \quad k = wavenumber$$

3. **Associated Legendre Polynomials of the First Kind**

Definition: Coefficients obtained by fitting
  - a differential cross section
  - or the product of a differential polarization and a differential cross section
  - or the product of a differential polarization and the square of a differential cross section

using an equation containing a sum of associated Legendre polynomials of the first kind (see, for example, Chapter 8 of Abramowitz [1] for the relationship between Legendre functions). See also **Polarization**.

REACTION Coding: AL1 in SF8.

Representations:

`FM/DA,,AL1` $= a_l$ (unit type DA *e.g.*, B/SR) where:

$$P(E,\theta)\times\frac{d\sigma}{d\Omega}(E,\theta) = \sum_{l=0}^{n}a_l(E)P_l^1(\cos\theta)$$

`FM2/DA,,AL1` $= a_l$ (unit type DA, *e.g.*, MB/SR) where:

$$P(E,\theta)\times\frac{d\sigma^2}{d\Omega}(E,\theta) = \sum_{l=0}^{n}a_l(E)P_l^1(\cos\theta)$$

4. **Sine-Squared Coefficients**

Definition: Coefficients obtained by fitting
  - a differential cross section
  - or the product of a differential polarization and a differential cross section
  - or the product of a differential polarization and the square of a differential cross section

by an equation containing a sum in powers of sine . (See also **Polarization**).

REACTION Coding: SN2 in SF8.

Representations:

`FM/DA,,SN2` $= a_l$ (unit type DA, *e.g.*, B/SR) where:

$$P(E,\theta)\times\frac{d\sigma}{d\Omega}(E,\theta) = \sum_{l=0}^{n}a_l(E)\sin^{2l}\theta$$

`FM2/DA,,SN2` $= a_l$ (unit type DA, *e.g.*, MB/SR) where:

$$P(E,\theta)\times\frac{d\sigma^2}{d\Omega}(E,\theta) = \sum_{l=0}^{n}a_l(E)\sin^{2l}\theta$$

4. **Cosine-Squared Coefficients**

Definition: Coefficients obtained by fitting a differential cross section using an equation containing a sum in powers of cosine.

REACTION Coding: CS2 in SF8.

Representations:

DA,,CS2 $= a_l$ (unit type DA, *e.g.*, B/SR) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = a_0 + a_1 \sin^2\theta + a_2 \sin^2\theta\cos\theta + a_3 \sin^2\theta\cos^2\theta$$

Note: The 1st and 2nd terms are equal to the sine^2 expansion.

Reference:

[1.] M. Abramowitz and I.A. Stegun, *Handbook of Mathematical Functions*, Dover Publications, 1970.

Flags

Flags are used to link information in the BIB section to specific lines in the DATA section. There are, currently, three types of flags in use in EXFOR.

Data Heading FLAG: To link free-text comments in the BIB section with one of more lines in the data table, fixed point numbers (compare, EXFOR Manual, page 4.2) are coded under the data heading FLAG with units NO-DIM. There may be more than one field with the heading FLAG (see EXFOR Manual, page 4.3)

The meaning of the flags is given under the Information-Identifier Keyword FLAG, where the actual flags are given in parenthesis, each on a separate line, starting in column 12, followed by a free text comment. (See EXFOR Manual Chapter 8, FLAG).

FLAG should not, in general, be used for entire sub-works or for one-line data tables. An exception would be where the BIB-information is given in the common subentry (SAN=1) and for some, but not all, of the following subentries, a flag world be used in a one line data table. (All flags given in the common subentry *must* be used in all data subentries.)

FLAG may not be used in the COMMON section.

Data Heading DECAY-FLAG: To link coded information on decay data in the BIB section with one or more lines in the data table, fixed point numbers (compare EXFOR Manual, page 4.2) are coded under the data heading DECAY-FLAG with units NO-DIM.

The data lines are linked to the appropriate coded information by giving the actual flags, enclosed in parenthesis, as the first in the coding string.

   Example: `DECAY-DATA ((1.)60-ND-138,5.O4HR,DG,328.,O.065)`

Usage is presently limited to the information-identifier keywords DECAY-DATA (see EXFOR Manual Chapter 8, DECAY-DATA) and RAD-DET (see EXFOR Manual Chapter 8, RAD-DET). (See also **Decay Data**).

Data Heading LVL-FLAG: To link coded information on level properties in the BIB section with one or more lines in the data table, fixed-point numbers (compare EXFOR Manual, page 4.2) are coded under the data heading LVL-FLAG with units NO-DIM.

The data lines are linked to the appropriate coded information by giving the actual flags, enclosed in parenthesis, as the first field in the coding string.

   Example: `LEVEL-PROP ((1.)82-PB-206,E-LVL=0.,SPIN=0.,PARITY=+1.)`

Free Text

(See also EXFOR Manual pages 3.3-3.4).

Be short and precise!

The language of the free text is English. The free text should be clear enough so that users who are not familiar with the system, can easily understand it; no abbreviations should be used that are not self-explanatory, and no codes from dictionaries should be used in the free text. (For general rules see EXFOR Manual, page 3.3).

Some examples:
- Write Nucl.Phys., and not NP
- Write % or percent, and not PC
- Separate a number and its unit by a blank for clarity.
- Element symbols and their A values may be written as, *e.g.*, 235U; the Z value can be omitted. For natural elements only the symbol should be used, *e.g.*, Fe.

Names of journals or other names should not be translated into English. Write "Yadernaya Fizika", and not "Nuclear Physics" which applies to another journal.

When writing formulas in free text, the compiler should attempt to use the FORTRAN conventions when they apply with liberal use of parentheses for clarity.

Free text information should be entered under the keyword to which it pertains. For example, comments which refer to any of the reaction subfield codes or which are necessary to understand a special coding or reaction type, should be given in the free text under REACTION rather than under COMMENT.

In general, the contents of the coded information should ***not*** be repeated in free text, since the coded information is either self-explanatory, as in the case of AUTHOR, or the codes are designed for machine processing. For others, the compiler may indicate, whether the code is expanded in the free text.

Standard values, parameters and other numerical values should, if suitable be entered in the DATA or COMMON section, although they maybe also given in free text.

Free text following codes can start right after the closing parenthesis; however, for clarity, it may be indented. Continuation lines may start in column 12. Blank lines should be used with discretion.

Parentheses "( )" can be used in the free text except in column 12 where the opening parenthesis marks a code. Beginning continuation lines after column 12 is good coding practice, as it eliminates the accidental coding of a parenthesis in this column.

Free text comments not originating with the author must be clearly labeled, *e.g.*, "(comment by the compiler)"', and unambiguously separated from authors comments, *e.g.*, by including it between quotation marks. See also **Comments**

Gamma Spectra

Data to be compiled in EXFOR

Neutron capture γ-ray spectra are not given high priority. Whether they are coded in EXFOR is left to the discretion of the individual data centers.

1. **Intensities of   lines**

   REACTION coding: SPC in SF6.

   > *Example*:   **(…(N,G)…,,SPC)**

   Unit type: SPC (*e.g.*, GAM/100N)

   The -ray energies are discrete values coded under the data heading E.

   Relative measurements require the addition of the modifier REL and units ARB-UNITS.

2. **Continuous spectra of unresolved γ's**

   REACTION coding: DE in SF6.

   > *Example*:   **(…(N,G)…,,DE)**

   Unit type: DE (e.g., MB/MEV)

   The γ-ray energy is a continuous variable coded under the data headings E-MIN and E-MAX.

3. **Partial radiation widths**

   REACTION coding: WID in SF6, PAR in SF5 (Branch).

   > *Example*:   **(…(N,G),PAR,WID)**

   Unit type: E (*e.g.*, EV)

   The secondary energy variable coded is:
   - either the γ-ray energy, coded under the data heading E.
   - or the final level energy, coded under the data heading E-LVL-FIN.

General Quantity Modifiers

The list of general quantity modifiers is given in Dictionary 34. They can be added to any quantity without requiring an entry in Dictionary 36. Some of them require clarification:

1. The RAW modifier is used for raw or uncorrected data such as transmission data, reaction yields, raw gamma spectra, *etc*. (See **Raw Data**).

2. The FCT modifier is used when the data has been multiplied by a defined factor not containing another quantity (*e.g.*, an arithmatic factor or a branching ratio). Explanatory free text is compulsory. If the factor contains another quantity, the appropriate reaction combination is to   be used, except in the case of a ratio of the same quantities (see REL modifier).

    The modifier FCT <u>must not</u> be used for factors for which specific codes have been introduced (such as isotopic abundance). (See **Products**).

3. The REL modifier is used in the case of shape normalized data, that is, data proportional to the quantity given; the normalization factor is unknown. The data unit ARB-UNITS (arbitrary units) should be used.

    The REL modifier always needs explanation in free text.

    An explicit ratio defined under the REACTION keyword does not require the modifier REL and will usually have the units NO-DIM. (See **Ratios**).

4. The MSC modifier is used for unusual data types, indicating that the exact definition of the quantity is given in free text following the REACTION code. This modifier should be used with discretion because the data will not be fully machine-retrievable.

5. The modifier A is used when a measured is made on a target of natural isotopic abundance and the reaction which produces the reaction product specified is known, but the data have not been corrected for the natural abundance of the target nuclide. The modifier (A) is used if the compiler is uncertain whether the data have been corrected for natural abundance of the target nuclide.

6. The modifer AV is used for data measured as a function of energy or angle and averaged over a given energy interval or angular range. It is not used for data measured over a brod spectrum. For such data one of the spectrum modifiers are used BRA, BRS, EPI, FIS, FST, MXW and SPA; see **Spectrum Average** for details

Half-lives

Half-life values in EXFOR entries may define a isomeric state, or they may be basic parameters for deducing the data value from the experiment. Consequently, the half-life should be coded in computer-intelligible form:

- for metastable states in all nuclei involved in a reaction,
- for the ground state of any radioactive nuclei involved in the reaction when its half-life is an essential parameter in the analysis of the experimental data.
- when it is a variable for the data presented, *e.g.*, delayed neutron groups.

Half-lives may be coded:

- in the BIB section using the keyword decay-data. See **Decay Data**.
- in the COMMON or DATA section using data headings from Dictionary 24 with the family code 6, *e.g.*, HL, HL1. These are linked to the BIB keyword HALF-LIFE (see below).

Numerical uncertainties may be entered using data headings from Dictionary 24 with the family code 7, *e.g.*, HL-ERR, with a free text explanation under ERR-ANALYS; see EXFOR Manual, ERR-ANALYS.

Furthermore, for certain data types, the half-life functions as an independent variable to be coded under the data heading HL; no explanation is needed under the keyword HALF-LIFE. Compare **Delayed Fission Neutron Data**.

If more than one half-life is given, the relevant nuclei *must* be coded under this keyword. If only one half-life value is given under the data heading HL with no explanation, then it refers to the half-life of the residual nucleus.

Information-identifier keyword HALF-LIFE: used to explain to which nucleus a half-life value given in the COMMON or DATA section refers. The coded information contains the data-heading keyword used and the relevant nucleus.

Example:
```
BIB
REACTION      ((Z-S-A-M1(N,G)Z-S-A -M,SIG)

              (Z-S-A-M1(N,G)Z-S-A -G,,SIG))
HALF-LIFE     (HL1,Z-S-A-M1)
              (HL2,Z-S-A'-M)
              (HL3,Z-S-A'-G)
ENDBIB
COMMON
HL1           HL1-ERR     HL2         HL2-ERR     HL3         HL3-ERR
MIN           MIN         YR          YR          HR          HR
…             …           …           …           …           …
ENDCOMMON
```
The free text should include the source of the half-life value, if known.

See EXFOR Manual, page 4.3 for the repetition of the data heading HL in coding half-lives in different units.

History

The information-identifier keyword history is used to document the chronological handling of the work within a data center. In particular, ***important*** corrections or revisions to an entry or subentry must be documented under history.

The coded information consists of a date and a one-character code, and is followed by free text. (See EXFOR Chapter 8, HISTORY, for coding details).

Important alterations are flagged with the code A in order to automate, as far as possible, follow-up actions resulting from the alteration, such as informing users who have received an earlier version. The following items are considered sufficiently important to be flagged with A:

- any change in the numbers given under COMMON or DATA

- any change in the meaning of these numbers (*e.g.*, due to change of reaction, units, the reaction under MONITOR, *etc.*)

Less important changes which the compiler wishes to document may be referenced flagged by the code U.[1]

Examples of possible entries under the HISTORY keyword

(19671119R)	Data received from author on tape
(19680220L)	Data entered into library
(19690411C)	AB
(19691015R)	Data on tape ND 1234 from Ribon.[2]
(19691223)	Proof copy sent to author
(19701003T)	Data converted from SCISRS-I, and checked for agreement with table 3 in Phys. Rev. 56, p. 78[3]
(19721130A)	Some errors in data table corrected
(19721130U)	Spelling error in BIB corrected

The rules concerning BIB information apply to history, *i.e.*, an entry under history in the common subentry (SAN=1) applies to all other subentries and should not be repeated in the data subentries.

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[1] Compilers are urged to document all changes under HISTORY
[2] The origin of the numerical data may be given here or under STATUS.
[3] For data converted from another data library, see also **Status**.

Incident Beam Source *(New)*

Data heading Keyword INC-SOURCE

This keyword is used exclusively for the nuclear reaction used as an incident- projectile source. The apparatus in which this reaction took place is entered under FACILITY, and the quality of the resulting particle beam is entered under INC-SPECT (see **Incident-Projectile Energy**). (For certain cases, *e.g.*, reactor neutrons used as source, the use of the keywords INC-SOURCE and FACILITY is somewhat overlapping.)

In general, the coded information is a code taken from Dictionary 19.

Photon Sources

The source codes for photons are divided into three categories, which may be used in combination:

1. The spectrum type, *e.g.*, monoenergetic, quasi-monoenergetic, or Bremsstrahlung.
2. The spectrum type, *e.g.*, hardened, tagged, *etc.*
3. The source, *e.g.*, laser, Compton scattering, *etc.*

Examples:

INC-SOURCE (QMPH,ARAD)	Quasi-monoenergetic photons obtained from annihilation radiation.
INC-SOURCE (BRST,HARD)	Hardened Bremsstrahlung spectrum.
INC-SOURCE (MPH,LASER)	Monoenergetic radiation from Laser scattering.

For monoenergetic photons resulting from reactions that do not have a code given in Dictionary 19, use the code MPH, followed by an equal sign (=) and the source reaction.

Example: `INC-SOURCE (MPH=(24-CR-52(N,G)24-CR-53)`

Incident-Projectile Energy

The energy of the incident projectile is entered in the COMMON or DATA section under the appropriate data heading (*i.e.*, a data heading from Dictionary 24 having an a in column 66).

Compare: **Secondary Particles, Secondary Energy**.

The **wave-length** of an incident neutron corresponds to the neutron energy:

$$E(eV) \;=\; \frac{hc}{\lambda} \;=\; \frac{0.0818}{\lambda\,/\text{Å}}$$

(Angstrom)	E(eV)
1.0	0.0818
1.8	0.0253
2.0	0.0205
4.0	0.0051
6.0	0.0023
10.0	0.0008

It is entered under the data heading EN with units ANGSTROM.

For data are averaged over an incident-neutron spectrum, see under **Spectrum Average** for energy specification.

Information on the **characteristics of the resolution and the spectrum** of the incident-projectile beam is entered in free text under the keyword INC-SPECT. (See EXFOR Manual Chapter 8, INC-SPECT).

Nuclear Quantities

No incident energy is entered for nuclear quantities, *i.e.*, data specified by reaction SF2 (incident projectile) = 0 (zero).

For nuclear properties such as the **Nuclear Temperature**, for which the incident-projectile energy is not quite irrelevant, the energy may be given in free text but should not be entered in the data table.

Independent Variables

Independent variables are identified by a Family Flag in Dictionary 24 (see EXFOR Manual, page 6.8. A given set of independent variables are required depending on the Quantity given in the REACTION string.[1]

In general, the same values of a set of independent variables (*e.g.*, energy, angle) will not occur more than one. If that does happen, (*viz.*, repetition of the measurement at same energy and angle), it is advisable to give the reason in free text in the BIB section. (Otherwise, it may be interpreted as a data entry error or as inadvertent duplication.)

---

[1] Which independent variables must be given for a given quantity are determined by the reaction type as given in Archive Dictionary 36, and defined in Archive Dictionary 13.

Institute

The laboratory, institute, or university at which the experiment was performed, or with which the author is affiliated, is entered in coded form under the information-identifier keyword institute. More than one institution may be entered for a given work. (See EXFOR Manual Chapter 8, INSTITUTE for coding details).

The institution to be entered first is, in general, the one containing the facility. Exceptions are:

a.) If an itinerant group uses the facility of another institution, the institution of the itinerant group should be given first;

b.) In an ambiguous case, that institution from which one is most likely to obtain further information on the experiment should be entered.

Compilation Responsibility

If two or more institutions of different service areas are involved, the institute to be coded first according to above rules shall determine the center responsible. See EXFOR Manual, Appendix P, page P.2.

If a publication reports the results of different experiments, done at different laboratories, or, measured at one laboratory, and, subsequently, analyzed at another laboratory, and either the laboratories are in different areas, or the incident-projectile is of a different type (*i.e.*, neutron, charged particle, or photon), the results are compiled in separate entries by the center responsible for the data. The entries may be linked using the STATUS code COREL; see **Status**, Interdependent Data.

Isobaric analog resonances *(Proposed)*

Definitions

The energy levels of isobaric (equal A) nuclei are relatively insensitive toward the interchange of a proton and a neutron. Given two isobaric nuclei (N,Z+1) and (N+1,Z), if T_0 is the ground state isospin of nucleus (N+1,Z), its isobaric analog state in nucleus (N,Z+1) will be the lowest state where $T=T_0$. The isobaric analog state will have the same properties, but will have a higher energy, δE_C, because of the additional Coulomb energy associated with the extra proton, less the neutron-proton mass difference.

In the above figure, T_0 is the isobaric analog of the ground state of (N+1,Z), T_1 is the analog of the first excited state, *etc*. T_0, T_1, *etc*., are not necessarily adjacent levels. E_T is the excitation energy of the $T = T_0$ state.

