LEXFOR
(EXFOR Compiler's Manual)

last revision edited by

Naohiko Otuka
IAEA Nuclear Data Section, Vienna, Austria

on behalf of the
International Network of Nuclear Reaction Data Centres

June 2022

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Abstract

EXFOR is the exchange format for the transmission of experimental nuclear reaction data between national and international nuclear data centres 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 Formats Manual (IAEA-NDS-207).

June 2022

PREFACE

EXFOR is the database for experimental nuclear reaction data maintained by the International Network of Nuclear Reaction Data Centres (NRDC) co-ordinated by the IAEA Nuclear Data Section. This manual describes the quantity definitions and compilation guidelines to be used by EXFOR compilers.

The various aspects of the EXFOR system are described in the following documents:

Name	Report code	Topics	Intended readership
LEXFOR	IAEA-NDS-208	Quantity definitions and compilation guidelines	Compilers
EXFOR Formats Manual	IAEA-NDS-207	Description of EXFOR exchange formats	Compilers, software developers
EXFOR/CINDA Dictionary Manual	IAEA-NDS-213	Description of dictionary formats	Compilers, software developers
NRDC Protocol	IAEA-NDS-215	Procedures for EXFOR exchange between NRDC centres	Compilers, centre heads
NRDC Network Document	INDC(NDS)-401	Scope of activities and cooperation of NRDC centres	Centre heads
EXFOR Basics Manual	IAEA-NDS-206	Explanation of basic formats	EXFOR users

How to use this manual

This manual serves two purposes: it may be used textbook-like as an introduction to the newcomer, and it serves as a reference manual for compilers. It is strongly recommended to any new compiler to first take a little time to browse through the complete manual (this will save much time later during the compilation work), and then have it at hand as a reference manual whenever compilation work is to be done.

Acknowledgements

Revision History (2002-)

Rev. 2022/06	LEXFOR (EXFOR Compiler's Manual)	Naohiko Otuka (ed.)
Rev. 2015/08	LEXFOR (EXFOR Compiler's Manual)	Otto Schwerer (ed.)
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Rev. 2006/01	LEXFOR (EXFOR Compiler's Manual)	Victoria McLane (ed.)
Rev. 2002/08	LEXFOR (EXFOR Compiler's Manual)	Victoria McLane (ed.)

Keyword Index to LEXFOR,
the EXFOR Formats Manual and the EXFOR/CINDA Dictionary Manual

C.9   =   LEXFOR page C.9
FM 7.25   =   Formats Manual page 7.25
Dict 14   =   Dictionary Manual page 14

For a detailed Table of Contents of the Formats Manual and the Dictionary Manual, see these.

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 Formats Manual, LEXFOR includes information essential for compilers using EXFOR, that is:

- physical definitions of codes defined in the EXFOR Formats Manual and EXFOR/CINDA 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 Nuclear Reaction Data Centres Protocol, section "Manuals".

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.

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Absorption

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

REACTION Coding: ABS in SF3

Sum rules: Absorption = total minus scattering
  = nonelastic minus inelastic

Absorption is a *sum* cross section. It should only be used where two or more reactions are energetically possible.

Note:

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

b.) The thermal "neutron absorption cross section" for gold should 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.

c.) The "photo-absorption cross section" below the nucleon emission threshold must be coded as (γ,sct), (γ,el) or (γ,inl) if there is no other channel (e.g., photo-fission). Above the threshold, photo-absorption (= total minus photo-scattering) (γ,abs) = (γ,n) + (γ,p) + (γ,2n) + … + (γ,f) is coded with ABS in SF3.

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

REACTION coding: G in SF3

Neutron Data
For fissile isotopes at thermal neutron energies below reaction (*e.g.*, n,2n) thresholds:
  Absorption = capture plus fission
Where absorption is, throughout an experimental data set, identical with the (n,γ) reaction, it should be coded as (n,γ), see above. (See also **Tautologies**).

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

REACTION coding: (…(N,ABS),,ALF)[1]
  at resonance energy: (…(N,ABS),,ALF,,RES)

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

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

Disappearance Cross Section

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

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[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 one of the following:

1. a specific reaction, and, therefore, the data given should be coded under the appropriate reaction, *e.g.*, (n,γ) or (p,n).

2. the production of a specific radioactive nuclide, which may be produced by two or more parallel reactions; this case is coded as a production cross section. (See also, **Production and Emission Cross Sections, Sums**).

Example: `(26-FE-0(N,X)25-MN-57,,SIG)`

The code `ACTIV` (activation) is entered under the 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 keyword ANALYSIS is used to enter all relevant information on how the experimental results have been analyzed to obtain the values (given under DATA) that 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, if known. 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 Formats Manual Chapter 7: ANALYSIS.

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

Angle
(See also **Differential Data)**.

Secondary-Particle Angle
The angle of a secondary particle with respect to the incident-projectile beam, or the angle between a correlated particle pair, 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 may be entered in two or three fields with the data heading repeated. See EXFOR Formats Manual, Chapter 4: Repetition of Data Headings.

For <u>relativistic data</u>, 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/fm). See Kerman[4] for more detail.

Data headings:

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

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

When <u>two or more angles</u> are considered (*e.g.*, for angular correlations), 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 <u>angle at which the data are normalized</u>, if different from the angle at which the data were measured, may be given under the data heading ANG-NRM in the COMMON or DATA section.

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**).

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

Assumed Values

Only values defined by the data specification keyword REACTION should be given in the data table under the data heading DATA (and its derivatives). 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 Formats Manual Chapter 7: **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 isotope in a natural isotopic mixture to derive a cross section for another isotope in the mixture.

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

Example:
```
  BIB
  ASSUMED      (ASSUM,6-C-12(N,EL)6-C-12,,DA)
  …
  ENDBIB
  DATA
  ANG          DATA         ASSUM
  ADEG         MB/SR        MB/SR
  …
  ENDDATA
```

Astrophysical S-factor
(See also **Thermonuclear Reaction Rate)**

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 that are 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

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

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

where

$\quad\quad v \quad\quad$ = relative velocity

$\quad\quad Z_1,\ Z_2\quad$ = charge of incident ion and target, respectively,

or

in terms of the Gamow energy

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

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

where

$\quad\quad E \quad\quad$ = center-of-mass incident energy (MeV)

$\quad\quad Z_1,\ Z_2\quad$ = charge of incident ion and target, respectively

$\quad\quad m \quad\quad$ = reduced mass of system:[5] $m = m_1\, m_2/(m_1 + m_2)$

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

Units: a code from Dictionary 25 with the dimension `B*E` (*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: a code from Dictionary 25 with the dimension `EDA` (*e.g.*, `B*MEV/SR`)

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

Author

The author(s) of a data set are entered under the 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 Formats Manual Chapter 7: AUTHOR for coding format.
If a data set has several references with varying co-authors, all co-authors may be entered.

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.

Some names contain character(s) that cannot be represented in the EXFOR permitted character set. If this is detected, the transliteration rules coded in the table below must be applied (these rules are not exhaustive):

Ç	Č	Ä	Ü	Ö	Æ	Ø	Å		
C	C	AE	UE	OE	AE	OE	AA		
ç	č	ä	ü	ö	æ	ø	å	ñ	ß
c	c	a, ae	u, ue	o, oe	ae	oe	aa	n	ss

For Austrian and German authors, ae, ue, oe should be used.

Cyrillic Names
For the transliteration of Cyrillic names, the transliteration published on an English translation must be adopted. When several English translations exist, the first one on the REFERENCE records must be adopted. The following list should be used when such an English translation is not published.

А	Б	В	Г	Д	Е	Ё	Ж	З	И	Й	К	Л	М	Н	О	П
A	B	V	G	D	E	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.

Note that ” (double apostrophes) is not allowed in transliteration from Cyrillic.

Asian Names
For Asian names the full name may be given with the family name given first:

Example: `Li Xiaodong`

Average Resonance Parameters

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

Average Widths
The average of the resonance widths of a specified type in a specified energy range.

REACTION Coding: AV in SF8

Units: a code from Dictionary 25 with the dimension E (*e.g.*, KEV)

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

Average Level-Spacing
The average energy distance (*D*) between nearest-neighbour 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: D in SF6

Units: a code from Dictionary 25 with the dimension E (*e.g.*, KEV).

Example: (…(N,0),,D)

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

Fermi-Gas Model Parameters
See **Nuclear Quantities**.

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:
$$S_l = \left\langle g\Gamma_n^l \right\rangle / \left(2l + 1\right)D_l$$
If *J* and *l* are not known, then *S* is understood to be the observed strength function.

REACTION Coding: STF in SF6

Units: NO-DIM

Example:

```
REACTION   (……(N,EL),,STF)

DATA
EN-RES-MIN EN-RES-MAX MOMENTUM L DATA
EV         EV          NO-DIM     NO-DIM
…
ENDDATA
```

Centre-of-Mass System

An indication that data are given in centre-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	=	sum of energies of incident projectile and target in the CMS (=centre-of-mass energy E_{cm}).
E-CM	=	energy of outgoing particle in the CMS.
ANG-CM	=	angle of outgoing particle in the CMS
NUMBER-CM	=	heading for the coefficient number when the Legendre or cosine fit refers to an angle given in the CMS[1]
DATA-CM	=	heading for data which are given in the CMS.

See also others given in Dictionary 24.

The compiler should use great care if converting the author's data from the centre-of-mass system to the laboratory system, and should document such conversions in free text under the keyword status. The author's original data should be retained.

Note that for certain quantities, such as cross section, Rutherford ratio, analyzing power (see page P.11), the numerical values are identical, whether the angle is given in the laboratory or centre-of-mass system. In such cases, only the heading DATA should be used, whether the dependent variable is given as ANG or as ANG-CM.

Note: Only one representation (*i.e.*, either laboratory or centre-of-mass) for each parameter may be coded as a variable in the data table. The 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.

<u>Centre-of-Mass Energy and Incident Energy per Nucleon</u>

The centre-of-mass energy (EN-CM) is defined as

$$E_{cm} = \frac{m_{targ}}{m_{proj} + m_{targ}} E_{proj,lab} = E_{proj,cm} + E_{targ,cm} = Mc^2 - (m_{proj} + m_{targ})c^2$$

(*M*: invariant mass in relativistic kinematics). It is clear from the 3rd and 4th term that the centre-of-mass energy is invariant under exchange of the incident projectile and the target. Because the numerator of the 2nd term can be rewritten as $(E_{proj,lab}/ m_{proj}) m_{proj} m_{targ}$, the incident energy in laboratory system per projectile mass (number) (MeV/*A, etc.*) is also invariant under this exchange. This invariance is not valid when the Debye effect (shielding of the nuclear Coulomb field by bound atomic electrons) enhances the cross section. This is observed in several reactions such as ^{3}He(d,p)^{4}He, ^{6}Li(p,α)^{3}He, ^{6}Li(d,α)^{4}He and ^{6}Li(p,α)^{4}He at low energy.

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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 a compound code, *e.g.*, CMP, with the element number and symbol of its main component, *e.g.*, 26-FE-OXI for iron oxide, or 26-FE-CMP for 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 209. (See also EXFOR Formats Manual Chapter 6: Coding of nuclides and compounds).

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 neutron 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

Free Text Comments

The language of the free text comments is English, and clear English phrasing should be used. (See **Free Text**, and EXFOR Formats Manual Chapter 3: Free Text).

Unlimited free text comments are permitted with each keyword; however, the compiler should aim to be as concise as possible.

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 or evaluator comments (see also CRITIQUE, below).

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

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

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 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 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, may be entered under COMMENT (see **Comments**), where they must be clearly labelled as compiler's comments.

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

For corrections done by others than author see **Data Type.**

Covariance

Definition

For a measured quantity at two points σ_i and σ_j (*e.g.*, cross section at two incident energies; $i, j = 1,...,m$), **covariance** between them are defined as

$$\operatorname{cov}(\sigma_i, \sigma_j) = \left\langle \left(\sigma_i - \langle\sigma_i\rangle\right)\left(\sigma_j - \langle\sigma_j\rangle\right)\right\rangle = \left\langle\sigma_i\sigma_j\right\rangle - \left\langle\sigma_i\right\rangle\left\langle\sigma_j\right\rangle \tag{1}$$

If the cross section depends on p parameters (source of uncertainties) $\{x^k\}$ ($k=1,2,...,p$),

$$\sigma_i - \langle\sigma_i\rangle = \sum_{k=0}^{p} \frac{\partial\sigma_i}{\partial x_i^k}\left(x_i^k - \left\langle x_i^k \right\rangle\right),$$

Eq.(1) can be rewritten as

$$\operatorname{cov}(\sigma_i, \sigma_j) = \sum_{k,l=0}^{p} \frac{\partial\sigma_i}{\partial x_i^k}\operatorname{cov}\!\left(x_i^k, x_j^l\right)\frac{\partial\sigma_j}{\partial x_j^l} = \Delta_0\sigma_i \cdot \Delta_0\sigma_j \cdot \delta_{ij} + \sum_{k,l=1}^{p} \frac{\partial\sigma_i}{\partial x_i^k}\operatorname{cov}\!\left(x_i^k, x_j^l\right)\frac{\partial\sigma_j}{\partial x_j^l}. \tag{2}$$

where $k, l = 0$ gives the uncorrelated uncertainty $\Delta_0\,\sigma_i = (\partial\sigma_i/\partial x_i^0)\Delta x_i^0$.and δ_{ij} is the Kronecker's delta.

$\Delta\sigma_{ij} = \operatorname{cov}(\sigma_i, \sigma_j)$ (i=1,...n) forms the following **covariance matrix**.

	1	2	3		*n*
1	$\Delta\sigma_{11}$	$\Delta\sigma_{12}$	$\Delta\sigma_{13}$	...	$\Delta\sigma_{1n}$
2	$\Delta\sigma_{21}$	$\Delta\sigma_{22}$	$\Delta\sigma_{23}$	...	$\Delta\sigma_{2n}$
3	$\Delta\sigma_{31}$	$\Delta\sigma_{32}$	$\Delta\sigma_{33}$	...	$\Delta\sigma_{3n}$
...	...	...	...	...	...
n	$\Delta\sigma_{1n}$	$\Delta\sigma_{2n}$	$\Delta\sigma_{3n}$	...	$\Delta\sigma_{nn}$

The covariance matrix is a measure of these errors and the correlations between them. It is symmetric and positive definite, and its diagonal elements give variances (squares of the total uncertainty) from the definition. See also **Errors**: Error Correlations.

Covariance matrices, if given by the experimentalist, should be included, where possible, in structured form as free text under the keyword COVARIANCE.

Note that the **correlation matrix**

$$\operatorname{cor}(\sigma_i, \sigma_j) = \frac{\operatorname{cov}(\sigma_i, \sigma_j)}{\left\langle\sigma_i - \langle\sigma_i\rangle\right\rangle\left\langle\sigma_j - \langle\sigma_j\rangle\right\rangle}$$

is also used instead of its covariance matrix. According to the definition, its diagonal elements are always 1.

Compact Expression of Covariance Matrix by Cholesky Decomposition

Eq.(2) is expressed as

$$V = MM^t + S_\alpha V_\alpha S_\alpha^t,$$

where $V = \text{cov}(\sigma_i, \sigma_j)$, $M = \{\Delta_0\sigma_i\}$, $S_\alpha = \{\partial\sigma_i/\partial x_i^k\}$ and $V_\alpha = \text{cov}(x_i^k, x_j^l)$. The $p\times p$ matrix $V_\alpha = \text{cov}(x_i^k, x_j^l)$ is positive definite and symmetric, and therefore there is a matrix L which satisfies $V_\alpha = LL^t$ (**Cholesky decomposition**):

$$V = MM^t + S_\alpha LL^t S_\alpha^t = MM^t + D_\alpha D_\alpha^t,$$

where $D_\alpha = S_\alpha L$ is a $m\times p$ matrix. The ij-th component of this equation is

$$\text{cov}(\sigma_i, \sigma_j) = \Delta_0\sigma_i \cdot \Delta_0\sigma_j \cdot \delta_{ij} + \sum_{k=1}^{p} \Delta_k\sigma_i \cdot \Delta_k\sigma_j.$$

($D_\alpha = \{\Delta_k\sigma_i\}$, $k=0, 1,2,\ldots,p$ and $I = 1,2,...,m$). We may regard the vector $\{\Delta_0\sigma_i\}$ as the total uncorrelated uncertainty and the vector $\{\Delta_k\sigma_i\}$ $(k = 1,...,p)$ as the k-th fully correlated uncertainty. They may be coded under ERR-1 etc. with the correlation property flag U (uncorrelated) or F (fully correlated).

These vectors allow us to keep the full covariance information with $(1+p)$ m elements instead of $m(m+1)/2$ elements, and effective to archive the full covariance information of high-resolution time-of-flight spectra (e.g., transmission, capture yield) where m is huge [1,2].

Example: Compilation of AGS vectors published in Table 1 of [3].

```
REACTION    (79-AU-197(N,TOT),,SIG,,AV)
...
ERR-ANALYS ERR-2, ERR-3 and ERR-4 are AGS vectors.
           (ERR-T,,,P) Total uncertainty
           (ERR-1,,,U) Uncorrelated uncertainty due to counting statistics
           (ERR-2,,,F) Background model (dK/K=3%)
           (ERR-3,,,F) Normalization    (dN/N=0.25%)
           (ERR-4,,,F) Sample areal density
STATUS     (TABLE) Table 1 of Eur.Phys.J.A49(2013)144
...
EN-MIN     EN-MAX    DATA     ERR-T     ERR-1     ERR-2      ERR-3      ERR-4
EV         EV        B        B         B         B          B          B
   4000.      5500.    20.10     0.22      0.12      0.11486   -0.14226    0.04020
   5500.      6500.    21.30     0.23      0.15      0.09843   -0.14226    0.04259
   6500.      8000.    20.15     0.20      0.12      0.07380   -0.14226    0.04030
   8000.     10000.    17.31     0.20      0.12      0.06558   -0.14226    0.03462
```

Keyword COVARIANCE

Covariance data may be stored in an EXFOR file under the keyword COVARIANCE. These covariance data can describe several types of correlations including: correlations between data measured on different energies (correlations between experimental points and energy intervals); correlations between data of different reactions; correlations between Legendre coefficients of angular distributions; full and fractional, covariance and correlation matrices.

The details of the format are given in the **EXFOR Formats Manual, Appendix B**.

References

[1] B. Becker et al., "Data reduction and uncertainty propagation of time-of-flight spectra with AGS", J. Instrum. **7** (2012) P11002.

[2] N. Otuka, A. Borella, S. Kopecky, C. Lampoudis, P. Schillebeeckx, "Database for time-of-flight spectra including covarainces", J. Kor. Phys. Soc. **59** (2011)1314.

[3] I. Sirakov et al., "Result of total cross section measurements for ^{197}Au in the neutron energy region from 4 to 108 keV at GELINA", Eur. Phys. J.A**49**(2013)144.

Cross sections

(For fission cross sections, see **Fission**).
(For cross sections leading to isomeric states, see **Isomeric States)**.
(See also **Differential Data** and LEXFOR entries for specific processes).

Definition: Cross sections are microscopic reaction probabilities, and are given as a function of incident projectile energy.

Cross Section

(Integrated, as opposed to differential with respect to angle and/or energy of secondary particles)
REACTION coding: SIG in SF6.

Units: code from Dictionary 25 with the dimension B (*e.g.*, MB).

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

Cross Section Integral Over for a Given Incident Energy Range (Integrated Cross Section)

Definition:

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

REACTION Coding: INT in SF6.

Units: code from Dictionary 25 with the dimension B*E (*e.g.*, MB*EV).

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

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 were integrated.

Compilation of such data is optional.

When integration was done for the cross sections obtained by unfolding of bremsstrahlung spectrum averaged cross sections, BRS is coded in SF8.

---

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

Example: `(82-PB-208(G,N)82-PB-207,,INT,,BRS)`

The cross section integrated over the resonance is the **resonance area** and `ARE` is used instead of `INT`.

Total Charge-Changing Cross Section

Definition: The cross section for the emission of all products whose charge differs from the incident projectile charge. That is, if Z_0 is the incident projectile charge and Z_1 is the charge of a given product nucleus, then σ_{tcc} is the cross section for the production of all nuclei such that $Z_1 \neq Z_0$.

REACTION Coding: `TCC` in SF3.

Units: code from Dictionary 25 with the dimension `B` (*e.g.*, `MB`).

Sum rule: $\sigma_{tcc} = \sigma_{tot} - \sigma_{Z0=Z1}$

Example: `(26-FE-56(6-C-12,TCC),,SIG)`

Note: the <u>partial charge-changing cross section</u>, which is given for particles for a given ΔZ (*e.g.*, $\Delta Z = -1$), is coded as a production cross section:

   Example: `(26-FE-56(6-C-12,X)ELEM,,SIG)`
   The charge is given in the COMMON or DATA section under the data heading `ELEMENT`.
   Units are `NO-DIM`.

Spin-Spin Cross Sections (See also **Polarization**).

Definitions: $\sigma_{ss} = (\sigma\uparrow\downarrow - \sigma\uparrow\uparrow)/2$
, where $\sigma\uparrow\uparrow$ = cross section for incident-projectile and target spins parallel

REACTION Coding: `SS` in SF8.

Units: a code from Dictionary 25 with the dimension `B` (*e.g.*, `MB`).

Example: `(…(N,TOT),,SIG,,SS)`

Spin-Dependent Difference Cross Sections (See also **Polarization**).

Definitions: $\Delta\sigma = \sigma\uparrow\downarrow - \sigma\uparrow\uparrow$
, 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: `DSP` in SF8.

Units: a code from Dictionary 25 with the dimension `B` (*e.g.*, `MB`).

Example: `(…(N,TOT),LON,SIG,,DSP)`
            Total spin difference cross section for pure longitudinal spin states

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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*.

Experimental Data

The default data type is experimental. That is, if the data are experimental this field is not used unless the data are derived data.

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. The derivation must be explained under the keyword ANALYSIS.

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 are 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 at one energy (*e.g.*, at 0.0253 eV) or spectrum averages derived from a smooth fit to measured points.

- Data calculated from the sum or difference of two or more measurements.

- Thick target yields derived from cross sections or cross sections calculated from thick target yields.

- Data calculated using measurements for an indirect reaction (e.g., inverse reaction, surrogate reaction, Trojan horse method).

- $\bar{\nu}$ calculated from fission yields.

- Non-elastic cross section (total reaction cross section) derived from differential cross section through optical potential analysis.

- Data obtained with an extrapolation which contributes a significant correction.

- P_n value obtained as the ratio of the measured delayed neutron yield to an assumed fission yield.

Data Renormalized by Other than the Author

Data renormalized by other than the author should not be compiled because even more recent values of a standard cross section can come up later, even more than once, and it is neither practical nor useful to follow such developments by repeatedly updating entries. Such renormalizations can be left to suitable software and, if needed, be stored in a separate database.

In this context, "renormalization" means a straightforward operation, usually a multiplication by a constant factor (e.g. due to a more recent value of a standard cross section or a gamma ray intensity).

Note:

The EXFOR master file may contain older entries with renormalized data, which are labelled with the STATUS code RNORM. While no new entries should be using this code, existing entries of this type may be kept.

Data Corrected or Reassessed by Other than the Author

Data sets corrected or reassessed by other than the author, when considered important, may be compiled in another entry, when the corrected or reassessed data are well documented in a peer-reviewed journal with the correction procedure.

In this context, "correction" or "reassessment" does not mean a straightforward operation such as multiplication by a constant factor, but e.g. taking into account a detector efficiency curve, geometry of the experiment, spectra shapes etc.

If such data are compiled in EXFOR, the data type CRCTD must be given.

A new entry must be created for such data with the provider of the renormalized or reassessed data under AUTHOR and the peer-reviewed journal under REFERENCE.

Example

```
ENTRY            21883   20110227
SUBENT        21883001   20110227
BIB               15          48
AUTHOR     (B.Haesner)
REFERENCE  (R,KFK3395,1982)
…
(Description on the experimental procedure)
…
SUBENT        21883010   20110227
BIB                3           4
REACTION   (2-HE-3(N,EL)2-HE-3,,DA)
REL-REF    (N,,M.Drosg+,J,NSE,172,87,2012)
           Corrected data given
STATUS     (TABLE) Appendix (p66) of KFK-3395
           (OUTDT,29883002) Data corrected by M.Drosg available
ENDBIB             4
NOCOMMON           0           0
DATA               4         183
EN         ANG-CM     DATA-CM     DATA-ERR
MEV        ADEG        MB/SR       MB/SR
 5.0        33.1       409.6        41.0
 5.0        58.7       264.0        15.8
...
```

```
ENTRY            29883   20140506
SUBENT          29883001  20140506

BIB              15         48
AUTHOR     (M.Drosg, R. Avalos Ortiz, P.W. Lisowski)
REFERENCE  (J,NSE,172,87,2012)
…
```

(Description on the correction procedure)

```
…

SUBENT          29883002  20140506
BIB               3         4
REACTION   (2-HE-3(N,EL)2-HE-3,,DA,,,CRCTD)
ANALYSIS   Corrections with better knowledge on …
REL-REF    (R,,B.Haesner,R,KFK3395,1982)
           Original data given
STATUS     (TABLE) Table VIII of Nucl.Sci.Eng.172(2012)87
           (CRCTD,21883010) Original data given
ENDBIB            4
NOCOMMON          0         0
DATA              4       183
EN        ANG-CM    DATA-CM   DATA-ERR
MEV       ADEG      MB/SR     MB/SR
 5.0      33.1      399.       43.
 5.0      58.7      259.       18.

…
```

Data Derived by Other than the Author

Data sets derived by other than the author (e.g., derivation of the ratio of the cross section to the standard from the absolute cross section) are not for compilation in general, but may be compiled in another entry exceptionally when there is a strong need from EXFOR users and the derived data are well documented in a peer-reviewed journal with the derivation procedure.

If such data are compiled in EXFOR, the data type DEROT must be given.