Coding

In the case where the experimentalist does not give the excitation energy of the isobaric analog state, the level number of the (N+1,Z) nucleus for which the isobaric analog state is given may be entered in the data section using the field heading `ISO-NUMB`, and the spin and parity, if given, may be specified under the keyword `LEVEL-PROP`.

Example: `LEVEL-PROP   (23-V-46,IAS-NUMB=0.,SPIN=0.,PARITY=+1.)`
The isobaric analog state for the ground state of ^{46}Ti.

References

[1.] G.R. Satchler, **Introduction to Nuclear Reactions**, John Wiley & Sons, New York, 1980, pp. 239-242.

[2.] P. Marmier and E. Sheldon, **Physics of Atomic Nuclei**, Vol. I, Academic Press, New York, 1969, p.227 ff.

Isomeric States

(See also **Cross Sections**).

Definition: An isomeric state is defined as a long-lived energy state, where long-lived is, generally, accepted as having a measurable half-life (*i.e.*, greater than ~105 sec). The term isomeric states refers to the ground and all known metastable states.

For practical applications, a ***metastable state*** is defined in EXFOR as an energy state having a half-life of the order of 0.1 milliseconds or longer.

Coding

Where a nucleus has a known metastable state, the isomeric states are indicated by an isomer code following the isotope code,[2] *e.g.*, `95-AM-242-M1`. (See EXFOR Manual, page 7.2 for a complete list of isomer codes.)

Partial reactions leading to isomeric states are coded by entering the isomer code in REACTION SF4. Sums and ratios are given algebraically (see EXFOR Manual, page 7.6).

Examples: `(…(…,…)Z-S-A-M1,,SIG)`
`(…(…,…)Z-S-A-M/G,,SIG/RAT)`
`(…(…,…)Z-S-A-M1+M2,,SIG)`

Isomer codes are used in SF4 only for partial reactions. They must not be used when the total cross section (including isomeric decay) is measured, *i.e.*, the extension G+M is never used.

When the variable nucleus formalism is used, *i.e.*, nuclei are coded within a data table under the data headings ELEMENT and MASS, the isomer is coded using the data heading ISOMER and numerical isomer codes; see EXFOR Manual, page 7.8, Variable Nucleus. These are linked to the decay information by the use of flags given using the field heading DECAY-FLAG (see **Flags**).

The assignment of isomeric states for a given nucleus may vary in the literature according to the growing knowledge of a particular nucleus. In order to define an isomeric state uniquely, at least the half-life for the isomer must be coded (see **Decay Data** and **Half-Lives**). Any other information about its decay properties, if given by the author, should be included under the keyword DECAY-DATA.

---

[2] For a target nucleus, the ground state is coded without an isomer code.

Uncertain Isomeric Contributions

Sometimes experimental data cannot be accurately assigned to specific isomeric states. If the cross section for the isomeric state specified was measured, and partial feeding from a metastable state via isomeric transition may be included, either because the isomeric state decays only partially by isomeric transition, or because its half-life is long in comparison with the lower isomeric state measured, one of the branch codes following (REACTION SF5) should be used.

M+   Including formation via partial isomeric transition
(M)   Uncertain whether formation via partial isomeric transition is included

These codes are used only for partial feeding from a higher isomeric state. Where 100% of the isomeric decay is included, the sum reaction should be coded, *e.g.*, G+M1.

See also **Independent and Cumulative Yields.**

Light-Nuclei Neutron Reactions (Z<6)

The light-nuclei reactions require special care, because many different notations exist. For example, the notations Li(n,d), Li(n,nd), Li(n,nα) may all describe the identical reaction, Li(n,nd)α .

Data retrievals for light-nuclei reactions are more difficult if the notations for these reactions are not standardized. Therefore, they should be entered using the following general rule: the heaviest of the reaction products is defined as the residual nucleus, and the remaining reaction products are sorted as given on EXFOR Manual page 7.3.

In angular or energy distributions the particle considered must be given in reaction SF7 when not self-evident. (See **Particles**).

Example: In the reaction 6Li(n,2np)^{4}He, the angular distribution:

of the neutrons:	**(3-LI-6(N,2N+P)2-HE-4,,DA,,N)**
of the protons:	**(3-LI-6(N,2N+P)2-HE-4,,DA,,P)**
of the alphas:	**(3-LI-6(N,2N+P)2-HE-4,,DA,,A)**

To aid the compiler, the following table lists all possible light-nuclei reactions induced by neutrons on stable nuclei, together with their thresholds and REACTION codes. Note that the table gives only the end products and that, in some cases, competing reactions exist that lead to the same end products.

No REACTION codes other than those listed on the following pages should be used in EXFOR for the light-nuclei neutron-induced reactions. In addition to the processes listed, only scattering processes as well as sum cross sections, such as absorption, nonelastic, charged-particles emission, etc., are defined for these nuclei.

Reaction	Threshold (MeV)[1]	REACTION
H(n,γ)D	0	1-H-1(N,G)1-H-2
D(n,γ)T	0	1-H-2(N,G)1-H-3
D(n,2np)	3.34	1-H-2(N,2N)1-H-1
T(n,2nd)	8.35	1-H-3(N,2N)1-H-2
T(n,3np)	11.31	1-H-3(N,3N)1-H-1
^{3}He(n,γ)^{4}He	0	2-HE-3(N,G)2-HE-4
^{3}He(n,pt)	0	2-HE-3(N,P)1-H-3
^{3}He(n,2d)	4.35	2-HE-3(N,D)1-H-2
^{3}He(n,npd)	7.32	2-HE-3(N,N+P)1-H-2
^{3}He(n,2n2p)	14.	2-HE-3(N,2N+P)1-H-1
^{4}He(n,dt)	21.97	2-HE-4(N,D)1-H-3
^{4}He(n,npt)	24.76	2-HE-4(N,N+P)1-H-3
^{4}He(n,2n)^{3}He	25.72	2-HE-4(N,2N)2-HE-3
^{4}He(n,n2d)	29.80	2-HE-4(N,N+D)1-H-2
^{6}Li(n,γ)^{7}Li	0	3-LI-6(N,G)3-LI-7
^{6}Li(n,tα)	0	3-LI-6(N,T)2-HE-4
^{6}Li(n,ndα)	1.71	3-LI-6(N,N+D)2-HE-4
^{6}Li(n,p)^{6}He	3.19	3-LI-6(N,P)2-HE-6
^{6}Li(n,2npα)	5.43	3-LI-6(N,2N+P)2-HE-4
^{6}Li(n,nt)^{3}He	18.42	3-LI-6(N,N+T)2-HE-3
^{7}Li(n,γ)^{8}Li	0	3-LI-7(N,G)3-LI-8
^{7}Li(n,ntα)[2]	2.81	3-LI-7(N,N+T)2-HE-4
^{7}Li(n,2n)^{6}Li	8.29	3-LI-7(N,2N)3-LI-6
^{7}Li(n,d)^{6}He	8.87	3-LI-7(N,D)2-HE-6
^{7}Li(n,2ndα)	11.06	3-LI-7(N,2N+D)2-HE-4
^{7}Li(n,np)^{6}He	11.41	3-LI-7(N,N+P)2-HE-6
^{7}Li(n,3npα)[3]	14.76	3-LI-7(N,3N+P)2-HE-4
^{9}Be(n,γ)^{10}Be	0	4-BE-9(N,G)4-BE-10
^{9}Be(n,α)^{6}He	0.67	4-BE-9(N,A)2-HE-6
^{9}Be(n,2n2)	1.85	4-BE-9(N,2N+A)2-HE-4
^{9}Be(n,t)^{7}Li	11.59	4-BE-9(N,T)3-LI-7
^{9}Be(n,p)^{9}Li	14.74	4-BE-9(N,P)3-LI-9
^{9}Be(n,d)^{8}Li	16.28	4-BE-9(N,D)3-LI-8
^{9}Be(n,n d)^{7}Li	18.54	4-BE-9(N,N+D)3-LI-7
^{9}Be(n,np)^{8}Li	18.76	4-BE-9(N,N+P)3-LI-8
^{9}Be(n,nt)^{6}Li	19.66	4-BE-9(N,N+T)3-LI-6
^{9}Be(n,3n)^{7}Be	22.85	4-BE-9(N,3N)4-BE-7
^{9}Be(n,n ^{3}He)^{6}He	23.54	4-BE-9(N,N+HE3)2-HE-6
^{10}B(n,γ)^{11}B	0	5-B-10(N,G)5-B-11
^{10}B(n,p)^{10}Be	0	5-B-10(N,P)4-BE-10
^{10}B(n,t2α)[4]	0	5-B-10(N,T+A)2-HE-4
^{10}B(n,α)^{7}Li[5]	0	5-B-10(N,A)3-LI-7

---

[1] R. J. Howerton, et al., ***Thresholds of Nuclear Reactions***, Lawrence Livermore National   Laboratory report **UCRL-14000**, (1964).

[2] Via ^{5}He, ^{7*}Li, ^{4}H, or three-particle breakup (***Nucl. Phys.*** **A98** (1967) 305.

[3] Including search for bound tri-neutron.

[4] Via ^{8}Be, ^{7}Li(2nd excited state), or three-particle breakup.

Reaction	Threshold (MeV)[1]	REACTION
^{10}B(n,d)^{9}Be	4.79	5-B-10(N,D)4-BE-9
^{10}B(n,nα)^{6}Li	4.90	5-B-10(N,N+A)3-LI-6
^{10}B(n,nd2α)	6.62	5-B-10(N,N+D+A)2-HE-4
^{10}B(n,np)^{9}Be	7.24	5-B-10(N,N+P)4-BE-9
^{10}B(n,2np2α)	9.28	5-B-10(N,2N+P+A)2-HE-4
^{10}B(n,^{3}He)^{8}Li	17.32	5-B-10(N,HE3)3-LI-8
^{10}B(n,n^{3}He)^{7}Li	19.56	5-B-10(N,N+HE3)3-LI-7
^{10}B(n,nt)^{7}Be	20.54	5-B-10(N,N+T)4-BE-7
^{10}B(n,3n)^{8}B	29.72	5-B-10(N,3N)5-B-8
^{11}B(n,γ)^{12}B	0.	5-B-11(N,G)5-B-12
^{11}B(n,α)^{8}Li	7.23	5-B-11(N,A)3-LI-8
^{11}B(n,nα)^{7}Li	9.44	5-B-11(N,N+A)3-LI-7
^{11}B(n,d)^{10}Be	9.82	5-B-11(N,D)4-BE-10
^{11}B(n,t)^{9}Be	10.42	5-B-11(N,T)4-BE-9
^{11}B(n,p)^{11}Be	11.70	5-B-11(N,P)4-BE-11
^{11}B(n,np)^{10}Be	12.25	5-B-11(N,N+P)4-BE-10
^{11}B(n,nt2α)	12.25	5-B-11(N,N+T+A)2-HE-4
^{11}B(n,2n)^{10}B	12.50	5-B-11(N,2N)5-B-10
^{11}B(n,nd)^{9}Be	17.25	5-B-11(N,N+D)4-BE-9
^{11}B(n,3np2α)	21.70	5-B-11(N,3N+P+A)2-HE-4
^{11}B(n,^{3}He)^{9}Li	25.73	5-B-11(N,HE3)3-LI-9
^{11}B(n,n^{3}He)^{8}Li	29.68	5-B-11(N,N+HE3)3-LI-8
^{12}C(n,γ)^{13}C	0	6-C-12(N,G)6-C-13
^{12}C(n,α)^{9}Be	6.17	6-C-12(N,A)4-BE-9
^{12}C(n,n3α)	7.98	6-C-12(N,N+2A)2-HE-4
^{12}C(n,p)^{12}B	13.63	6-C-12(N,P)5-B-12
^{12}C(n,d)^{11}B	14.87	6-C-12(N,D)5-B-11
^{12}C(n,np)^{11}B	17.29	6-C-12(N,N+P)5-B-11
^{12}C(n,t)^{10}B	20.50	6-C-12(N,T)5-B-10
^{12}C(n,2n)^{11}C	20.28	6-C-12(N,2N)6-C-11
^{12}C(n,^{3}He)^{10}Be	21.09	6-C-12(N,HE3)4-BE-10
^{12}C(n,n^{3}He)^{9}Be	28.47	6-C-12(N,N+HE3)4-BE-9
^{12}C(n,nd)^{10}B	27.28	6-C-12(N,N+D)5-B-10
^{12}C(n,npt2α)	29.65	6-C-12(N,N+P+T+A)2-HE-4
^{12}C(n,3n)^{10}C	34.47	6-C-12(N,3N)6-C-10

---

[5] To ground state and 1st excited state; 2nd excited state decays to t+α.

Measurement Techniques

Physics information on experimental measurement techniques is entered under several information-identifier keywords (see EXFOR Chapter 8 for coding rules).

FACILITY:[1] used to identify the main apparatus or machine used in the experiment, *e.g.*, reactor or cyclotron.

When there is more than one institute code for an entry, the code for the institute at which the facility is located should be entered following the facility code, if known.

Information on the facility used should always be given, if known, except when not relevant, *e.g.*, with respect to spontaneous fission.

INC-SOURCE: used to enter the source of the incident-projectile beam used in the experiment (see **Incident Beam Source**).

SAMPLE: used to identify information on sample material characteristics (see also **Sample**).

DETECTOR[1]: used to enter information on detectors used in the measurement. Detectors used as monitors are also entered under this keyword.

For particles detected and the keyword PART-DET see **Particles**; for their energies and the keyword EN-SEC, see **Secondary Energy**.

Information on the facility used should always be given, if known.

METHOD: describes the experimental technique(s) employed in the experiment, *e.g.*, activation.

Information that can be entered under one of the more specific keywords, below, should not be entered under METHOD.

---

[1] One of the following keywords must be present: FACILITY, DETECTOR, ANALYSIS, or METHOD.

Miscellaneous Data

(For reaction modifier MSC, see **General Quantity Modifiers**).

Supplementary information for which no data heading has been defined may be entered in a data field using the data heading MISC (or MISC1, MISC2, *etc*., if more than one is given). Such data are usually entered in the DATA section, but may also be entered in the COMMON section, although the latter is not recommended.

The meaning of these data headings is explained in the BIB section under the keyword MISC-COL. In order to link explanations when more than one miscellaneous data field is given, the data heading is given as a code under MISC-COL, followed by the free text explanation. This formalism is the same as for error fields. See EXFOR Manual Chapter 8, MISC-COL for coding example.

If the information under the data heading MISC is given in units for which no data unit exists, the data unit SEE TEXT is entered and the explanation is given in free text under the keyword MISC-COL. (This is to avoid introducing data units that are unlikely to occur often.) The data unit SEE TEXT must not be used for an independent variable or a dependent variable.

Multilevel Resonance Parameters

(See also **Single-Level Resonance Parameters**, **Quantum Numbers**).

In analyzing resonance structure for fissile nuclides, it is necessary to use a multilevel formalism to account for interference effects from neighboring resonances and also those due to distant resonances.

Three different multilevel formalisms are generally used: Vogt, Reich-Moore and Adler-Adler. All three are derived from the R-matrix theory of Wigner and Eisenbud.

Reich-Moore and Vogt Resonance Parameters

In the Vogt and Reich-Moore formalisms, cross sections are expressed in terms of R-matrix level parameters. Cross sections due to resonance levels of the same spin and parity are related to the elements U_{nc} of the collision matrix by relations of the form:

    Total cross section: $\sigma_{nT} = 2\pi\lambda_n^2 g \operatorname{Re}(1 - U_{nn})$

    Other cross sections: $\sigma_{nR} = \pi\lambda_n^2 g \left| \delta_{nR} - U_{nR} \right|$

        where: λ_n = neutron wave length in the center-of-mass system

                    g = statistical weight factor

                    δ_{nc} = Kronecker delta

    and Re stands for the real part of the expression in parentheses.

The collision matrix **U** is related to the nuclear level properties by means of the derivative matrix R, in the following form: $R = \sum_\lambda \dfrac{\vec{\gamma}_\lambda \times \vec{\gamma}_\lambda}{E_\gamma - E}$

        where: $\vec{\gamma}_\lambda \times \vec{\gamma}_\lambda$ is the direct product of the vectors γ_λ; λ refers to levels.

                  The diagonal elements of γ_λ are reduced width parameters.

The collision matrix **U** can be related to the derivative matrix R through the matrix:

$$\left(1 - RL^0\right)^{-1} R$$

      where: L^0 = L-B; B is a constant diagonal matrix; L is a complex matrix with elements being a function of momentum l.

Both the Vogt and the Reich-Moore formulas require that off-diagonal matrix elements describing interference in the radiative capture channels must vanish.

The **Reich-Moore formula** (see Reich [2]) involves summation over levels and a matrix inversion with respect to channels.

The matrix (1 - RL) is partitioned into a 2×2 matrix, each element of which leads to a definition on the matrix

$$K_{00} = \frac{i}{2} \sum_{\lambda} \frac{\Gamma_{\lambda c}^{1/2} \Gamma_{\lambda c'}^{1/2}}{E_{\lambda} - E - \frac{i}{2}\Gamma_{\lambda \gamma}}$$

The fission cross section can be expressed by:

$$\sigma_{nf} = \sum_{c=2}^{l+1} 4\pi\lambda_n^2 g \left|\left(1 - K_{nC}\right)^{-1}\right|^2$$

where l = number of fission channels

Similar expressions are obtained for other partial cross sections.

Reich-Moore Resonance Parameters are entered under the quantity codes:

`(N,0),,EN`	E_{λ}	Resonance energy; units of energy (e.g., eV)
`(N,TOT),,WID,,RM`	Γ_{λ}	Total width; units of energy
`(N,G),,WID,,RM`	$\Gamma_{\lambda\gamma}$	Capture width; units of energy (including all primary gamma decays not followed by neutron or charged-particle emission).
`(N,F),1,WID,,RM`	$\Gamma_{\lambda f1}$	[2]Fission width for channel 1; units of energy
`(N,F),2,WID,,RM`	$\Gamma_{\lambda f2}$	[2]Fission width for channel 2; units of energy
`(N,F),,WID,,RM`	$\Gamma_{\lambda f}$	Total fission width; units of energy
`(N,EL),,WID,,RM`	$\Gamma_{\lambda n}$	Neutron width; units of energy
`(N,EL),,WID/RED,,RM`	$\Gamma_{\lambda n}^{\ l}$	Reduced neutron width, l = orbital angular momentum; units of energy

The **Vogt Formula** (see Vogt [3]) involves summation of channels and matrix inversion with respect to levels, and requires that level interference in the neutron channel be equal to zero. The inversion of the channel matrix (1-RL0) leads to the definition of the level matrix A, which s given by:

$$\left(A^{-1}\right)_{\lambda\lambda} = \left(E_{\lambda} - E\right)\delta_{\lambda\lambda'} - \frac{1}{2}\sum_{c} \Gamma_{\lambda c}^{1/2} \Gamma_{\lambda'c}^{1/2}$$

where: c is the channel number.

A reduced neutron width for an s-wave resonance is defined as: $\Gamma_{\lambda n}^0 = 2g\Gamma_{\lambda n} E^{1/2}$

---

[2] The relative phases of $\Gamma_{\lambda f1}$ and $\Gamma_{\lambda f2}$ are 0 or 180 degrees; therefore, the parameter values are given with either a positive or negative sign.

Vogt Resonance Parameters are entered under the quantity codes:

`(N,0),,EN,,VGT`	E	Resonance energy; units of energy (*e.g.*, eV)
`(N,TOT),,WID,,VGT`	Γ_λ	Total width; units of energy
`(N,G),,WID,,VGT`	$\Gamma_{\lambda\gamma}$	Capture width; units of energy (including all primary gamma decays not followed by neutron or charged-particle emission)
`(N,F),1,WID,,VGT`	$\Gamma_{\lambda f1}$	Fission width for channel 1; units of energy
`(N,F),2,WID,,VGT`	$\Gamma_{\lambda f2}$	Fission width for channel 2; units of energy
`(N,EL),,WID,,VGT`	$\Gamma_{\lambda n}$	Neutron width; units of energy
`(N,EL),,WID/RED`	$\Gamma_{\lambda n}{}^l$	Reduced neutron width, where l = orbital angular momentum; units of energy $\times$ square-root of energy
`(N,0),,PHS,,VGT`	$\theta_{\lambda i \lambda j}$	Relative phase of channel λ_i and λ_j; units of angle

Adler-Adler Resonance Parameters

The Adler-Adler formalism (see Adler [4]) is a generalized Kapur-Peierls formalism in which cross sections are given in terms of Kapur-Peierls poles μ and ν, and residues G and H.

The resonance part of the reaction cross section (without Doppler Broadening) in the Adler-Adler formalism is given by:

$$\sigma_\lambda(E) = \frac{1}{\sqrt{E}} \sum_k \frac{G_{rk}\nu_k + H_{rk}(\mu_k - E)}{(\mu_k - E)^2 + \mu_k^2}$$

where: G, H, μ and ν are treated as constants, since they have only a weak energy dependence.

Adler-Adler coefficients are entered under the quantity codes:

`(…,0),,EN,,AA`	μ_k	Resonance energy; units of energy (*e.g.*, eV)
`(…,TOT),,WID,,AA`	ν_k	Corresponding to half the total width; units of energy
`(…,F),,AG,,AA`	$G_{\lambda f}$	Fission symmetry coefficient; in B*EV*RT-EV
`(…,F),,AH,,AA`	$H_{\lambda f}$	Fission asymmetry coefficient; in B*EV*RT-EV
`(…,G),,AG,,AA`	$G_{\lambda\gamma}$	Capture symmetry coefficient; in B*EV*RT-EV
`(…,G),,AH,,AA`	$H_{\lambda\gamma}$	Capture asymmetry coefficient; in B*EV*RT-EV
`(…,TOT),,AG,,AA`	G_γ	Total symmetry coefficient; in B*EV*RT-EV
`(…,TOT),,AH,,AA`	H_γ	Total asymmetry coefficient; in B*EV*RT-EV

The parameters are functions of μ which corresponds to the resonance energy. Since this representation of the energy causes difficulty in a data retrieval by energy, the energy limits of the Adler-Adler fit must be entered explicitly in the COMMON section under the data-heading keywords EN-MIN and EN-MAX.

R-Matrix Resonance Parameters *(Proposed)*

The R-Matrix reduced width γ^2 is given by:

$$\ni = 2\,\gamma^2\,P$$

      where: P = penetrability

    Reaction coding: `(…,WID/RED,,RMT)`
    Units: energy, *e.g.*, EV

The square root of this quantity, γ, is referred to as the reduced width amplitude.

    Reaction coding: `(…,WID/RED,,RMT/AMP)`
    Units: square root of energy, *e.g.*, RT-EV

References

[1.]   M. S. Moore, Idaho Nuclear Engineering Laboratory report **IN-1222** (1969) p. 199

[2.]   C. W. Reich, and M. Moore, ***Phys. Rev.*** **111**, 929 (1958)

[3.]   E. Vogt, ***Phys. Rev.*** **112**, 203 (1958)

[4.]   D. B. Adler, and F. T. Adler, Argonne National Laboratory report **ANL-6792** (1963) p. 695

Multiple Reaction Formalism

At present, the following classes of data may be coded using *Multiple Reaction Formalism* (compare EXFOR Manual, page 7.7).

1. Resonance parameters of the same isotope;

    Example: `REACTION   1(…(N,0),,EN)`
                          `2(…(N,EL),,WID)`

2. Multiple representations of the same data; when one of the reactions given has been deduced from the other *e.g.*, if absolute ^{235}U σ_{nf} data were deduced from relative data using standard reference data from another author), the appropriate status code is entered with the relevant pointer.

    Example:

    ```
    REACTION   1((92-U-235(N,F),,SIG)/(94-PU-239(N,F),,SIG))
               2(92-U-235(N,F),,SIG)
    STATUS     2(DEP,12345006)    free text.
    ```

    Explanation in free text may be given following the status code and/or following the reaction code.

3. Partial cross sections of the sum reaction (*i.e.*, for the REACTION keyword, all subfields except SF5 (Branch) are equal).
    a) isomer data (branches, ratios, *etc.*) of the same reactions.
    b) compound nucleus and direct interaction parts for the same reactions.
    c) high-energy fission and spallation parts for the same reactions.
    d) binary and ternary parts for fission measured.
    e) light and heavy fragment parts for a given fission yield.

    Example: `REACTION   M(39-Y-89(N,INL)39-Y-89-M,,SIG)`
                          `G(39-Y-89(N,INL)39-Y-89-G,,SIG)`

4. Data measured simultaneously for the production of specific particles or nuclides where the author has assigned values to given reactions based on systematics or theoretical considerations.

    Examples:
    a.) `REACTION   1(…(P,2N)…)`
                      `2(…(P,3N)…)`
                      `3(…(P,4N)…)`
    b.) `REACTION   1(…(N,A)…)`
                      `2(…(N,NA)…)`

    Where only the product nucleus is variable for a given reaction, (*i.e.*, for the REACTION keyword, SF1, SF2 and SF3 are constant) the *Variable Nucleus Formalism* may be used (see EXFOR manual, page 6.6).

5. <u>Data for the same reaction obtained by different types of analysis</u> on the same experimental data; in this case the code must be repeated for each analysis.

Example: **REACTION**   **1(79-AU-197(N,G)79-AU-198,,SIG)**
                                  2(79-AU-197(N,G)79-AU-198,,SIG)
                DETECTOR   **1(NAICR)**
                                    2(GELI)

Multiplicity

Definition: Particle yield per event.

REACTION Coding: MLT in SF6.

   Examples:
       `(…(P,A)…,,MLT,G)`   γ yield from (p, γ) reaction
       `(…(N,X)0-G-0,,MLT)` γ yield from all neutron-induced reactions

Partial Multiplicity

In many cases the experimental arrangement will be such that not all of the particles produced will be detected. In such cases the branch code PAR must be used in REACTION SF5. The most common experimental occurrence of this will be limits on the energies of the particle detected.

Authors often deduce the <u>multiplicities as a function of spin or momentum transfer</u>; these deduced results should not be compiledas experimental data.

Neutron Multiplicity

The neutron multiplicity should be coded as given above only for those reactions for which special codes do not exist. For neutron multiplicity from neutron-induced reactions or from spontaneous fission, see **Neutron Yield**.

Multipolarity

Definition: Angular momentum of γ-quanta absorbed by the nucleus. These are given as electrical   or magnetic monopoles, dipoles, quadrupoles, or octupoles.

REACTION coding: Branch code in SF5:   EP (for electric polarity) or MP (for magnetic polarity).

The polarity is coded in the data table under the data heading POLAR:
    0. = monopole, 1. = dipole, 2. = quadrupole, 3. = octupole.

Examples:

a.) Electric dipole component of photo-neutron cross section

```
REACTION    (…(G,N)…,EP,SIG,,,EXP)
 …
COMMON
POLAR
NO-DIM
 1.
ENDCOMMON
```

b.) Magnetic quadrupole component of photo-absorption cross section

```
REACTION    (…(G,ABS),MP,SIG,,,EXP)
 …
COMMON
POLAR
NO-DIM
 2.
ENDCOMMON
```

Neutron Yield

The following special terms are defined for neutron yields from neutron-induced reactions or from spontaneous fission. For other neutron yields, see **Multiplicity**.

Nu-bar $\left(\bar{\nu}\right)$

Definition: Average number of fission neutrons emitted per fission event.

REACTION Coding:

`(...(N,F),,NU)`	total neutron-induced fission nu-bar ($\bar{\nu}$)
`(...(0,F),PR,NU)`	spontaneous fission prompt nu-bar ($\bar{\nu}_p$)
`(...(N,F),DL,NU)`	neutron-induced fission delayed nu-bar ($\bar{\nu}_d$)
`(...(N,F+XN),,NU)`	probability for the emission of x neutrons from neutron-induced fission

Sum rule: $\bar{\nu} = \bar{\nu}_p + \bar{\nu}_d$

See also **Delayed Fission Neutrons**

Eta (η)

Definition: The average neutron yield per nonelastic event.

For the thermally fissile isotopes, where fission and capture are, up to a certain threshold, the only nonelastic processes, η is defined as average neutron yield per absorption.

REACTION Coding:

`(N,NON),,ETA)`	η, in general
`(N,ABS),,ETA)`	η for thermally fissile nuclei
`(N,ABS),,ETA,,RES)`	η at resonance for thermally-fissioning nuclei

In the case of thermal neutron fission, η is related to $\bar{\nu}$ by:

$$\eta = \nu \frac{\sigma_f}{\sigma_{abs}}$$

For further related quantity codes see Dictionary 36.

Nonelastic

Definition: The sum of all energetically possible interactions with $Q \neq 0$; effectively, the sum of all interactions except elastic scattering.

The nonelastic cross section is a ***sum*** cross section and should only be used when two or more of the relevant interactions are possible.

REACTION Coding: Process code NON in SF3

    Example: `(...(N,NON),,SIG)`

Sum-rules: Nonelastic = Total minus Elastic
                   = Absorption plus Inelastic.

For average neutron yield per nonelastic process, see **Neutron Yield**, Eta.

Nuclear Quantities

A quantity that does not refer to a nuclear reaction, but is a property of a given nuclide, is coded by entering the nucleus to which the data are pertinent as the target nucleus (SF1) under REACTION; a zero is entered in SF2 (incident projectile field).

At present, the following nuclear quantities are coded in EXFOR.

1. **Spontaneous fission**, see **Fission**.

2. **Level-Density Parameter**: proportional to single-particle level spacing at at top of Fermi-sea in the Fermi-gas model of the nucleus, in specified formalism.

REACTION Coding: LDP in SF6 (Parameter).

>   *Example*: **(…(0,0),,LDP)**

For nuclei around A = 208, neutron emission spectra can only be interpreted by assuming a variable level-density parameter, *i.e.*, increasing density with increasing excitation energy. Therefore, the incident projectile must be specified in REACTION SF2 and its energy must be coded.

>   *Example*: **(…(N,INL)…,,LDP)** where, Z-S-A is the target nucleus

The incident-neutron energy is coded, as usual, under the data heading EN.

3. **Nuclear Temperature** - from Fermi-gas model of the nucleus.

REACTION Coding: TEM in SF6 (Parameter).

>   *Example*: **(…(0,0),,TEM)**

4. **Spin-cut-off factor**

REACTION Coding: SCO in SF6 (Parameter).

>   *Example*: **(…(0,0),,SCO)**

Subentries with nuclear quantities should, if applicable, contain the STATUS code DEP with cross reference to the subentry containing the reaction data from which the nuclear quantity was derived.

>   *Example*: **STATUS   (DEP,30343003)**

Partial Reactions

Definition: A partial reaction is a reaction leading to or proceeding through a given excited state. An *excitation function* is the energy dependence of a partial reaction cross section leading to the excitation of a discrete level or to the production of a particular radiation or particle group.

REACTION Coding: PAR in SF5 (Branch)

> *Example*: **(...(N,INL)...,PAR,SIG)**

The energy must be given in the COMMON or DATA section under a secondary-energy data heading (Family E), *e.g.*, E-EXC.

Partial reactions leaving the residual nuclus (reaction product) in an excited state, excluding isomeric states. The excited state is defined by specifying one, several or a range of:

- level energies (default is level energy of reaction product)
- excitation energies (default is level energy of reaction product)
- reaction Q-values (default is Q-value for excitation in reaction product)
- secondary particle energy (of particle considered)
- energy gain (primary to particle considered)
- energy degradation (primary to particle considered)

The particle considered in an experiment is
- either the particle given in REACTION SF3,
- or, for other particles,, the particle given in SF7.

When the data is a function of the secondary energy of more than one secondary particle, the secondary energy for the particles must be defined under the information-identifier keyword EN-SEC (see EXFOR Manual Chapter 8, EN-SEC, and **Secondary Particles**).

> *Example:*
> ```
> REACTION   (…,N+P)…, ,DA2/DE2,P/A)
> EN-SEC     (E1,P)
>            (E2,A)
> ```

For the excitation of an isomeric states, see **Isomeric States**.

For partial reactions specified by the sequence of outgoing particles, see **Sequence of Outgoing Particles**.

If ratios of partial reactions are given, they should be coded using the reaction separator "//", see **Ratios**.

For other partial reactions due to competing reaction mechanisms, see **Reaction Mechanisms**.

<u>Reactions that lead by the same particle sequence to the same reaction products</u>, but through different reaction-decay mechanisms.

Examples:
a.) $^{12}C(n,n')^{12*}C \rightarrow \alpha + {}^{8*}Be \rightarrow 2\alpha$
b.) $^{12}C(n,n')^{12*}C \rightarrow 3\,\alpha$
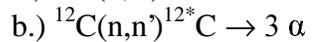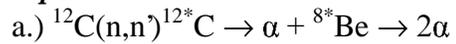
The intermediate states should be specified in the data table and explained under the information-identifier keyword EN-SEC as clearly as possible.

Example:
```
REACTION    1(6-C-12(N,N+2A)2-HE-4,PAR,SIG)
            2(6-C-12(N,N+2A)2-HE-4,PAR,SIG)
EN-SEC      1(E-LVL,4-BE-8)
            2(E-LVL,6-C-12)
```

Particles

(See also **Secondary Particles**).

Particles participating in a reaction

The incident projectile is coded in reaction SF2. Particles resulting from the REACTION to be defined are given in SF3 and SF4.

Sometimes, data are given for **partial reactions where the sequence of outgoing processes/ particles is defined**, for example:

   total (n,np) = partial (n,np) + partial (n,pn)
       (1)   (2)   (3)

The corresponding REACTION codes are:

(1) `(...(N,N+P)...,,SIG)`

(2) `(...(N,N+P)...,SEQ,SIG)`

(3) `(...(N,P+N)...,SEQ,SIG)`

Note that the code SEQ should be given within the reaction code *only when it is a partial reaction*. If the author states that the reaction proceeds, *e.g.*, totally in the sequence (n,pn) without any contribution in the sequence (n,np), then the reaction is coded primarily as (1), above. A comment stating that the reaction proceeds entirely in the sequence (n,pn) may be added in free text (if this occurs at all) or, alternatively, both codes may be given in the form of a tautology:

> *Example*:
> `REACTION ((...N,N+P)...,,SIG)=( ...(N,P+N)...,SEQ,SIG))`

For the following partial reactions the specified sequence of process and particle codes is always indicated by the code SEQ.

1.) Excitation of excited level(s) that decay by fission:
   (n,n'f) cross section: `(N,N+F),SEQ,SIG`
   (n, f) cross section: `(N,G+F),SEQ,SIG`

2.) Emission of a primary gamma ray followed by unidentified decays:
   (n, x) cross section: `(N,G+X),SEQ,SIG`
   This formalism can occur only for the process codes F and X.

For general rules on the coding of sequence of process/particle codes in REACTION SF3 and SF4 see EXFOR Manual, page 7.3-7.4.

For correlation data on secondary particles, see **Correlations**.

Particle Considered

Definition: The particle considered is the particle to which a given function refers, *e.g.*, an angular or energy distribution, or a reaction to a specific particle group. In a reaction where only one outgoing particle is specified in SF3, the particle considered is assumed to be that particle, unless there is an entry in SF7 (particle considered).

When the quantity given refers to a specific secondary particle (*e.g.*, angular distributions), the particle considered must be entered in reaction SF7 if:
- more than one particle is given in reaction SF3,
- the particle considered is not given in reaction SF3,
- the quantity is a function of more than one secondary particle.

See EXFOR Manual, page 7.5 for coding rules.

Examples:

    (...(P,P+A)...,PAR,SIG,A)   partial cross section for a specific group.
    (...(N,P)2-HE-4,,DA,A)   angular distribution of α particles.

If the code given in REACTION SF3 is a process code, and the reaction refers to a specific particle, the particle considered is determined as follows:

INL: The particle considered is assumed to be the same as the incident projectile. If γ-rays are considered, the code G must be entered in REACTION SF7.