A new entry must be created for such data with the provider of the derived data under AUTHOR and the peer-reviewed journal under REFERENCE.

Example

```
ENTRY            14329   20130626
SUBENT          14329001  20130626
BIB              15         68
AUTHOR     (J.L.Kammerdiener)
REFERENCE  (R,UCRL-51232,1972)

…
```

(Description on the experimental procedure)

```
…
SUBENT          14329090  20130626
BIB               3         3
REACTION   (92-U-235(N,X)0-NN-1,,DA/DE)
REL-REF    (N,19329002,T.Kawano,J,NDS,120,272,2014)
           EDX derived from DDX given
STATUS     (CURVE) Fig.87 of UCRL-51232 (1972)
…
DATA              3        67
E         DATA
MEV       MB/SR/MEV
 9.329E-02 7.850E+02
 1.399E-01 5.686E+02
…
```

```
ENTRY              19329   20140506
SUBENT          19329001   20140506
BIB                   15          68
AUTHOR     (T.Kawano)
REFERENCE  (J,NDS,120,272,2014)
…
```
(Description on the derivation procedure)
```
…
SUBENT          19329002   20140506
BIB                    3           4
REACTION   (92-U-235(N,X)0-NN-1,,DE,,,DEROT)
REL-REF    (R,14329090,J.L.Kammerdiener+,R,UCRL-51232,1972)
           Double differential cross section given
STATUS     (TABLE) Data received from T.Kawano
           (DEP,14329090)
…
E-MIN      E-MAX      DATA
MEV        MEV        MB/MEV
 6.5        8.0        127.01
 8.0        9.5         69.86
…
```

Evaluated and Theoretical Data

Evaluated and theoretical data are, generally, not included in EXFOR with the current exception for photonuclear data.

If such data are compiled in EXFOR, the data type EVAL or CALC must be given.

Decay Data
(See also **Half Lives)**.

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

Keyword DECAY-DATA
The following decay data pertinent to the table given in the DATA section are entered in the BIB section under DECAY-DATA in 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

- intensity of the radiation measured.

These data may be given for more than one decay mode. See EXFOR Formats Manual Chapter 7: **DECAY–DATA** for coding rules.

Decay data are entered:

- in order to define an isomeric state, or

- 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.

- If the authors quote only the source of the decay data but not their numerical values, the source should be coded under REL-REF.

- If the data given are taken from a known source, the reference for it may be coded under the keyword REL-REF.

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 the energy range containing all (unresolved) γ-rays that 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 intensity 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-transitions, the photon intensity should be included, if given by the authors.

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.

Keyword DECAY-MON
Decay data assumed or measured by the author for a reaction used in the experiment as a standard (or monitor) are entered under the keyword DECAY-MON. See EXFOR Exchange Formats Manual Chapter 7: **DECAY-MON**, for coding rules. (See **Standards** for example).

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 heading ELEMENT and MASS, the decay data information is coded as strings of information under the keyword DECAY-DATA and may be linked to the reaction product using the data-heading keyword DECAY-FLAG. 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 6: **Variable Nucleus**). (See also **Flags**).

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
```


Decay Data Errors
Numerical values for the errors in the decay data given may be entered in the COMMON or DATA sections using the data headings:

ERR-HL	=	error in half-life given in DECAY-DATA
ERR-EDD	=	error in energy given in DECAY-DATA
ERR-IDD	=	error in intensity given in DECAY-DATA

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:
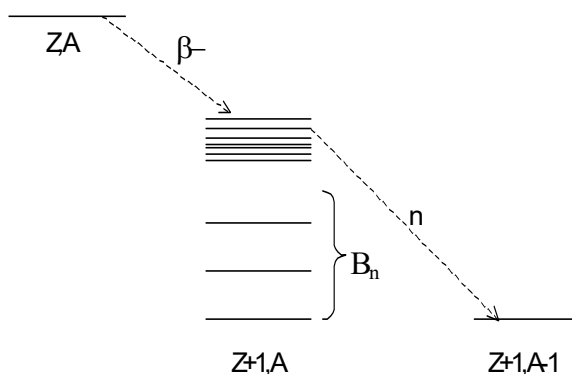
where B_n = neutron binding energy of the nucleus $Z+1,A$

Delayed-Neutron Groups

Delayed-neutron emission is sometimes represented by delayed-neutron groups (usually 6), distinguished by their half-lives. Each group is associated with, perhaps, several different precursor nuclides with similar half-life values (*e.g.*, 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].

Total Average Delayed Fission Neutron Yield ($\overline{\nu}$)

REACTION Coding: NU in SF6 and DL in SF5

    a. Absolute delayed neutron yield

        Units: a code from Dictionary 25 with dimension FY (*e.g.*, PRT/FIS)[1]

        Example: (...(N,F),DL,NU)

    b. Delayed neutron fraction ($\overline{\nu}_d / \overline{\nu}$): coded as a ratio with the units NO-DIM:

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

---

[1] Older entries may have used the units NO-DIM.

Partial Delayed Fission Neutron Yields

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: a code from Dictionary 25 with dimension `FY` (*e.g.*, `PRT/FIS`).

Delayed-Neutron Energy Spectrum for a Given Neutron Group

REACTION Coding: `(…(N,F),DL/GRP,NU/DE)`

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 neutrons/fission/MeV - the data unit `PRT/FIS/MEV` 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.

c.   delayed neutron fraction: group ratio to total delayed neutron yield – coded as a ratio with units `NO-DIM`.

Delayed Fission Neutron Yield for a Given Precursor Nuclide

The cumulative and independent delayed fission neutron yields are the delayed neutron yields from an individual precursor including or excluding its formation via radioactive decay and isomeric transition, respectively. It is the same as the product of the Pn-value and the cumulative or independent fission yield of the precursor.

REACTION Coding: `(…(N,F)...,DL/CUM,NU) or (…(N,F)...,DL,NU)`

---

[2] The group number should only be given if the half-life or decay constant is not given.

Delayed Neutron Data for Individual Precursors

There are delayed-neutron quantities that are not properties of the fissioning nucleus but of the fission-product nucleus that is the "precursor" of the delayed neutron, *e.g.*, **delayed-neutron emission probability**, **delayed-neutron energy spectrum** for a specific precursor. They may be also compiled in EXFOR for users although they are not reaction data. Delayed neutron quantities for a specific precursor can be studied not only by production of the precursor by fission but can be also by other method (*e.g.*, light-induced spallation, heavy-ion induced fragmentation) [4].

Delayed-Neutron Emission Probability (P_n value)

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

REACTION Coding:

    ((Z-S-A(0,B-)[Z+1]-S'-A,,PN)

    where: `Z-S-A` is the fission product nucleus (precursor nucleus before β decay);
                     `[Z+1]-S'-A` is the delayed-neutron emitting fission fragment.

Units: `NO-DIM`

For delayed neutron emission probabilities see for example, Amarel [5], Tomlinson [6], and Asghar [7].

Probability of Emission of N β-delayed Neutrons (P_{Nn})

Definition: Probability to emit N neutrons after β decay

REACTION Coding: `(Z-S-A(0,B-)[Z+1]-S'-A,NUM,PN)`

Units: `NO-DIM`

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

Delayed Neutron Emission Multiplicity <n>

Definition: Multiplicity of delayed neutrons per decay

$$<n> = P_{1n} + 2P_{2n} + 3P_{3n} + ...$$

REACTION Coding: `(Z-S-A(0,B-)[Z+1]-S'-A,MLT,DN)`

Units: `PRT/DECAY` or `PC/DECAY`

Energy Spectrum of Delayed Neutrons Emitted by a Specific Precursor
REACTION Coding: `(Z-S-A(0,B-)[Z+1]-S'-A,,PN/DE)`

Units: a code from Dictionary 25 with dimension `1/E` (*e.g.*, `1/KEV`)

From the above definitions follows $P_n = P_{1n} + P_{2n} + P_{3n} + \ldots$ and $\langle n \rangle = P_{1n} + 2P_{2n} + \ldots$ If only one neutron emission is energetically possible, $P_n = P_{1n} = \langle n \rangle$, the coding `,PN` must be used. Note that some authors use the symbol "P_n" not for the probability but for the multiplicity.

Data not Presently Compiled in EXFOR
- The energy spectrum of all delayed neutrons together, which 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.

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.] L. Mathieu et al., J. Instrum., 7, P08029 (2012)

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

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

[7.] M. Asghar, *et al*., Nucl. Phys. **A247**, 359 (1975)

Dependent Data

Data that are deduced by a trivial operation from other data sets entered into the EXFOR System should be labelled with the code DEP 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 that would be labelled 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 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 labelled with the status code DEP.

Compare: **Status:** Interdependent Data.

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).

The following derivatives of the heading DATA are used:

DATA-MIN	=	Lower limit
DATA-MAX	=	Upper limit
DATA-APRX	=	Approximate value
DATA-CM	=	Given in centre-of-mass system (see **Centre-of-Mass System**).

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

Forbidden:
```
DATA
EN          DATA        MONIT
MEV         B           B
 1.0          2.22
 2.0                       4.
 3.0          3.33
ENDDATA
```

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

Differential Data
(See also **Fitting Coefficients**, **Angle, Polarization**).

Definitions: The differential data refer, in general, to one of the following:

- the particle given in the REACTION SF3 (Process),

- for production or fission, the product given in SF4 (Product) or in the data table

- the particle defined in the REACTION string SF7 (Particle considered).

A particle must be specified in SF7 (Particle considered) if:

- there is more than one particle given in SF3,

- the data refers to a different particle or nuclide than those specified above,

- or the data refers to more than one outgoing particle.

The use of the term **distributions** shall also refer to data measured for an individual point.

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

Reaction Plane
The plane defined by the incident beam direction and the outgoing particle direction. For the following discussions plane A is defined by the incident beam direction and the outgoing particle a direction

Angular Distributions[3] ($d\sigma/d\Omega$)
1. Angular distribution: probability for a particle to be emitted into an area of solid angle $d\Omega$ lying at a mean angle of θ to the incident beam direction in the reaction plane; given as $\sigma(\theta) = d\sigma/d\Omega$. The data are given in units of cross section per unit solid angle (*e.g.*, mb/sr).
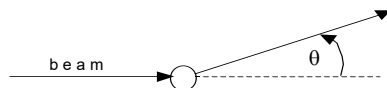
REACTION coding: DA in SF6 (Parameters).

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

If angular differential cross section integrated over a partial range of the angle, it must be coded with IPA in SF6.

---

[3] Historically the term <u>differential cross section</u> has been used to refer to $d\sigma/d\Omega$ and the term <u>excitation function</u> to $d\sigma/d\Omega$ at one angle as a function of incident projectile range.

2. <u>Relative angular distributions</u>
   a.) The <u>shape of the angular distribution</u> $W(\theta)$; the data are dimensionless, and are most often normalized to $W(90°) = 1$.

   REACTION coding: DA in SF6; REL in SF8.

   Units: ARB-UNITS.

   b.) <u>Ratio to 90°</u>
   REACTION coding: DA in SF6 ; RSD in SF8.

   Units: NO-DIM

   c.) <u>Ratio to 0°</u>
   REACTION coding: DA in SF6; RS0 in SF8.

   Units: NO-DIM

   d.) <u>Ratio to average value from 0° - 180°</u>: $\dfrac{d\sigma}{d\Omega}(\theta)\Big/\dfrac{\sigma}{4\pi}$

   REACTION coding: DA in SF6; RS in SF8.

   Units: NO-DIM

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

   Code as a ratio using the separator //, see **Ratios**. The angle for the numerator is coded under ANG-NM; the angle for the denominator is coded under ANG-DN.

   f.) <u>Ratios to the integrated cross section</u>:
   Code as a ratio with the separator /, see **Ratios**.

   g.) <u>Ratio to Rutherford or Mott scattering</u>[4] (See also **Scattering**.)
   REACTION coding: DA in SF6; RTH or MOT in SF8.

   Units: NO-DIM

3. <u>Angular distribution for a correlated pair</u>: Probability that a particle a and a particle b will be emitted at a mean angle θ_m to the incident beam, $d\sigma/d\Omega$ for θ_m:
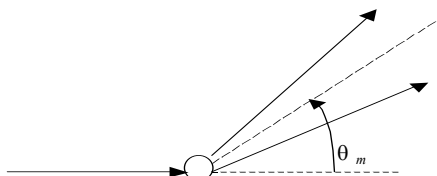
REACTION coding: DA in SF6; particles in SF7 as $a+b$ (*e.g.*, P+A).

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

---

[4] See **Scattering** for definitions of Rutherford and Mott scattering.

The angle is given under the heading `ANG-MN`

4. <u>Angular correlation</u>: probability that, if a particle *a* in emitted at a mean angle of θ_a to the incident beam direction in the reaction plane, particle *b* will be emitted at a mean angle of θ_b to the incident beam direction in the same plane (coplanar); given as $d^2\sigma/d\Omega_a d\Omega_b$. The data are given in units of cross section per unit solid angle squared (*e.g.*, mb/sr^2).
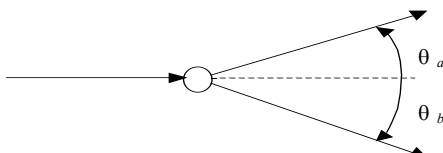
REACTION coding: `DA/DA` in SF6; particles in SF7 as *a*/*b* (e.g., `P/D`).

Unit type: `DA2` (*e.g.*, `MB/SR2`)

The angles θ_a and θ_b are coded under the headings `ANG1` and `ANG2`, in the same order as the particles appear in SF7. If the particles are measured on opposite sides of the beam direction, the angles will be given as, for example, 30. and –30.

Alternately, the angle of particle *b*, θ_b, may be given with the angle between the two emitted particles θ_{rel}.
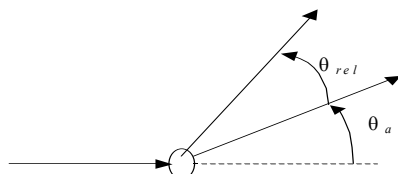
REACTION coding: `DA/DA` in SF6; particles in SF7 as *a*/*b*/*a+b* (e.g., `P/P+A`).

Unit type: `DA2` (*e.g.*, `MB/SR2`)

The angles are given as `ANG1` and `ANG-RL`.

The angular correlation is often given as an angular correlation function $W(\theta_a, \theta_b)$; the data are dimensionless.

REACTION coding: Same as above, but also `REL` in SF8.

Units: `ARB-UNITS`.

5. <u>Non-coplanar angular correlations</u>: The more general situation is for particle *a* and particle *b* not in the same reaction plane. Then θ_a is the angle of particle *a* relative to the beam direction in plane *A*, θ_b is the angle of particle *b* relative to the beam direction in plane *B*, and a third angle ϕ is defined as the angle between the *A* and *B* reaction planes (azimuthal angle).
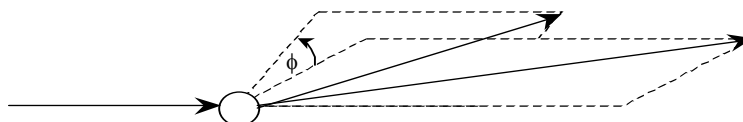
REACTION coding: DA/DA in SF6; particles in SF7 as *a/b* (e.g., P/P) in SF7; NCP in SF8.

Unit type: DA2 (*e.g.*, MB/SR2).

The angles θ_a and θ_b are coded under the headings ANG1 and ANG2, in the same order as the particles appear in SF7. The azimuthal angle is coded under the heading ANG-AZ-RL.

The angular correlation function is then given as $W(\theta_a,\theta_b,\phi)$.

REACTION coding: DA/DA in SF6; particle in SF7 as *a*; NCP/REL in SF8.

Units: ARB-UNITS

Secondary Energy Distributions (dσ/d*E'*)

1.   <u>Energy distribution</u>: probability for a particle to be emitted with a given energy *E'* or to be left in a given excitation energy *E'*, given as $\sigma(E') = d\sigma/dE'$. The data are given in units of cross section per unit of secondary energy (*e.g.*, mb/MeV). The type of the energy *E'* is specified by the data heading (*e.g.*, E, E-EXC, Q-VAL).

REACTION coding: DE in SF6.

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

2. <u>Energy distribution for a correlated pair</u>: Probability that a particle *a* and a particle *b* will be emitted at a relative energy E_{rel}, which gives the centre-of-mass energy of the relative motion of the correlated pair

REACTION coding: DE in SF6; particles in SF7 as *a+b* (*e.g.*, P+A).

Unit type: DE (*e.g.*, B/MEV)
The energy is given under the data heading E-RL. The definition of the relative energy does not depend on the frame (i.e. laboratory system or centre-of-mass system.).

Secondary Momentum Distributions (dσ/d*p'*)

1. <u>Linear momentum distribution</u>: probability for a particle to be emitted with a given momentum p′; given as σ(*p'*) = dσ/d*p*. The data are given in units of cross section per unit of secondary linear momentum (*e.g.*, mb/MeV/c).

REACTION coding: `DP` in SF6.

Unit type: `DP` (*e.g.*, `MB/MEV/C`)

Example: (… (N,X) …… , LP, DP)
    Longitudinal momentum distribution of emitted particles.

The linear momentum is given under the data heading `MOM-SEC`.

2. <u>Linear momentum distribution for a correlated pair</u>: Probability that a particle *a* and a particle *b* will be emitted at a mean linear momentum p_m or a relative linear momentum p_{rel}.

REACTION coding: `DP` in SF6; particles in SF7 as *a+b* (*e.g.*, `P+A`).

Unit type: `DP` (*e.g.*, `MB/MEV/C`)

The linear momentum is given under the heading `MOM-SEC-MN` or `MOM-SEC-RL`.

Secondary 4-Momentum Transfer Distributions (dσ/dt)

Probability for a particle to be emitted with a given 4-momentum transfer squared *t*; given as σ(*t*) = dσ/d*t*, where 4-momentum transfer squared of the particle is defined by
$$t = (E'-E)^2 - (\vec{p}'-\vec{p})^2$$
for scattering of the particle $(E, \vec{p}) \rightarrow (E', \vec{p}')$.

Note that *t* is a Lorentz scalar, and $t = -4\,p^2\,\sin^2(\theta/2) < 0$ for elastic scattering and $t = -4EE'\sin^2(\theta/2) < 0$ for relativistic limit.

REACTION coding: `DT` in SF6.

Unit type: `D4` (*e.g.*, `MB/GEV2/C2`)

The 4-momentum transfer squared is given under the data heading `-t` with the opposite sign.

Angle/Energy Distributions

1.   <u>Angle/energy distribution</u> $d^2\sigma/d\Omega/dE'$: probability for a particle to be emitted at a given energy E′ or to be left in a given excitation energy *E'*, and into an area of solid angle Ω lying at a mean angle of θ to the incident beam direction in the reaction plane; given as σ(*E'*,θ) = $d^2\sigma/d\Omega/dE'$. The data are given in units of cross section per unit solid angle per unit of energy (*e.g.*, mb/sr/MeV). The type of the energy E′ is specified by the data heading (*e.g.*, `E`, `E-EXC`, `Q-VAL`).

REACTION coding: `DA/DE` in SF6.

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

The energy is given under the data heading `E` or `E-MIN` and `E-MAX`.

2. <u>Angle/energy correlations</u>:
a.) $d^3\sigma/d\Omega d\Omega dE'$: probability that, if:

- either a particle *a* emitted at a mean angle of θ_a to the incident beam direction in the reaction plane and an energy E′, particle *b* will be emitted at a mean angle of θ_b to the incident beam direction in the same plane (coplanar); given as $d^3\sigma/d\Omega_a d\Omega_b dE_a$

    REACTION coding: `DA/DA/DE` in SF6, particles in SF7 as *a/b/a* (*e.g.*, `P/A/P`)

    The angles θ_a and θ_b are coded under the headings `ANG1` and `ANG2` in the same order as the particles appear in SF7; the energy is coded under the heading `E1` or `E2` to correlate the energy with the angle of the same particle.

- or particles *a* and *b* will be emitted at mean angles of θ_a and θ_b to the incident beam direction in the reaction plane, with a relative energy E_{rel}, usually given as the centre-of-mass energy of the relative motion of the correlated pair; given as $d^2\sigma/d\Omega_a d\Omega_b dE_{\text{rel}}$

    REACTION coding: `DA/DA/DE` in SF6, particles in SF7 as *a/b/a+b* (*e.g.*, `P/A/P`)

    The angles θ_a and θ_b are coded under the headings `ANG1` and `ANG2` in the same order as the particles appear in SF7; the energy is coded under the heading `E-RL`.

    The data are given in units of cross section per unit solid angle squared per unit energy (*e.g.*, mb/sr^2/MeV).

    Unit type: `D3A` (*e.g.*, `MB/SR2/MEV`)

    Examples:
    ```
    BIB
    REACTION    (...(P,N+P)...,,DA/DA/DE,P/N/P)
    ...
    DATA
    ANG1        ANG2        E1          DATA
    ADEG        ADEG        MEV         MB/SR2/MEV
    ...
    ```
    For the case where the mean energy is given for a correlated pair:

    ```
    BIB
    REACTION    (...(P,T+A)...,DA/DA/DE,A/T/A+T)
    …
    DATA
    ANG1        ANG2        E           DATA
    ADEG        ADEG        MEV         MB/SR2/MEV
    ...         ...         ...         ...
    ```

b.) $d^3\sigma/d\Omega/dE'/dE'$: probability that, if a particle a in emitted at a mean angle of θ_a to the incident beam direction in the reaction plane and an energy E_a, particle b will be emitted at an energy E_b; given as $d^3\sigma/d\Omega_a/dE_a/dE_b$. The data are given in units of cross section per unit solid angle per unit energy squared (*e.g.*, mb/sr/MeV^2).

    REACTION coding: `DA/DE/DE` in SF6, particles in SF7 as *a/b/a* (*e.g.*, `P/A/P`)

    Unit type: `D3` (*e.g.*, `MB/SR/MEV2`)
The energies are coded under the data heading `E1` and `E2` in the same order as the particles appear in SF7; the angle θ_a is coded under `ANG1` or `ANG2` to correlate with the energy of the same particle.

c.) $d^4\sigma/d\Omega/d\Omega/dE'/dE'$: probability that, if a particle a in emitted at a mean angle of θ_a to the incident beam direction in the reaction plane and an energy E_a, particle b will be emitted at a mean angle of θ_b to the incident beam direction in the reaction plane and an energy E_b; given as $d^4\sigma/d\Omega_a/d\Omega_b/dE_a/dE_b$. The data are given in units of cross section per unit solid angle per unit energy squared (*e.g.*, mb/sr^2/MeV^2).

    REACTION coding: `DA2/DE2` in SF6, particles in SF7 as *a/b* (*e.g.*, `P/A`)

    Unit type: `D4A` (*e.g.*, `MB/SR2MEV2`)
The angles θ_a and θ_b are coded under the headings `ANG1` and `ANG2` in the same order as the particles appear in SF7; the energies are, similarly, coded under the headings `E1` and `E2`.

d.) <u>Angle/linear momentum distribution</u> $d^2\sigma/d\Omega/dp$: probability for a particle to be emitted with a given momentum p' and angle θ, given as $\sigma(\theta, p') = d^2\sigma/d\Omega/d\,p'$. The data are given in units of cross section per unit of solid angle per unit of secondary linear momentum (*e.g.*, mb/MeV/c).

    REACTION coding: `DA/DP` in SF6.

    Unit type: `DAP` (*e.g.*, `MUB/SRMEVC`)

    The linear momentum is given under the data heading `MOM-SEC`.

<u>**Separators in REACTION SF7**</u>
When differentiation involves parameters associated with two or more particles, they may be combined by a slash (/) or plus sign (+). A slash is used when several parameters are associated with several particles, while a plus is used when a parameter is associated with several particles.

Examples:
    `,DA/DA,N/P:`
        Differential for the outgoing angles of neutron and proton ($d\sigma/d\Omega_n/d\Omega_p$)

    `,DE,N+P:`
        Differential for the relative energy between neutron and proton ($d\sigma/dE_{n-p}$).

Relation between REACTION SF7 and Headings
The relation between particle codes in REACTION SF7 and headings of the differential data are summarized (not exhaustive):

	θ_a	θ_b	θ_{ab}	E_a	E_b	E_{ab}
,DA/DA,a/b	ANG1	ANG2				
,DA/DA,a/a+b	ANG1		ANG-RL			
,DA/DA/DE,a/b/a	ANG1	ANG2		E1		
,DA/DA/DE,a/b/b	ANG1	ANG2			E2	
,DA/DA/DE,a/b/a+b	ANG1	ANG2				E-RL
,DA/DE/DE,a/a/b	ANG1			E1	E2	
,DA/DE/DE,b/a/b		ANG2		E1	E2	

(A heading with -CM may replace the heading in the table, e.g. ANG2-CM may replace ANG2.)

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 centre-of-mass system.
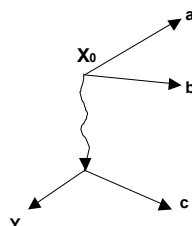
For photonuclear reactions in the centre-of-mass system, it is the angle between the (X,a) and (Y,b) or (Y,c) planes, where X is the incident gamma, Y is the target nucleus.
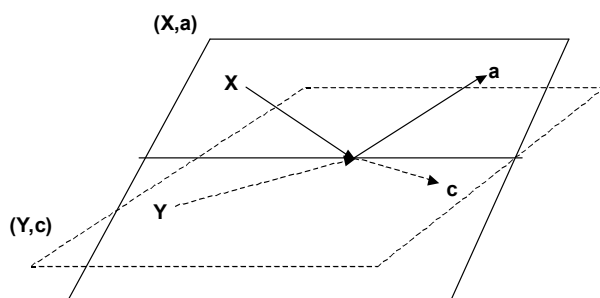
See Shapiro[5] for more information.

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)

---

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

REACTION coding: parameter code `DA/TYA` in SF6, outgoing particle in SF7.

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

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

Digitization

When the author's original numerical values have been lost or are not obtainable, data digitized from graphs, if available, should be entered for completeness. Data of this type should be labelled with the STATUS code CURVE.

Example:

```
STATUS (CURVE) Scanned from Fig. 1 of Yad.Fiz.12(1951)345.
```

Below are some recommendations and guideline agreed in the IAEA Consultant's Meeting on Benchmarking of Digitization Software (Vienna, 12-14 November 2012). See the summary report of the meeting (INDC(NDS)-0629) for more details.

Recommendations

- Ask for numerical data from the authors. Explain to the authors that the original numerical data from the authors are preferable than values digitized from images.

- Avoid adoption of digitized values when the original values are explicitly given in the article (e.g., incident energy, detection angle).

- Enlarge the image as much as possible when the image file is created and digitized. Utilise functions available on the software for this purpose (*e.g.*, "magnifying glass").

- Digitize the beginning and end points of scales with special care to avoid systematic errors.

- Check the values of the beginning and end points (labels on scales) after digitization of the image.

- Quote the digitization uncertainty to two significant digits to avoid an unexpected coincidence in digitized values.

Guideline for Expression of Digitized Data

1. Keep consistency for the number of digits between the digitized values and uncertainties.

   Example:

   ```
   DATA
   EN          DATA          DATA-ERR
   MEV         MB            MB
    14.1        12.34         2.34
    14.3        12.3          2.3
    14.5         1.234E+01  0.234E+01
    14.6         1.23 E+01  0.23 E+01
   …
   ENDDATA
   ```

2. Use the fixed and floating decimal point expression for the numbers digitized from linear and logarithmic scale, respectively.

LEXFOR

*Examples***:**

```
12.345        (a value digitized from linear scale)
1.2345E+02    (a value digitized from logarithmic scale)
```

3. Digitization accuracy may be given in the absolute unit (*e.g.*, `ADEG`) or relative unit (*e.g.*, `PER-CENT`) for the numbers digitized from linear and logarithmic scale, respectively.

Example:

```
COMMON
ANG-ERR-D  ERR-DIG
ADEG       PER-CENT
 0.12       1.2
ENDCOMMON
DATA
ANG-CM     DATA        DATA-ERR
ADEG       MB          MB
  5.67       3.456E+02  0.234E+02
 12.31       2.345E+02  0.123E+02
…
ENDDATA
```

4. Consider rounding of digitized values to integers if values are for atomic numbers, mass numbers etc., and digitized values are close to integers.

Dosimetry Neutron Reaction Data
(See also **Standards)**.

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

Activation Reactions
(for use with neutron threshold detectors)

^{6}Li(n,x)^{4}He	^{48}Ti(n,n+p)^{47}Sc	^{90}Zr(n,p)^{90}Y
^{10}B(n,x)^{4}He	^{55}Mn(n,2n)^{54}Mn	^{90}Zr(n,2n)^{89}Zr
^{14}N(n,p)^{14}C	^{55}Mn(n,γ)^{56}Mn	^{93}Nb(n,n')^{93m}Nb
^{19}F(n,2n)^{18}F	^{54}Fe(n,p)^{54}Mn	^{93}Nb(n,2n)^{92m}Nb
^{23}Na(n,γ)^{24}Na	^{54}Fe(n,α)^{51}Cr	^{98}Mo(n,γ)^{99}Mo $\rightarrow$ ^{99m}Tc
^{23}Na(n,2n)^{22}Na	^{56}Fe(n,p)^{56}Mn	^{103}Rh(n,n')^{103m}Rh
^{24}Mg(n,p)^{24}Na	^{58}Fe(n,γ)^{59}Fe	^{109}Ag(n,γ)^{110m}Ag
^{27}Al(n,α)^{24}Na	^{59}Co(n,p)^{59}Fe	^{115}In(n,n')^{115m}In
^{27}Al(n,p)^{27}Mg	^{59}Co(n,α)^{56}Mn	^{115}In(n,γ)^{116m}In
^{31}P(n,p)^{31}Si	^{59}Co(n,2n)^{58}Co	^{127}I(n,2n)^{126}I
^{32}S(n,p)^{32}P	^{59}Co(n,γ)^{60}Co	^{181}Ta(n,γ)^{182}Ta
^{45}Sc(n,γ)^{46}Sc	^{58}Ni(n,p)^{58}Co	^{186}W(n,γ)^{187}W
^{45}Sc(n,2n)^{44}Sc	^{58}Ni(n,2n)^{57}Ni $\rightarrow$ ^{57}Co	^{197}Au(n,γ)^{198}Au
^{45}Sc(n,2n)^{44m}Sc	^{60}Ni(n,p)^{60}Co	^{197}Au(n,2n)^{196}Au
^{46}Ti(n,p)^{46}Sc	^{63}Cu(n,α)^{60}Co	^{197}Au(n,3n)^{195}Au
^{47}Ti(n,n+p)^{46}Sc	^{63}Cu(n,2n)^{62}Cu	^{197}Au(n,4n)^{194}Au
^{47}Ti(n,d)^{46}Sc	^{63}Cu(n,γ)^{64}Cu	^{199}Hg(n,n')^{199m}Hg
^{47}Ti(n,p)^{47}Sc	^{65}Cu(n,2n)^{64}Cu	^{232}Th(n,2n)^{231}Th
^{47}Ti(n,p)^{47}Sc	^{64}Zn(n,p)^{64}Cu	^{232}Th(n,γ)^{233}Th $\rightarrow$ ^{233}Pa
^{48}Ti(n,p)^{48}Sc	^{64}Zn(n,2n)^{63}Zn	^{238}U(n,γ)^{239}U $\rightarrow$ ^{237}Np

Fission Reactions

^{232}Th(n,f)	^{238}U(n,f)	^{239}Pu(n,f)
^{235}U(n,f)	^{237}Np(n,f)	^{241}Am(n,f)

Elements

Naturally Occurring Elements
Naturally occurring elements are, in general, entered with $A=0$ (*e.g.*, `26-FE-0`).

Monoisotopic Elements
When target nuclide belongs to a monoisotopic element, the atomic weight of the naturally occurring isotope is coded. 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
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 isotopes 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	7-N-14	57-LA-139
2-HE-4	8-O-16	73-TA-181
6-C-12	23-V-51	

Synthetic Elements
Synthetic elements must always be entered with a mass number A ($\neq 0$).

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

Super-Heavy Elements
Super-heavy elements that do not have an element symbol are coded using an * for the element symbol (*e.g.*, `120-*-302`). See Dictionary 8.

Note:
The **hydrogen isotopes** are always coded using the element symbol H, (*e.g.*, `1-H-2`, `1-H-3`).

See also **Target Nucleus**.

Errors

(See also **Covariance, Resolution**).

Definition: The uncertainty on the mean value of a variable[1].

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 Formats Manual Chapter 7: **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 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 useful 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   68% probability that the true value is within error bars in Gaussian distribution
   - 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 the same experiment; see also **Status:** Interdependent Data.

---

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

Energy Uncertainties

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 has not been done or the compiler does not have enough information to know if a complete analysis has been done.

The uncertainties 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. Unsymmetrical errors are identified using the data headings +DATA-ERR and –DATA-ERR. Statistical uncertainty may be entered as ERR-S; total systematic or correlated uncertainty may be entered as ERR-SYS.

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 statistical and systematic uncertainties are entered in the COMMON or DATA section under the data headings ERR-S and ERR-SYS, as above, The total uncertainty is entered under ERR-T (total) with the partial uncertainties entered under ERR–1, ERR–2, *etc.* (see Dictionary 24). The definition of the different partial uncertainties is given under ERR-ANALYS in free text comments preceded by a code containing the relevant data heading.

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 before entering. Other types of uncertainty information may be entered in free text.

3. The correlation property for the systematic uncertainties is coded under ERR-ANALYS following the data-heading code, if known (see EXFOR Formats Manual Chapter 7: **ERR-ANALYS**).

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 Neutron 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.

Error Correlations

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

Evaluators must carefully consider error correlations. 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.

The correlation properties of the source of uncertainty are entered as a fourth field under the information-identifier keyword ERR-ANALYS (see. EXFOR Formats Manual Chapter 7: **ERR-ANALYS**).

Digitizing Errors

Errors in the digitizing of a data set by a compiler are given under a separate set of heading:

ERR-DIG	=	Error in digitizing data values
ANG-ERR-D	=	Error in digitizing the angle values.
E-ERR-DIG	=	Error in digitizing the secondary energy values.
EN-ERR-DIG	=	Error in digitizing the incident energy values.

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.

Heading	Usage
ERR-T	Total uncertainty which components are also given under ERR-S, ERR-SYS, ERR-1, MONIT-ERR etc.
ERR-S	Statistical uncertainty
ERR-SYS	Total systematic uncertainty (partial systematic uncertainties are known or unknown)
ERR-1, ERR-2, …	Partial uncertainty for which more specific one (*e.g.*, MONIT-ERR) is not defined.
MONIT-ERR	Uncertainty in monitor reaction cross section
DATA-ERR	1. Uncertainty which property (statistical or systematic) is uncertain for the compiler 2. Total uncertainty which components are not given under ERR-S, ERR-SYS, ERR-1, MONIT-ERR etc.
DATA-ERR1, DATA-ERR2, …	Similar to DATA-ERR, but more than two components of uncertainties are given by authors.
ERR-DIG EN-ERR-DIG …	Uncertainty due to digitization.

<u>Reference</u>
D.L. Smith and N. Otuka, Nucl.Data Sheets **113**(2012)3006, in particular Section V.E.

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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.

When a 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 of comparable mass. 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**.

Fission can occur either spontaneously, or by the capture of an incident particle. In spontaneous fission, the nucleus exists in a deformed state and with a potential energy high enough to allow tunnelling through the potential fission barrier. In the case of capture, a particle is absorbed forming a highly excited nucleus which then undergoes deformation.

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

Compare: **Reaction Mechanisms.**

Binary Fission
REACTION Coding: `F` in SF3.

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

Special rules apply for the coding of the **Reaction Product** (see EXFOR Formats Manual Chapter 6).

Spontaneous Fission
REACTION Coding: `0` in SF2; `F` in SF3..

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); the code `FF` is used for quantities that apply to both heavy and light fragments.

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

Example:

`(…(N,F)2-HE-4,TER,SIG)`	Alpha production cross section in ternary fission
`(…(N,F)2-HE-4,TER,DA)`	Angular distribution of fission fragment 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 α-accompanied ternary fission

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),,SIG`
(n,2nf)	`(N,2N+F),,SIG`
(n,γf)	`(N,G+F),,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.

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[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 SF5 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:

$$\chi(E) \propto \sqrt{E}e^{-\frac{E}{kT}}$$

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

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

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

$$E_p = \frac{1}{2}kT = \frac{1}{3}\overline{E}$$

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

$$\chi(E) \propto e^{-\frac{E}{kT}}\sinh\left(\frac{2}{T}\sqrt{EE_f}\right)$$

where kT 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 $\overline{E}$ is given as:

$$\overline{E} = E_f + \frac{3}{2}kT$$

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

$$\chi(E) \propto \frac{1}{2}\left[f_n\left(E, E_{HF}\right) + f_n\left(E, E_{LF}\right)\right]$$

where E energy of the fission neutron
         E_{HF}, E_{LF} 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 accurately known, suggests that none of the presently-used fits is sufficient.
[4] See Terrell [1].
[5] See Watt [3].
[6] See Madland [4]. See this reference for a complete definition of the spectrum.

Use of SF5=PR for Prompt Fission Neutron Spectra

The branch code PR is used when (1) the authors explain their fission neutron spectra with the word "prompt" explicitly, or (2) the time-of-flight (fission fragment signal and neutron detection signal) is used to identify each neutron.

Absolute Spectra of Fission Neutrons

REACTION coding: NU/DE in SF6.

Units: a code from Dictionary 25 with the dimension FYDE (*e.g.*, PT/FIS/MEV)

Examples:

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

The spectrum is often given as the ratio to reference prompt fission neutron spectrum (e.g., prompt neutron fission spectrum for ^{252}Cf spontaneous fission)

Example:

    ((92-U-235(N,F),PR,NU/DE)/98-CF-252(0,F),PR,NU/DE))

Spectra Normalized to Probability Distribution

The fission neutron energy spectrum normalized to probability distribution is given by:

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

    where: E is the fission neutron energy,
                  $X(E)$ is the spectrum.

REACTION coding: NU/DE in SF6; NPD in SF8.

Units: a code from Dictionary 25 with the dimension FYDE (*e.g.*, 1/FIS/MEV)

Data are also often given in arbitrary units, which require the REL modifier in the reaction code.

Example: (98-CF-252(0,F),PR,NU/DE,,NPD)

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

Spectra Relative to Maxwellian Spectrum

The fission neutron energy spectrum given as a ratio of the Maxwellian spectrum is given by

$$C \frac{\chi(E)}{\sqrt{E}\exp(-E/kT)}$$

. These data are coded using the modifier code MXD in SF8; the spectrum temperature for the Maxwellian spectrum is given under the data heading KT-NRM.

REACTION coding: Parameter code NU/DE in SF6, modifier code MXD in SF8.

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

Example: (98-CF-252(0,F),PR,NU/DE,,MXD)

<u>Spectra Divided by Square-Root of Neutron Energy</u>
The neutron spectra divided by square-root of the neutron energy

$$C\frac{\chi(E)}{\sqrt{E}}$$

are sometimes shown. Because χ(*E*) is well approximated by the Maxwellian spectrum, the logarithm of this quantity is proportional to the neutron energy.

REACTION coding: Parameter code NU/DE in SF6; RRE in SF8.

Units: usually given in arbitrary units (ARB-UNITS)

Example: (98-CF-252(0,F),PR,NU/DE,,RRE)

<u>Average Kinetic Energy of Fission Neutrons</u>
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*.).

The particle code N is coded under reaction SF7 when the neutron was measured with fission fragment coded in reaction SF4, otherwise 0-NN-1 is coded in reaction SF4.

REACTION coding: Parameter code KE in SF6.

Units: a code from Dictionary 25 with the dimension E (*e.g.*, KEV)

Example:

(…(N,F)0-NN-1,PR,KE)	Average kinetic energy of prompt neutrons
(---(-,F)ELEM/MASS,PR,KE,N)	Average kinetic energy of prompt fission neutrons measured with product nuclei which are given in the DATA table under headings mass.

<u>References</u>

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

[2.] A. B. Smith, Fission Neutron Spectra: Perspectives 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 Neutron Yield

Nu-bar $\left(\overline{v}\right)$

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

REACTION Coding: `NU` in SF6.

Examples:

`(…(N,F),,NU)`	total neutron-induced fission nu-bar ($\overline{v}$)
`(…(0,F),PR,NU)`	spontaneous fission prompt nu-bar ($\overline{v}_p$)
`(…(P,F),DL,NU)`	proton-induced fission delayed nu-bar ($\overline{v}_d$)
`(…(N,F),NUM,NU)`	probability for the emission of *n* neutrons from neutron-induced fission (*n* is coded in the data section under the heading `PART-OUT`).

Sum rule: $\overline{v} = \overline{v}_p + \overline{v}_d$

See also **Delayed Fission Neutrons**

For average neutron yield per nonelastic process, see **Nonelastic**: Eta.

Quantities for Neutrons at Specific Total Kinetic Energy

Total kinetic energy dependence of prompt fission neutron quantities (*e.g.*, multiplicities, average emission energy) which is not partial for the total kinetic energy (*i.e.*, not additive for total kinetic energy).

REACTION Coding: `TKE` in SF6.

Example:

`(…(0,F),PR,NU/TKE)` Prompt fission neutron multiplicities at the total kinetic energy specified.

The total kinetic energy is given under the heading `TKE`.

Quantities for Neutrons Emitted from a Specific Fragment

If a prompt fission neutron quantity (*e.g.*, multiplicities, average emission energy) is given for a specific fragment (e.g., `MASS` in REACTION SF4) and the quantity is for neutrons emitted from the fragment specified, the branch code `FRG` is coded in SF5. Fragment mass dependence of such quantities $Q(A)$ for fissioning of compound (mass A_c) is characterized by asymmetry with respect to the half of the compound mass $Q(A_c-A) \neq Q(A)$ (*e.g.*, fragment mass dependence of fission neutron multiplicities known as "saw-tooth curve").

Examples:

`(…(0,F)MASS,PR,NU)` Multiplicities of the prompt fission neutrons emitted **with** the fragment whose mass is specified.

`(…(0,F)MASS,PR/FRG,NU)` Multiplicities of the prompt fission neutrons emitted **from** the fragment whose mass is specified.

Fission Yields

(See also **Fission Neutron Yields**).

Theory

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

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

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

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

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

The sum of the yield for all fission products will, in general, add up to 200%, *i.e.*, 100% for each of the heavy and light product distributions (see example in figure[7]). Since in ternary fission more than two fragments are formed per fission, the yields for all fragments sum up to a bit more than 200%.

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

---
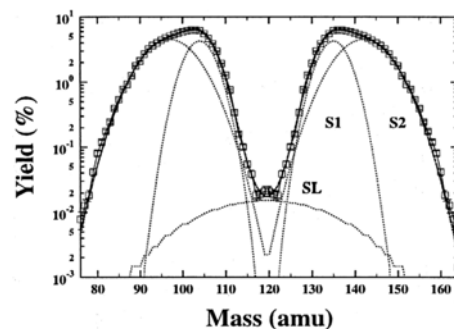
[7] Taken from F. Vivès *et al.*, "Investigation of the fission fragment properties of the reaction ^{238}U(n,f). at incident neutron energies up to 5.8 MeV", Nucl. Phys. **A662**, 63 (2000).

Absolute Yields (Fissions and fission fragments are counted independently.)
REACTION coding: `FY` in SF6; yield type is specified in SF5

Units: a code from Dictionary 25 with the dimension `FY` (*e.g.*, `PC/FIS`).

Relative Yields
REACTION Coding: same as above with `REL` in SF8

Units: `ARB-UNITS`

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

The fission product considered is coded under reaction SF7 when the product is gamma, neutron or light charged particle measured with fission fragment coded in reaction SF4, otherwise the fission product considered is coded either in reaction SF4 or as a variable in the data table. Note that fission neutron yield is always coded by `NU` in SF6.

Examples for product nuclei coded within the reaction code:

`(92-U-235(N,F)54-XE-124,IND,FY)`	independent yield of the fission product ^{124}Xe
`(92-U-235(N,F)54-XE-133-G,CUM,SIG)`	cumulative production cross section for the fission product ^{133g}Xe for coding product nuclei as variables in the DATA tables:
`(92-U-235(N,F)ELEM/MASS,IND,FY)`	independent yield of specified product nuclei which are given in the DATA table under the data headings element, mass and isomer (if applicable).
`(92-U-235(N,F)MASS,CHN,FY)`	chain yield of several mass numbers given in the DATA table under the data heading mass.
`(92-U-235(N,F),PR,NU)`	prompt fission neutron multiplicity
`(92-U-235(N,F)0-G-0,,FY)`	fission gamma yield
`(92-U-235(N,F)ELEM/MASS,PR,NU)`	prompt fission neutron multiplicity measured with product nuclei which are given in the DATA table under headings element, mass and isomer (if applicable).
`(92-U-235(N,F)MASS,,FY,G)`	fission gamma yield measured with product nuclei which are given in the DATA table under headings mass.

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

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

Absolute Cross Sections (Fission fragment production cross section)
The absolute yield may be also expressed by the fission fragment production cross section. The relation between the cross section and fission yield is $\sigma(Z,A) = FY(A,Z) \cdot \sigma_f$, where σ_f is the fission cross section of the reaction.

REACTION coding: SIG in SF6. Branch codes (SF5) for absolute yields may be used.

Units: a code from Dictionary 25 with the dimension B (*e.g.*, MB).

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: PRE in SF5.

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

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: SEC in SF5

Example: (…(N,F)MASS,SEC,FY)

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

REACTION coding: IND in SF5.

Example: (…(N,F)ELEM/MASS,IND,FY)

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

Experimental data for independent yields of the product (Z,A) include yields from the delayed-neutron emission of the product ($Z,A+1$) or from the β 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.

Cumulative Fission-Product Yield

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

REACTION coding: `CUM` in SF5.

Example: (…(N,F)ELEM/MASS,CUM,FY)

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

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

- independent yield from fission

- β decay from product ($Z-1,A$) in ground state

- β decay from product ($Z-1,A$) in a metastable state

- delayed-neutron emission from product ($Z,A+1$)

- isomeric transition from a metastable state of product (Z,A)

In addition, the product Z,A may be formed from neutron capture in the product ($Z,A-1$); this product is <u>not included</u> in the "cumulative yield".

Unlike cross sections, the fission product yield excluding feeding via decay of another nuclide but including partial feeding via isomeric transition is coded not with `M+` but with `CUM` in SF5.

Example:
   (92-U-235(N,F)51-SB-126-G,CUM,FY) if the yield is reported in products/fission.

   (92-U-235(N,F)51-SB-126-G,IND/M+,SIG) if the yield is reported in barn.

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 Formats Manual Chapter 6: **Variable Nucleus**.

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: CHN in SF5.

Example: (…(N,F)MASS,CHN,FY)

If the total chain yield is derived from cumulative yield by charge distribution correction assuming Gaussian distribution of independent variable, a code CHGDS must be coded under the keyword ANALYSIS. In the correction, unchanged charge distribution (UCD) assumption $Z_p = Z_f A/A_f$ is often used to determine Z_p, where A_f and Z_f are mass and atomic number of compound nucleus, and *A* is the fragment mass.

Fractional Yields

Ratios of fission-product yield to total chain yield *Y(A)*. The distribution of charge *Z* within a given fragment mass 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 FIY(*Z,A*) and fractional cumulative yield FCY(*Z,A*) of a fission product at the beta-minus decay side (after prompt neutron emission) is given by:

$$FIY(Z, A) = Y_{ind}(Z, A)/Y(A)$$

$$\sim \frac{1}{\sigma\sqrt{2\pi}} \int_{z-1/2}^{Z+1/2} \exp\left[-\left(z - Z_p\right)^2 / 2\sigma^2\right] dz \sim \frac{1}{\sqrt{c\pi}} \exp\left[-\left(z - Z_p\right)^2 / c\right]$$

$$FCY(Z, A) = Y_{cum}(Z, A)/Y(A) \sim \frac{1}{\sigma\sqrt{2\pi}} \int_{0}^{Z+1/2} \exp\left[-\left(z - Z_p\right)^2 / 2\sigma^2\right] dz$$

The parameters *c* and σ are width of the distributions related by $c \sim 2(\sigma^2+1/12)$.

For charge dispersion, fractional yields are defined only as ratios to total chain yield. For further information, see Wahl [3].

REACTION coding: FRC in SF8

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

```
REACTION    ((92-U-235(N,F)ELEM/MASS,IND,FY,,FRC)
REACTION    ((92-U-235(N,F)ELEM/MASS,CUM,FY,,FRC)
```

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).

Most Probable Mass
The most probable mass A_p is the mean mass for fragments specified in SF7 or with SF4=`ELEM`.

REACTION Coding: `AP` in SF6

Example: `(…(N,F),PRE,AP,HF)`
             Most probable mass of heavy primary fragments.

In the 2*v*2*E* method [4], both kinetic energies and velocities of two secondary fragments are measured and then primary fission fragment masses are determined.

In the 2*E* method [5], fragment masses are determined only from the kinetic energies of secondary fragments on the assumption that the kinetic energies are unchanged by prompt neutron emission. The mass of a primary fission fragment derived with this approximation is defined as **provisional mass** (pseudo mass).

REACTION Coding: `PRV` in SF5

Example: `(…(N,F),PRV,AP,HF)`
             Most probable provisional mass of heavy fragments

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

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

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

REACTION Coding: `CHG` in SF5.

Example: `(…(N,F)ELEM,CHG,FY)`

R-Values
The R-value is a double ratio of fission product count rates. The numerator is the activity of any fission product due to fissions in <u>any fissionable material</u> and neutron energy relative to the activity of a reference fission product (e.g., ^{99}Mo) from the same material at the same energy. The denominator is the activity ratio of the same two fission products in <u>a reference fissioning isotope</u> (e.g., ^{236}U) and neutron spectrum (e.g., neutrons in the room temperature).

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

Examples:
```
REACTION    (((94-PU-239(N,F)55-CS-137,CUM,FY,,FIS)/
            (94-PU-239(N,F)42-MO-99,CUM,FY,,FIS))//
            ((92-U-235(N,F)55-CS-137,CUM,FY,,MXW))
            (92-U-235(N,F)42-MO-99,CUM,FY,,MXW)))
RESULT      (RVAL)

REACTION    (((92-U-235(N,F)ELEM/MASS,CUM,FY,,FIS)/
            (92-U-235(N,F)42-MO-99,CUM,FY,,FIS))//
            ((92-U-235(N,F)ELEM/MASS,CUM,FY,,MXW))
            (92-U-235(N,F)42-MO-99,CUM,FY,,MXW)))
RESULT      (RVAL)
```

Yields of Correlated Fragment Pairs
The independent yield of a correlated pair is entered under the field headings such as ELEM1, MASS1, ELEM2 or MASS2.

REACTION coding: IND/CRN in SF5.

Examples:
(1) Independent yield of a correlated fragment pair

```
REACTION (...(N,F)ELEM/MASS,IND/CRN,FY)
...
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) Independent yield of a correlated fragment pair (ternary fission)

```
REACTION  (...(N,F)ELEM/MASS,IND/TER/CRN,FY)
...
COMMON
ELEM1       ELEM2       ELEM3       MASS3
NO-DIM      NO-DIM      NO-DIM      NO-DIM
 56.         42.         2.          4.
ENDCOMMON
DATA
MASS1       MASS2       DATA
NO-DIM      NO-DIM      PC/FIS
 138.        104.        ...
 138.        105.        ...
 ... ... ...
ENDDATA
```

(3) Charge yield of a correlated fragment pair (ternary fission)

```
REACTION  (...(N,F)ELEM,CHG/TER/CRN,FY)
...
ENDBIB
COMMON
ELEM1
NO-DIM
 2.
ENDCOMMON
DATA
ELEM2       DATA
NO-DIM      PC/FIS
 56.         ...
 56.         ...
 ... ... ...
ENDDATA
```

Note:
The mass and charge numbers are given without redundancy. For example, (1) MASS1 and MASS2 are not used when the mass of one fragment can be determined by the mass of the other fragment for the primary fission yield in a binary fission, (2) ELEM1 and ELEM2 are not used when the charge of one fragment can be determined by the charge of the other fragment for the charge yield in a binary fission.