    (…(N,INL)…,,DA,G)   angular distribution of γ-rays from inelastic neutron scattering.

F: The particle considered is ambiguous and should be entered in REACTION SF7.

    (…(N,F),,DA,FF)   angular distribution of fission fragments.

X: The particle considered is assumed to be the particle (or nuclide) for which the production is measured. See **Production Cross Sections**.

Particles/Radiations Detected

Particles actually detected in the experiment may be identified using the keyword PART-DET (see EXFOR Manual, Chapter 8, PART-DET, for coding rules). This keyword should be used only in those cases where the particle detected is not obvious from the quantity given (see preceding).

If the particle detected may be attributed to the decay of a specific nucleus, it may be coded using the keyword RAD-DET (see EXFOR Chapter 8, RAD-DET, for coding rules). However, the keyword RAD-DET should not be used to duplicate information also coded under the keyword DECAY-DATA.

The particles detected in a monitor reaction should not be included under the keywords PART-DET or RAD-DET.

See Dictionary 13 for a list of permissible codes.

Distinguish the different codes:

    DG   - decay γ-rays
    G   - other γ-rays
    B-   - decay electrons (β^-)
    B+   - decay positrons (β^+)
    ICE   - internal conversion electrons
    E   - other electrons

Particle pairs

If the angle given is the angle between a secondary particle pair or a secondary energy (in c.m.) is given for a pair of particles emitted in the reaction, the particles are specified in SF7.

    Example: REACTION   (…(…,…)…,,DA,N/P) angular distribution of n-p pair.

                                    (…(…,…)…,,DE,P/A) energy spectrum on p-α pair.

Variable number of emitted nucleons.

When a mass or element distribution of product nuclei is given and their Z and/or A values act as independent variables, a variable sum of outgoing nucleons may be indicated in reaction SF3 using the process codes XN, YP or XN+YP. The numerical values of the multiplicity factors X and Y are entered in the DATA table under the data headings N-OUT and P-OUT, respectively. See EXFOR Manual, page 7.9.

This formulation is only permitted if all REACTION subfields except SF3 and SF4 remain unchanged.

This formulation should not be used for frequently occurring reactions such as (n,2n), otherwise, retrievals for such important reactions would become difficult. If data for only a few reactions are given, *e.g.*, (n,2n), (n,3n), *etc.*, the Multiple Reaction Formalism should be used instead (see **Multiple Reaction Formalism**).

Do not confuse the code XN with "neutron emission" (compare **Production Cross Sections**).

Undefined Reaction Channels.

In some cases a given residual nucleus may be produced by more than one reaction channel, *e.g.*, (p,α) and (p,2n2p), but only the residual nucleus has been investigated. If it is clear that more than one channel contributes (*e.g.*, for energies well above the threshold for (p,2n2p)), the process code X is entered in SF3 of the REACTION string. See **Production Cross Sections**.

Undefined/Defined Reaction Channels.[1] *(Obsolete?)*

In some cases a given residual nucleus may be produced by more than one reaction channel, *e.g.*, (p,) and (p,2n2p), but only the residual nucleus has been investigated. If it is clear that more than one channel contributes (*e.g.*, for energies well above the threshold for (p,2n2p)), the branch code UND (undefined reaction channel) should be given in reaction SF5. In this case, the particles coded in SF3 denote only the sum of emitted nucleons, implying that the product nucleus coded in SF4 has been formed via different reaction channels. The reaction is coded as given by the author or by giving only the emitted nucleons.

Example: (… (P,2N+2P) …,UND,SIG)

Where it is not clear whether the reaction channel is undefined or defined, the reaction is coded as specified by the author with the code (def) in SF5.

Examples: (…(P,A)…,(DEF),SIG)
                 (…(P,2N+2P)…,(DEF),SIG)

Where the reaction channel is unambiguously defined either by measuring the outgoing particles, or, due to theoretical considerations, the reaction is written as specified by the author and no special code is given in SF5; the codes UND and (DEF) are not used. Absence of these codes gives a positive indication that the reaction coded is defined with respect to the reaction channel and the outgoing particles coded in SF3.

Free text comments should explain any reasons not explicitly given in the publication, by which the reaction is proven to be defined.

The 'undefined' processes X and F are not combined with the branch code UND. In cases where an explicit specification of the number of outgoing nucleons is meaningless (*e.g.*, too many outgoing nucleons, spallation, *etc.*), the coding (...,X) should be used.

---

[1] This formalism is used *only* for charged-particle reaction data.

Pointers

A pointer is a numeric or alphabetic character used to link pieces of EXFOR information. (See EXFOR Manual Chapter 5 for details.)

Where feasible, the compiler may choose as pointers meaningful digits or characters. For example, when the pointers refer to an isomeric ratio and the partial isomeric cross sections leading to ground state and metastable states, the characters R, G and M, respectively, may be chosen as pointers. Or, when the pointers refer to the Legendre coefficient numbers 0., 2. and 4., the digits 0, 2 and 4 may be chosen.

Caution to Compilers: Since a pointer links the information given only to other information with the same pointer, or to information with no pointer, only one set of pointers may be used for each data set.

The following is an example of an illegal use of pointers.
```
BIB
REACTION     M(79-AU-197(N,G)79-AU-198-M,,SIG)
             G(79-AU-197(N,G)79-AU-198-G,,SIG)
MONITOR      1(29-CU-63(N,2N)29-CU-62,,SIG)
             2(29-CU-65(N,2N)29-CU-64,,SIG)
MONIT-REF    1(LISKIEN+,J,JNE,19,73,65)
             2(POLLEHN,J,ZN/A,16,227,61)
ENDBIB
```

(The monitor data is not linked to either reaction because the pointers are different.)

Pointers should be used carefully and only for those cases specified in the EXFOR Manual, Chapter 5.

Polarization[2] *(new)*

If the spins of a collection of particles, either stationary or in a beam, are oriented in all directions with equal probability, the assembly is said to be unpolarized. If the spins are predominantly oriented in one direction, the assembly is said to be polarized.

Under the influence of a spin-orbit force upon scattering from a target, an unpolarized beam of particles becomes polarized.
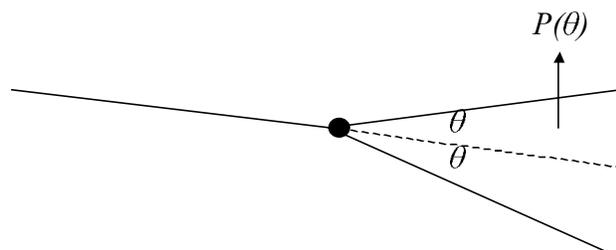
The inverse of this situation is the asymmetric scattering of a polarized beam of particles. The degree of polarization of such a beam may be determined by measuring the left-right asymmetry upon scattering from a target nucleus which plays the role of an analyzer.
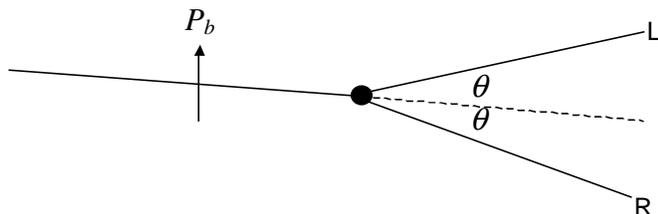
For elastic scattering from a spin-0 nucleus: the principle of *Polarization-Asymmetry Equality* states that, for time-reversal invariant reactions, the polarization induced in a previously completely unpolarized beam is identically equal to the asymmetry ensuing from the scattering of a perfectly polarized beam under the same conditions.

Conventions for quantities given in Cartesian coordinates

Basel Convention for spin-½ particles[3]

In nuclear reactions, the positive polarization of spin-½ particles is taken in the direction of the vector product $\vec{k}_{in} \times \vec{k}_{out}$ where $\vec{k}_{in}$ and $\vec{k}_{out}$ are the circular wave vectors of the incoming and outgoing particles.

---

[2] See [1970Ma].
[3] See [1960Hu].

Madison Convention for spin-1 particles; quantities given in Cartesian coordinates[4]

1. ***Polarization (P)***, the state of spin orientation of an assembly of particles, is referred to a right-handed coordinate system in which the positive z-axis is along the direction of momentum of the incident particles, and the positive y-axis along $\vec{k}_{in} \times \vec{k}_{out}$ (perpendicular to the beam direction in the reaction plane) for the nuclear reaction which the polarized particles initiate, or from which they emerge.

2. ***Analyzing power (A)*** is referred to a right-handed coordinate system in which the positive z-axis is along the direction of the incident beam, and the positive y-axis along $\vec{k}_{in} \times \vec{k}_{out}$ for the reaction.

   The cross section for a reaction initiated by polarized particles with spin-1 may be written in terms of Cartesian tensors as:

   $$\sigma = \sigma_0 \left[1 + \tfrac{3}{2} p_y A_y + \tfrac{1}{2} p_{zz} A_{zz} + \tfrac{2}{3} p_{xz} A_{xz} + \tfrac{1}{6} (p_{xx} - p_{yy})(A_{xx} - A_{yy}) \right]$$

3. In the expression for a nuclear reaction A(b,c)D, an arrow placed over the symbol denotes a particle in a polarized state.
   ***Example***: $A(\vec{b}, \vec{c})D$

Additional conventions

1. The following subscripts are defined:
   b   refers to the beam polarization
   t   refers to the target polarization
   ↑   spin up
   ↓   spin down
   i i^{th} component for beam   **k** k^{th} component for scattered particle
   j j^{th} component for target   **p** p^{th} component for recoil nucleus
   N=**n**=**y**   normal to the scattering plane
   L=**l**=**z**   longitudinal, *i.e.*, parallel to incident particle momentum in scattering plane
   S=**s**=**x** $N\times L$ (sideways), *i.e.*, perpendicular to particle momentum in scattering plane
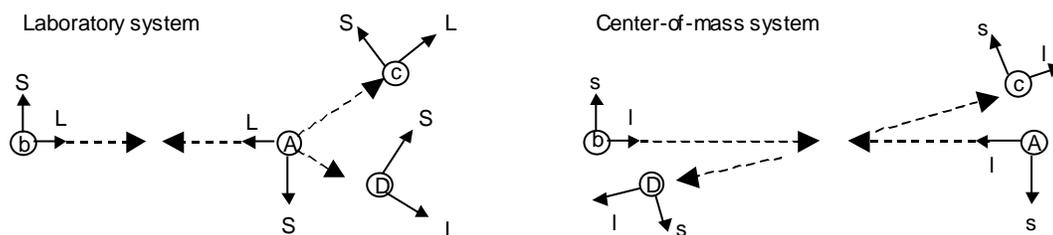
$\overline{N}$ and $\vec{n}$ are identical with direction out of page for all particles.

---

[4] See [1971Sa].

Occasionally, a 4-index notation is used; the order of the subscript in a 4-index notation is (i,j;k,p). A zero in a field denotes unpolarized or polarization not measured.

2. **Y** is the normalized yield.

3. σ_0 is the differential cross section for an unpolarized (spin-averaged) beam.

Quantities given in Cartesian coordinates and compiled in EXFOR

<u>**Polarization**</u>:refers to the degree of polarization of a single particle or ensemble.

$P_s(\theta)$ is the polarization of the outgoing particle beam as a function of angle.

where $\qquad \sigma_P = \sigma_0 P(\theta)$

REACTION Coding: `,POL/DA`

<u>**Asymmetry:**</u> Asymmetry is the relative difference between:

a.) the number of particles scattered to the right and to the left in the reaction plane.
$$\varepsilon = (L - R)/(L + R) = P_b A_y$$

where $\varepsilon = \qquad$ asymmetry
$\qquad P_{b =} \qquad$ incident beam polarization
$\qquad A_{y =} \qquad$ analyzing power of target
$\qquad L, R = \qquad$ intensity of particles scattered left and right in the same plane under the same angle.

REACTION coding: `POL/DA,,ASY`

b.) the angular distribution for incident projectiles with their polarization vectors
$$\varepsilon = \left(d\sigma_\perp - d\sigma_\parallel\right)\big/\left(d\sigma_\parallel + d\sigma_\perp\right)$$
perpendicular and parallel to the reaction plane.

REACTION coding: `,POL/DA,,ASY/PP`

If data are given as $(d\sigma_\parallel - d\sigma_\perp)/(d\sigma_\parallel + d\sigma_\perp)$, the negative of the value given is coded.

c.) the angular distribution for forward and backward scattered particles.
$$\varepsilon = \left(d\sigma_F - d\sigma_B\right)\big/\left(d\sigma_F + d\sigma_B\right)$$

REACTION Coding: `,POL/DA,,ASY/FB`

The angles are given as ANG1 and ANG2.

Analyzing Power: the relative difference in the cross sections for corresponding spin up vs. spin down.

Vector analyzing power (A_i or $A_{i,0;0,0}$ and A_j or $A_{0,j;0,0}$):

Coding: Modifier ANA in SF8**.**

> *Example***:**
>> ,POL/DA,,ANA   Analyzing power, A_n, incident projectile spin normal to scattering plane.

Tensor analyzing power (A_{ij} or $A_{i,j,0,0}$): initial spin state correlation parameters.

$$A_{yy} = A_{NN} = \varepsilon \Big/ \left|P_b\right|\left|P_t\right|$$

Coding: Modifier A in SF8, branch code in SF5 giving components of beam and target spin

> *Example***:**
>> NN,POL/DA,,ANA   Tensor analyzing power, A_{NN}, incident projectile and target spins normal to scattering plane.

Spin-Correlation Parameter (C_{kp} or $C_{0,0,k,p}$)**:** final spin state correlation parameters.

For spins in the scattering plane:

$$C_{kp} = \frac{d\sigma/d\Omega_{\uparrow\uparrow} + d\sigma/d\Omega_{\downarrow\downarrow} - d\sigma/d\Omega_{\uparrow\downarrow} - d\sigma/d\Omega_{\downarrow\uparrow}}{d\sigma/d\Omega_{\uparrow\uparrow} + d\sigma/d\Omega_{\downarrow\downarrow} + d\sigma/d\Omega_{\uparrow\downarrow} + d\sigma/d\Omega\downarrow\uparrow} = \frac{1}{p_b P_t}\frac{Y_{\uparrow\uparrow} + Y_{\downarrow\downarrow} - Y_{\uparrow\downarrow} - Y_{\downarrow\uparrow}}{Y_{\uparrow\uparrow} + Y_{\downarrow\downarrow} + Y_{\uparrow\downarrow} + Y_{\downarrow\uparrow}}$$
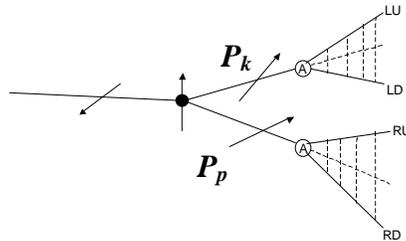
For spins normal to the scattering plane:

$$C_{NN} = \frac{1}{p_b P_t}\frac{(LL)(RL) + (LR)(RR) - (LL)(RR) - (LR)(RL)}{(LL)(RL) + (LR)(RR) + (LL)(RR) + (LR)(RL)}$$
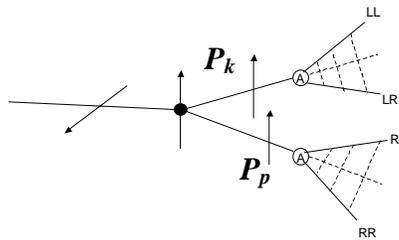
REACTION Coding: Modifier `C` in SF8, branch code in SF5 giving components of beam and target spin.

> ***Example:*** `LL,POL/DA,,C` C_{LL}, spin correlation function, outgoing particle and recoil nucleus spins parallel to beam direction in scattering plane

If time reversal holds: $C_{NN} = A_{NN}$

Spin-Rotation-Depolarization Parameters (D_{ik} or $D_{i,0,k,0}$ for incident beam and D_{jp} or $D_{0,j,0,p}$ for target)

The spin-rotation parameter is a measure of the rotation of the spin of the scattered beam. The three orthogonal components of the outgoing particle polarization are related to the components of the incident particle polarization through the set of spin-rotation parameters.

These parameters are related to the Wolfensein [1956Wo] parameters as follows:

	Wolfenstein Parameter	Representation	
$D_{NN} =$	D		$\otimes$ signifies normal to the scattering plane
$D_{SS} =$	R		
$D_{LS} =$	R′		
$D_{SL} =$	A		
$D_{LL} =$	A′		
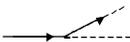
D_{NN} is also known as the **Spin-Depolarization Parameter**

REACTION Coding: Modifier `D` in SF8, branch code in SF5 giving components of beam and target spin.

> ***Example:***
>
> `LL,POL/DA,,D`   Spin-Rotation Parameter D_{LL}, beam and scattered particle spins parallel to beam direction in scattering plane.
>
> `LL,POL/DA,*,D`   Spin-Rotation Parameter D_{LL}, target and recoil nucleus spins parallel to beam direction in scattering plane.

Spin-flip probability (S_{nn})

REACTION coding: `POL/DA,,SF`

The Spin-Flip Probability is related to the spin depolarization parameter by: $S_{flip} = \frac{1}{2}(1 - D_{NN})$.

Spin-Rotation Function (SRF or Q): gives the coupling between the longitudinal component of the beam polarization and the component of the outgoing particle spin perpendicular to the beam direction.

$$Q = \sqrt{1 - P^2} \sin \beta$$

where β is the angle through which the projection of the polarization upon the scattering plane is rotated.