Angular Differential Fission Yield
REACTION coding: FY/DA (or NU/DA for neutron) in SF6.

Units: a code from Dictionary 25 with the dimension FYDA (*e.g.*, PRT/FIS/SR)

Example: (98-CF-252(0,F),,NU/DA,N+LF)
Differential fission neutron multiplicity with respect to angle between the neutron and light fragment

Energy Differential Fission Yield
REACTION coding: `FY/DE` in SF6.

Units: a code from Dictionary 25 with the dimension `FYDE` (*e.g.*, `PC/FIS/MEV`)

Examples:
`(98-CF-252(0,F),PRE,FY/DE,FF/LF+HF)`
      Differential yield of fission fragments with respect to total kinetic energy

`(98-CF-252(0,F)MASS,PRE,FY/DE,LF+HF)`
      Differential yield of fission fragments specified with respect to total kinetic energy

The total kinetic energy is given under the heading `TKE`.

Double Differential Fission Yield
REACTION coding: `FY/DA/DE` (or `NU/DA/DE` for neutron)in SF6.

Units: a code from Dictionary 25 with the dimension `FYAE` (*e.g.*, `P/FS/MEVSR`)

Example: `(98-CF-252(0,F),,NU/DA/DE,N+LF)`
      Double differential fission neutron multiplicity with respect to the outgoing energy
      of neutron and angle between the neutron and light fragment

Average Kinetic Energy of a Fission Product
The particle code `FF`, `LF` or `HF` is coded under reaction SF7 when the kinetic energy is related to the bulk of fission fragments, light fission fragments or heavy fragments, respectively, otherwise the fission product considered is coded either in reaction SF4 or as a variable in the data table.

REACTION coding: `KE` in SF6 if one of the fission fragments is specified, otherwise parameter code `AKE` in SF6 with `FF`, `LF` or `HF` in SF7.

Units: a code from Dictionary 25 with the dimension `E` (*e.g.*, `KEV`)

Example:

`(---(-,F),,AKE,FF)`	Average kinetic energy of fission fragment.
`(---(-,F),,AKE,LF)`	Average kinetic energy of light fission fragment.
`(---(-,F)0-G-0,,KE)`	Average kinetic energy of fission gamma.
`(---(-,F)42-MO-99,,KE)`	Average kinetic energy of fission fragment ^{99}Mo.
`(---(-,F)MASS,SEC,KE)`	Average kinetic energy of secondary fission fragment of several mass numbers given in the DATA table under the data heading mass.
`(---(-,F)ELEM/MASS,PRE,KE)`	Average kinetic energy of specified product nuclei which are given in the DATA table under the data headings element, mass and isomer (if applicable).

`(--- (-,F)ELEM/MASS,,KE,G)`	Average kinetic energy of fission gamma measured with product nuclei given in the DATA table under the data headings element, mass and isomer (if applicable).

Average Total Kinetic Energy of Fission Products

Total kinetic energy is defined as the sum of the kinetic energies of fission fragments. The particle code `LF+HF` is always coded under reaction SF7. If one of the fission fragments is specified, it is coded either in reaction SF4 or as a variable in the data table.

REACTION coding: `KE` in SF6 if one of the fission fragments is specified, otherwise parameter code `AKE` in SF6 with `LF+HF` in SF7.

Example:

`(---(N,F),,AKE,LF+HF)`	Average total kinetic energy
`(---(-,F)ELEM/MASS,,KE,LF+HF)`	Average total kinetic energy for which one of fragment is specified in the DATA table under headings mass.

References

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

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

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

[4.] For example, I. Nishinaka *et al*., Phys. Rev. C **70**(2004)014609 (EXFOR E1905)

[5.] For example, H. W. Schmitt *et al*., Phys. Rev. **141**(1966)1146.

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 **Centre-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 * 4 pi 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.

The following pages contain examples of data to be coded in EXFOR. For a complete list of the fitting coefficient codes, see Dictionary 236.

Cosine Coefficients
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:

$\quad$ `DA,,COS` $\qquad$ = a_l (unit type `DA`, *e.g.*, `B/SR`) where:

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

$\quad$ `DA,,COS/RS` $\qquad$ = 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/RS0   = a_l (units NO-DIM) where:

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

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

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{d\sigma}{d\Omega}(E,90°)\sum_{l=1}^{n} a_l(E)\cos^l\theta$$

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

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

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/RS0 = a_l (units NO-DIM) where:

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{d\sigma}{d\Omega}(E,0°)\left[a_0 + \sum_{l=1}^{n} a_l(E)P_l(\cos\theta)\right]$$

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

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{d\sigma}{d\Omega}(E,90°)\left[a_0 + \sum_{l=1}^{n} a_l(E)P_l(\cos\theta)\right]$$

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   (*deleted, never used*)

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

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

Note: According to the orthogonal condition between $P_n(x)$ ($n \geq 1$) and $P_0(x)$,

$\int_{-1}^{1} P_n(x)P_0(x)\,dx = \int_{-1}^{1} P_n(x)\,dx = 0$ ($n \geq 1$).

Associated Legendre Polynomials of the First Kind
Definition: Coefficients obtained by fitting

- a differential (with respect to angle) cross section or polarization
- 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 plus a code indicating the exact representation used.

Representations:

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

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

Sine-Squared Coefficients

REACTION Coding: S2T in SF8 plus a code indicating the exact representation used.

Representations:

,DA,,,S2T   = a_l (unit type DA, *e.g.*, B/SR) where:
$$d\sigma/d\Omega(E,\theta) = a_0 + a_1 \sin^2(\theta) + a_2 \sin^2(2\theta)$$

,DA,,,S2T/RS0 = a_l (units NO-DIM) where:
$$d\sigma/d\Omega(E,\theta) = d\sigma/d\Omega(E, 0°) [1 + a_1 \sin^2(\theta) + a_2 \sin^2(2\theta)]$$

,DA,,,S2T/RSD = a_l (units NO-DIM) where:
$$d\sigma/d\Omega(E,\theta) = d\sigma/d\Omega(E, 90°) [a_0 + a_1 \sin^2(\theta) + a_2 \sin^2(2\theta)]$$
with $a_0 + a_1 = 1$

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 plus a code indicating the exact representation used.

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-squared 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. The flags are given as fixed point numbers (compare, EXFOR Formats Manual, page 4.2) and coded in the data table with the units `NO-DIM`. There are, currently, three types of flags in use in EXFOR.

Data Heading FLAG

Flags are used to link free-text comments in the BIB section with one of more lines in the data table.

The meaning of the flags is given under the 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 Formats Manual Chapter 7: FLAG). These flags are repeated under the data heading FLAG. There may be more than one field with the heading `FLAG` (see EXFOR Formats Manual Chapter 4: Multiple representations of independent variables).

`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.)
The data heading `FLAG` may not be used in the COMMON section.

Example:
```
  BIB
  ...
  FLAG        (1.) Resonance assignment uncertain
              (2.) Spin assignment uncertain
  ENDBIB
  NOCOMMON
  DATA
  DATA        DATA        FLAG
  MEV         MILLI-EV    NO-DIM
  756.         0.          1.
  876.         1.          2.
  ENDDATA
```

Flags must not be used to distinguish two distinct complemental results. For such cases, the multiple reaction formalism should be used, so that the two data sets can be recognized as distinct sets by processing software. An exception is compilation of complemental results where each dataset has only one data point and use of flags does not lose processing ability (*e.g.*, two data points distinguished by two sample foils having different chemical composition). See **Multiple Reaction Formalism**.

Data Heading DECAY-FLAG

Flags are used to link coded information on decay data in the BIB section with one or more lines in the data table.

The flags are given under the keyword DECAY-DATA or RAD-DET (see EXFOR Formats Manual Chapter 7: **DECAY-DATA** and **RAD-DET**) as the first field of the coded information, enclosed in parenthesis. These flags are then repeated in the DATA section under the data heading DECAY-FLAG.
 (See also **Decay Data**).

Example:
```
BIB
...
DECAY-DATA ((1.)60-ND-138,5.04HR,DG,328.,0.65)
           ((2.)60-ND-141,2.49HR,DG,....,....)
ENDBIB
…
DATA
ELEMENT     MASS        DATA        DECAY-FLAG
NO-DIM      NO-DIM      PC/FIS      NO-DIM
 60.        138.        ...          1.
 60.        140.        ...          2.
ENDDATA
```

Data Heading LVL-FLAG

Flags are used to link coded information on level properties in the BIB section with one or more lines in the data table.

The flags are given under the keyword LVL-PROP (see EXFOR Formats Manual Chapter 7: **LEVEL-PROP**) as the first field of coded information, enclosed in parenthesis. These flags are repeated in the DATA section under the data heading LVL-FLAG.

Example:
```
BIB
...
LEVEL-PROP ((1.)82-PB-206,E-LVL=0.,SPIN=0.,PARITY=+1.)
           ((2.)82-PB-206,E-LVL=0.803,SPIN=2.,PARITY=+1.)
ENDBIB
...
DATA
E-LVL       DATA        LVL-FLAG
MEV         MB          NO-DIM
 0.         ...          1.
 0.803      ...          2.
ENDDATA
```

Free Text

(See also EXFOR Formats Manual Chapter 3).

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.

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` or `U-235`; the *Z* value can be omitted. For natural elements only the symbol should be used, *e.g.*, `Fe`.

The text may include any character from the permitted character set; see EXFOR Formats Manual, page 1.3. Computer-compatible substitutes should be used where necessary according to the following substitution table:

° deg, degree, degrees	α alpha	β beta	γ gamma	μ mu, micro	θ theta
Ω Omega	$\overline{\nu}$ nu-bar	ħ h-bar	≤ <=	≥ >=	≈ ~

When μ is connected with a basic unit (e.g., μm, μA, μg), u may be used.

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. A double asterisk (**) may also be used for exponentiation.

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. 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. Continuation lines may start in column 12, however, 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 labelled, *e.g.*, "(comment by the compiler)'", and unambiguously separated from authors comments, *e.g.*, by including it between quotation marks. See also **Comment.**

Unnecessary use of hyphenation should be avoided as it cannot automatically be removed.

Example:
```
TITLE      Total cross sections in the kilovolt region by time-
           of-flight
```

Forbidden:
```
TITLE      Refined interpretation of Christiansen-filter experi-
           ments and neutron scattering lengths of the lead iso-
           topes
```

Fusion

Definition

For heavy ion reactions under suitable conditions, the incident projectile can overcome or tunnel the Coulomb barrier formed between projectile and target nuclei, and a composite system is formed. When nucleons which are contained in the interacting nuclei are fully equilibrated in the composite system with a time longer than those for the other reaction channel, the system reaches the condition called compound nucleus with a certain excitation energy, and thus the system does not have any memory in the entrance channel, it results in a compound nucleus in an excited state. This result is called <u>fusion</u>.

Evaporation Residue Production

A compound nucleus produced in the fusion reaction has two major de-excitation modes, <u>fission</u> and <u>particle evaporation</u>. The final product of the de-excitation process in which the nucleus undergoes the emission of one or several light particles (e.g. neutron, proton, alpha, γ- and X-rays) without interruption by fission is defined as <u>evaporation residue</u>.

Evaporation residues are clearly separated from the elastic-like products on the $E - \Delta E$ plot. Recoil mass separators are used especially when the cross-sections are small due to the competition against fission in order to make a clear separation from the projectile- and target-like nuclei. Alternative methods to detect evaporation residues are measurement of their characteristic γ-, X-rays or α decays.

REACTION coding: `FUS` in SF3

***Example*:**

`(…(8-O-16,FUS),,SIG)`	Fusion cross section
`(…(8-O-16,FUS),,SIG,ER)`	Evaporation residue (production) cross section
`(…(8-O-16,FUS)0-NN-1,,SIG)`	Production cross section of neutron from evaporation of compound nucleus

Quasi-Fission

The quasi-fission is defined as a process when the interacting two nuclei overcome or penetrate the Coulomb barrier and the system exchanges larger number of nucleons which is followed by disintegration into two fragments. The reaction time is far shorter than the decay time of a compound nucleus. In this case, the quasi-fission process is influenced by the entrance channel parameters such as mass asymmetry and bombarding energy between the colliding nuclei.

Do not mix up quasi-fission with <u>fast fission</u> which occurs when the Coulomb barrier disappears due to fast rotation of heavy systems (e.g. actinide beam) and the compound nucleus cannot be defined.

Because decomposition of fission into quasi-fission and fusion-fission is not straightforward, the yields for each fission are not separated from the measured spectra, and therefore only the sum of both contributions is compiled with the process code `F` under the keyword reaction SF3. (See **Fission**).

Deep Inelastic Scattering (Not presently compiled)
The case where the dinucleus system may or may not be formed, and a large part of the kinetic energy of the incident projectile is dumped into internal energy, but breaks apart after rotation, is called <u>deep inelastic scattering</u>.

Quasi-Elastic Scattering (Not presently compiled)
The case where the overlap of two nuclei is small and a few degrees of freedom are involved in the reaction is called <u>quasi-elastic scattering</u>. Quasi-elastic includes elastic scattering, inelastic scattering leading primarily to low excitation and nuclear transfer with small Q-value.

The reaction time decreases in the order of fusion, quasi-fission/deep inelastic scattering, quasi-elastic scattering, and Coulomb excitation; although the boundaries between these processes are not well defined. Especially, the boundary and order between quasi-fission and deep inelastic scattering is not very clear.

Sum Rule
The fusion cross section is the sum of fusion-fission cross section and evaporation residue cross section. The fission cross section is the sum of fusion-fission cross section plus quasi-fission cross section.

- In Light system ($Z_{targ} + Z_{proj} \leq 90$):
  Fission cross section is negligible.

- Intermediate system ($90 \leq Z_{targ} + Z_{proj}$ and $Z_{targ} \cdot Z_{proj} \leq 1600{-}1800$):
  Quasi-fission cross section is small

- Heavy system ($Z_{targ} \cdot Z_{proj} \geq 1600{-}1800$):
  The evaporation residue cross section is significantly small.

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Gamma Spectra

(See also **Partial Reactions**).

Neutron capture γ-ray spectra were not given high priority in the past, so data compilation was not required until 2004.

Intensities of Discrete Gamma Lines

REACTION coding: `SPC` in SF6.

Units: code from Dictionary 25 with the dimension `YLD` (*e.g.*, `PRT/INC`)

Example: `(…(N,G)…,,SPC)`

The γ-ray energies are discrete values coded under the data heading `E`. Relative measurements require the addition of the `REACTION` modifier `REL` and units `ARB-UNITS`.

Spectra of Continuous Gammas

1. Spectra in units of dimension `YLD` (*e.g.*, `PRT/INC`):

    REACTION coding: `PAR` in SF5, `MLT` or `PY` in SF6

    Examples:
    `(…(N,G)…,PAR,MLT)`
    `(…(N,X)0-G-0,PAR,PY)`

2. Spectra in units of dimension `DE` (*e.g.*, `MB/MEV`):

    REACTION coding: `DE` in SF6.

    Exemples:
    `(…(N,G)…,,DE)`
    `(…(N,X)0-G-0,,DE)`

The γ-ray energy is a continuous variable coded either as a range with data headings `E-MIN` and `E-MAX`, or with the mid-point of the energy bin given under the data heading `E` and the bin width given under `E-RSL`.

Partial Radiation Widths

REACTION coding: `WID` in SF6, `PAR` in SF5.

Units: code from Dictionary 25 with the dimension `E` (*e.g.*, `EV`)

Example: `(…(N,G),PAR,WID)`

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`,

- or the initial and final energy, coded under the headings `E-LVL-INI` and `E-LVL-FIN`.

General Quantity Modifiers

The general quantity modifiers (reaction SF8) are flagged with GENQ in Archive dictionary 34 and are listed in the beginning of Archive and TRANS dictionary 236. They can be added to any quantity without requiring an entry in Dictionary 236. Some of them require clarification:

A-modifier
Used when a measurement is made on a target of natural isotopic abundance and the reaction that produces the reaction product specified is known, but the data have not been corrected for the natural abundance of the target nuclide. The A modifier is used if the compiler is uncertain whether the data have been corrected for natural abundance of the target nuclide.

FCT-modifier
Used when the data has been multiplied by a defined factor not containing another quantity (*e.g.*, an arithmetic factor or a branching ratio). Explanatory free text is compulsory. If the factor contains another quantity, the appropriate reaction combination is to be used.

The modifier FCT <u>must not</u> be used for factors for which specific codes have been introduced (e.g., use modifier A for isotopic abundance). See also **Products**.

REL-modifier
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 even if authors state only that the data are given in "arbitrary units".

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

The modifier REL <u>must not</u> be used for factors for which specific codes have been introduced (e.g., use modifiers A and FCT for isotopic abundance and branching ratio, respectively).

RAW-modifier
Used for RAW (e.g. raw gamma spectra) or uncorrected data (e.g. data not corrected for background, efficiency). Compilers must **determine** whether appropriate corrections are made for the data (especially for transmission and reaction yield). The data unit ARB-UNITS is used when data are not normalized. (See also **Raw Data**).

MSC-modifier
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. The data unit ARB-UNITS is used when data are not normalized.

Notes:

a. Only one modifier of A, FCT, REL, RAW or MSC may be coded in SF8. If there are two or more applicable modifiers, the widest modifier (A < FCT < REL < RAW < MSC) is used.

   Example:

   - ,DA,,MSC for nuclear interaction part of dσ/dΩ in arbitrary unit

   - ,DE,,RAW for uncorrected neutron spectrum in arbitrary unit

   - ,RYL,,RAW for uncorrected reaction yield

b. If a data set contains several subsets or "curves", distinguished by different values of a certain parameter (e.g. incident energy, angle, level energy) and all given in arbitrary units (ARB-UNITS), they may be combined in one subentry only when they have a common normalization factor to an absolute value. The same applies to multiple reactions when they are all given in ARB-UNITS. In case of doubt, the data should go into separate subentries.

c. When the data unit ARB-UNITS is used, the subentry must contain two or more data points.

d. The data unit is always ARB-UNITS when the modifier REL is applied. The modifiers RAW and MSC may be used with ARB-UNITS or absolute data unit (e.g., MB).

AV-modifier
Used for data measured as a function of energy or angle and averaged over a given energy interval or angular range.

This modifier is also used for an averaged dataset compiled with the individual datasets before averaging. This distinction is important to avoid double counting due to use of averaged and individual datasets. They must not be compiled together as a single dataset.

Spectrum Average Modifiers

Used for data measured over a broad incident energy spectrum. For such data the spectrum modifiers used are BRA, BRS, EPI, FIS, FST, MXW, SDT, and SPA; see **Spectrum Average** for details. The spectrum average modifier must be coded before other general quantity modifiers.

Example:
   ,FY,,MXW/REL   Maxwellian averaged fission yield in arbitrary unit

Half-lives

Half-life values in EXFOR entries may define an isomeric state, or they may be basic parameters for deducing the data value from the experiment.

Half-lives may be coded in one of the following ways.

1. In the BIB section using the keyword DECAY-DATA (see **Decay Data**). This is the preferred method for the following:

   - 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.

2. When the half-life is a variable for the data presented, *e.g.*, delayed neutron groups, it must be coded in the COMMON or DATA section using data headings from Dictionary 24 with the family code 6, *e.g.*, HL, HL1[1]. These are linked to the BIB keyword HALF-LIFE (see below).

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.

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 Formats Manual, **ERR-ANALYS**.

Example:

```
BIB
REACTION    (…(N,F),DL/GRP,NU)
...
ENDBIB
NOCOMMON
DATA
HL          DATA
SEC         ...
...         ...
ENDDATA
```

See EXFOR Formats Manual Chapter 4 for the repetition of the data heading HL in coding half-lives in different units.

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. (See EXFOR Formats Manual Chapter 7: **HALF-LIFE**, for coding details).
The free text should include the source of the half-life value, if known.

---

[1] For the decay of a nucleus, the use of DECAY-DATA is preferred.

History

The keyword HISTORY is used to document the chronological handling of the work within a data centre. In particular, ***important*** alterations 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 Formats Manual Chapter 7: **HISTORY**, for coding details; see Dictionary 15 for list of codes).

History Code A
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 the code 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.*)

- any change in the validity of these numbers (*e.g.*, superseded by another data set.)

and must be explained in free text, too. This explanation should be specific, e.g. saying what change was made to the REACTION coding, rather than saying only 'REACTION corrected'.

All important alterations must be documented in the affected subentries, and be summarized (without repeating the details) in the common (first) subentry.

Less important alterations that the compiler wishes to document may be flagged by the code U.

History Code C
When a new entry is created, the date must be entered with the code C in the common subentry. When a new subentry is inserted to an existing entry, the date must be entered with the code C in the inserted subentry.

History Code D
When a data subentry is replaced with a NOSUBENT record, the date must be entered with the code D in the common subentry. The reason (*e.g.*, duplication) must always be explained in free text.

History Code R
When the compiler receives a data set from the author, the date must be entered with the history code R.

History Code U

Unimportant alterations need not be documented in all affected subentries. Compilers may summarize them in the common subentry.

HISTORY Coding in the Common Subentry

Detailed HISTORY information applying only to one particular subentry should not be copied to the common subentry, in line with the general rules concerning BIB information. However, an important alteration to one subentry constitutes at the same time an important alteration to the entry as such and should therefore be reflected in the HISTORY entry in the common subentry, so that users need not check every single subentry to see whether there was an important alteration.

The following alterations must be included in HISTORY of common subentry:
- Any important alteration in either common subentry itself or in any data subentry (without repeating the details). See above for what constitutes an important alteration.
- The deletion of a data subentry (with code D)
- The addition of a data subentry (with code C in the new subentry and code A in common subentry)
- If only unimportant changes were made, an entry with code U.

Examples:

```
HISTORY     (19671119R) Data received from author on tape
            (19690411C) AB
            (19691015R) Data on tape ND 1234 from Ribon.
            (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
            (19721130A) Some errors in data table corrected
            (19721130U) Spelling error in BIB corrected

            (20081123A) SF3: P -> INL
```
              This is better (because it is more specific) than
```
            (20081123A) REACTION corrected
```

```
            (20120728A) ERR-ANALYS added. Data corrected in
                        subentries 3 and 7.
```
              Example for the common subentry, documenting an alteration in the common subentry and summarizing alterations in data subentries. Details of corrections will be given in subentries 3 and 7.

```
            (20120905U) Spelling corrected in subentries 1,5,8.
```
              Unimportant corrections summarized in the common subentry

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Incident Beam Source
(See also Polarization)

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.*, when the neutron source is a reactor, 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 Particles

The incident projectile is coded in REACTION SF2 and the target is given in REACTION SF1. See also Inverse kinematics. Particles resulting from the REACTION to be defined are given in SF3 and SF4, see **Outgoing Particles**.

Incident-Projectile Energy

(See also **Spectrum Average**.)
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) =	$\dfrac{0.0818}{(\lambda/Å)^2}$	(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 WVE-LN with units angstrom[1].

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 Exchange Formats Manual Chapter 7: INC-SPECT).

Inverse Kinematics

If the incident energy is given in centre-of-mass energy (EN-CM) or laboratory incident energy per nucleon (MEV/A etc.), $A_{\text{targ}} \leq 4$ and $A_{\text{proj}} \geq 5$ in the experiment, and reversing the order of the target and the projectile does not change the numerical data, reaction must be coded using the tautology formalism. This helps users when inverse kinematics technique is applied. The target and projectile used in the experiment should be in the left hand side of REACTION. See also, **Centre-of-Mass System.**

Examples:

```
REACTION    ((1-H-2(9-F-19,P)9-F-20,,SIG)=
            (9-F-19(D,P)9-F-20,,SIG))
```
(Cross section of ^{2}H(^{19}F,p)^{20}F given at a given centre-of-mass energy.)
```
REACTION    ((1-H-1(9-F-19,EL)1-H-1,,DA,P)=
            (9-F-19(P,EL)9-F-19,,DA,RSD))
```

---

[1] Older data sets may use the data heading EN.

(Angular distribution of proton in ^{1}H(^{19}F,p)^{19}Li elastic scattering in the centre-of-mass system at a given centre-of-mass energy.)

```
REACTION    ((1-H-2(3-LI-9,EL)1-H-2,,DA)=
            (3-LI-9(D,EL)3-LI-9,,DA))
```

(Angular distribution of ^{9}Li in ^{2}H(^{9}Li,^{9}Li)^{2}H elastic scattering in the centre-of-mass system at a given centre-of-mass energy. See below[2].)
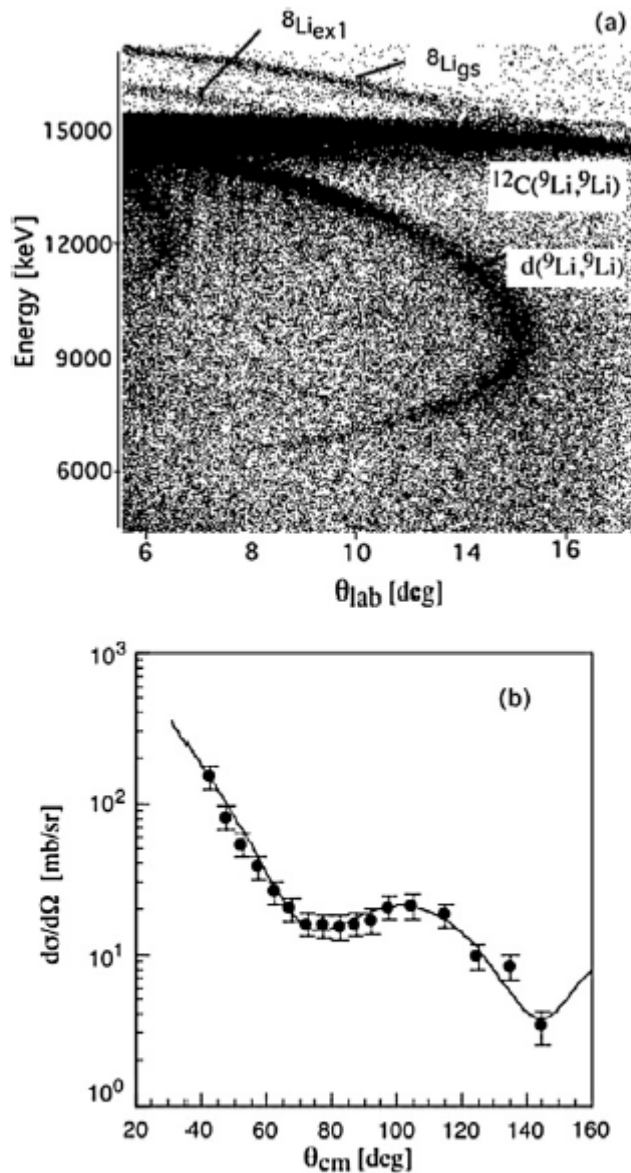
Fig. 2. (a) Laboratory energy vs scattering angle correlation for events in the S2 detector. (b) The elastic scattering ^{9}Li(d,d)^{9}Li angular distribution in the center-of-mass frame. The solid line shows the calculation with a phenomeno-logical optical potential.