For spin-0 particles:

$$Q = A \cos \theta_{lab} + R \sin \theta_{lab} = D_{SL} \cos \theta_{lab} + D_{SS} \cos \theta_{lab}$$

REACTION coding: `POL/DA,,SRF`

Spin-Transfer Parameter (K_{ip} for incident beam and K_{jk} for target)
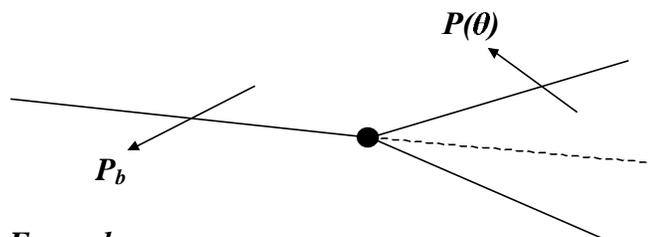
Coding Example:

`NN,POL/DA,,K`   **K_{NN},** spin transfer parameter, incoming particle and recoil nucleus spins normal to scattering plane

`LL,POL/DA,*,K`   **K_{NN},** spin transfer parameter, target nucleus and outgoing particle spins longitudinal in scattering plane

The spin-transfer parameter is related to the spin-rotation parameter by: $D_{ij}(\theta) = K_{ij}(\pi - \theta)$.

Quantities given in Spherical Coordinates

Madison convention for spin-1 particles quantities given in spherical coordinates[5]

The following subscripts are defined:
k refers to the rank
q refers to the projection

For particles of spin ≥ 1, the polarization may be described in terms of tensor quantities of integer rank $k \geq 2i$: $0 \leq |q| \leq k$.

The differential cross section for a reaction initiated by a beam with tensor components t_{kq} is

$$\sigma = \sigma_0 \left(\sum_{k,q} t_{kq} T_{kq}^* \right)$$

If parity is conserved, $T_{10}=0$, T_{11} is pure imaginary, and T_{2q} is pure real; the cross section may be written as

$$\sigma = \sigma_0 \left[1 + 2iT_{11} \operatorname{Re}(t_{11}) + T_{20} t_{20} + 2T_{21} \operatorname{Re}(t_{21}) + 2T_{22} \operatorname{Re}(t_{22}) \right]$$

Polarization (t_{kq})
(Not presently compiled).

Analyzing Power (T_{kq})

Vector analyzing power (iT_{11})

Coding: quantity code VAP in SF6

Example: POL/DA,,VAP

Tensor analyzing power (T_{20}, T_{21}, T_{22})

Coding: quantity code TAP in SF6; k and q are specified under the branch field using the codes 20, 21, and 22.

Example: 20,POL/DA,,TAP

---

[5] See [1971Sa].

Associated Information

Polarized beam specification

For a polarized incident neutron beam, enter the code `POLNS` under the keyword `INC-SOURCE`; for a polarized ion beam, enter `POLIS`. If the incident source is known, it should follow in the same set of parenthesis.

> *Example*; `INC-SOURCE    (POLNS,D-T)`

Atomic beam and Lamb-shift sources are entered using the codes `ATOMI` and `LAMB`, respectively.

Polarized target specification

For a polarized target, enter the code `POLTR` under the keyword `INC-SOURCE`.

The polarization of the incident beam and target should be given in the data table, if known, using the data headings `POL-BM` and `POL-TR`, respectively. The numerical uncertainties are entered using the headings `POL-BM-ERR` and `POL-TR-ERR`; an explanation may be given in free text under `ERR-ANALYS` (see EXFOR 8.10).

REFERENCES

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1970Ma   P. Marmier and E. Sheldon, **Physics of Nuclei and Particles**, (Academic Press, NY, 1970) Vol. II, Ch. 13.

1971Sa   G. R. Satchler et al., **Polarization Phenomena in Nuclear Reactions** (The University of Wisconsin Press, Madison, WI, 1971) pp. xxv-xxix; see also S. E. Darden, pp. 39-56.

1972Oh   G. G. Ohlsen, *Polarization transfer and spin correlation experiments in nuclear physics*, **Rev. Prog. Phys. 35**,(1972) 717-801.

1978As   J. Ashkin et al., *Convention for spin parameters in high energy scattering experiments*, **Higher Energy Polarized Proton Beams** (American Institute of Physics, 1978).

1981Oh   D. Crabb, *Spin correlation measurements in nucleon-nucleon scattering at high energy*, **Polarization Phenomena in Nuclear Physics - 1980**, (American Institute of Physics, 1981).

Product Yields

Independent and cumulative yields

The formation of the residual nucleus may sometimes occur:
- by direct (independent formation), and/or
- via isomeric transition, and/or
- via radioactive decay from other nuclides.

For <u>fission yields and isotope production</u>, the following codes are used to distinguish which of these processes are measured.

In general, the branch codes IND and CUM should be used only for production reactions (*i.e.*, with the process codes F and X). For specific processes, *e.g.*, (d,np), the codes CUM and IND are not used, however, the codes M+ and (M) are used for partial feeding from an metastable state.

Branch Code	Definition
IND	Data is given for <u>independent formation</u> of the product nucleus. To be used only when formation via radioactive decay from other nuclides is possible and it is clearly specified by the author that it is excluded.
CUM	Data given for reaction <u>includes</u> the formation via radioactive decay and isomeric transition.
(CUM)	Data given for reaction is <u>assumed by the compiler</u> to include the formation via radioactive decay from other nuclides, but no definitive statement is made by the author.
M+	Data given for isomeric state specified <u>includes</u> the formation by **partial** feeding via isomeric transition from a metastable state of higher excitation energy. (See also **Isomeric States**).
M-[6]	Data given for isomeric state specified <u>excludes</u> the formation by **partial** feeding via isomeric transition from a metastable state of higher excitation energy.
(M)	Data given for reaction is <u>assumed by the compiler</u> to include the formation via radioactive decay, but no definitive statement is made by the author.

Examples:

`REACTION`   `(92-U-235(N,F)56-BA-140,IND,FY)` Independent formation only.

`REACTION`   `(50-SN-0(P,X)21-SC-44-M,,TTY)` Independent formation of 5.6-hr ^{44}Sc (nucleus is shielded from formation by radioactive decay).

`REACTION`   `(42-MO-0(P,X)27-CO-62-G,CUM/M+,SIG)` Includes formation via decay of 68-sec. ^{62}Fe, and partial feeding from 13.91-min. isomer.

`REACTION`   `(42-MO-0(P,X)27-CO-62-G,CUM/M-,SIG)` Includes formation via decay of 68-sec. ^{62}Fe, but excludes partial feeding from 13.91-min. isomer.

---

[6] To be combined only with the code CUM.

Production Cross Sections

Definition: The **production cross section** for a particle Y is defined as the sum of all energetically possible reactions resulting in the production of at least one particle Y in the exit channels, each reaction weighted by the multiplicity of particle Y. The interactions involved and their multiplicity need not be known.

The term **emission cross section** is defined as a special case and excludes elastic scattering. Where the incident projectile is not equal to Y, the production and emission cross sections are equal.

These quantities are sum cross sections, which should be used only when two or more reactions producing particle Y are energetically possible.

Sum rules: neutron production   = neutron emission + elastic

neutron emission   = (n,n') + 2(n,2n) + 3(n,3n) + (n,np)……+ $\bar{\nu}$ (n,f)

REACTION Coding:
  Production cross section: code X in SF3 (Process).
  Emission cross section: code X in SF3, code EM in SF5 (Branch).

The product measured is coded either in reaction SF4, or as a variable in the data table (see EXFOR page 6.6, Variable Nucleus).

For inelastic gamma emission, see **Inelastic Scattering**.

Examples:
  `(…(P,X)0-G-0,,SIG)`   proton-induced gamma-production cross section
  `(…(N,X)0-NN-1,EM,SIG)`   neutron-induced neutron emission cross section
  `(…(N,X)ELEM/MASS,,SIG)`   neutron-induced isotope production cross section

For isotope production on a natural target, the reaction is coded:
  `(Z-S-0(…,X)Z'-S'-A',,SIG)`
  `(Z-S-A(…,X)Z'-S'-A',,SIG,,A)`   if only one reaction is possible.

Unweighted production cross section.   Sometimes the arithmetic sum of all reactions resulting in the production of one or more outgoing particles Y is given without weighting by the multiplicity of Y.

If only a few reactions are contributing in the energy range measured, the quantity can be given as an explicit sum of these reactions. However, if more than 2-3 reactions contribute, the data are coded as a production cross section with the branch code UNW in SF5.

Example: `(…(G,X)0-NN-1,UNW,SIG)`   = (γ,n) + (γ,2n) + (γ,np) + (γ,3n) + *Products*

Products

Products of 2 or more reactions can be expressed as a reaction combination using the separator   (see EXFOR Manual, page 7.6.)

Example:
```
REACTION        ((42-MO-98(N,TOT),,WID)•(42-MO-98(N,EL),,WID))
```

Products implicit in the quantity codes

For certain products which can be measured directly, or are frequently used, special quantities have been introduced. The following factors are coded using special codes in reaction SF8 (modifier):

S0	σ_0 (peak cross section at resonance)
A, (A)	a (isotopic abundance); (A) = uncertain if multiplied by abundance (see **General Quantity Modifiers**)
G,AG,2G,2AG,4AG	g,ag,2g,2ag,4ag (g = statistical weight factor)
RTE	$\sqrt{E}$
4PI	4π
SQ	$(\ldots)^2$
RS	$4\pi/\sigma_{el}$
FCT	factor to be defined in free text (see **General Quantity Modifiers**)

(See also **Fitting Coefficients**).

Quantum Numbers

Resonance levels in compound nuclei

Momentum l   orbital angular momentum of neutrons exciting a compound-nucleus resonance

Resonance spin J   total spin value of the compound-nucleus resonance

Parity π parity of a compound-nucleus resonance

Statistical weight g   statistical weight of a compound-nucleus resonance:

$$\frac{(2J+1)}{(2i+1)(2I+1)}$$

where i = spin of incident projectile
           I = spin of target nucleus

These quantum numbers can be entered in two different ways:

1. Frequently such quantum numbers are assumed as parameters of strength functions, reduced neutron width, or other quantities. Then they are entered as parameters in an additional field of the data table, either in the COMMON or in the DATA section, under the data headings: MOMENTUM L, SPIN J, PARITY, STAT-W G.

Example:
```
DATA
MOMENTUM L  SPIN J      PARITY       STAT-W G DATA
NO-DIM      NO-DIM      NO-DIM       NO-DIM   MILLI-EV
 1.0         0.5        -1.0          1.5     …
 …
ENDDATA
```

2. If the quantum number is the result of the resonance parameter analysis, one of the following   reaction codes is used:

```
(…(N,0),,L)
(…(N,0),,J)
(…(N,0),,PTY)
(…(N,0),,SWG)
```

In this case the data are entered into the data table under the data heading DATA, and the data unit NO-DIM.

Quantum numbers, when entered in the DATA table, should be entered with the decimal point (in the case of parity as 1. or -1.).

The statistical weight factor may also be used as modifier in the quantity code (see **Products**).

Excited states in product nuclei

When an excited state is defined in a reference by its quantum numbers:

    spin J   the spin value of a level in a product nucleus,

    parity π the parity of a level in a product nucleus,

these quantum numbers may be entered in the BIB section under the keyword LEVEL-PROP to define the level for which the data are measured. These properties may be associated with specific data lines through in one of the following ways.

1. Through the level energy (which may be assigned by the compiler).
   Example:
   ```
   BIB
   LEVEL-PROP  (26-FE-56,E-LVL=0.845,SPIN=2.,PARITY=+1.)
               (26-FE-56,E-LVL=2.085,SPIN=4.,PARITY=+1.)
   ENDBIB
   NOCOMMON
   DATA
   EN          E-LVL       DATA
   MEV         MEV         MB
    1.          0.845      …
    1.          2.085      …
    2.          0.845      …
   ENDDATA
   ```

2. Through the level number (which may be assigned by the compiler).
   Example:
   ```
   BIB
   LEVEL-PROP  (26-FE-56,LVL-NUMB=1.,SPIN=2.,PARITY=+1.)
               (26-FE-56,LVL-NUMB=2.,SPIN=4.,PARITY=+1.)
   ENDBIB
   NOCOMMON
   DATA
   EN          LVL-NUMB    DATA
   MEV         NO-DIM      MB
    1.          1.         …
    2.          1.         …
    1.          2.         …
   ENDDATA
   ```

3. Using flags.
   Example:
   ```
   BIB
   LEVEL-PROP  ((1.)26-FE-56,,SPIN=2.,PARITY=+1.)
               ((2.)26-FE-56,,SPIN=4.,PARITY=+1.)
   ENDBIB
   NOCOMMON
   DATA
   EN          DATA        LVL-FLAG
   MEV         MB          NO-DIM
    1.          …           1.
    1.          …           2.
    2.          …           1.
   ENDDATA
   ```

See EXFOR Manual Chapter 8, LEVEL-PROP.

Ratios

Ratios of 2 or more reactions can be expressed as a reaction combination using the separator '/' (see EXFOR Manual, page 7.6).

> **Units**: NO-DIM

> *Example*:   `((3-LI-6(N,T)2-HE-4,,SIG)/(92-U-235(N,F),,SIG))`

Ratio of reactions with different independent variables. In the case where the numerator and denominator of the reaction ratio refer to different values for one or more of the independent variables, the separator '//' is used. The independent variables that differ are coded in the data table using data headings with the extension -NM and -DN for the numerator and denominator, respectively.

Example:
```
REACTION    ((13-AL-27(N,INL)13-AL-27,PAR,SIG)//
            (13-AL-27(N,INL)13-AL-27,PAR,SIG))
 …
COMMON
E-LVL-NM    E-LVL-DN
MEV         MEV
…
ENDCOMMON
```

Ratios implicit in the quantity codes.

For certain frequently used ratios, special quantity codes have been introduced.
>   ALF (SF6) = capture-to-fission ratio (see Alpha)
>   ETA (SF6) = average neutron yield/nonelastic event (see Neutron Yield)
>   RS (SF8) = 4π/elastic scattering cross section

Isomeric Ratios are coded using the separator '/' in the isomer field of the reaction product (SF4), and with the modifier rat in SF6. (See **Isomeric States**.)

REACTION Parameter Code RAT

The code RAT in reaction SF6 is given for, and only for
- isomeric ratios, *i.e.*, when the separator '/' appears in the isomer extension of the reaction product (see above).
- binary to ternary fission ratios, *i.e.*, when SF5 contains the codes TER/BIN or BIN/TER.

Raw Data

Definition: "Raw" data are experimental data that are not yet reduced to the final form but still contain, for example, contributions from detector efficiency, instrumental resolution, or sample thickness.

Although such data are of little use to usual data center customers, it has been recognized that "raw" data should be stored by the data centers. Such data would then be available:
- for re-analysis when improvements in analysis techniques are made
- for realistic assessments of data errors as they become increasingly important to evaluators.[1]

The following types of "raw" data have been encountered to date:

1. transmissions: $\left\langle e^{-n\sigma_T} \right\rangle = 1 - n\left\langle \overline{\sigma_T} \right\rangle + \frac{1}{2}n^2\left\langle \overline{\sigma_T^2} \right\rangle$

2. reaction yields: $\left\langle y_r \right\rangle = \left\langle \left(1 - e^{-n\overline{\sigma_T}}\right)\frac{\overline{\sigma_r}}{\overline{\sigma_T}} + \sum_{i=1}^{\infty} y_{r,i} \right\rangle$

   where: $\langle \ldots \rangle$ denotes resolution broadening
            n is the sample thickness in nuclei/barn
            σ_T and σ_r are the Doppler-broadened, abundance-weighted total and partial reaction cross sections, respectively
            $y_{r,i}$ is the reaction yield from neutrons scattered i times before inducing the reaction of type r, *e.g.*, fission, scattering or radiative capture.

Note that the following simple relationship with the (broadened) cross section exists for thin samples $\left(n\langle \sigma_T \rangle << 1 \right)$:

$$-\frac{1}{n}\ln\left\langle e^{-n\sigma_T} \right\rangle \cong \left\langle \overline{\sigma_T} \right\rangle; \quad \frac{1}{n}\left\langle y_r \right\rangle \cong \left\langle \overline{\sigma_r} \right\rangle$$

Data may be given as *counts* or as uncorrected cross sections in barns.

Additional data types may be added as they are encountered.

The data may be transmitted in EXFOR using the modifier RAW in *reaction* SF8; it should always be explained in free text.

Voluminous files of "raw" data may be stored on special archival tapes. An EXFOR entry is then transmitted, using the keyword STATUS to give a cross-reference to the special archival file, the approximate number of data records, and information on how to request the data. If appropriate, a warning should be given in free text that the raw data should be used only after consultation with the author.

The BIB section of the entry should be prepared as usual, containing at least the obligatory keywords (see EXFOR Manual, page 8.2). A data subentry should be included for each set

---

[1] See recommendation by the NEANDC/NEACRP meeting on neutron data for structural materials, Geel, December 1977.

of raw data stored. The BIB section should include, at minimum, the reaction. The COMMON section should contain minimum and maximum of the incident-projectile energy. The system identifier NODATA replaces the DATA section (see EXFOR Manual, page 2.4).

Reaction Mechanisms

Definitions: An author may assign fractions of a measured cross section to different reaction mechanisms. The following reaction mechanisms are defined, based on currently accepted nuclear models, and may be entered into EXFOR in the manner described on the following pages.

1. Compound-Nucleus Interaction: A reaction in which the incident projectile is absorbed by the target nucleus and its initial energy is assumed to be shared by all other nucleons, such that the mode of disintegration of the "compound nucleus" is independent of the way in which it was produced.

2. Direct Interaction: A reaction in which there is direct interaction between the incident projectile and single nucleons or clusters of nucleons in the target.

3. Spallation: A reaction where several particles are ejected from the target nucleus by direct interaction leaving behind a nucleus in an excited state which then evaporates nucleons or clusters of nucleons.

4. High-energy Fission (Energies > about 50 MeV): proceeds in essentially the same manner as spallation except that the excited nucleus divides into roughly two fragments.

   See **Fission** for fission process at lower energies.

Data Specification

1. **Compound-Nucleus Interaction and Direct Interaction**: Some reactions may proceed by either mechanism, in which case the total reaction is equal to the sum of the compound-nucleus interaction and direct interaction portions. In this case, the partial cross sections for the compound-nucleus interaction and direct interaction portions of a reaction may be coded with the modifiers CN and DI, respectively, in SF5 (branch) for the keyword reaction[2].

   Examples:
`(…(N,P),CN,SIG)`	Compound nucleus portion of (n,p) cross section
`(…(N,P),DI,SIG)`	Direct interaction portion of (n,p) cross section

   These partial cross sections cannot be measured directly but are deduced from theoretical considerations. Therefore, careful explanation in free text is required whenever these modifiers are used.

---

[2] If the reaction proceeds totally through direct interaction, then the modifier DI is not used.

2. **Spallation and High-energy Fission**[3]

The breakup of a nucleus at high energies may, in some cases, proceed by either mode. In this case, the partial quantity for fission or spallation may be coded under the keyword reaction using the branch codes spl and fis, respectively, in SF5.

Examples:

    `(6-C-12(P,X),SPL,SIG)`   Spallation cross section
    `(6-C-12(P,X),FIS,SIG)`   High-energy fission cross section

For the production of specified product nuclei see **Product Yields**.

3. **High-energy and Low-energy Components of Cross Section**

The higher and lower components of the "configurational splitting" of the giant dipole resonance include the sum of the cross sections for a number of different reactions with different outgoing particle energies. These data are often presented in evaluations as a "high-energy" and "low-energy" component of the secondary particle spectrum.

The "high-energy component is due to the nucleon transitions from the lower filled shells of the nucleus to unfilled valence shells. The "low-energy" component is due to the nucleon transitions from the unfilled valence shell of the nucleus to various empty upper shells. The difference between the centers-of-gravity of two such components defines the energy value for the configurational splitting.

In this case, the partial quantity for these components may be coded under the keyword REACTION using the branch codes HEN and LEN in SF5. The contributing reactions may be defined in free text.

Examples:

    `(…(G,ABS),HEN,SIG)` High-energy component of photo-absorption cross section
    `(…(G,ABS),LEN,SIG)` Low-energy component of photo-absorption cross section

---

[3] If the author measures the total break-up or production of a given product and states that this reaction is totally due to spallation or to fission, then the codes SPL or FIS must not be given because these designate *partial* reactions.

Reaction Product

Definition: In general, the heaviest of all identifiable products of the reaction specified is defined as the Reaction Product (also called the residual nucleus) and is entered into SF4 of the reaction keyword. See EXFOR Manual, page 7.4 for a complete discussion of the use of the Reaction Product subfield.

Coding

For coding rules, see EXFOR Manual, page 7.4.

If no isomer code is given, then the reaction is to a nucleus in the ground state and includes decays from isomeric states. If an isomer code is given, a partial reaction for the formation of that isomeric state is given, and, in general, decays from higher isomeric states are not included.

In the case of **product yield data** for which the reaction specified may lead to the production of more than one reaction product, the *Variable Nucleus Formalism* may be used (see EXFOR Manual, page 7.8).

A description of the decay information about the reaction product may be given using the information-identifier keyword DECAY-DATA (see **Decay Data**). This information should always be given, where known, for an activation measurement or for a nucleus in an isomeric state.

Reference

Information-Identifer Keyword REFERENCE. All bibliographic references which contain information of importance directly relating to the data compiled in EXFOR, *i.e.*, not only the reference from which the data were taken, but also other important references, such as journal articles, conference papers, and laboratory reports may be coded under the keyword REFERENCE. Progress reports and abstracts should, in general, be excluded, if they contain no additional useful information.

Other related references must not be coded under this keyword, but may be coded under the keywords REL-REF or MONIT-REF (see following page).

For the coding rules see EXFOR Manual Chapter 8, REL-REF and MONIT-REF.

The purpose of the bibliography is
> to help compilers:
> - avoid duplicate entry of data in EXFOR,
> - identify a data set when data are requested by reference;
> to help users of EXFOR:
> - get easy access to any additional information available in the published references,
> - check whether a given reference has been considered by the compiler.

Therefore, the free text should indicate to users of EXFOR:
- the main reference.
- the kind of information contained in each reference given, *e.g.*, "instrumentation only", "graphs   only", "no data", "theoretical analysis", *etc*.

When *translations* of references exist, these should be included also, for the convenience of users of EXFOR.

Important references which are *published after the first compilation* of the EXFOR entry, should be added subsequently and the entry retransmitted as specified in EXFOR Manual Chapter 9. Usually such a new reference will provide additional information on the experiment or the numerical data, which should be added and retransmitted simultaneously.

When referencing a document that has more than one document code, the primary code (*i.e.*, the document code assigned by the originating laboratory) should be given first, in most cases. The main exceptions are reports issued by advisory committees where the agency-assigned number is the primary report number.

Private Communications If data are received via a private communication, the correspondent and the date of the private communication may be entered as a reference (see EXFOR Manual Chapter 8, REFERENCE) or under the information-identifier keyword STATUS.

Conferences. If conference proceedings are issued within a report series, so that they can be identified with a report number, then the report number must be used, not the conference code.

Example: The proceedings of the standards panel 67BRUSSELS were issued as report IAEA-107. In this case, the code 67BRUSSELS is not used.

Paper Number. If two or more papers start on the same page of a given reference, they should be differentiated in the paper number field. If no paper number is given, the papers should be numbered sequentially.

Example:

```
(J,PR,104,482(1),5612)   first paper on page 482 of Phys. Rev., 104
(J,PR,104,482(2),5612)   second paper on page 482 of Phys. Rev., 104
```

Information-Identifier Keyword REL-REF. A reference relating to, but not directly pertaining to the data given, may be entered under REL-REF. Examples are: critical remarks or corrections applied by another author, *e.g.*, within a data review or evaluation. (See EXFOR Manual Chapter 8, REL-REF, for coding rules.)

Information-Identifier Keyword MONIT-REF. References from which the standard (or monitor) data used in the experiment were taken are coded under MONIT-REF. (See EXFOR Manual Chapter 8, MONIT-REF for coding rules.)

Resolution

Incident-projectile Energy Resolution: the energy spread or channel width (or a combination) of the incident projectile.

The energy resolution describes the distribution curve of the energy spread. It is usually defined as full-width at half-maximum (FWHM), but may be given in other representations. The shape and definition of the resolution function should be given in free text under INC-SPECT, if known.

Resolution is coded using the following data headings:

EN-RSL-FW	Incident-particle energy resolution (FWHM)
EN-RSL-HW	Incident-particle energy resolution (±HWHM)
EN-RSL	Incident-particle energy resolution (unspecified)

The energy resolution can be given in energy units, in percent, or in units of a reciprocal velocity (*e.g.*, NSEC/M).

Example:
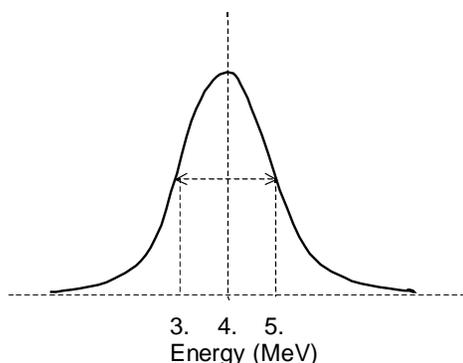
EN-RSL-FW: Energy resolution = 2 MeV

EN-RSL-HW: Energy = 4. + 1. MeV

3.   4.   5.
Energy (MeV)

Note: The terms resolution and error are often misused in the literature. Distinguish between them, where possible. See **Errors**.

Secondary-energy resolution: the energy spread of an outgoing (secondary) particle (see **Secondary Particles**).

Angular resolution: the angular spread of an outgoing (secondary) particle (see **Angle**)

Resonance Integral

Definition: Index of epithermal reaction by a material in a reactor flux.

REACTION coding: RI in SF6 (Parameter)

  Example: `(…(N,ABS),,RI)`

The energy limits are specified under the data headings EN-MIN and EN-MAX.

Infinitely dilute resonance integrals for a 1/E spectrum are defined as:

$$I_r = \int_{E_c}^{\infty} \sigma_r(E) \frac{dE}{E}$$

  where E_c = cutoff energy near the lower limit of the epithermal region.

These are usually measured as cadmium ratios where E_{Cd} is the cadmium cutoff energy which is dependent on the thickness of the cadmium cover.

In some cases, an upper limit is given for the energy (*e.g.*, 10 MeV) and should be coded. When an upper limit is not given, en-max may be omitted.

For further details, see Baumann [1] and Scoville [2].

Resonance integrals over smaller energy ranges, where the sum over the partial energy ranges given from the cutoff energy to the maximum energy is equal to the total resonance integral, should be coded with the quantity modifier LIM in reaction SF8.

Reduced resonance integrals, where the 1/v part has been subtracted, should be coded with the quantity modifier RNV in reaction SF8.

Resonance integrals calculated from resonance parameters should be entered using the code DERIV in reaction SF9 (data type). See also **Data Type**.

Effective Resonance Energies. The 'ideal' resonance integral is defined for an epithermal flux as being proportional to 1/E. This is an approximation that may be sufficiently accurate only in certain cases. Directly measured resonance integrals and those computed from cross-section curves assuming a 1/E flux are often discrepant due to the fact that realistic epithermal fluxes deviate from the 1/E shape.

Ryves has developed a better approximation, which is sufficiently accurate for most applications, in which the epithermal part of the reactor neutron spectrum is proportional to $1/E^{1+\alpha}$.

Accordingly, the realistic resonance integral is defined as:

$$I(\alpha) = \int_0^\infty \frac{\sigma(E)dE/eV}{\left(E_c/eV\right)^{1+\alpha}}$$

where α =   a constant close to zero (either positive or negative) which can be determined for each reactor spectrum

         E_c =   cutoff energy near the lower limit of the epithermal

For $\alpha = 0$ this formula goes to the ideal infinite dilute resonance integral.

The realistic resonance integral and the 'ideal' resonance integral are related by:

where σ_0 =   2200 m/sec cross section

         E_r =   effective resonance energy

The effective resonance energy is a microscopic nuclear constant representing a kind of average over the major resonances. It is tabulated in the literature and can be determined by experiment and evaluation.

Note: For (n,γ) activation analysis, the effective resonance energy is needed as a correction factor of similar importance to the resonance integral. Its value need not be known with high accuracy; a 50% uncertainty in the effective resonance energy may lead to a 1% uncertainty in activation analysis measurements; whereas, ignoring the parameter α may lead to a 25% error in the measurements.

When directly measured resonance-integral data are compiled in EXFOR, it is essential
- to give all available information on the epithermal neutron spectrum and to quote the α parameter if given
- to state whether the resonance integral given is for the realistic epithermal neutron spectrum, or whether appropriate corrections have been applied so that the value given is for the ideal epithermal 1/E spectrum.
-

For further information see Ryves [3], Simonits [4], jovanovic [5].

References
[1.] N. P. Baumann, *Resonance integrals and self-shielding factors for detector foils*, duPont Savannah River Laboratory report **DP-817** (1963)
[2.] J. J. Scoville and J. W. Rogers, *Topical report: resonance integrals measured in the advanced reactivity measurements facilities*, Idaho Nuclear Corporation report **IN-1195** (1968)
[3.] T. B. Ryves, *A New Thermal Flux Convention*, **Metrologia 5**, 119 (1969)
[4.] A. Simonits, F. deCorte, L. Moens, J. Hoste, **J. Radioanal. Chem. 72**, 209 (1982); see page 215.
[5.] S. Jovanovic, F. deCorte, L. Moens, A. Simonits, J. Hoste, **J. Radioanal. Chem. 82**#2, 379 (1984).

Sample

Properties of the sample used in the experiment are coded, in general, as free text under the Information-Identifier Keyword SAMPLE. Information on chemical composition, sample thickness, isotopic composition, *etc.*, should be entered if known. Sample thickness and sample temperature may alternately be entered into the data tables.

Sample Thickness

In the case of sample thickness, especially if data are measured for more than one thickness, the sample thickness may be entered into the data section using the heading THICKNESS.

Example:
```
DATA
EN          DATA        THICKNESS
MEV         B           ATOMS/B
...         ...         ...
ENDDATA
```

Sample temperature

At low energies, the data may be dependent on the temperature of the sample. In this case, the data should be coded using the parameter code TMP in REACTION SF6. The sample temperature is coded in the data section under the Heading TEMP.

Example:
```
BIB
REACTION
(1-H-1(N,TOT),,SIG/TMP)
...
ENDBIB
COMMON
TEMP
K
300.
ENDCOMMON
DATA
EN          DATA        DATA-ERR
...         ...         ...
ENDDATA
```

Scattering

(See also **Differential Data, Thermal Scattering**).

Definition: Two-body interaction with only one particle, which is the same as the incident particle, in the exit channel.

The following scattering processes are defined:

1. **Total Scattering.** The sum of all scattering interactions.

    Sum Rule: Total scattering   = elastic scattering plus inelastic scattering
        = total minus absorption

    REACTION Coding: SCT in SF3 (Process).

    Example: (.....(P,SCT)...,,SIG)
      alternately: (....(P,P)...,,SIG)   for use only when the scattering type need not be distinguished.

Note: In some experiments (*e.g.*, Lane[1]), the data may be called scattering even though they extend above a threshold where other reactions producing the scattered particle are also possible. Whether such data have to be corrected for the effects of such threshold reactions should be specified. If they were not, the quantity should be coded as neutron production.

2. **Elastic Scattering**. Scattering without excitation of the scattering nucleus (Q=O).

    REACTION Coding: EL in SF3 (Process).

    Example: (...(N,EL)...,,DA)

3. **Inelastic Scattering**. Two-body interaction in which the incident projectile re-emerges with an energy less than its' initial energy by the amount of energy deposited in the target nucleus (Q<O). The residual nucleus is left in an excited state which then decays, primarily, by γ-ray emission.

    Method of Measurement. Inelastic scattering may be measured by detecting the inelastically scattered particle or by detecting the de-excitation γ radiation. Due to γ-ray cascades, the production of a specific γ-ray may differ from the excitation of its state of origin. They will be equal, however, if γ-ray cascades to and from the level can be excluded.

    REACTION Coding: INL in SF3 (Process).

    For inelastic γ emission, G is coded in SF7 (Particle considered).

    For partial reactions due to the excitation of a discrete level or the production of a specific γ ray, the code PAR is entered into SF5 (Branch).

---

[1] Lane,et al., Phys. Rev. 107, 1077 (1957).

For the excitation of a discrete level or group of levels, the level energy or excitation energy must be given under the data heading E-LVL or E-EXC.

For the production of a discrete inelastic scattering cascade γ or range of γ's, the γ-ray energy must be given under the data heading E.

See EXFOR 5.3 for the coding of two or more unresolved levels.

Examples:

`(...(..,INL)...,,SIG)`	total inelastic-scattering cross section
`(...(..,INL)...,,SIG,G)`	total inelastic γ-emission cross section (= inelastic-scattering cross section)
`(...(..,INL)...,PAR,SIG)`	partial inelastic-scattering cross section for the excitation of a discrete level or range of levels
`(...(..,INL)...,PAR,SIG,G)`	partial cross section for the production of a discrete inelastic γ or range of γ's
`(...(..,INL)...,,DA)`	angular distribution of inelastically scattered particles
`(...(..,INL)...,,DA,G)`	angular distribution of inelastic γ's
`(...(..,INL)...,,DE)`	energy distribution of inelastically scattered particles
`(...(..,INL)...,,DE,G)`	energy spectrum of inelastic γ's
`(...(..,INL)...,,DA/DE)`	double differential inelastic-scattering cross section
`(...(..,INL+F)...,,SIG)`	inelastic-scattering cross section to a fission isomer

4. **Potential Scattering**. Elastic scattering which proceeds without the formation of an intermediate nucleus. (Elastic scattering is a mixture of potential and resonance scattering.)

   REACTION Coding: POT in SF5 (Branch).

   Example: `(...(N,EL)...,POT,SIG)`

5. **Thermal Scattering**. Low energy scattering processes for which molecular and crystalline
forces are involved. See **Thermal-Neutron Scattering**.

Secondary Particles

See also **Angle, Particles**.

Secondary Energy
Information on the energy state of a nucleus after reaction, or on the energy values of detected particles, or on any other energies related to the secondary particles, is entered as follows:

1. **Numerical values** are entered in the COMMON or DATA section using data headings from Dictionary 24 with the family code E, *e.g.*, E-LVL.

    In the case of two or more unresolved energy levels, the data heading may be repeated (see EXFOR 5.4).

    If it is not evident to which reaction product the secondary energy refers, this must be specified under the keyword EN-SEC. see below.

    The secondary-energy uncertainty or resolution may be entered using a data heading from Dictionary 24 with the family code F, *e.g.*, E-RSL, E-LVL-ERR. Further information can be given under the keyword ERR-ANALYS (see EXFOR 8.10). See also **Errors, Resolution**.

2. T**he information-identifier keyword EN-SEC** may be used:
    *   to specify to which reaction product the secondary energy given in the COMMON or DATA section refers. (See EXFOR 8.9).
    *   to give free text information about the secondary energy.

    This keyword must always be coded when the data headings El, E2, *etc*., are used.

    A secondary-energy data heading which is not defined under the keyword EN-SEC must be defined by the REACTION code.

3. **Energy Correlation of Secondary Particles**

    REACTION Coding: ECO in SF6 (parameter)

    Example: (...(G,N+P)...,,ECO)   neutron-proton energy correlation

4. **Average Kinetic Energy**

    REACTION Coding: AKE in SF6 (parameter)

    Example: (.(G,X)O-NN-1,,AKE)   average kinetic energy of neutrons

Secondary Effective Mass
Information about the effective squared mass of detected particles or particle systems may be entered as follows:

1. **Numerical values** are entered in the COMMON or DATA section using data headings from Dictionary 24 with the family code S, *e.g.*, EMS.

2. **The information-identifier keyword EMS-SEC** may be used:

    •   to specify to which reaction product the effective squared mass refers

    •   to give free text information about secondary mass.

    The keyword is always coded when more than one effective secondary squared mass is given in the COMMON or DATA section using the data headings EMS1, EMS2, etc.

3. **Mass Correlation of Secondary Particles**

    REACTION Coding: EMC in SF6 (parameter)

    Example: (...(G,N+P)...,,EMC)   neutron-proton mass correlation

Secondary Linear Momentum
Information about the linear momentum of a secondary particle may be entered as follows:

1. **Numerical values** are entered in the COMMON or DATA section using data headings from Dictionary 24 with the family code L, *e.g.*, MOM-SEC.