---

[2] R. Kanungo *et al.*, Phys. Lett. **B660**(2008)26 (EXFOR C1604).

<u>Nuclear Quantities</u>

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 and Cumulative Data

The formation of a residual nucleus may occur:

- By direct (independent) formation, and/or

- Via isomeric transition,

- Via radioactive decay from other nuclides.

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

Branch code	Definition
IND	- Feeding via radioactive decay is absent or excluded. - To be used only with the parameter code FY.
CUM	- Feeding via radioactive decay of another nuclide (and via isomeric transition when it exists) is included. - To be used only with the process codes X or F.
(CUM)	- Uncertain if the formation via radioactive decay (and isomeric transition when it exists) is included. - To be used only with the process codes X or F.
M+	- Partial feeding via isomeric transition is included. - To be used only with the isomeric flag –G in SF4[3]. - Use CUM instead of M+ when feeding via decay of another nuclide is also included.
M-	- Feeding via isomeric transition exists, but is excluded. - To be used only with the isomeric flag –G in SF4 and CUM in SF5.
(M)	- Uncertain if the formation via isomeric transition is included. - To be used only with the isomeric flag –G in SF4[1]. - Use (CUM) instead of (M) when also uncertain if feeding via decay of another nuclide is included.

---

[3]Or another isomeric state code when the possible contribution of a higher state is considered, e.g. -M1 when M2 exists.

When a nuclide ^{A}J has an isomer, the cross section derived by observation of the ground state of nuclide ^{Ag}J (e.g., detection of β delayed gamma from ^{Ag}J) is

$$\sigma_{obs}\,(^{Ag}\text{J}\,)= \sigma_{dir}(^{Ag}\text{J}) + a\,\sigma_{dir}(^{Am}\text{J}) +\Sigma_i\,b_i\,\sigma_{pre,i}\,,$$
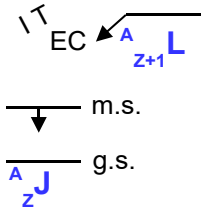
where "dir" is for the cross section for direct production of the nuclide wihtout decay, and "pre,i" is for contribution of the precursor i which may decay to ^{Ag}J. The figure shows a β$^+$+EC decay precursor ^{A}L contributing to the 3rd term. For simplicity we assume there is only one precursor, and

$$\sigma_{obs}\,(^{Ag}\text{J}\,)= \sigma_{dir}(^{Ag}\text{J}) + a\,\sigma_{dir}(^{Am}\text{J}) +b\,\sigma_{pre}.$$

The coefficients a and b may depend on decay data ($T_{1/2}$, IT transition probability etc.) as well as measurement conditions like cooling time. The combinations of SF4 and SF5 are summarized below for various conditions for a and b:

		No isomer exists, or full feeding via IT (No a or a=1)	IT absent (a=0)	IT exists, but excluded (a excl.)	Partial feeding via IT (0<a<1)	Uncertain if feeding via IT exists (a=?)
No feeding via decay of another nuclide (No b, b=0 or b excl.)	SF6≠FY	Z-S-A	Z-S-A-G	Z-S-A-G	Z-S-A-G,M+	Z-S-A-G,(M)
	SF6=FY	Z-S-A,IND	Z-S-A-G,IND	Z-S-A-G,IND	Z-S-A-G,IND/M+	Z-S-A-G,IND/(M)
Feeding via decay of another nuclide exists (0<b≤1)		Z-S-A,CUM	Z-S-A-G,CUM	Z-S-A-G,CUM/M-	Z-S-A-G,CUM	Z-S-A-G,CUM/(M)
Uncertain if feeding via decay of another nuclide exists (b=?)		Z-S-A,(CUM)	Z-S-A-G,(CUM)	Z-S-A-G,(CUM)/M-	Z-S-A-G,(CUM)/M+	Z-S-A-G,(CUM)

No: ^{Am}J or ^{A}L does not exist.

excl.: Contribution is excluded (*e.g.*, subtraction of its contribution, short cooling time, decay-curve analysis, on-line separation etc.)

=0: ^{Ag}J is physically shielded from ^{Am}J or ^{A}L (*e.g.*, stable state, no decay branch to ^{Ag}J, $T_{1/2}(^{Ag}\text{J})\ll T_{1/2}(^{Am}\text{J})$ or $T_{1/2}\,(^A\text{L})$).

=1:   Full contribution is expected (*e.g.*, 100% branching ratio to ^{Ag}J, long cooling time, $T_{1/2}(^{Ag}\text{J})\gg T_{1/2}(^{Am}\text{J})$ or $T_{1/2}\,(^A\text{L})$ etc.)

Nuclides Never Coded as the Reaction Product (SF4) with SF5=CUM

The following table lists all product nuclides which cannot be produced by beta decay, electron capture or delayed-neutron emission; cumulative production is not possible, and therefore REACTION SF5=CUM must not be used for these reaction products.

17-CL-36	33-AS-76	41-NB-94	47-AG-110	55-CS-130	69-TM-168
19-K-40	35-BR-78	43-TC-96	49-IN-112	63-EU-154	69-TM-170
21-SC-46	35-BR-80	43-TC-98	49-IN-114	65-TB-156	71-LU-176
25-MN-54	35-BR-82	45-RH-102	51-SB-120	65-TB-158	77-IR-192
27-CO-58	37-RB-84	45-RH-104	51-SB-122	65-TB-160	79-AU-196
29-CU-64	37-RB-86	47-AG-106	51-SB-124	67-HO-162	79-AU-198
33-AS-74	41-NB-92	47-AG-108	53-I-126	67-HO-164	

Examples:

(92-U-235(N,F)56-BA-140,IND,FY)	Independent formation only.
(42-MO-0(P,X)27-CO-62-G,CUM,SIG)	Cumulative cross section; includes formation via decay of 68-sec. ^{62}Fe and feeding from 13.91-min. ^{62}Co isomer.
(42-MO-0(P,X)27-CO-62-G,CUM/M+,SIG)	Cumulative cross section; includes formation via decay of 68-sec. ^{62}Fe and only partial feeding from 13.91-min. ^{62}Co isomer. I.e., CUM/M+ includes less than CUM alone.
(42-MO-0(P,X)27-CO-62-G,CUM/M-,SIG)	Cumulative cross section that includes formation via decay of 68-sec. ^{62}Fe, but excludes feeding from 13.91-min. ^{62}Co isomer.

Conditional Cumulative Cross Section

This term (also known as "supracumulative cross section") is sometimes used for the situation that the observed cross section is bigger than the 'actual' cumulative cross section because production of the measured nuclide continues after the end of irradiation. The conditional cumulative cross section determined by the ground state activity measured after complete decay of the metastable state is $\sigma_{dir}(^{Ag}J) + a\, \sigma_{dir}(^{Am}J)$ with $a = f\, \lambda_m/(\lambda_m - \lambda_g)$ when $\lambda_g < \lambda_m$ and there is no precursor nuclide (f: isomeric transition probability). It approximate the 'actual' cumulative cross section when $\sigma_{dir}(^{Ag}J) \gg f\, \sigma_{dir}(^{Am}J)$ or $\lambda_g \ll \lambda_m$. Many relevant publications do not make this distinction and no special EXFOR code for it exists so far; if such data are compiled, explanation in free text is needed.

See e.g., Yu.E. Titarenko *et al.*, Phys. Rev. C**65**(2002)064610, and INDC(CCP)-434, pp. 7-15 (2003).

Independent Variables

Independent variables are identified by a Family Flag in Dictionary 24 (See EXFOR/CINDA Dictionary Manual). A given set of independent variables are required depending on the Quantity given in the REACTION string.[4]

Only those independent variable data headings specified in the EXFOR Exchange Formats Manual Chapter 4 may be repeated (*e.g.*, angles in degrees and minutes).

In general, the same values of a set of independent variables (*e.g.*, energy, angle) will not occur more than once. If there is a repetition of a measurement for a given independent variable *(e.g.*, at a given energy), the reason should be given in free text in the BIB section. Otherwise, it may be interpreted as a data entry error or as an inadvertent duplication.

In the case the duplicated measurement is a function of two or more independent variables, flags should be used to link those data given for the second (or third, *etc*.) variable.

Example:

```
BIB
...
FLAG        (1.) First set of measurements
            (2.) Second set of measurements
...
DATA
EN          ANG         DATA        FLAG
MEV         ADEG        MB/SR       NO-DIM
 1.          10.         ...          1.
 1.          10.         ...          2.
 1.          20.         ...          1.
 1.          20.         ...          2.
 1.          30.         ...          1.
 1.          30.         ...          2.
...
```

Flags should also be used in the case where data are a function of only one independent variable, if it is known that the data were measured as two or more overlapping sets and the data from each set can be identified. For example, data are often measured in two experiments for different energy ranges with overlapping energy.

Note:
Alternately, if data are measured in two experiments for different energy ranges and the experimental conditions differ, the data may better be coded as separate data sets.

---

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

Independent Variables in Reaction Combination

1) Each term of a reaction combination may be function of different variables. The terms must have the same value for the independent variables they have in common. One term may be a function of independent variable not shared by the other terms in the ratio. **The variables of a ratio expressed by the separator "/"** are coded using extensions without the extensions -NM and -DN.

   Examples:
   `((5-B-10(N,A)3-LI-7,PAR,SIG,,MXW)*(5-B-10(N,A)3-LI-7,,SIG,,MXW))`
   Only the first term refers to the secondary energy as an independent variable, which is coded under, e.g., `E-LVL`.

   `((5-B-10(N,A)3-LI-7,PAR,SIG,,MXW)/(5-B-10(N,A)3-LI-7,,SIG,,MXW))`
   Only the numerator refers to the secondary energy as an independent variable, which is coded under, e.g., `E-LVL`.

2) If the terms of a reaction ratio have different values of the same independent variable they must be coded using the separator "//" and headings with the extensions -NM and -DN are used for the independent variable.

   Example:
   `((5-B-10(N,A)3-LI-7,PAR,SIG,,MXW)//`
   `(5-B-10(N,A)3-LI-7,PAR,SIG,,MXW))`
   Both numerator and denominator refer to the secondary energy as an independent variable, which are coded under, e.g., `E-LVL-NM` and `E-LVL-DN`.

Institute

The laboratories, institutes, or universities with which all authors are 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 Exchange Formats Manual Chapter 7: **INSTITUTE**, for coding details). If a data set has several references with varying institutes, all institutes may be entered.

Institutes not listed in the dictionary
If an institute is given in a reference which does not yet exist in the institute dictionary (Dictionary 3), normally a new dictionary code will be proposed according to the format described in the EXFOR/CINDA Dictionary Manual. Proposal of a new institute code is mandatory if this is the institute of the facility.

If the new institute is not the institute of the facility, it is possible to use the country code instead (*e.g.* 1USAUSA) with the institute's name in free text. This option is recommended if the institute is not expected to produce more experimental publications in the future. If there are more than one institute codes given and not all of them are country codes, a country code must not be the first institute.

Institute of facility
If an itinerant group used the facility (i.e. no author of the facility's institute is included), it is sufficient to code this institute under the keyword FACILITY (see EXFOR Formats Manual, p. 7.11).

Compilation responsibility if institutes from different service areas are involved
In case of doubt, the other affected center and NDS must be contacted before compilation to avoid duplication.

Separation of entries by areas
If separate experiments from different service areas with clearly separated results are reported in the same paper, the results should be compiled in separate entries. This applies also if the data were measured at one laboratory, and, subsequently, analysed at another laboratory and the laboratories are in different areas.

In all such cases cross references to the other entry must be given using the REL-REF code O with a free text explanation (see also **REFERENCE**).

Isobaric Analogue Resonances

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.
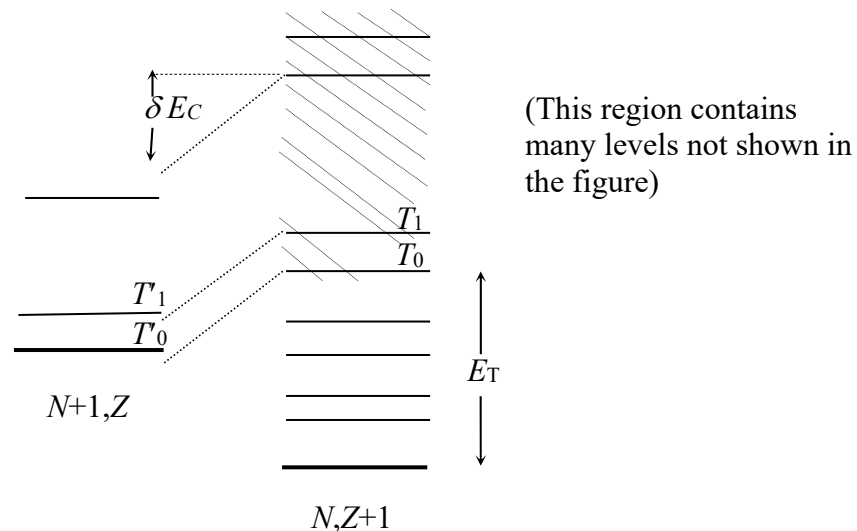
where T_0 is the isobaric analog of the ground state T'_0 of $(N+1,Z)$,
T_1 is the analog of the first excited state T'_1, *etc.*
T_0, T_1, *etc.*, are not necessarily adjacent levels.
E_T is the excitation energy of the $T = T_0$ state.

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 IAS-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 greater than ~0.1 sec.

A ***metastable state*** is an excited state having a half-life of the order of 0.1 seconds or longer. The term 'isomeric states' refers to the ground and all known metastable states.

Coding
Where a nucleus has a known metastable state, (1) the target nucleus in an isomeric state, and (2) an isomeric state populated by direct production as well as by transition of higher levels to the isomeric state are indicated by an isomer code following the isotope code,[5] e.g., `95-AM-242-M1` (See EXFOR Exchange Formats Manual Chapter 6: Coding of nuclides and compounds).

If the isomeric state is produced only directly, without transition from higher levels, the isomer code must not be used. Instead, the reaction is to be coded with SF5=`PAR`.

Isomeric states are coded by entering the isomer code in REACTION SF4. Sums and ratios are given algebraically.

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

Isomer codes 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 Chapter 6: **Variable Nucleus**. These are linked to the decay information by the use of flags given using the field heading DECAY-FLAG (see **Flags**).

Assignment of Isomeric States
The assignment of isomeric states for a given nucleus may vary in the literature according to the growing knowledge of a particular nucleus. The compiler should assign the isomer code based on the current knowledge of the structure and decay data while the decay data given by the authors must be kept. For some nuclides, two isomers are known today but it is not known which one is the ground state; in this case, the compiler may decide what isomer extension to use in the particular subentry (G or M). In order to define an isomeric state uniquely, at least the half-life for the isomer must be coded (see **Decay Data**). Any other information about its decay properties, if given by the author, should be included under the keyword DECAY-DATA.

---

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

Examples:

```
BIB
REACTION  1(39-Y-89(N,2N)39-Y-88-L1,,SIG)
          2(39-Y-89(N,2N)39-Y-88-L2,,SIG)
          G(39-Y-89(N,2N)39-Y-88-G,,SIG)
SAMPLE      99.99% enriched Y2O3 sample.
DECAY-DATA1(39-Y-88-L1,320.MICROSEC,DG,392.7)
          2(39-Y-88-L2,14.6MSEC,DG,232.2,,DG,442.8)
          G(39-Y-88-G,107.D,DG,898.,,DG,1836.)
ENDBIB

BIB
REACTION  (81-TL-203(N,2N)81-TL-202-L/G,,SIG/RAT)
SAMPLE     99.99% enriched TlCl sample.
DECAY-DATA (81-TL-202-L,536.MICROSEC,DG,459.6,,DG,490.7)
           (81-TL-202-G,12.5D,DG,439.7,,DG,969.6)
ENDBIB
```

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 <u>only for partial feeding</u> from a higher isomeric state. Where 100% of the isomeric decay is included the sum reaction should be coded, *e.g.*, G+M1.

Quasi-Metastable States (states with a measurable half-life less than 0.1 seconds).

When activation data are measured for quasi-metastable states, that is, the half-life and decay radiations are measured for the level, the excited state is specified using an isomer extension of the type L, L1, *etc*., in the isomer code in REACTION SF4. The significance of the extension is simply to link the levels with the decay data, and would be significant only within a given data set.

See also **Independent and Cumulative Data.**

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Kerma Factors (New)

Definition: Kerma (Kinetic energy released per unit mass) is the sum of the kinetic energies of the secondary (outgoing and residual) charged particles, per sample mass, from a reaction induced by an uncharged particle projectile. It is related to the energy differential cross section by

$$K = N\,\Phi\,\Sigma_i \int dE_i\, E_i\, (d\sigma/dE_i)$$

where N is the number of atom per unit mass, Φ is the incident particle flux, and E_i is the energy of the i-th secondary charged particle. The quantity $k = K/\Phi$ is known as the **kerma factor** (also known as kerma coefficient).

The kerma factor can be determined

1) directly by measurement of the absorbed dose and flux, or

2) indirectly by measurement of the energy differential cross section.

Typical units of kerma factor in articles are $fGy*m^2 = 10^{15}$ J/kg m^2 (SI base units) and rad $cm^2 = erg/g\ cm^2$ (CGS base units). They are related by 1 $fGy*m^2 = 10^9$ rad cm^2.

REACTION Coding: KER in SF6.

Units: a code from Dictionary 25 with the dimension KER (*e.g.*, FGY*M2).

Examples:

(…(N,TOT),,KER)   kerma factor summed over all secondary charged particles

(…(N,X)1-H-1,,KER) kerma factor for secondary protons

Reference

U.J. Schrewe et al., Phys. Med. Biol. **45** (2000) 651.

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Light-Nuclei 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 Formats Manual Chapter 6: **Reaction field**.

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

Example:
In the reaction ^{6}Li(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)`

In resonance parameters, the reaction product (*i.e.,* the heaviest of the products) is not coded.

Example:
In the reaction ^{6}Li(n,tα), $\Gamma_t=\Gamma_\alpha$ is coded as `(3-LI-6(N,T),,WID)` even if the width is determined by detection of alpha particles.

The ground states of the following nuclei (Z≤6) are unstable against prompt particle decay, and normally not coded in REACTION:

2-HE-5	(Γ=0.6 MeV)	4-BE-8	(Γ= 6.8 eV)	3-LI-10	(Γ=1.2 MeV)
3-LI-5	(Γ=1.5 MeV)	6-C -8	(Γ=230 keV)	4-BE-13	(Γ=0.9 MeV)
4-BE-6	(Γ= 92 keV)	2-HE-9	(Γ=0.30 MeV)	5-B-16	($T_{1/2}$ < 200 ps)
2-HE-7	(Γ=160 keV)	5-B-9	(Γ=0.54 keV)		
5-B-7	(Γ=1.4 MeV)	2-HE-10	(Γ=0.3 MeV)		

Breakup Reactions

General rule
When a reaction proceeds through an intermediate nucleus that is unstable against emission of particles (*e.g.* n, p, d, t, α), the reaction is coded with the products of the breakup as the output particles.

> ***Example***: The cross section for ^{9}Be(n,2n 2α) is compiled as:
>
> REACTION   (4-BE-9(N,2N+A)2-HE-4,,SIG)

Exception

The ground states of the following nuclides have been identified as unstable:
- ^{5}He → n + d

- $^5\text{Li} \rightarrow p + \alpha$
- $^6\text{Be} \rightarrow 2p + \alpha$
- $^8\text{Be} \rightarrow 2\alpha$
- $^9\text{B} \rightarrow p + 2\alpha$

Also, some nuclides have a particle decay threshold

Example: $^{12}\text{C} \rightarrow 3\ \alpha$; threshold $E_x = 7.65$ MeV

Therefore, an exception is made to the above general rule for only those cases *where the reaction is not a function of the final product* and when one or both of the following is true:

- The reaction is a function of the unstable product, e.g., proceeds through a given excited state of the unstable product.

- The unstable product is identified unambiguously, and the data given is for only the reaction that proceeds through that reaction channel, e.g., where the unstable product is measured with a track detector.

In the above cases, the intermediate nucleus is coded in SF4. The branch code PAR is used to specify the level of the intermediate nucleus. The definition of the nucleus using the BIB keyword EN-SEC is optional.

Example:

$^9\text{Be}(n,2n)^8\text{Be}(g.s.) \rightarrow 2\alpha$

```
REACTION    (4-BE-9(N,2N)4-BE-8,PAR,SIG)
```

However, if the reaction is a function of one or more of the final products it must be coded with the final products in SF3 and SF4. In this case, if the reaction is also a function of a level the intermediate nucleus, the intermediate state is specified using the branch code ISP. The intermediate nucleus must be given under the BIB keyword EN-SEC.

Example:

$^{12}\text{C}(^{14}\text{N},d)^{24}\text{Mg}^* \rightarrow \alpha + {}^{20}\text{Ne}(g.s.)$
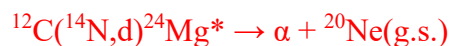
```
REACTION    (6-C-12(7-N-14,D+A)10-NE-20,ISP/PAR,……
…
EN-SEC      (E-LVL1,12-MG-24)
            (E-LVL2,10-NE-20)
```

Neutron Reactions

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 tables should be used in EXFOR for the light-nuclei neutron-induced reactions, except when the branch code SEQ is given (see under **Particles**).

A further exception is made for intermediate nuclei that are unstable and break up with the emission of particle (*e.g.* n, p, α). In this case, if the data are given for only that portion of the reaction that proceeds through the intermediate nucleus, and <u>if contributions to all decay branches of the intermediate state are included into the data</u>, the intermediate nucleus is given as the product of the reaction.

Example:
There are two contributions to ^{6}Li(n,ndα):

      1. n + ^{6}Li → d + ^{5}He then ^{5}He → n+α (sequential decay through ^{5}He).

      2. n + ^{6}Li → n + d + α (direct three body break up).

and the sum of two contributions is coded as `3-LI-6(N,N+D)2-HE-4`. However, where the experiment identifies the intermediate state ^{5}He and excludes direct three body break up contribution, the reaction should be coded as: `3-LI-6(N,D)2-HE-5`.

In addition, only scattering processes as well as sum cross sections, such as absorption, nonelastic, charged-particles emission, *etc.*, are defined for these nuclei.

Note:
n-p scattering is always coded as `1-H-1(N,EL)1-H-1`.

List of REACTION codes for neutron induced reaction with Z≤6 target nuclides

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,2d)	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`

---

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

Reaction	Threshold (MeV)[1]	REACTION
^{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,2n2α)	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
^{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

---

[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.

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

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Reaction	Threshold (MeV)[1]	REACTION
^{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

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Measurement Techniques

Physics information on experimental measurement techniques is entered under several information-identifier keywords (see EXFOR Formats Manual Chapter 7 for coding rules).

FACILITY is used to identify the main apparatus or machine used in the experiment, *e.g.*, reactor or cyclotron.

The institute at which the facility resides may be entered, if known, following the facility code. This is especially important if there is more than one institute associated with the experiment.

Example: `(LINAC,1USAORL)`

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

INC-SOURCE is used to enter the source of the incident-projectile beam used in the experiment (see Incident Beam 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 under Incident Projectile Energy).

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

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

For coincidence measurements, the code `COIN` may be entered followed by the detectors used in coincidence.

Example: `(COIN,NAICR,SILI)`

For telescopes or spectrometers, the code `TELES` or the code for the spectrometer may be entered followed by the component detectors.

Examples: `(TELES,PROPC,SCIN)`
`(MAGSP,MWDC,SCIN)`

When the spectrometer system is complex and cannot be expressed by a set of detector codes clearly (e.g., high-energy experiment, radioisotope beam experiment), the code `SPEC` (large spectrometer system) may be used instead of the set of detector codes.

---

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

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

METHOD[1] describes the experimental technique(s) employed in the experiment, *e.g.*, activation. Information that can be entered under one of the more specific keywords, above, should not be entered under 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 coding example, below.

If uncertainties are given, they are entered in the COMMON or DATA section using the headings MISC1-ERR, MISC2-ERR, *etc*. The data heading is not coded under MISC-COL, but the source of the uncertainties should be given, if known.

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.

Example:

```
BIB
...
MISC-COL    (MISC1)  Comment describing contents of 1st
                     miscellaneous field and its uncertainty,
                     and the units in which it is given.
            (MISC2)  Comment describing contents of 2nd
                     miscellaneous field
ENDBIB
NOCOMMON
DATA
EN          DATA       MISC1       MISC1-ERR  MISC2
 ...        ...        ...         ...        ...
ENDDATA
```

It follows that MISC may not be used for
:

- any data defined under REACTION,

- information for which a data heading keyword has been defined,

- independent variables.