2. **The information-identifier keyword MOM-SEC** may be used:

    •   to specify to which of several particles the secondary linear momentum given in the COMMON or DATA section refers.

    •   to give free text information about secondary linear momentum.

The keyword is always coded when more than one secondary linear momentum is given in the COMMON or DATA section using the data headings MOM-SEC 1, MOM-SEC2, *etc.*

3. **Linear Momentum Correlation of Secondary Particles**

    REACTION Coding: MCO in SF6 (parameter)

    Example: (...(G,N+P)...,,MCO)   neutron-proton   linear   momentum correlation

Self-Indication

For elements of interest in reactor physics it is often necessary to know some energy averaged characteristics of these elements. One of such characteristics are transmission functions and their dependence on the sample thickness. They are determined as

$$T_t(x) = \frac{\int\limits_{\Delta E} \varphi(E)\varepsilon(E)\exp\left(-\sigma_t(E)\cdot x\right)dE}{\int\limits_{\Delta E} \varphi(E)\varepsilon(E)dE} \qquad (1)$$

where $\varphi(E)$ = neutron spectrum in ΔE energy interval,
$\varepsilon(E)$ = detector efficiency,
σ_t = total neutron cross-section,
x = the sample thickness.

"Partial" transmission function $T_p(x)$ are defined as follows:

$$T_p(x) = \frac{\int\limits_{\Delta E} \varphi(E)\sigma_p(E)\exp\left(-\sigma_t(E)x\right)dE}{\int\limits_{\Delta E} \varphi(E)\sigma_p(E)dE} \qquad (2)$$

where σ_p = cross section for process p; p = f, inl, γ, *etc*.

For a known $\varepsilon(E)$ and $T_p(x)$, equations (1) and (2) represent a set of decoupled integral equations of the first kind for determining the cross-sections $\sigma_t(E)$ and $\sigma_t(E)$. By measuring the functions $T_t(x)$ by the well-known experimental procedures[2], one may obtain $\sigma_t(E)$ from Eq. (1). Similarly, by measuring $T_p(x)$, one can obtain $\sigma_p(E)$ from Eq. (2). The quantities $T_t(x)$ and $T_p(x)$, are the so-called Self-Indication Functions (SIF).

Using an energy subgroup formalism for energy group approximation, one may obtain the explicit expressions for self-indication functions [2]:

$$f_t(\sigma_0) = \frac{1}{\langle\sigma_t\rangle}\left[\frac{\langle 1/(\sigma_t+\sigma_0)\rangle}{\langle 1/(\sigma_t+\sigma_0)^2\rangle} - \sigma_0\right]$$

$$\qquad (3)$$

$$f_p(\sigma_0) = \frac{1}{\langle\sigma_p\rangle}\frac{\langle\sigma_p/(\sigma_p+\sigma_0)\rangle}{\langle 1/(\sigma_p+\sigma_0)\rangle}, \quad p = f, inl, \gamma, ...,$$

where $f_t(x)$, $f_p(x)$ are subgroup representations of self-indication functions $T_t(x)$, $T_p(x)$, p = f, inl, γ, . . ., angular brackets < > denote the averaging over the energy interval in question, σ_0 is the so-called dilution cross-section[3], *i.e.*, cross-section of all admixture isotopes in sample. Values f_t and f_p are those which are obtained experimentally.

---

[2] See Liou *et al.* [1].
[3] See Abagyan *et al.* [2].

<u>Coding Rules</u>

Use the modifier SIF in SF8.

Examples:

(Z-S-A(N,TOT),,SIG,,SIF/AV)	Total self-indication function
(Z-S-A(N,F),,SIG,,SIF/AV)	Fission self-indication function
(Z-S-A(N,G)Z-S-A+1,,SIG,,SIF/AV)	Radiative capture self-indication function
(Z-S-A(N,INL)Z-S-A,,SIG,,SIF/AV)	Inelastic scattering self-indication function

REFERENCES

[1] H.I.Liou et.al. Phys.Rev. C,.7, 823 (1973), and references therein.
[2] L.Abagyan et.al., Group Constants for Nuclear Reactor Calculations. (Atomizdat, USSR, 1964); English translation by Consultents Bureau, New York, 1964.

Single-Level Resonance Parameters

See also **Average Resonance Parameters, Quantum Numbers, Multilevel Resonance Parameters**.

Resonance cross sections as a function of energy may be described using a Breit-Wigner single-level formalism.

For s-wave scattering the formula is:

$$\sigma_{sc}(E) = 4\pi\lambda_0^2 g \left| \frac{\Gamma_n}{(E - E_0) + i\Gamma/2} + \frac{R'}{\lambda_0} \right|^2 + 4\pi R'^2 (1 - g)$$

where: $\quad 4\pi\, R'^2 = \sigma_{pot}$

For reactions (capture, fission, *etc.*):

$$\sigma_{sc}(E) = 4\pi\lambda_0^2 g \left(\frac{E_0}{E} \right)^{1/2} \frac{\Gamma_n \Gamma_r}{(E - E_0)^2 + (\Gamma/2)^2}$$

For further detail see References 1 and 2.

Definitions and codes for data to be compiled in EXFOR.

(See Dictionary 36 (REACTION) for a complete list of codes.)

Resonance Energy (E_0) is coded in EXFOR in on of two ways.

1. When the resonance energy is determined by the author, it is assigned a REACTION code and entered into the data table under the corresponding DATA field.

    REACTION Coding: 0 (zero) in SF6 (process); EN in SF6 (parameter)

    Example: `(...(N,0),,EN)`

2. When the resonance energy is not determined by the author, but is taken from other sources, it should be entered into the data table as an independent variable under the data heading EN-RES. In this case, it should only be entered for those resonances for which the author has presented other resonance parameters.

Negative energy resonances, in many cases, will influence very low energy cross sections. These *bound levels* should be coded with the negative energy, as given.

Resonance widths (Γ_γ)

REACTION Coding: WID in SF6 (parameter) and the code for the reaction described in SF3

   Examples:

```
REACTION    (...N,TOT),,WID)   = total width (Γ)
            (...(N,EL),,WID)   = neutron width (Γn)
            (...(N,G),,WID)    = capture  width,  or  radiation  width  (Γγ),
                                 including   all   preliminary   γ   decays   not
                                 followed  by  a  neutron  or  charged-particle
                                 emission.
```

The units are that of energy, *e.g.*, eV or milli-eV.

For partial radiation width, see **Gamma Spectra**.

Reduced neutron widths are defined at 1 eV as follows:

$$\Gamma_n^l = \frac{\Gamma_n}{v_t \sqrt{E_0/1eV}}$$

   where: E_0 is the resonance energy in eV.
                   v_t is the penetration factor of the nucleus.

Or, more specifically:

   for s-wave resonances: (v_0=1): $\Gamma_n^0 = \dfrac{\Gamma_n}{\sqrt{E_0/1eV}}$

   for p-wave resonances: $\Gamma_n^1 = \dfrac{\Gamma_n}{\sqrt{E_0/1eV}}\left(1 + \dfrac{1}{k_0^2 R^2}\right)$

      where: k_0 = wave number
                    R = nuclear radius

REACTION coding: `(...(N,EL),,WID/RED)`

The angular momentum should be specified under the data heading MOMENTUM L. (See Quantum Numbers for coding of angular momentum).

The units are that of energy, *e.g.*, eV or milli-eV.

Note: Some authors give the reduced neutron width (for s-wave neutrons) as: $\Gamma_n^0 = \Gamma_n \Big/ \sqrt{E_0}$

which has the dimension of the square-root of an energy. (Compare: Hennies, 1966 Paris Conf., Vol. 2, page 333). For consistency, only definition (1) with the dimension of an energy should be used in EXFOR, the numerical values of definitions (3), and (1) being anyway identical except for the dimensions.

Peak cross section is defined as a cross section at the peak of the resonance, assuming the line shape in a Breit-Wigner formalism, corrected (where important) for instrumental and temperature effects. The peak cross section for s-wave neutrons can be expressed by:

Total: $\quad \sigma_0 = 4\pi\lambda_0^2 g \dfrac{\Gamma_n^2}{\Gamma}$

Partials: $\quad \sigma_{0r} = \sigma_0 \dfrac{\Gamma_n \Gamma_r}{\Gamma}$

These are coded with the modifier code RES in combination with the code for the reaction described.

> ***Example***:   (...(N,TOT),,PCS)   Total peak cross section

Note: Eta or Alpha at resonance are coded as:
> (...(N,ABS),,ETA,,RES)
> (...(N,ABS),,ALF,,RES)

Resonance area is defined:

For scattering: $\qquad\qquad A_{sc} = 2\pi^2 \lambda_0^2 g \dfrac{\Gamma_n^2}{\Gamma}$

For other reactions: $\qquad A_r = 2\pi^2 \lambda_0^2 g \dfrac{\Gamma_n \Gamma_r}{\Gamma}$

These are coded with the parameter code ARE in combination with the relevant reaction code.

> ***Example***:   (...(N,EL),,ARE)   Scattering area

The units are cross section times energy, e.g., b *eV.

The quantity $(\Gamma_n\Gamma_r)/\Gamma$ is often presented as a result of the resonance analysis and is proportional
to the capture area. It is coded the reaction combination followed by the keyword RESULT, using the code CAPTA.

Example:

```
REACTION   (((....(N,EL),,WID,,G)*(....(N,G),,WID))/
           (....(N,TOT),,WID))
RESULT     (CAPTA)
```

The units are energy, *e.g.*, eV.

Some examples of special representations are as follows:

$\sigma_0\Gamma_f$	`(.....(N,F),,WID,,S0)`	
$\sigma_0\Gamma^{-2}$	`(.....(N,TOT),,WID))`	
$g\Gamma_n$	`(.....(N,EL),,WID,,G)`	g = statistical weight factor
$ag\Gamma_n$	`(.....(N,EL),,WID,,AG)`	a = isotopic abundance

References

1. A. M. Lane and R. A. Thomas, *Rev. Mod. Phys.* **30**, 257 (1958).

2. **Experimental Neutron Resonance Spectroscopy**, J. A. Harvey, ed. (Academic Press, 1970).

Spectrum Average

Cross sections averaged over a broad incident-projectile energy spectrum may be entered into EXFOR using the proper modifier to REACTION SF8. The type of spectrum and its characteristic should be entered in free text under the information-identifier keyword INC-SPECT.

The following spectrum types are defined:

1. **Maxwellian Averag**e: Modifier MXW
   The spectrum temperature should be given, if known. For thermal Maxwellian spectrum averaged data, see **Thermal Neutron Energies**.

2. **Epithermal Spectrum Average**: Modifier EPI
   The energy quoted will be, typically the low energy cutoff.

3. **Fission-Neutron Spectrum Average**: Modifier FIS
   For details, see **Fission-Neutron Spectra**.

4. **Fast Reactor Spectrum Average**: Modifier FST

5. **Bremsstrahlung Spectrum Average**: Modifier BRA
   The energy quoted will be, typically, maximum energy.

6. **Average over part of Bremsstrahlung Spectrum**: Modifier BRS
   The energy quoted will be, typically, mean energy.

7. **Spectrum Average (unspecified Spectrum)**: Modifier SPA
   Used for all other spectra, *e.g.*, thermal reactor spectra. Care should be taken to compile only those data that would be of value to the user of EXFOR.

For pile or reactor spectrum, see **Thermal Neutron Energies**.

The spectrum energy should be entered into the data table using one of the following data headings:

KT	- spectrum temperature
EN-MEAN	- mean energy
EN-DUMMY	- dummy energy (characteristic of spectrum)
0.0253 eV	thermal Maxwellian and thermal reactor spectra
1.5 MeV	fission-neutron spectra
4.5 MeV	a-Be neutron sources

Standards

(See also **Dosimetry Reaction Data**).

Standard and/or monitor information should be entered into an EXFOR data set using the information-identifier keyword MONITOR (see EXFOR 8.16 for coding rules). Only that standard data to which the data given are proportional should be coded. Other information should be entered under the information-identifier keyword ASSUMED (see **Assumed Values**).

Note: Data that are measured as consistency checks should not be coded under MONITOR. They should, however, be coded as a separate data table if the data are given.

Standard information should be coded except when it is not relevant, as for quantities that are usually obtained without a standard, that is:
- total cross sections,
- nuclear quantities (see **Nuclear Quantities**),
- ratios,
- quantities defined using the modifiers RS, RSL, RSD, REL,
- scattering radius, strength function, average level spacing,
- resonance parameters; however, for resonance areas, peak cross sections and similar quantities, either the standard should be given or a cross-reference to the data from which the resonance parameters were deduced.

For all other quantities which can be measured either with a standard or absolutely, the positive statement in free text that the data are measured absolutely is pertinent information and, therefore, should be included.

However, so-called "absolute" data often depend on the assumption of certain numerical values (*e.g.*, for calibrations or corrections); it is desirable to give such values in free text. The compiler should restrict the use of the term absolute to those cases in which it is known that there are no "hidden" standards.

For complicated descriptions of standards or normalization procedures, a cross-reference to published literature may be sufficient.

The reference pertinent to the standard(s) used in coded using the information-identifier keyword MONIT-REF (see EXFOR 8.17 for coding rules).

Decay data for the standard(s) used is coded using the information-identifier keyword DECAY-MON (see EXFOR 8.8 for coding rules).

Entry of standard values into DATA or COMMON. (See examples on following page).

1. If standard values are given at several points (i.e., energies, angles), these values are given in the data table as an additional field under the data heading MONIT. See example (1) on following page.

2. If the data is normalized to a standard at one point (i.e., energy, angle), there are two possibilities:
- the standard is entered as in case (1), above; the data field headed by MONIT is blank for all but one line.
- the standard is entered in the COMMON section under the data heading MONIT. The incident energy, secondary energy, angle, etc., at which the normalization was done are entered under the data headings EN-NRM, E-NRM, ANG-NRM, respectively. These are omitted if the data table includes only one data point for which the independent variables are the same as those for the normalization value. See example (2) on following page.

3. If the originally measured ratio (data/standard) is also given, see example (3) on following page.

4. If the data are normalized at two or more energies in an unspecified way, this should be noted in free text in an appropriate place.

Note: Every data line must have a dependent variable entry; therefore, standards may not be entered on a separate line in the data table.

5. If two or more standard reactions are given for the same data set, see EXFOR 8.16 for coding rules.

Numerical values for the uncertainty are entered using the data heading MONIT-ERR. Further information can be entered under the keyword ERR-ANALYS, see EXFOR 8.10.

List of commonly accepted neutron reaction standards

1-H-1(N,EL)1-H-1	SIG and DA	1 keV to 20 MeV
2-HE-3(N,P)1-H-3	SIG	<50 keV
3-LI-6(N,A)2-HE-4	SIG	<100 keV
5-B-10(N,A)3-LI-7	SIG	to gnd, 1st exc.st. <100 keV
6-C-12(N,EL)6-C-12	SIG	<2 MeV
25-MN-55(N,G)25-MN-56	SIG	thermal
27-CO-59(N,G)27-CO-60	SIG	thermal
79-AU-197(N,G)79-AU-198	SIG	thermal, 200 - 3500 keV
92-U-235(N,F)	SIG	100 keV - 20 MeV
98-CF-252(0,F)	NU and DE	---

Examples:

(1)
```
      BIB
      MONITOR     (MONIT1,…)
                  (MONIT2,…)
      …
      ENDBIB
      NOCOMMON
      DATA
      EN          DATA        MONIT1      MONIT2
      MEV         B           B           B
       1.         …           …
       2.         …           …           …
       3.         …           …
      ENDDATA
```

(2)
```
      COMMON
      EN-NRM      E-LVL-NRM   MONIT
      MEV         MV          MB
       ----        ----        ----
      ENDCOMMON
```

(3)
```
      BIB
      REACTION  1((3-LI-6(N,T)2-HE-4,,SIG)/(92-U-235(N,F),,SIG)
                2(3-LI-6(N,T)2-HE-4,,SIG)
       MONITOR  2(92-U-235(N,F),,SIG)
       …
      ENDBIB
      NOCOMMON
      DATA
      EN          DATA        1DATA       2MONIT       2
      MEV         NO-DIM      B           B
       …           …           …           …
      ENDDATA
```

Status

Various types of information are combined under the information-identifier keyword STATUS. See EXFOR 8.24 for coding rules and Dictionary 16 for a complete list of codes and their use. Some general items should be kept in mind:

Preliminary - Superseded - Final Data

If the STATUS codes PRELM and SPSDD are absent, the data are understood to be final.

The frequent case in which a preliminary data set is replaced by its final version can be handled in one of two ways:

1. the final set replaces the preliminary set in the same subentry so that the preliminary set is deleted from the file.

2. the final set is entered into a new subentry (preferably in the same entry). The earlier set is
labeled as superseded with a cross-reference to the data set which supersedes it. If the earlier set has the status code PRELM, it is removed. (The codes PRELM and SPSDD exclude each other.)

    Example: STATUS   (SPSDD,10048009)

The superseding subentry should have a free text cross-reference to the superseded subentry. This is the preferred method if the earlier data has already been published.

The code SPSDD can also be used when a data set is withdrawn by the author without replacement. Explanation is required in free text.

Dependent Data - see **Dependent Data**.

Author Approval

After the proof copy of a data set has been approved by the author, the code APRVD is entered under STATUS. The absence of the code APRVD means that no reply on the proof copy has been received from the author.

Source of the data

The actual source from which the numerical values given in the data set were taken may be entered in free text under STATUS.

When the author's original numerical values have been lost or are not obtainable, data read from graphs, if available, should be entered into EXFOR for completeness. Data of this type should be labeled with the status code CURVE.

Note: Older entries may have been labeled only under the keyword COMMENT or HISTORY.

Normalization

If the codes OUTDT and RNORM are absent, the data are compiled as resulting from the author's corrections and normalizations.

Only in exceptional cases should renormalizations or reassessments of the data as given by an evaluator be compiled. However, some "renormalizations" are not trivial multiplication by a factor; for instance, when a detector-efficiency curve or the geometry of the experiment is involved. For such cases, see **Corrections**.