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.

The multilevel formalism generally used is Reich-Moore. Vogt, and Adler-Adler have also been used in the past. All three are derived from the R-matrix theory of Wigner and Eisenbud.

Resonance Energy
Resonance energy (E_0) is coded in EXFOR in one 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 (see codes under parameter type).

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 (see codes under parameter type). 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 Parameters
In the **Reich-Moore** and **Vogt** 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 as follows:

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

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

$$
\begin{aligned}
\text{where:} \quad \lambda_n &= \quad \text{neutron wave length in the center-of-mass system} \\
g &= \quad \text{statistical weight factor} \\
\delta_{nc} &= \quad \text{Kronecker delta}
\end{aligned}
$$
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:

$$
R = \sum_\lambda \frac{\vec{\gamma}_\lambda \times \vec{\gamma}_\lambda}{E_\gamma - E}
$$

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: $L^0 = L\text{-}B$; 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.

Reich-Moore Formalism [2]

The Reich-Moore formalism involves summation over levels and a matrix inversion with respect to channels. If the target nuclide is non-fissile and only the elastic scattering channel remains, the R-matrix becomes a 1×1 matrix. This is just a function known as the **R-function**, a special case of the Reich-Moore formalism.

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

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

The neutron 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:

Code	Symbol	Description
`(N,0),,EN`	E_λ	Resonance energy[2]; 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`	$\Gamma_{\lambda f1}$	[3]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

---

[2]The resonance energy, if not assigned by the author, is entered in the data table using the heading `EN-RES`.
[3] 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 Formalism[4][3]

The Vogt Formalism 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-RL^0) leads to the definition of the level matrix A, which is 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: $\Gamma_{\lambda n}^0 = 2g\Gamma_{\lambda n}E^{1/2}$

Vogt Resonance Parameters are entered under the quantity codes:

`(N,0),,EN`	E	Resonance energy[5]; 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,,VGT`	$\Gamma_{\lambda n}^l$	Reduced neutron width, where l = orbital angular momentum; units of energy × 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 Formalism [6][4]

The Adler-Adler formalism 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:

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

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

---

[4] Seldom used

[5] The resonance energy, if not assigned by the author, is entered in the data table using the heading `EN-RES`

[6] Seldom used.

Adler-Adler coefficients are entered under the quantity codes:

`(…,0),,EN,,AA`	μ_k	Resonance energy[7]; 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

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

$$\Gamma = 2\,\gamma^{\,2}\,P$$

where: P = penetrability

Reaction coding: `(…,WID/RED,,RMT)`

Units: code from Dictionary 25 with the dimension `E` (*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: code from Dictionary 25 with the dimension `RE` (*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.

---

[7] The resonance energy, if not assigned by the author, is entered in the data table under the heading `MU-ADLER`.

Multiple Reaction Formalism

At present, the following classes of data may be coded using **Multiple Reaction Formalism**[8] (compare EXFOR Formats Manual Chapter 6). In all cases, SF1 and SF2 of the REACTION string must be the same. See *Example* on following page.

1. Resonance parameters of the same isotope and target, determined in the same analysis;

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; the appropriate status code is entered with the relevant pointer. Some examples are:

- absolute cross sections deduced from ratio measurements using standard reference data.

- S-factors deduced from cross sections.

Example:
```
REACTION  1((94-PU-239(N,F),,SIG)/((92-U-235(N,F),,SIG))
          2(94-PU-239(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 a 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.) Data from different reaction mechanisms not measured directly but deduced by author (see **Reaction Mechanisms** for defined mechanisms).

c) High energy and spallation parts of the same reactions

d) Binary and ternary parts for fission measured.

e) Light and heavy fragment parts for a given fission yield.

---

[8] Please submit a LEXFOR entry for any additional types of data before transmitting these data.

Example:
```
REACTION  M(39-Y-89(N,INL)39-Y-89-M,,SIG)
          G(39-Y-89(N,INL)39-Y-89-G,,SIG)
ENDBIB
NOCOMMON
DATA
EN        DATA      GDATA      M
 ...       ...       ...
ENDDATA
```

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

Example:
```
REACTION   1(24-CR-52(P,2N)25-MN-52,,SIG,,,DERIV…)
           2(24-CR-52(P,3N)25-MN-51,,SIG,,,DERIV
ANALYSIS   Derived by decomposition of the measured (p,xn) spectra by
           using the statistical model
```

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)
ENDBIB
NOCOMMON
DATA
EN        DATA      1DATA      2
 ...       ...       ...
ENDDATA
```

6. <u>Components of polarization for a given reaction</u> measured in a given experiment.

Examples:
```
REACTION  1(…(P,A)…,,POL/DA,,VAP)
          2(…(P,A)…,20,POL/DA,,TAP)
          3(…(P,A)…,21,POL/DA,,TAP)
          4(…(P,A)…,22,POL/DA,,TAP)

REACTION  1(…(N,P)…,,POL/DA)
          2(…(N,P)…,,POL/DA,,ANA)
```

Where only the product nucleus is variable for a given reaction, (*i.e.*, for the REACTION keyword, SF1, SF2 are constant and subfield 3 is either X or F) the **Variable Nucleus Formalism** may be used (see EXFOR Formats Manual Chapter 6).

Multiplicity and Product Yield
(See also **Fission Yields, Neutron Yield, Thick- and Thin-Target Yields**)

Definition
Number of particles or nuclei (per the reaction), except for yield from fission (Fission yield). The quantity is referred to **multiplicity** when the particle considered is in REACTION SF3 or SF7, and **product yield** when the particle considered is in REACTION SF4.

REACTION Coding: `,MLT` (for multiplicities) or `,PY` (for product yields)

Units: a code from Dictionary 25 with the dimension `MLT`. The unit code `PRT/REAC` and its derivative for multiplicities and `PRD/REAC` and its derivative for product yields.

Examples:

`(…(P,A)…,,MLT,G)`	γ yield from a (p,αγ) reaction
`(…(N,G)…,,MLT)`	γ yield from a neutron capture
`(…(P,X)0-G-0,,PY)`	γ yield from a proton induced reaction

See LEXFOR **Thick target yields** for the number of particles or nuclei per incident particle.

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, and the energy range of the selected particles must be entered in the COMMON or DATA section. A common experimental occurrence of this will be limits on the energies of the particle detected.

Example:
Multiplicity of capture gamma from the capture state to the ground state (direct capture)

```
BIB
REACTION    (6-C-12(N,G)6-C-13,PAR,MLT)
...
ENDBIB
COMMON
E-LVL
MEV
 0.
NOCOMMON
DATA
EN          DATA
 ...         ...
 ENDDATA
```

Authors often deduce the <u>multiplicities as a function of spin or momentum transfer</u>; these deduced results should not be compiled as 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 fission, see **Neutron Yield**.

Multipolarity

__Definition__

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

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

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

Examples:

1. Electric dipole component of photo-neutron cross section

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

2. Magnetic quadrupole component of photo-absorption cross section

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

3. E1 and E2 components of alpha capture cross sections and S-factors

```
REACTION  1(6-C-12(A,G)8-O-16,EP/PAR,SIG)
          2(6-C-12(A,G)8-O-16,EP/PAR,SIG,,SFC)
...
NO-COMMON
DATA                    6          4
EN-CM       POLAR       DATA      1DATA      2
MEV         NO-DIM      NB         B*KEV
 ...         1.          ...        ...        ...        ...
 ...         2.          ...        ...        ...        ...
ENDDATA                 6          0
```

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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.

Nonelastic cross section is also called as **reaction cross section**.

REACTION Coding: Process code NON in SF3.

Example: (…(N,NON),,SIG)   Nonelastic cross section

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

Eta (η)

Definition: The average neutron yield per nonelastic event for neutron-induced reactions:

$$\eta = \frac{\sum_i n_i \sigma_i}{\sum_i \sigma_i} = \frac{\sum_i n_i \sigma_i}{\sigma_{\text{nonelastic}}}$$

where the summation is taken over all nonelastic channels, and n_i is the average neutron multiplicity of the i-th nonelastic channel. For example, $n_i = 0$ for (n,γ), (n,p), (n,α); =1 for (n,n'), (n,np), (n,nα); =2 for (n,2n); $\overline{\nu} =$ for (n,f).

For the 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:

$$\eta = \overline{\nu}\, \frac{\sigma_f}{\sigma_{\text{abs}}} = \overline{\nu}\, \frac{\sigma_f}{\sigma_f + \sigma_\gamma}$$

REACTION Coding: NON or ABS in SF3, and ETA in SF6.

Units: a code from Dictionary 25 with the dimension YLD (*e.g.*, PRT/REAC)

Examples:

   (N,NON),,ETA)   η, in general

   (N,ABS),,ETA)   η below (n,n') threshold

   (N,ABS),,ETA,,RES)   η at resonance below (n,n') threshold

For further related quantity codes see Dictionary 236.

References
[1] P.P. Lebedev et al., J. Nucl. Energy A **11**(1959) 39.
[2] E.R. Graves et al., Phys. Rev. **97** (1955) 1205.

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).

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)

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

Spontaneous Fission
See **Fission**.

Level-Density Parameter
Level-density parameter *a* is proportional to single-particle level spacing *g* at top of Fermi-sea (Fermi energy) in the Fermi-gas model of the nucleus, in specified formalism. In Fermi-gas model, $a = (\pi^2/6)\, g$.

REACTION Coding: LDP in SF6.

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.

Nuclear Temperature
Temperature derived from Fermi-gas model of the nucleus. In Fermi-gas model, it is related to excitation level energy as $E_x = aT^2$

REACTION Coding: TEM in SF6 (Parameter).

Example: (…(0,0),,TEM)

Level Density

Level density derived from gamma spectra or particle emission spectra. It is a function of excitation energy, and proportional to $\exp(2\sqrt{aE_x})$ in the Fermi-gas model. The reaction measured for derivation of the level density must be given in free text with an appropriate code under the keyword ANALYSIS (e.g., PGS, PES).

REACTION Coding: LD in SF6 (Parameter).

Example: (…(0,0),,LD)

Spin-Cut-Off Factor

Spin-cut-off factor is defined as $\sqrt{aE_x}$.

REACTION Coding: SCO in SF6 (Parameter).

Example: (…(0,0),,SCO)

Nuclear Resonance Fluorescence

Nuclear resonance fluorescence (NRF) is emission of photons following the photon absorption by the target nuclide which leads to the excitation of a strong resonance level. The excited nucleus decays back to the ground state either by emission of a single photon or cascade of several photons. This is equivalent to elastic or inelastic scattering of photon if the emission corresponds to transition from the initially excited resonance level to the ground state or to another level, respectively. Incident photons are usually produced by bremsstrahlung source which has continuous spectrum up to the end-point energy E_0, therefore several levels may be excited simultaneously. . The incident photons may also be produced by quasi-monoenergetic gamma-ray sources, with the spectrum typically defined as a Gaussian with a centroid energy of E (~ a few MeV), and width W (~ 100 keV). Several resonances may still be excited by such sources, but with greater selectivity.
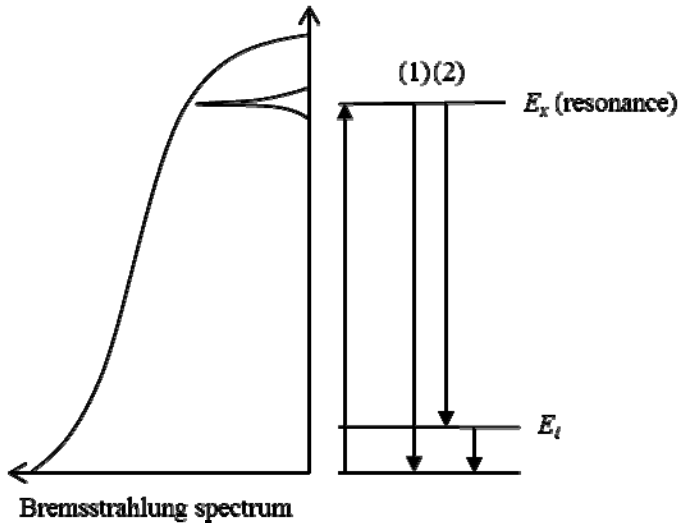
Figure: Schematic depiction of NRF. On the left side the Bremsstrahlung spectrum with a part leading to the excitation of the narrow resonance is shown. On the right side the excitation and de-excitation of a specific resonance E_x is shown (1: elastic transition, 2: inelastic transition). Transitions to the E_x level from higher resonances are omitted.

The energy E_x of level excited in NRF is of the order MeV while the width of the resonances is of the order meV. Scattered photons are detected by High-Purity Germanium (HPGe) detectors with resolution of several keV. The recoiled nucleus has energy just a few eV and is often neglected in derivation of the excitation energy.

Because of poor detector energy resolution, the experimental cross section is actually an integral over the resonance width (i.e., resonance area). Assuming that (1) the incident photon spectrum is constant over the narrow resonance width (E_x-δ, E_x+δ) and (2) the observed transition is from the initially excited resonance level E_x, namely, no contribution of feeding of levels higher than E_x, the number of emitted photons N with the energy $E_{\gamma'}$ (= E_x - E_i) is related with the resonance area:

$$\frac{N(E_{\gamma'},E_0)}{n_T n_{\gamma,x}} = \int_{E_x-\delta}^{E_x+\delta} \sigma(E_\gamma,E_{\gamma'})dE_\gamma = 2\left(\frac{\pi\hbar c}{E_x}\right)^2 g_x \frac{\Gamma_{x\to 0}\Gamma_{x\to i}}{\Gamma_{x,tot}} \text{ with } g_x = \frac{2J+1}{2(2J_T+1)} \qquad (1)$$

where n_T and $n_{\gamma,x}$ are the sample thickness and the number of incident photons in (E_x-δ, E_x+δ), respectively. The detected gamma energy $E_{\gamma'}$ corresponds to the transition from the resonance E_x to the level E_i. The statistical factor g_x depends on the spin of target nuclide (J_T) and resonance (J_x). The resonance area is not sensitive to the end-point energy E_0 if chosen

appropriately. Though there are two possible helicity states for incoming photons (+1 and -1), the factor 2 is usually excluded from the denominator of the statistical factor as a convention in NRF study:

$$\frac{N(E_{\gamma'},E_0\,)}{n_T n_{\gamma,x}} = \int_{E_x-\delta}^{E_x+\delta} \sigma(E_\gamma,E_{\gamma'}\,)dE_\gamma = \left(\frac{\pi\hbar c}{E_x}\right)^2 g_x'' \frac{\Gamma_{x\to0}\Gamma_{x\to i}}{\Gamma_{x,tot}} \text{ with } g_x' = \frac{2J+1}{2J_T+1} \qquad (2)$$

Resonance area (integrated cross section)
REACTION coding: SCT, EL or INL in SF3, ARE in SF6

Independent variables:
- when EL in SF3: resonance energy
- when SCT or INL in SF3 (with PAR in SF5): resonance energy and secondary energy

Units: code from Dictionary 25 with the dimension B*EV (*e.g.*, B*EV)

When the authors specify (or assume) the observed transition as population of the ground state or an excited state, EL or INL is coded. Otherwise the data set is treated as partial scattering (SCT in SF3, PAR in SF5) with the transition energy under the heading EN-RES and E (repeated twice).

Example:
1. Resonance area for the ground state transition excluding feeding from higher-lying states.

```
REACTION    (93-NP-237(G,EL),,ARE)
...
EN-RES      EN-RES-ERR DATA        DATA-ERR
KEV         KEV        B*EV        B*EV
 1697.8     0.5         5.3         1.4
 1728.8     0.2         0.6         2.3
...
```

2. Resonance area for the ground state transition including feeding from higher-lying states.

```
REACTION    (93-NP-237(G,SCT),PAR,ARE,,BRA)
...
EN-RES-MAX
MEV
 2.8
...
E           E-ERR       DATA        DATA-ERR
KEV         KEV         B*EV        B*EV
 1697.8     0.5         5.3         1.4
 1728.8     0.2         0.6         2.3
...
```

In this case, the resonance energy range may be chosen by the compiler so that the all outgoing photon energies are covered by this range. The end-point energy may be coded under the heading EN-RES-MAX when bremsstrahlung photon source was used. Both the lower and upper boundary may be coded under the headings EN-RES-MIN and EN-RES-MAX when laser Compton scattering photon source was used. The

modifier BRA is coded in SF8 when such a photon source is used. Resonance parameters derived from the resonance area (e.g., resonance energy, resonance width) are however coded without this modifier.

When correction is done to subtract the feeding effect, it must be mentioned under the keyword CORRECTION.

<u>Reference</u>
F. Metzger, Prog. Nucl. Phys. **7** (1959) 53.

Outgoing Particles
(See also **Secondary Energies**).

Particles Participating in a Reaction
In general, the incident projectile is coded in reaction SF2. Particles resulting from the REACTION to be defined are given in SF3 and SF4.

If the <u>incident energy is given in centre-of-mass</u>, the projectile (A) is heavier than the target (B), and reversing the order of the target and the projectile does not change the numerical data, the reaction is coded using the "tautology" formalism:

Example*:*
```
REACTION    ((9-F-19(1-H-2,P)..........)=(1-H-2(9-F-19,P)............))
```

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 without the code `SEQ`.

1. Particle emission or process followed by fission:

    Example: `(N,G+F),,SIG`   (n,γf) cross section

    The process code `F` is always coded at the end in REACTION SF3.

2. A process followed by an unspecified process:

    Example: `(N,G+X),,SIG`   cross section for γ-ray emission followed by unspecified process

Only two process codes F and X may be combined with other codes in REACTION SF3. For general rules on the coding of sequence of process/particle codes in REACTION SF3 and SF4 see EXFOR Formats Manual Chapter 6.

For correlation data on secondary particles, see **Differential Data**.

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 Formats Manual Chapter 6 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.
- (…(P,N+P)…,,DA/DA,P/A) double differential cross section, $d^2\sigma/d\Omega_n/d\Omega_p$
- (…(P,INL)29-CU-65,,DE,RSD) distribution of ^{65}Cu secondary energy

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 (SF4). See **Production Cross Sections**.

Particles/Radiations Detected
Particles actually detected in the experiment may be identified using the keyword PART-DET (see EXFOR Formats Manual Chapter: 7 **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 7: **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 33 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 is given as the c.m. energy of the relative motion of a particle pair emitted in the reaction, the particles are specified in SF7.

Example:

(…(…,…)…,,DA,N+P)   angular distribution of n-p pair.

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

Variable Number of Emitted Particles

If the data table contains yields or production cross sections as a function of the number of secondary particles, and the number of particles is entered as a variable in the data table, SF5 contains the code NUM.
See also EXFOR Formats Manual Chapter 6.

Example:

```
BIB
REACTION    (...(...,X)1-H-1,NUM,SIG)
…
ENDBIB
NOCOMMON
DATA
EN          PART-OUT    DATA
MEV         NO-DIM      B
 ...          2.          ...
 ...          3.          ...
 ...          ...         ...
ENDDATA
```

<u>Undefined Reaction Channels</u>

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**.

Partial Reactions

Definition

A partial reaction, as defined for EXFOR, is a reaction leading to or proceeding through a specific level or emitting a specific gamma or partial group, and excludes production of an isomeric state fed from higher levels to the isomeric state (see **Isomeric States**).

Data differential for secondary energy are not partial (see **Differential Data)**.

REACTION Coding: PAR in SF5

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, E-LVL, E.

Partial reactions leaving the residual nucleus (reaction product) in an excited state are defined by specifying one, several or a range of:

- level energies (default is level energy of reaction product in discrete level)
- excitation energies (default is excitation energy of reaction product in broad or continuum level)
- 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 (Process),
- or, for other particles, given in SF7 (Particle Considered).

When the data is a function of the secondary energy of more than one secondary particle, the secondary energies for the particles must be defined under the information-identifier keyword en-sec (see EXFOR Formats Manual Chapter 7: **EN-SEC** and **Secondary Particles**).

Example:
```
REACTION    (8-O-16(6-C-12,INL)8-O-16,PAR,DA)
EN-SEC      (E-LVL1,6-C-12)
            (E-LVL2,8-O-16)
```

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

If ratios of partial reactions for different secondary energies are given, they should be coded using the reaction separator "//", see **Ratios**. The secondary energies are given under the data headings with the extensions -NM and -DN (e.g., E-EXC-NM and E-EXC-DN).

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

Gammas in the Continuum Region

When data are measured for a range of gamma energies that includes the continuum region, data may be deduced for a range of discrete gammas as separated from the range of continuum gammas.

REACTION coding: DIS (discrete) or CON (continuum) in SF5 (Branch).

Note: The code DIS should not be used below the continuum region.

Example:
```
  REACTION  1(26-FE-56(N,X)0-G-0,DIS,SIG)
            2(26-FE-56(N,X)0-G-0,CON,SIG)
```

Excitation Level of Intermediate Nucleus

When data are partial for an excitation level in an intermediate nucleus that is not coded in SF3-SF4, a branch code ISP is used. This code may be used in combination with PAR when levels are given for both the intermediate nucleus and the final nucleus coded in SF3-SF4.

Example:

$$^9\text{Be}(^{10}\text{C,x})^{10}\text{C*} \rightarrow p + {}^9\text{B}_{\text{g.s.}} \rightarrow 2p + 2\alpha$$

```
  REACTION    (4-BE-9(6-C-10,P+X)5-B-9,ISP/PAR,SIG)
  …
  EN-SEC      (E-LVL1,5-B-9)
              (E-LVL2,6-C-10)
```

Same Reaction Products through Different Decay Path

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

Example:
  a.) $^{12}\text{C}(n,n')^{12*}\text{C} \rightarrow \alpha + {}^{8*}\text{Be} \rightarrow 2\alpha$
  b.) $^{12}\text{C}(n,n')^{12}*\text{C} \rightarrow 3\ \alpha$

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

Reactions Characterized by a Secondary Energy which are not Partial

While partial reactions are always connected with a secondary energy, the reversal is not always the case. There are data which are characterized by a secondary energy which are not related with a partial reaction.

When such a secondary energy, given by authors, can be coded as an equivalent incident particle energy without numerical conversion by the compiler, such data can be compiled. Otherwise such data are not presently compiled in EXFOR.

Examples:

- Photonuclear data characterized by the excitation energy of the initial compound nucleus. (This excitation energy is coded as the incident energy in the laboratory system, *e.g.*, under the heading EN.)

- Proton elastic scattering data characterized by the centre-of-mass energy or excitation energy of the initial compound nucleus. (This centre-of-mass energy and excitation energy are coded under EN-CM and E-EXC-CMP, respectively.)

- (p,n_0) data characterized by the outgoing neutron energy. (The outgoing neutron energy is uniquely determined from the incident energy by the two-body kinematics. However these data are presently not compiled because a numerical conversion by the compiler is required to determine the incident energy.)

Pointers

A pointer is a numeric or alphabetic character used to link pieces of EXFOR information. (See EXFOR Formats 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.