A data set which is renormalized by an evaluator is labeled with the status code RNORM. The older data set which is superseded by the later renormalization or reassessment is labeled with the status code OUTDT. Both must give a cross reference to the other data set as follows:

```
STATUS        (OUTDT,10231002)
STATUS        (RNORM,10231003)
```

Renormalization, in general, should be done by the compiler *only* with the advice and/or consent of the author.

Interdependent Data

Different results for the same quantity obtained in the same experiment by two different methods of analysis may be coded in the same subentry, see EXFOR Manual, page 5.4.

Such data may also be entered in separate subentries, in which case, the subentries should be linked to each other using STATUS code COREL. (See EXFOR Manual Chapter 8, STATUS for coding details).

Unobtainable data

In the case where a center is aware that data exist, but the center is unable to obtain the data, an entry may be made in EXFOR to inform the other centers (and their users) of the status of the data; this will eliminate many repeated requests for the same data and needless bookkeeping concerning data which will be entered into the system with extensive delays or not at all.

The BIB section of the entry should be prepared as usual, containing at least the obligatory keywords (see EXFOR Manual, page 8.2). The code UNOBT is entered under the keyword STATUS, followed by free text giving, if known, the approximate date when the data may be released, or the reason the data cannot be obtained.

The COMMON section should contain minimum and maximum of the incident-projectile energy, if known.

At least one data subentry should be included containing, at minimum the reaction; the system identifier NODATA replaces the DATA section (see EXFOR Manual, page 2.4).

Data translated from older libraries

Data which have been converted from older data libraries are given a status code to indicate the library from which they were converted. Such data may not have all the required BIB information.

Sums

Sums of 2 or more reactions} can be expressed as a reaction combination using the separator `+´ (see EXFOR 8.R.9).

Examples:

1. Single target nucleus; sum of reactions
   ```
   REACTION((28-NI-58(N,N+P)27-CO-57,,SIG)+
            (28-NI-58(N,D)27-CO-57,,SIG))
   ```

2. More than one target nucleus; more than one reaction
   ```
   REACTION ((28-NI-58(N,P)27-CO-58,,SIG)+
            (28-NI-60(N,T)27-CO-58,,SIG))
   ```

For mathematical correctness, certain reaction combinations require that isotopic abundances be coded in SF8:

Example:
```
REACTION    ((28-NI-58(N,P)27-CO-58,,SIG,,A)+
            (28-NI-60(N,T)27-CO-58,,SIG,,A))⁴
```

Sum reactions such as absorption or nuclide production, where the individual competing reactions may not be known, are not coded using the form above.

Reactions to sums of isomeric states are coded using the separator "+" in the isomer field of the reaction product; see **Isomeric States**.

Example: `(…(…,…_)39-Y-102-M1+M2)`

---

⁴ This may alternately be coded as a production cross section, see **Production**.

Target Nucleus

The target nucleus to be coded is the one to which the data refer; this is not necessarily the same as the actual material which was irradiated in the experiment. If an isotopic mixture or a chemical compound was used as the experimental target, the data may, nevertheless, be given for one isotope, and that isotope should be coded.

Codes valid for target nuclei are flagged in column 13 of Dictionary 27 (see EXFOR Manual, page 6.9).

If a reaction can occur, by energetic reasons, for only one of the isotopes in the irradiated target, that isotope should be coded as the target nucleus. In these cases, compilers must take care that, if corrections for isotopic abundance have not been applied, one of the following modifiers is given with the quantity code:

A   - for a natural isotopic mixture
(A)   - for a natural isotopic mixture, where it is not clear whether the data were corrected
             for abundance
FCT   - for an enriched target. (In this case free text explanation is necessary.)

In these cases the target description must be entered under the keyword sample.

The <u>neutron as target nucleus</u>, (*e.g.*, for neutron-neutron interactions) is coded as `0-NN-1`.

For <u>elemental targets</u>, see also **Elements**.

For <u>compounds as targets</u>, see also **Compounds**.

The <u>isomeric state code</u> -g is never used for a target nucleus. See also, **Isomeric States**.

For coding rules see EXFOR Manual, page 7.2.

Tautologies

Tautologies may be used when a data set can be equally well described by two or more reactions which are identical in the energy range considered. If used, the sequence of the reactions should be such that the one with the narrowest definition (as outlined below) is given first.

Tautologies are expressed as a ***reaction combination*** using the separator "=" (see coding rules EXFOR Manual, page 7.6). Its use is optional, *i.e.*, at the discretion of the compiler.

Two types of tautologies are considered:
1. Below thresholds. For example, total scattering equals elastic scattering below the inelastic threshold.
2. Emission cross sections, for certain secondary energies. For example, the γ-ray emission cross section equals the inelastic γ cross section for some γ-ray energies.

Broader definitions, in general, should be used only when two or more competing reactions are present. This rule seems to avoid any real cases of a tautology. However, where the author uses the broader definition to define the reaction, it may be useful to code both for purposes of identification.

The tautology formalism should **not be used** in the following cases:

1. When a data set extends beyond a known threshold, the broader definition, and ***only*** the broader definition, should be used. (See also **Thresholds**).

2. Where a compiler has doubts about which quantity is actually given in a data set, the compiler must decide in favor of one of the possible codes.

3. In old papers obsolete designations such as "inelastic collision cross section" for nonelastic or "absorption" for (n,γ) may have been used. In these cases, the presently valid definition is always used. The author's designation may be given in free text.

Thermal Neutron Energies

Thermal energy is defined as 2200 m/sec or 0.0253 eV or 273 K.

Cross sections given for a thermal reactor spectrum must be coded with:
SPA   if the spectrum has a non-negligible epithermal part.
MXW   if the result has been corrected for the epithermal part of the spectrum, or if the epithermal part is negligible.

In the Westcott formalism [1], which assumes that the thermal part of the spectrum is Maxwellian, a cross section averaged over a thermal reactor spectrum (effective cross section) is described as:

$$\bar{\sigma} = \sigma_0 \left(g + rs \right)$$

where $\sigma_0 =$ cross section at 2200 m/sec.
         $g =$ ratio of Maxwellian to 2200 m/sec cross section
         $r =$ epithermal index: measure of the proportion of epithermal neutrons in the spectrum ($r = 0$ for Maxwellian spectrum)
         $s =$ temperature dependent quantity given by:

$$s = \sqrt{\frac{4T}{\pi T_0}} \left[\frac{RI}{\sigma_0} - g \sqrt{\frac{4E_0}{E_{Cd}}} \right]$$

where $RI =$ resonance integral
         $E_{Cd} =$ cadmium cutoff energy

If the cross section varies as $1/v$, $g = 1$ or $\sigma_0 = \sigma_{MXW}$.

See also **Spectrum Average**.

Reference

[1.]   C. W. Westcott, AECL Chalk River report **AECL-1101** (1960).

Thermal-Neutron Scattering

(See also **Scattering**).

Theory: The scattering of slow neutrons (energies less than 0.1 eV), with matter depends on the atomic structure of the material (because the wavelength of slow neutrons is of the order of inter-atomic distances) and on the atomic dynamics in the scattering medium (because the energy of slow neutrons is of the same order as the chemical bonding energy and the energy of thermal motion of atoms in crystals and solids). At these energies, two types of scattering must be considered; nuclear scattering and magnetic scattering due to the interaction between the magnetic moment of the neutron and the magnetic moment of the electrons of the target.

Coding: For all scattering processes where molecular and crystalline forces are involved the code THS is used in reaction SF3.

The sample temperature should be given using the data heading TEMP.

The crystal structure of the sample is given using the information-identifier keyword SAMPLE.

The following special processes are defined:

1. **Free-Atom Scattering**. Scattering by a free nucleus, originally at rest.

   REACTION coding: FA in SF5 (Branch)

2. **Bound-Atom Scattering**. Scattering by a nucleus bound in a crystal lattice.

   REACTION coding: BA in SF5 (Branch)

3. **Coherent Scattering**.   Collective scattering by a regular arrangement of scattering centers with common physical properties that will ensure a constant phase relationship between waves scattered by different centers. That is, a single wave is produced with a resultant amplitude due to scattering by a set of particles as a whole.

   REACTION coding: COH in SF5 (Branch)

4. **Incoherent Scattering**.   Scattering by a non-regular arrangement of scattering centers which will lead to random phase differences by the scattered waves. That is, the incoherent scattering cross section is the sum of the section for the individual centers.

   Isotopic Incoherence: due to a random distribution of different isotopes in the scattering target. If there is only one isotope in the target, there will be no isotopic incoherence.

   Spin Incoherence: due to orientation of the neutron and nuclear spins. Spin incoherence may be eliminated by using polarized neutrons and polarized targets.

   REACTION coding: INC in SF5 (Branch)

Scattering Amplitude

Definition: $$\frac{d\sigma}{d\Omega} = |f(\theta)|^2$$

where the scattering amplitude (f) is a function of the wavelength of the incident projectile and of the relative orientation of the incident-projectile spin and target spin.

For <u>neutrons</u>, for which only s-wave scattering is possible (and for which the scattering is, therefore, isotropic), and for zero energy: f = -a, where a is the Fermi scattering length.

REACTION Coding: AMP in SF6 (Parameter)
    Example: `(…(N,THS)…,COH,AMP)`

References

[1.] I. I. Gurevich and L. V. Tarasov, **Low-Energy Neutron Physics** (North Holland Publishing Co., Amsterdam, 1968).

[2.] W. Marshall and S. W. Lovesey, **Theory of Thermal Neutron Scattering** (Oxford University Press, London, 1971).

Thermonuclear Reaction Rate

Reaction Rate

Definition: The thermonuclear reaction rate is defined as cross section times ion velocity averaged over the Maxwellian-Bolzmann distribution of relative ion velocity distribution of the temperature kT:

$$\langle \sigma \cdot v \rangle = \frac{\int_0^\infty (\sigma \cdot v) e^{-mv^2/kT} v^2 dv}{\int_0^\infty e^{-mv^2/kT} v^2 dv}$$

The ion with the mass m_2 has the velocity v relative to the target ion of mass m_1. The reduced mass m of the ion pair is $m = m_1 m_2/(m_1 + m_2)$.

REACTION Coding: (…,SGV,,MXW)

Unit type: data are given in units of B*V , *e.g.*, CM3/SEC.

Energy Coding: Data are given as function of the Maxwellian temperature (kT) which is coded under the data heading KT with units of energy. See **Spectrum Average** for definition of incident spectrum.

Thermonuclear S-factor

Definition: The reactivity of a plasma in thermal equilibrium at temperature T can be written in a form in which its main temperature dependence, which arises from the energy dependences in the cross section produced by the de Broglie wavelength and the Coulomb penetrability, is factored out, leaving a Maxwellian-Boltzmann averaged S function <S>.

REACTION Coding: (…,SGV,,SFC)

Unit type: data are given in units of B*E , *e.g.*, B*EV.

References

[1.] D. D. Clayton, **Principles of Stellar Evolution and Nucleosynthesis** (McGraw-Hill, N.Y., 1968).
[2.] W. A. Fowler, et al, *Thermonuclear Reaction Rates*, **Ann. Rev. Astron. Ap. 5**, 525 (1967)
[3.] T. A. Tombrello, *Energy from charged particle reactions among light nuclei*, **Nuclear Cross Sections and Technology**, Proc. Cong., Washington, D. C., 1975, National Bureau of Standards Special Publication 425 (1975) p. 659
[4.] J. M. Davidson, et al, *Low Energy Cross-Sections for B-11(p,3à)*, **Nucl. Phys. A 315**, 253 (1979).
[5.] C. A. Barnes, **Advances in Nuclear Physics**, Vol. 4 (Plenum, New York, 1971) p. 133

Thick-Target Yields

Definitions:

Thick-target yield: measured on a target whose thickness is such that the incident beam is completely stopped within the target. Therefore, the energy of the interacting particle is a function of its depth within the target.

The thick target yield is given by

$$Y_{thick} \approx \int_0^E \sigma(E) \left[\frac{dE}{dX}(E) \right]^{-1} dE$$

where E is the incident particle energy and E′ is the energy at a given depth in the target.

Stopping Power: $S = -dE/dX$, where X = thickness in g cm^{-2}.

Data compiled in EXFOR

1. **Thick-target yield**: yield of an outgoing particle (or radiation) measured for an incident beam stopped in a thick target and given as decay rate per unit of incident beam current.
   REACTION Coding: TTY in SF 6
   Units: a code from Dictionary 25 with dimension TTY, *e.g.*, MCI/MUA or PART/MUAHR.

2. **Thick-target yield per unit time**: yield of an outgoing particle (or radiation) measured for an incident beam stopped in a thick target and given as decay rate per unit of beam current * time.
   REACTION Coding: TTY,,DT
   Units: a code from Dictionary 25 with dimension TTT, *e.g.*, mci/muahr or DPS/MUAHR.

3. **Thick-target cross section**: cross section measured for an incident beam stopped in a thick target.
   REACTION Coding: SIG in SF 6; TT in SF8.
   Units: a code from Dictionary 25 with dimension B, *e.g.*, MB

4. **Thick-target product yields**: product yield measured for an incident beam stopped in a thick target.
   REACTION Coding: PY in SF 6; tt in SF8.
   Units: dimensionless, *e.g.*, NUC/PART

5. **Thick-target particle yields**: particle yield measured for an incident beam stopped in a thick target.
   REACTION Coding: MLT in SF 6, TT in SF8.
   Units: dimensionless, *e.g.*, N/PART or GAM/PART.
   Example: `(…(A,X)0-NN-1,,MLT,,TT)`

Threshold

A data set may extend beyond a threshold. For example, a data table resulting from a neutron-detecting experiment may actually give in a single data set:

1. elastic scattering below the inelastic threshold energy, and total scattering above the inelastic threshold energy;

2. total scattering below the (n,2n) threshold energy, and neutron production above the (n,2n) threshold energy.

In these cases the wider definition should be used, that is: in the first case, the table should be entered as total scattering; in the second case, as neutron production.

The compiler is not allowed to split the data set in two parts below and above the threshold.

When retrieving, for example, elastic scattering data, one should realize that it may also be worthwhile to retrieve total scattering, with energy below the threshold energy.

If, however, as in (1.), above, the data table has been corrected for inelastic neutrons, or if the portion of inelastic neutrons measured is negligible, the data set may be given as elastic scattering.

See also **Tautologies.**

Title

Full title of work, document or experiment is given in free text. If the original title is not in English, only a literal English translation is given. Computer-compatible substitutes should be used where necessary (*e.g.*, alpha for the Greek letter α).

Where no title is given, *e.g.*, private communications, a title which describes the experiment may be provided by the compiler.

See EXFOR Manual Chapter 8, TITLE for coding rules.

Total

Total cross section

Definition: the sum of all energetically possible interactions.

REACTION Coding: TOT in SF3

  Examples: `(…(N,TOT),,SIG)`
        `(…(N,TOT),,WID)`

Sum-rules: Total = elastic plus nonelastic
        = scattering plus absorption.

Note: At thermal energies, where a large portion of the total cross section may be due to crystal effects (thermal scattering), the sample structure should be given using the keyword sample, if provided by the author.

Total as distinct from partial: no code is given under REACTION for "total", except when it

refers to the total cross section, see above. Instead, codes are given in the branch field for "partial" reactions.

Examples: `(N,F),,NU`   = total
      `(N,F),PR,NU` = prompt
      `(N,INL),,SIG` = total inelastic scattering cross section
      `(N,INL),PAR,SIG` = partial inelastic scattering cross section

Units

A datum or value is always a combination of a number and a unit. For example, 500 mb and .5 b is the same value. mb and b are units of the same dimension (or units group). Units of the same dimension can be converted into each other by multiplication with a numerical (dimensionless) factor.

   Example: Angstrom and cm are units of the same dimension.

A quantity can have only one dimension, *i.e.*,
- a quantity (reaction code) can be combined with only one group of units,
- or, data with different dimensions cannot have the same quantity code.

In general, in order to avoid errors in conversion, data are coded in the units given by the author. However, every effort should be made to compile the data in existing codes, since the proliferation of non-standard unit codes is not desirable. For exotic unit codes, the compiler may choose to convert the data to standard units. This should be accompanied by a comment in the BIB section giving the relationship used for the conversion.

In Dictionary 36 (REACTION), each quantity code given is followed by a code indicating the dimension of the quantity. For example, E means energy units (milli-eV, eV, keV, MeV, *etc.*), no means dimensionless (*i.e.*, unit "one").

The same dimension codes are also given in Dictionary 25 (Units), so that it is possible to check by computer whether a given quantity code is combined with a unit code which has the correct dimension. For example, the reaction quantity code SIG has the dimension B and can only be given in units B, MB, *etc.*, which also have the dimension code B.

In Dictionary 25, a conversion factor is given for each unit code, which allows computerized conversion between different units of the same dimension.

See EXFOR, Chapter 4, for use of unit codes.

Special cases:

1. An <u>angle given in degrees and minutes</u> must be entered in two separate fields with the data heading ANG repeated.

   Example:
   ```
   ANG          ANG          ANG
   ADEG         AMIN         ASEC
    90.          47.          10.
   ```

2. If <u>data are given in arbitrary units</u> (ARB-UNITS), the quantity code is marked as "relative" by entering the modifier REL in reaction SF8. See **Relative**.

3. <u>Errors must have the same dimension</u> (not necessarily the same units) as the quantity to which they refer, or must be in percent.

4. The unit PER-CENT is used only for errors and *must not be used under the data-heading keyword DATA*. If data were given using PER-CENT, the meaning of PER-CENT in the error field would be ambiguous. Data given by the author in percent should be converted to NO-DIM by dividing the results by 100. If the data error is given in percent, this always means a percentage of the relevant data.

5. The unit SEE TEXT may be used in a misc data field when no code from Dictionary 25 applies. It is explained in free text under misc-col. *It must not be used with any other data heading*. (See **Miscellaneous**).

Note: The compiler should avoid any carelessness in the use of units. This would jeopardize any automatic data processing. It is forbidden to set the light velocity c = 1 or Planck's constant   = 1 as is usually done in high-energy physics.