Forbidden:
```
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(H.Liskien+,J,JNE,19,73,1965)
          2(H.Pollehn,J,ZN/A,16,227,1965)
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 Formats Manual Chapter 5.

Polarization

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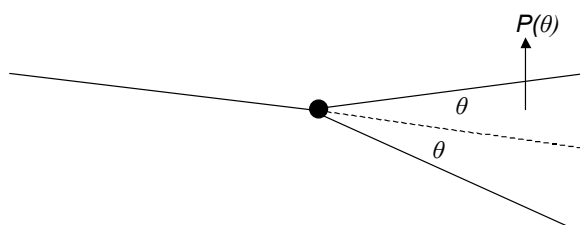
The inverse of this situation is the asymmetric scattering of a polarized beam of particles. The degree of polarization of such a beam may be determined by measuring the left-right **asymmetry** upon scattering from a target nucleus that plays the role of an **analyzer**.
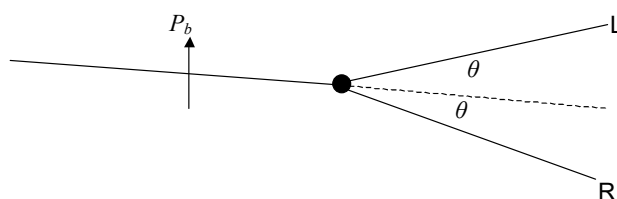
For elastic scattering from a spin-0 nucleus: the principle of *Polarization-Asymmetry Equality* states that, for time-reversal invariant reactions, the polarization induced in a previously completely unpolarized beam is identically equal to the asymmetry ensuing from the scattering of a perfectly polarized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

Conventions for quantities given in Cartesian coordinates

Basel Convention for Spin-½ Particles [2]
In nuclear reactions, the positive polarization of particles with spin-½ 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.

Madison Convention for Spin-1 Particles
In Madison convention for spin-1 particles, quantities given in Cartesian coordinates [5] are as follows:

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:
$A(\vec{b}, \vec{c})D$ Polarizations of beam and outgoing particles are measured.

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	ith component for beam	***k***	kth component for outgoing particle
j	jth component for target	***p***	pth component for reaction product

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×L (sideways), *i.e.*, perpendicular to particle momentum in scattering plane
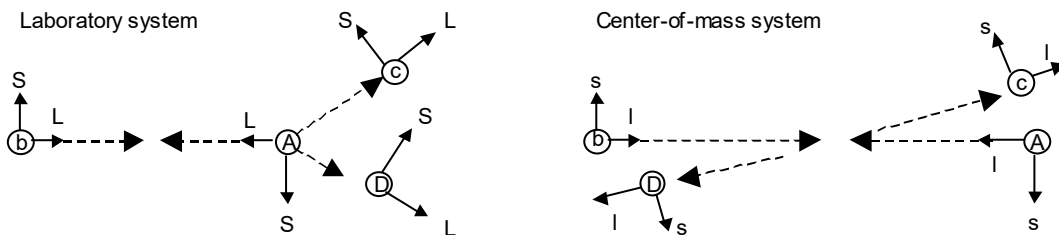
$\overline{N}$ and $\vec{n}$ are identical with direction out of page for all particles.

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.

Example:
(N,0;0,0): *y*-component of the beam polarization is measured.

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

3. **σ₀** is the differential cross section for an unpolarized (spin-averaged) beam.

1. Quantities given in Cartesian coordinates compiled in EXFOR

Polarization
Polarization refers to the degree of polarization of an ensemble of particles.
P$_s$(θ) is the polarization of the outgoing particle beam as a function of angle.
    where
$$\sigma_P = \sigma_0 P(\theta)$$
REACTION Coding: POL/DA in SF6.

Asymmetry
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 ε =   asymmetry
                  P_b =   incident beam polarization
                  A_y =   analyzing power of target
                  L,R   =   intensity of particles scattered left and right in the same plane under the same angle.

REACTION coding: ASY in SF8.

b. the angular distribution for incident projectiles with their polarization vectors perpendicular (φ=90° or 270°) and parallel (φ=0° or 180°) to the reaction plane.

$$\varepsilon = \left(d\sigma_\perp - d\sigma_\parallel\right)/\left(d\sigma_\parallel + d\sigma_\perp\right)$$
REACTION coding: ASY/PP in SF8.

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.
$$\varepsilon = \left(d\sigma_F - d\sigma_B\right)/\left(d\sigma_F + d\sigma_B\right)$$
REACTION Coding: ASY/FB in SF8.

The angles are given as ANG1 and ANG2.

Spin-Spin Asymmetry

$\varepsilon = (N_p - N_a)/(N_p + N_a)$

where N_p and N_a are counts from the reaction between target and projectile which spins are in parallel (p) and anti-parallel (a), respectively.

REACTION Coding: TRS or LON in SF5, POL in SF6, DSP/ASY in SF8.

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

Vector analyzing power
(e.g., A_y, A_{i00n0} for y-component of beam polarization)

REACTION Coding: ANA in SF8.

Examples:
,POL/DA,,ANA	Analyzing power, A_n, beam spin normal to scattering plane.
LON,POL/DA,,ANA	Analyzing power, A_l, beam spin parallel to incident particle momentum in scattering plane (longitudinal).

Tensor analyzing power (A_{ij} or $A_{ij,0,0,0}$)

REACTION Coding: ANA in SF8, and a branch code in SF5 giving two components of beam spin

Example:
NN,POL/DA,,ANA	Tensor analyzing power, A_{NN}, beam spin normal to scattering plane.

Initial State Spin-Correlation Parameter
(e.g., $C_{y,y}$, A_{00nn} for y-component of beam and target polarization)

$$C_{y,y} = \varepsilon / |P_b\|P_t|$$

REACTION Coding: C in SF8, and a branch code in SF5 giving components of beam and target spin.

Example:
LL,POL/DA,,C	C_{LL}, initial-state spin correlation function, beam and target spins parallel to beam direction in scattering plane

Final State Spin-Correlation Parameter (Not presently compiled)
(e.g., $C_{n,n}$ for y-component of beam and target polarization)

Spins in the scattering plane:

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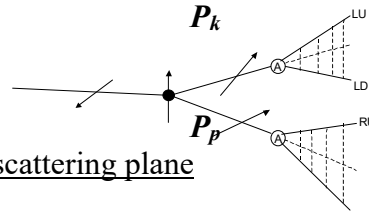
Spins normal to the scattering plane

$$C_{NN} = \frac{1}{P_b P_t} \frac{(LL)(RL) + (LR)(RR) - (LL)(RR) - (LR)(RL)}{(LL)(RL) + (LR)(RR) + (LL)(RR) + (LR)(RL)}$$
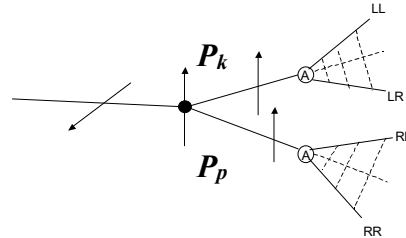
If time reversal holds: $C_{n,n} = C_{y,y}$.

Spin-Rotation Parameters
(e.g. D_{NN} or D_{n0n0} for spin rotation from beam to outgoing particle)

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 [1] 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: D in SF8, and a branch code in SF5 giving components of beam and outgoing particle.

Example:

    `SL,POL/DA,,D`   Spin-Rotation Parameter D_{SL}, rotation from x-component of beam polarization to z-component of outgoing particle spins.

Total Spin-Transfer

Total spin-transfer is used as an index to distinguish spin-flip ($\Delta S=1$) and non-spin-flip ($\Delta S=0$) excitation. The quantity is defined as:

$$\Sigma = \left[3 - \left(D_{SS} + D_{NN} + D_{LL} \right) \right] / 4 = \left(S_{SS} + S_{NN} + S_{LL} \right) / 2$$

REACTION coding: `TST` in SF8.

Spin-Transfer Parameter

(e.g. K_{NN} or K_{0nn0} for spin rotation from beam to reaction product)

P(θ)

P_b
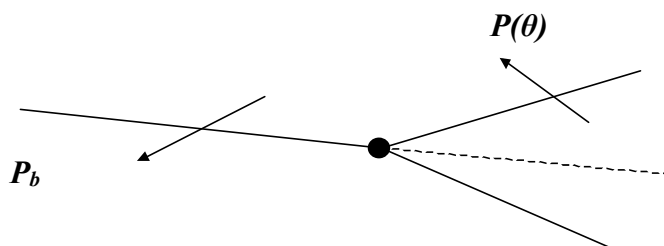
REACTION Coding: K in SF8, and a branch code in SF5 giving components of beam and reaction product.

Examples:

    `LS,POL/DA,,K`   Spin transfer parameter K_{LS}, transfer from z-compounent of beam polarization to x-component of reaction product

The spin-transfer parameter is related to the spin-rotation parameter by:.

$$D_{ij}(\theta) = K_{ij}(\pi - \theta)$$

Spin-Flip Parameter (S_{kp} or $S_{0,0,k,p}$)

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

Example:

    `NN,POL/DA,,SF`   Spin-flip probability (S_{nn})

The Spin-Flip Probability is related to the spin depolarization parameter by:

$$S_{\text{flip}} = (1 - D_{NN}) / 2$$

Spin-Rotation Function (SRF or Q)

Spin-rotation function 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:

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

REACTION coding: `SRF` in SF8, and a branch code in SF5 giving components of beam and target spin.

2. Quantities given in Spherical Coordinates

Madison Convention for Spin-1 Particles [5]

In Madison convention for spin-1 particles quantities given in spherical coordinates, 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.

For projectiles of spin 1 the cross section may be written as

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

For projectiles of spin 3/2 three third rank tensors complete the set: T_{31}, T_{32}, and T_{33}.

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

Analyzing Power (T_{kq})

Vector analyzing power (iT_{11})
REACTION Coding: `VAP` in SF8

<u>Tensor analyzing power</u> (T_{20}, T_{21}, T_{22}, *etc.*)
REACTION Coding: `TAP` in SF8; k and q are specified under the branch field using the codes `20`, `21`, *etc*.

Example: `(……,20,POL/DA,,TAP)`

Data presented in the <u>technical transversity coordinate frame</u> are written with the superscript T, *i.e.*, $^{T}T_{kq}$. $^{T}T_{10} = \sqrt{2} \ iT_{11}$.
These are not presently defined in EXFOR.

3. 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 Formats Manual, Chapter 7, **ERR-ANALYS**).

4. Comparison of Notations for Spin Parameters

Below is a list of various notations for spin parameters (reproduced from Table I of N. Hoshizaki, J. Phys. Soc. Jpn. **55**, Suppl. p.549-552 (1986).

Arrow in the column head "Type" indicates the particles whose spin polarization is known or measured. Suffixes in O_{SRBT} and letters in (B,T;S,R) are as follows. B: beam, T: target, S: scattered, R: recoil.0: unpolarized or polarization unmeasured. N,L,S: spin directions referred to Fig.1(c) [13] or Fig.2 [11]. (B.T;S,R) without * and # is common to [11] and [13]..

a: incident particle; B: target; c: outgoing particle; D: reaction product (residual)

Type	[10] Fig.1a	[11] Fig.2	[12] Fig.1b O_{SRBT}	[13] Fig.1c	[14] Fig.1c	[6] & others	[13]#, [11]* (B,T;S,R)
Total cross section							
a+B→ anything			σ_{0tot}	σ^{Tot}		σ_{tot}	
$\vec{a}+\vec{B}\rightarrow$anything		$\Delta\sigma_T$	$-2\sigma_{1tot}$	$\Delta\sigma_T^{Tot}$		$\Delta\sigma_T^1$	
		$\Delta\sigma_L$	$\Delta\sigma_L$	$\Delta\sigma_L^{Tot}$		$\Delta\sigma_L^1$	
	Note: $\Delta\sigma_T = \sigma_{\uparrow\downarrow}-\sigma_{\uparrow\uparrow}$ $\Delta\sigma_L = \sigma_{\leftrightarrows} -\sigma_{\rightrightarrows}$						
Differential cross section							
a+B→c+D	I_0	$d\sigma/dt$	I_{0000}	σ		I_0	(0,0;0,0)
	Note: $d\sigma/dt = \pi \lambda^2$ $d\sigma/d\Omega = \pi \lambda^2 I_0$ Normalization: (0,0;0,0) = 1						
Analyzing powers							
$\vec{a}+B\rightarrow c+D$	P	A^a	A_{00n0}	P	A, A_y	A_y, A_{y0})2	(N,0;0,0)
$\vec{A}+B\rightarrow c+D$	P	A^b	A_{000n}	P	A, A_y	A_y^T, A_{0y}2	(0,N;0,0)
Polarizing powers or polarizations							
$a+B\rightarrow \vec{c}+D$	P	P^c	P_{n000}	P	P	$P_{y'}$	(0,0;N,0)
$a+B\rightarrow c+\vec{D}$	P	P^d	P_{0n00}	P	P		(0,0;0,N)
Initial state correlation of polarizations							
$\vec{a}+\vec{B}\rightarrow c+D$	A_{yy}	A_{NN}	A_{00nn}	C_{NN}	A_{NN}, A_{nn}	$C_{y,y}$	(N,N;0,0)
	A_{zz}	$-A_{LL}$	A_{00kk}	C_{LL}	A_{LL}34	$C_{z,z}$	(L,L;0,0)# -(L,L;0,0)*
	A_{xx}	$-A_{SS}$	A_{00ss}	C_{SS}		$C_{x,x}$	(S,S;0,0)# -(S,S;0,0)*
	A_{xz}	$-A_{SL}$	A_{00sk}	C_{SL}	A_{SL}4	$C_{x,z}$	(S,L;0,0)# -(S,L;0,0)*
	A_{zx}	$-A_{LS}$	A_{00ks}	C_{LS}		$C_{z,x}$	(L,S;0,0)# -(L,S;0,0)*
	Note: $A_{zx} = A_{xz}$						

1 [13,15]
2 [16]
3 [17]
4 [18]

Type	[10] Fig.1a	[11] Fig.2	[12] Fig.1b O_{SRBT}	[13] Fig.1c	[14] Fig.1c	[6] & others	[13]# [11]* (B,T;S,R)

Final state correlation polarizations

$\overrightarrow{a}+\overrightarrow{B}\rightarrow c+D$	C_{nn}	C_{NN}	C_{nn00}			$C_{n,n}$	(0,0;N,N)
	C_{kp}	C_{SS}	$C_{s's''00}$			$C_{p,p}$	(0,0;S,S)
	C_{pp}	C_{LS}	$C_{k's''00}$			$C_{k,p}$	(0,0;L,S)
	$-C_{kk}$	C_{SL}	$C_{s'k''00}$			$C_{p,k}$	(0,0;S,L)

Polarization transfer or Wolfenstein parameters

$\overrightarrow{a}+B\rightarrow \overrightarrow{c}+D$	D	D^a_{NN}	D_{n0n0}		D_{NN}	$K^{y'}_y$	(N,0;N,0)
	R	D^a_{SS}	$D_{s'0s0}$		D_{SS}	$K^{x'}_x$	(S,0;S,0)
	A	D^a_{LS}	$D_{s'0k0}$		D_{LS}	$K^{z'}_x$	(S,0;L,0)
	A'	D^a_{LL}	$D_{k'0k0}$		D_{LL}	$K^{z'}_z$	(L,0;L,0)

Note: D=1-2S, S being spin-flip probabilities.

$\overrightarrow{a}+B\rightarrow c+\overrightarrow{D}$	D_t	K^a_{NN}	K_{0nn0}	K_{NN}	K_{NN}		(N,0;0,N)
	R_t	K^a_{SS}	$K_{0s''s0}$	K_{SS}	K_{SS}		(S,0;0,S)
	A_t	K^a_{LS}	$K_{0s''k0}$	K_{LS}	K_{LS}		(L,0;0,S)
	$-R'_t$	K^a_{SL}	$K_{0k''s0}$	K_{SL}	K_{SL}		(S,0;0,L)
	$-A'_t$	K^a_{LL}	$K_{0k''k0}$	K_{LL}	K_{LL}		(L,0;0,L)

Note: $K_{ij}(\theta_{CM}) = Dij(\pi-\theta_{CM})$ for $p+p \rightarrow p+p$

$a+\overrightarrow{B}\rightarrow \overrightarrow{c}+D$		D^b_{NN}	D_{0n0n}	D_{NN}			(0,N;0.N)
		$-D^b_{SS}$	$D_{0s''0s}$	D_{SS}		R^5 R_r^6	(0,S;0.S)# -(0,S;0,S)*
		$-D^b_{LS}$	$D_{0s''0k}$	D_{LS}			(0,L;0.S)# -(0,L;0,S)*
		$-D^b_{SL}$	$D_{0k''0s}$	D_{SL}		$R'_r{}^6$	(0,S;0.L)# -(0,S;0,L)*
		$-D^b_{LL}$	$D_{0k''0k}$	D_{LL}			(0,L;0.L)# -(0,L;0,L)*

$a+\overrightarrow{B}\rightarrow c+\overrightarrow{D}$		K^b_{NN}	K_{n00n}				(0,N;N,0)
		$-K^b_{SS}$	$K_{s'00s}$				(0,S;S,0)# -(0,S;S,0)*
		$-K^b_{LS}$	$K_{s'00k}$				(0,L;S,0)# -(0,L;S,0)*
		$-K^b_{SL}$	$K_{k'00s}$				(0,S;L,0)# -(0,S;L,0)*
		$-K^b_{LL}$	$K_{k'00k}$				(0,L;L,0)# -(0,L;L,0)*

Three spin observables

$\overrightarrow{a}+\overrightarrow{B}\rightarrow \overrightarrow{c}+D$			$M_{\mu'0\alpha\beta}$				$\pm(\alpha,\beta;\mu,0)^7$
$\overrightarrow{a}+\overrightarrow{B}\rightarrow c+\overrightarrow{D}$			$N_{0v''\alpha\beta}$	$H_{\alpha\beta v}$			$\pm(\alpha,\beta;0,v)^7$
$\overrightarrow{a}+B\rightarrow \overrightarrow{c}+\overrightarrow{D}$	$C^{\alpha}_{v\mu}$		$C_{\mu'v''\alpha0}$				$(\alpha,0;\mu,v)$
$a+\overrightarrow{B}\rightarrow \overrightarrow{c}+\overrightarrow{D}$	$C'^{\beta}_{v\mu}$		$C_{\mu'v''0\beta}$				$\pm(0,\beta;\mu,v)^7$

---

[5] [19]

[6] [20]

[7] The minus sign is for [11] with β=L or S.

Type	[10] Fig.1a	[11] Fig.2	[12] Fig.1b O_{SRBT}	[13] Fig.1c	[14] Fig.1c	[6] & others	[13]# [11]* (B,T;S,R)
Four spin observables							
$\vec{a}+\vec{B}\rightarrow\vec{c}+\vec{D}$			$C_{\mu'\nu''\alpha\beta}$				$\pm(\alpha,\beta;\mu,\nu)^{7}$

References

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Production and Emission Cross Sections
 (See **Fission Yields** for fission fragment 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:　`X` in SF3.
　　Emission cross section:　　`X` in SF3; `EM` in SF5.

The product measured is coded either in reaction SF4, or as a variable in the data table (see EXFOR Formats Manual Chapter 6: **Variable Nucleus**).

For <u>inelastic gamma emission</u>, see **Scattering**: Inelastic.

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
`(…(P,X)1-H-1,NUM,PY)`	yield for production of *n* protons with *n* given in the data table under the heading `PART-OUT`

Isotope Production Cross Section for Natural Sample
For isotope production on a natural target, the reaction is coded as:
　`(Z-S-0(…,X)Z'-S'-A',,SIG)`
　`(Z-S-A(…,X)Z'-S'-A',,SIG,,A)`　　if only one reaction is possible and the data are not corrected for the isotopic abundance of the contributing target isotope.

When data are given for a specific target isotope, and there are two or more contributing target isotopes, sum of reaction code is coded under keyword reaction with modifier `RAB`.

Example:
Production cross section of ^{47}Sc measured with a natural titanium sample above the thresholds of ^{48}Ti and ^{49}Ti contributions, and cross section for natural target divided by the isotopic abundance of ^{47}Ti is given:

Above the ^{48}Ti (n,x) ^{47}Sc threshold:
```
(22-TI-47(N,P)21-SC-47,,SIG)+(22-TI-48(N,X)21-SC-47,,SIG,,RAB)
```

Above the ^{49}Ti (n,x) ^{47}Sc threshold:
```
(22-TI-47(N,P)21-SC-47,,SIG)+(22-TI-48(N,X)21-SC-47,,SIG,,RAB)+
(22-TI-49(N,X)21-SC-47,,SIG,,RAB)
```

When the modifier RAB is used, isotopic abundance of the sample used to derive the cross section by authors must be coded under the keyword sample.

Probability for Emission of *n* Particles

REACTION Coding: X in SF3,; EM/NUM in SF5 (Branch). The particle measured is given in SF4.

Example: `(…(…,X)2-HE-4,EM/NUM,SIG)`

The number of particles is given in the DATA section under the data heading part-out with units of no-dim.
See **Outgoing Particles**: Variable number of emitted particles.

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)` $= (\gamma,n) + (\gamma,2n) + (\gamma,np) + (\gamma,3n) +$ Products

Production Cross Section Defined with Excitation Energy

Sometimes the production cross section is given as a function of the excitation energy of the reaction product from a specific process (*e.g.*, two body reaction). This may happen when the contribution of the direct process is expected to be dominant (*e.g.,* data at forwarded angle). In this case the production cross section may be coded with the specific process considered by the author under REACTION with a branch code ICL.

Example:
`(28-NI-58(P,N)29-CU-58,ICL,DA/DE,N/RSD)`

Double differential cross section $d\sigma/d\Omega_n dE_x$(^{58}Cu) for ^{58}Ni(p,n+x) reaction.

Products

Products of 2 or more REACTIONs

Products of 2 or more REACTION codes can be expressed as a reaction combination using the separator * (see EXFOR Formats Manual, page 6.6.)

Example:

```
REACTION    ((42-MO-98(N,TOT),,WID)*(42-MO-98(N,EL),,WID))
```

Products Implicit in the Quantity Codes

For certain products that 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 (isotopic abundance);
(A)	=	uncertain if multiplied by abundance
		(See **General Quantity Modifiers**.)
G	=	*g* (*g* = statistical weight factor)
AG	=	*ag*
2G	=	*2g*
2AG	=	*2ag*
4AG	=	*4ag*
RTE	=	$\sqrt{E}$
4PI	=	4π
SQ	=	$(\dots)^2$
RS	=	$4\pi/\sigma_{el}$
FCT	=	factor to be defined in free text (see **General Quantity Modifiers**)

(See also **Fitting Coefficients**).

Quantum Numbers

Resonances of 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:

$$g = \frac{2J + 1}{(2J_p + 1)(2J_t + 1)}$$

where J_p =   spin of incident projectile
            J_t =   spin of target nucleus

These quantum numbers can be entered in two different ways:

1. <u>Quantum numbers are assumed as parameters</u> of strength functions, reduced neutron width, or other quantities. These 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. <u>Quantum number that is the result of the resonance parameter analysis</u>. One of the following reaction codes is used:

- Momentum *l*   `(...(N,0),,L)`

- Resonance spin J   `(...(N,0),,J)`

- Parity   `(...(N,0),,PTY)`

- Statistical weight *g*   `(...(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 (REACTION SF8) for resonance parameters (see **Products**).

Excited States in Product Nuclei (see also **Isobaric Analogue Resonances**).

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 (see also EXFOR Exchange Formats Manual Chapter 7, LEVEL-PROP). These properties may be associated with specific data lines 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       ...
 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,LVL-NUMB=1,SPIN=2.,PARITY=+1.)
           ((2.)26-FE-56,LVL-NUMB=2,SPIN=4.,PARITY=+1.)
...
ENDBIB
NOCOMMON
DATA
EN         LVL-NUMB    DATA       LVL-FLAG
MEV        NO-DIM      MB         NO-DIM
 1.         1.          ...        1.
 1.         2.          ...        2.
...
ENDDATA
```

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Ratios

Ratios of 2 or More Reactions
Ratio of 2 or more reactions can be expressed as a reaction combination using the separator '/' (see EXFOR Formats Manual Chapter 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))
ENDBIB
COMMON
E-LVL-NM    E-LVL-DN
MEV         MEV
 ...         ...
```

Frequently Occurring REACTION Ratios

The reaction ratio formalism is not used for certain frequently occurring ratios for which specific quantity codes have been introduced.

***Example*:**

Alpha value = Capture cross section / fission cross section
```
(92-U-235(N,G)92-U-236,,SIG)/
(92-U-235(N,F),,SIG)
→ (92-U-235(N,ABS),,ALF)
```

Resonance strength (Capture kernel)
```
((82-PB-208(N,EL),,WID,,G)*(82-PB-208(N,G),,WID)/
(82-PB-208(N,TOT),,WID))
→ (82-PB-208(N,G),,WID/STR)
```

Ratios Implicit in the Quantity Codes
For certain frequently used ratios, special quantity codes have been introduced.

`ALF` (SF6) = capture-to-fission ratio (see **Absorption**: Alpha)

`ETA` (SF6) = average neutron yield/non-elastic event (see **Neutron Yield**)

`RS` (SF8) = 4π/elastic scattering cross section

Isomeric Ratios

Isomeric ratios are coded using the separator '/' in the isomer field of the reaction product (SF4), and with the modifier RAT in SF6. For isomeric ratios of the fission product yields, FY/RAT (rather than SIG/RAT) is used in SF6. (See **Isomeric States**.)

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 may be of little use to usual data centre customers, it has been recognized that "raw" data should be stored by the data centres. 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]
- for resonance analysis.

Self-indication measurement: see **Transmission and Reaction Yield**

Transmission measurement: see **Total**.

Reaction yields: see **Transmission and Reaction Yield**

Additional data types may be added as they are encountered.

Voluminous Files of "Raw" Data 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 Formats Manual Chapter 7). A data subentry should be included for each set of raw data stored; the BIB section should include, at minimum, the reaction.

COMMON section should contain minimum and maximum of the incident-projectile energy. The system identifier NODATA replaces the DATA section (see EXFOR Formats Manual Chapter 2).

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[1] See recommendation by the NEANDC/NEACRP meeting on neutron data for structural materials, Geel, December 1977.

Reaction Mechanisms

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.

These partial cross sections cannot be measured directly but are deduced from theoretical considerations[2]. Therefore, careful explanation in free text is required whenever these quantities are given.

Compound-Nucleus Interaction and Direct Interaction

1. <u>Compound-Nucleus Interaction</u>: 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. <u>Direct Interaction</u>: A reaction in which there is direct interaction between the incident projectile and single nucleons or clusters of nucleons in the target.
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.

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

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 centres-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.

---

[2]   These reactions are partial, therefore, if the reaction proceeds totally through one branch, no modifier is used.

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

Fusion, Fast Fission, and Deep Inelastic Scattering
See **Fusion**.

Spallation and High-energy Fission[3]
As the bombarding energy becomes high (~100 MeV/nucleon), a series of individual nucleons, or small groups of nucleons, may be ejected (spallation) or the target may break into several large fragments (fragmentation or fission).

In spallation 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. In fission the incident projectile penetrates the target and a compound nucleus is formed, which then breaks apart.

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.

In this case, where the measured product yield has been separated into to its fission and spallation components by the author, the partial quantity spallation or fission may be coded under the keyword reaction using the branch codes SPL and FIS, respectively, in SF5.

Examples:
```
(82-PB-208(92-U-238,X)31-GA-69,SPL,SIG)
(82-PB-208(92-U-238,X)31-GA-69,FIS,SIG)
```

See **Fission** for fission process at lower energies.

For the production of specified product nuclei see **Production and Emission Cross Sections** and **Independent and Cumulative Data**.

Reference
[1]   H. Feshbach, Theoretical Nuclear Physics: Nuclear Reactions (John Wiley and Sons, 1992) Chapter VIII, Heavy Ions.

---

[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 keyword REACTION.

See EXFOR Formats Manual Chapter 6 for a complete discussion of the use of the Reaction Product subfield, including coding rules.

If no isomer code is given without PAR in SF5, then the reaction is to a nucleus in the ground state and all isomeric states. If an isomer code is given, a reaction for the formation of that isomeric state is given, and, in general, the other isomeric states are not included. (See **Isomeric States**).

Examples:

(63-EU-151(N,G)63-EU-152,,SIG) Sum of production cross sections for ^{152g}Eu (13.5 years), ^{152m1}Eu (9.3 hours), and ^{152m2}Eu (96 min)

(63-EU-151(N,G)63-EU-152-M1,,SIG) Production cross sections for ^{152m1}Eu (9.3 hours).

In the case of **product yield data or production cross sections** 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 Formats Manual Chapter 6).

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.

Variable Product
The reaction product may be a variable of the data table (See EXFOR Formats Manual Chapter 6: Variable nucleus). When the quantity is for a correlated pair of reaction products, they are entered under headings such as ELEM1 and MASS1 with CRN in REACTION SF5. The following table summarises presence of the headings characterizing variable product depending on REACTION SF4 and SF5:

	CRN is not in SF5			CRN is in SF5		
SF4	ELEM	MASS	ELEM/MASS	ELEM	MASS	ELEM/MASS
ELEM	X		X			
MASS		X				
ELEM1				X		X
MASS1					X	
ELEM2				X		X
MASS2					X	
ELEM3				(X)		(X)
MASS3					(X)	

X: Presence is obligatory. (X): Presence is optional

Use of CRN in REACTION SF5 is allowed only for fission yields (i.e., FY is in SF6).

Reference

Keyword REFERENCE

All bibliographic references which contain the preliminary or revised data as well as information of the specific experiment 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.

The primary reference (a published reference in general) should be given first, as this is the reference that will be used when referring to the data. If it has an English translation, this must be coded first.

A reference (or the first reference) given in a data subentry, supersedes any reference given in the common subentry as the primary reference.

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 Formats Manual Chapter 7: **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.

Only the references checked and analysed by the compiler can be included under this keyword. When two or more references are coded, their contents should be indicated in free text.

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 Formats Manual Chapter 8. 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 Formats Manual Chapter 7: **REFERENCE**) or under the information-identifier keyword STATUS[4].

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[5]. The date given is the date of the report.

Example:

`REFERENCE   (S,IAEA-107,196802)`   The proceedings of the standards panel `67BRUSSELS` issued as report IAEA-107.

Reports
If an INDC report number is assigned to the report, it must be always coded in addition to the primary report number of the report (e.g., the report code-number containing an abbreviation of the originating laboratory).

Progress Reports and Abstracts
Progress reports, preprints and abstracts should, in general, be excluded, if they contain no additional useful information.

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),1956)`   first paper on page 482 of Phys. Rev., 104
`(J,PR,104,482(2),1956)`   second paper on page 482 of Phys. Rev., 104

---

[4]   This is preferred, if there is a published reference.
[5]   Exceptions are conference proceedings identified with a CEA-CONF, CONF, NBS-SPEC-PUB or STI/PUB report number. They are generally not considered as reports and coded with a conference code.

Compilation in Separate Entries

If data sets from different works of an experimental group published in one article are compiled in several entries (e.g., data from different areas published in the same paper), these entries may be linked using the REL-REF code O with a free text explanation.

Examples:

1. Two entries in two different areas (neutron and photon-induced reaction data)

```
TITLE        Isomeric yield ratios in the productions of Sm-143-m,g,
             Nd-141-m,g, Zr-89-m,g and Pd-109-m,g by 14 MeV neutrons
             and 15-20.5 MeV bremsstrahlung
REFERENCE    (J,BJP,14,152,1987)
              Both neutron and photon reaction data given
REL-REF      (O,G0004001,Hoang Dac Luc+,J,BJP,14,152,1987)
              Photon induced reaction data compiled
```

2. Two entries in the same area (proton and deuteron-induced reaction data)

```
TITLE        Investigation of proton and deuteron induced reaction
             on cobalt
...
REFERENCE    (J,KPS,59,1697,2011)
              Both proton and deuteron reaction data given
REL-REF      (O,D4232001,F.Ditroi+,J,NIM/B,268,2571,2010)
              Deuteron induced reaction data compiled

...
```

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 Formats Manual Chapter 7: **REL-REF**, for coding rules.)

Keyword MONIT-REF

References from which the standard (or monitor) data used in the experiment were taken are coded under MONIT-REF. (See EXFOR Formats Manual Chapter 7: **MONIT-REF** for coding rules.)

Resolution

Incident-Projectile Energy Resolution

Incident-projectile energy resolution is 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 such as standard deviation. 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 (full width)

    EN-RSL-HW   Incident-particle energy resolution (half width)

    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). Note that

$\Delta E = E (\gamma + 1) \gamma |\Delta\tau| \, v \sim 2E (2E/m)^{1/2} |\Delta\tau| \sim 2.766 \times 10^{-2} E^{3/2} |\Delta\tau|$

at the non-relativistic limit ($\gamma \rightarrow 1$) with ΔE in MeV and $\Delta\tau$ in nsec/m. (See also Sect. II.B of P. Schillebeeckx et al., Nucl. Data Sheets **113** (2012) 3054.)

Example:

EN-RSL-FW = 2 MeV

EN-RSL-HW = 1. MeV
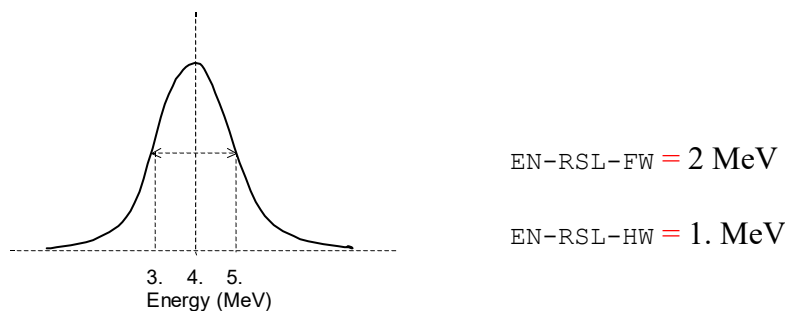
Note:

The terms resolution and error are often misused in the literature. Distinguish between them, where possible. See **Errors**.

Secondary-Energy Resolution

Secondary-energy resolution is the energy spread of an outgoing (secondary) particle (see **Secondary Particles**).

Angular Resolution

Angular resolution is the angular spread of an outgoing (secondary) particle (see **Angle**).

Resonance Integral

Definition
Effective cross section of the epithermal part of a reactor flux.

REACTION coding: `RI` in SF6.

Units: a code from Dictionary 25 with the dimension `B` (e.g., `MB`)

Example: `(…(N,ABS),,RI)`
The energy limits are specified under the data headings `EN-MIN` and `EN-MAX`.

Infinitely Dilute Resonance Integrals
Infinitely dilute resonance integrals for a 1/E spectrum are defined as:

$$I_r = \int_{E_c}^{\infty} \sigma_r(E)\frac{dE}{E}$$

(Hogdahl convention) where E_c = cut-off energy near the lower limit of the epithermal region.

These are usually measured as cadmium ratios where Ec is the cadmium cut-off energy (~0.55 eV for 1-mm thick Cd filter), which is dependent on the thickness of the cadmium cover and also geometrical relation between the cadmium cover and sample.

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
Resonance integrals over smaller energy ranges, where the sum over the partial energy ranges given from the cut-off 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
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
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 $1/E^{1+\alpha}$.

$$I(\alpha) = \int_0^\infty \frac{\sigma(E)dE \, / \, \mathrm{eV}}{(E \, / \, \mathrm{eV})^{1+\alpha}}$$

Accordingly, the realistic resonance integral is defined as:
   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.

$$I_0 = \int_{E_c}^\infty \frac{\sigma(E)dE}{E}$$

The realistic resonance integral $(\alpha \neq 0)$ and the 'ideal' resonance integral ($\alpha=0$) are related by:

$$I(\alpha) = \frac{I_0 - 0.429\sigma_0}{(\overline{E}_r \, / \, \mathrm{eV})^\alpha} + \frac{0.429\sigma_0}{(2\alpha+1)(E_c \, / \, \mathrm{eV})^\alpha}$$

   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).

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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
If the quantity depends on the sample thickness (*e.g.*, transmission, thick target yield) and it is not expressed by an alternative way (*e.g.*, incident energy at the entrance and exit of the sample), the sample thickness must be entered into the COMMON or DATA section under the heading THICKNESS.

Example:
```
COMMON
THICKNESS
ATOMS/B
.....
ENDCOMMON
DATA
EN          DATA        DATA-ERR
MEV         NO-DIM      NO-DIM
.....
ENDDATA
```

The heading THICKNESS should not be used when the quantity does not depend on the sample thickness by its definition (e.g., cross section).

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 modifier TMP in REACTION SF8. Note that TMP should be omitted for data measured at the room temperature (~300 K). The sample temperature is coded in under the heading TEMP.

Example:
```
BIB
REACTION  (1-H-1(N,TOT),,SIG,,TMP)
...
ENDBIB
COMMON
TEMP
K
 10.
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:

Total Scattering
The sum of all scattering interactions.

REACTION Coding: SCT in SF3

Example: `(.....(P,SCT)...,,SIG)`

Sum Rule: Total scattering = elastic scattering plus inelastic scattering
= total minus absorption

The following formalism is **no longer used**; instead use SCT in SF3.

`(....(P,P)...,,SIG)`   used 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.

Elastic Scattering
Scattering without excitation of both the projectile and target nucleus ($Q = 0$).

REACTION Coding: el in SF3 (Process).

Example: `(...(N,EL)...,,DA)`

Elastic scattering cross section cannot be defined for charged-particle induced reaction because of Coulomb interaction.

Forbidden: `(...(P,EL)...,,SIG)`

---

[1] Lane,*et al*., Phys. Rev. **107**, 1077 (1957).

Inelastic Scattering
Scattering with (de-)excitation of the projectile and/or target nucleus ($Q \neq 0$).

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. For inelastic γ emission, g is coded in SF7. 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.

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 Formats Manual Chapter 4 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

Partial Scattering
The sum of elastic scattering and a part of inelastic scattering.

REACTION Coding: `SCT` in SF3 and `PAR` in SF5

Example: `(...(N,SCT)...,PAR,SIG)`

Potential Scattering
Elastic scattering that proceeds without the formation of an intermediate nucleus. (Elastic scattering is a mixture of potential and resonance scattering.)

REACTION Coding: POT in SF5.

Example: (...(N,EL)...,POT,SIG)

Coulomb Scattering
Coulomb scattering is defined as the elastic scattering of a charged particle under the influence of the Coulomb force. Differential data are often given as a ratio to Coulomb scattering, since the scattering cross section approaches infinity at very small angles.

1. Ratio to Rutherford scattering
Differential cross section of Rutherford scattering is

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{Rutherford}} = \left(\alpha \frac{Z_{\text{proj}} Z_{\text{targ}}}{2\mu v_{\text{rel}}^2}\right)^2 \frac{1}{\sin^4\left(\theta_{\text{cm}}/2\right)}$$

(α: fine structure constant (~1/137), μ: reduced mass, v_{rel}: relative velocity).

REACTION Coding: RTH in SF8.

Example:
(6-C-12(6-C-13,EL)6-C-12,,DA,,RTH)   Ratio of ^{12}C(^{13}C,^{13}C$_{\text{g.s.}}$)^{12}C$_{\text{g.s.}}$ differential cross section to the Rutherford scattering differential cross section (Rutherford ratio)

The Rutherford ratio at the angle θ_{lab} in the laboratory system and at the corresponding angle in the centre-of-mass system θ_{cm} are the same. Therefore the heading DATA is used instead of DATA-CM even if the Rutherford ratio is given with θ_{cm}.

2. Mott Scattering
Rutherford scattering for identical particle scattering where interference between the projectile and the target must be considered, and differential cross section must be symmetric with respect to 90 degree.

REACTION Coding: MOT in SF8.

Example:
(6-C-12(6-C-12,EL)6-C-12,,DA,,MOT)   Ratio of ^{12}C(^{12}C,^{12}C$_{\text{g.s.}}$)^{12}C$_{\text{g.s.}}$ differential cross section to the Mott scattering differential cross section

Thermal Scattering
Low energy scattering processes for which molecular and crystalline forces are involved. See **Thermal-Neutron Scattering**.

Secondary Energy

See also **Angle**, **Outgoing Particles.**

Definition

Information on the energy state of a nucleus after reaction, or on the energy value of detected particles, or on any other energy related to the secondary particles, is entered as follows:

Numerical Values

Values are entered in the COMMON or DATA section using data headings from Dictionary 24 with the family code E, *e.g.*, E-LVL, E.

a. In the case of two or more unresolved energy levels, the data heading may be repeated (see EXFOR Formats Manual Chapter 4), or the energy range may be, *e.g.*, E-LVL-MIN, E-LVL-MAX.

b. If it is not evident to which reaction product the secondary energy refers, this must be specified under the keyword EN-SEC; see below.

c. Only one representation of the secondary energy should be coded, therefore, if, *e.g.*, a γ-ray energy is given along with the initial and final excited states for the decay, the energy of the gamma is coded under the heading E and the headings LVL-INI and LVL-FIN are used to give the levels as associated information.

d. In some cases, where the data is a function of the energy of two secondary particles, in order to reduce a 3-dimensional plot to two dimensions, the data are given as a function of the distance along the kinematic locus of the energies (S):

$$\Delta S = \sqrt{\Delta E_1^2 + \Delta E_2^2}$$

That is, the allowed energies of particle 1 (E_1) vs. particle 2 (E_2) are described by a curve showing the kinematically allowed values of E_1 vs. E_2. The point where $E_1 = E_2$ is assigned the value $S = 0$. In this case the kinematic locus is entered under the heading S. The right figure[2] is an example of the kinematical locus.
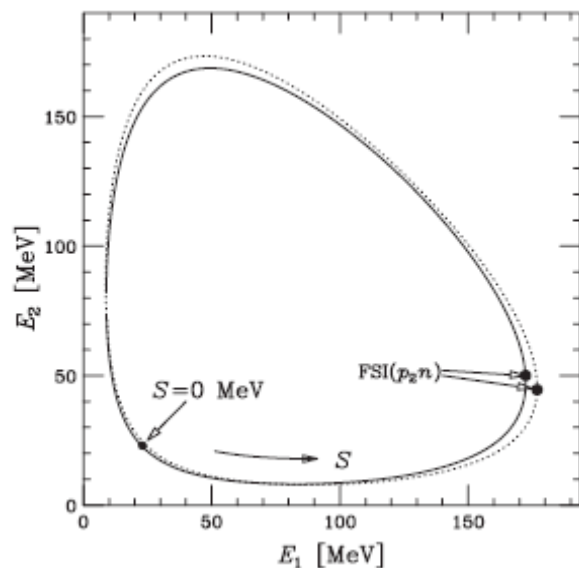
e. The secondary-energy uncertainty or resolution may be entered using a data heading from Dictionary 24 with the family code E, *e.g.*, E-RSL, E-LVL-ERR. Further information can be given under the keyword ERR-ANALYS (see EXFOR Formats Manual Chapter 7: **ERR-ANALYS**). See also **Errors, Resolution**.

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[2] Reprinted figure with permission from [K. Sekiguchi *et al.*, Phys. Rev. C79(2009)054008]. Copyright 2022 by the American Physical Society.

f. When authors do not give the level energy explicitly but only the level number[3], the heading `LVL-NUMB` must be used in place of the level energy (except for the ground state). Compilers must not take the level energy from a nuclear database when authors give only the level number.

Keyword EN-SEC
The 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 Exchange Manual Chapter 7: **EN-SEC**). This keyword must always be coded when it is not evident to which reaction product the secondary energy refers, e.g. because more than one particle is specified in SF3 and/or SF7, or when the data is a function of the secondary energy of more than one secondary particle.
- to give free text information about the secondary energy.

A secondary-energy that is not defined[4] by the reaction code must be defined under the keyword EN-SEC.

Energy Correlation of Secondary Particles
See **Differential Data**.

Average Kinetic Energy
REACTION Coding: `KE` or `AKE` in SF6.

Example: `(...(G,X)0-NN-1,,KE)`   average kinetic energy of neutrons

See **Fission Yields** for details.

Most Probable Kinetic Energy
REACTION Coding: `KEP` in SF6

Example: `(...(P,F),,KEP,FF)`   most probable kinetic energy of fission fragments

## Secondary Linear Momentum
Numerical values of the linear momentum of a secondary particle are entered in the COMMON or DATA section using data headings from Dictionary 24 with the family code `L`, *e.g.*, `MOM-SEC`.

---

[3] For example, LVL-NUMB=1 for (p,n$_1$) reaction.
[4] That is, if the particle to which it applies is not obvious (See Particles).

Keyword MOM-SEC

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.

A secondary-linear momentum that is not defined[2] by the REACTION code must be defined under the keyword MOM-SEC.

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-SEC1, MOM-SEC2, *etc*.

Quantities as a Function of Linear Momentum of Secondary Particles

See **Differential Data.**

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:

$$\sigma_{cc}(E) = 4\pi\lambdabar_0^2 g \left| \frac{\Gamma_c/2}{(E-E_0)+(i\Gamma_{tot}/2)} + \frac{R'}{\lambdabar_0} \right|^2 + 4\pi R'^2 (1-g)$$

$$g = \frac{2J+1}{(2J_i+1)(2J_t+1)},$$

where

$$4\pi R'^2 = \sigma_{pot}$$

λ_0 = de Broglie wavelength at the resonance energy,

$\lambdabar_0$ = $\lambda_0 / 2\pi = 1/k$ (inverse of wave number),

J = spin of resonance,

J_i = spin of incident projectile,

J_t = spin of target

For reactions (capture, fission, *etc.*):

$$\sigma_{cc'}(E) = \pi\lambdabar_0^2 g \left(\frac{E_0}{E}\right)^{1/2} \frac{\Gamma_c \Gamma_{c'}}{(E-E_0)^2 + (\Gamma_{tot}/2)^2}$$

where c = channel for formation of compound nucleus

c' = channel for decay of compound nucleus

For further detail see References [1] and [2].

Note:

Resonance parameters are compiled when both the projectile and target leading to the compound resonance are clarified by authors, and also the parameters are given as a function of incident energy on resonance (compiled under data heading EN-RES or, when determined in the same experiment, EN under keyword REACTION SF6).

Resonance Energy

Resonance (E_0) is coded in EXFOR in one of three 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 SF3; `EN` in SF6

   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.

3. If both types of resonance energies are given by the author, they may be on one data set.

   Example:
   ```
   REACTION  1(48-CD-113(N,0),,EN)
             2(48-CD-113(N,EL),,WID,,G)
   ...
   EN-RES      DATA       1DATA 2
   EV          EV          MILLI-EV
    21.830                 0.00662
               49.767     0.0144
   ...
   ```

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 Width (Γ_r)

REACTION Coding: `WID` in SF6and the code for the reaction described in SF3

Examples:

`(...(N,TOT),,WID)`	=	total width (Γ_{tot})
`(...(N,EL),,WID)`	=	neutron width (Γ_n)
`(...(N,G),,WID)`	=	capture width, or radiation width (Γ_γ), including all primary γ decays not followed by a neutron or charged-particle emission.

If the resonances have a clear shape (no overlap with nearby resonances), **shape analysis** (`SHAPE`) is applicable, or else **area analysis** (`AREA`) is a major method. Analysis method may be entered under the keyword `ANALYSIS`.

Units: a code from Dictionary 25 with the dimension `E` (*e.g.*, `EV`).

For partial radiation width, see **Gamma Spectra**.

Reduced Neutron Width

Reduced neutron width is defined at 1 eV as follows: (1)

$$\Gamma_n^l = \frac{\Gamma_n}{v_t \sqrt{E_0 / 1\,\text{eV}}}$$

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): (2)

$$\Gamma_n^0 = \frac{\Gamma_n}{\sqrt{E_0 / 1\,\text{eV}}}$$

    for p-wave resonances: (3)

$$\Gamma_n^1 = \frac{\Gamma_n}{\sqrt{E_0 / 1\,\text{eV}}} \left(1 + \frac{1}{k_0^2 R^2} \right)$$

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).

Units: a code from Dictionary 25 with the dimension E (*e.g.*, `EV`).

Note:

Some authors give the reduced neutron width (for s-wave neutrons) as:

$$\Gamma_n^0 = \Gamma_n / \sqrt{E_0}$$

which has the dimension of the square-root of an energy. (Compare: Hennies [3]). For consistency, only definition (1) with the dimension of energy should be used in EXFOR, the numerical values being anyway identical except for the dimensions.

Peak Cross Section

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: $\sigma_c = 4\pi \lambdabar_0^2 g \dfrac{\Gamma_c}{\Gamma_{\text{tot}}}$

    Partials:

These are coded $\sigma_{cc'} = \sigma_c \dfrac{\Gamma_{c'}}{\Gamma_{\text{tot}}}$ with the modifier code res in combination with the code for the reaction   described.

Example: `(...(N,TOT),,SIG,,RES)`   Total peak cross section

Resonance Area (cross section integrated over the resonance)
Resonance area is defined:

For scattering:
$$A_{cc} = 2\pi^2 \lambdabar_0^2 g \frac{\Gamma_c^2}{\Gamma_{tot}}$$

For other reactions:
$$A_{cc'} = 2\pi^2 \lambdabar_0^2 g \frac{\Gamma_c \Gamma_{c'}}{\Gamma_{tot}}$$

REACTION coding: ARE in SF6.

Units: a code from Dictionary 25 with the dimension B*E (*e.g.*, B*EV).

Example :   (...(N,EL),,ARE)   Scattering area

Resonance Strength
The resonance strength is defined as:
$$\omega\gamma = g \frac{\Gamma_c \Gamma_{c'}}{\Gamma_{tot}}.$$

where: ω =statistical weight factor (=g)
 γ = channel dependent width ($\Gamma_c\Gamma_{c'}/\Gamma$)

Resonance strength for capture reaction may also be called **capture kernel** or **capture area** A_γ. Resonance strengths are determined experimentally by measuring the area under the resonant yield curve over the resonance:

$$\omega\gamma = \frac{2}{\lambda_{0,cm}^2} \frac{\int Y_{c'}(E)dE}{n_t},$$

or by measuring the thick target yield
$$\omega\gamma = \frac{2\varepsilon}{\lambda_0^2} \frac{M_t}{M_t + M_i} Y_{c',thick},$$

where n_t =number of atom per unit area of target
 ε = stopping power
 M_t =mass of target,
 M_i =mass of incident projectile,
 $Y_{c'}$ = yield for channel c'

Partial resonance strengths are given for transitions to a specific energy level.

REACTION Coding: WID/STR in SF6.

Units: a code from Dictionary 25 with the dimension E, *e.g.,* EV

Examples:
    (...(P,G),,WID/STR)   resonance strength for proton capture $g\Gamma_p\Gamma_\gamma/\Gamma_{tot}$)
    (...(N,G),PAR,WID/STR)   resonance strength for a given level excitation.

Sometimes resonance strength is reported with a **modified statistical factor (2J+1)**,

$$(2J+1)\frac{\Gamma_c\Gamma_{c'}}{\Gamma_{tot}}.$$

This may be coded with a modifier `RG`.

REACTION Coding: `WID/STR` in SF6; `RG` in SF8.

Example: `(...(P,G),,WID/STR,,RG)` (2J+1) $\Gamma_p\Gamma_\gamma/\Gamma_{tot}$ for proton capture

<u>Special Representations</u>
Some examples of special representations are as follows:

$\sigma_0\Gamma_f$	`(.....(N,F),,WID,,S0)`
$\sigma_0\Gamma^2$	`(.....(N,TOT),,WID,,SQ/S0)`
$g\Gamma_n$	`(.....(N,EL),,WID,,G)`
$ag\Gamma_n$	`(.....(N,EL),,WID,,AG)`

where
- g = statistical weight factor
- a = isotopic abundance
- σ_0 = total peak cross section (=σ_c)

<u>References</u>
[1]   A. M. Lane and R. A. Thomas, Rev. Mod. Phys. **30**, 257 (1958).

[2]   J. A. Harvey, ed., Experimental Neutron Resonance Spectroscopy (Academic Press, 1970).

[3]   Hennies, Nuclear Data for Reactors, Paris Conference, Vol. 2 (1966) page 333.

Spectrum Average

Cross sections averaged over a broad incident-projectile energy spectrum may be entered into EXFOR using the proper modifier to REACTION SF8[5]. The type of spectrum and its characteristic should be entered in free text under the keyword INC–SPECT.

The following spectrum types are defined:

Maxwellian Average
REACTION coding: MXW in SF8.

The spectrum temperature should be given, if known. For thermal Maxwellian spectrum averaged data, see **Thermal Neutron Energies**.

Maxwellian spectrum averaged cross section (MACS) is defined as

$$\sigma_{\text{MXW}}(kT) = \frac{2}{\sqrt{\pi}} \frac{\int_0^\infty \sigma(E) E_n \exp(-E/kT) dE}{\int_0^\infty E \exp(-E/kT) dE} \ .$$

It is also denoted as $<\sigma \cdot v>/v_T$, where v_T is the most probable velocity of the incident particle, e.g., 2200 m/s for neutrons equilibrated to Maxwell distribution at the room temperature $kT = 0.0253$ eV. If the cross section is proportional to $1/\sqrt{E}$, the MACS is equal to the pointwise cross section at $E=kT$.

Note that some authors define MACS with out the factor $2/\sqrt{\pi}$.

Epithermal Spectrum Average
REACTION coding: EPI in SF8.

The energy quoted will be, typically the low energy cut-off.

Fission-Neutron Spectrum Average
REACTION coding: FIS in SF8.

Fission-neutron spectrum averaged cross section is defined as

$$\sigma_{\text{FIS}}[\chi(E)] = \frac{\int_0^\infty \sigma(E) \chi(E) \sqrt{E} dE}{\int_0^\infty \chi(E) \sqrt{E} dE}$$

---

[5] Cross sections measured as a function of energy and then averaged over a discrete energy range are entered as average (modifier AV). See **General Quantity Modifiers**.

It should 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 derive 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 $\chi(E)$-versus-E scale or in a $\chi(E)/E$-versus-$E^{1/2}$ scale.

Fast Reactor Spectrum Average
REACTION coding: FST in SF8.

Bremsstrahlung Spectrum Average
REACTION coding: BRA in SF8.

$$\sigma_{\mathrm{BRA}}(E_{\max}) = \frac{\int_0^{E_{\max}} n(E, E_{\max})\,\sigma(E)dE}{\int_0^{E_{\max}} (E/E_{\max})\,n(E, E_{\max})dE}$$

where $n(E, E_{\max})$ is the Bremsstrahlung spectrum distribution. The energy quoted will be, typically, EN-MAX, or EN-MIN with EN-MAX. The incident source code BRST is coded under the keyword INC-SOURCE.

The modifier BRA is also applied to data measured by a virtual photon source (*i.e.*, irradiation of the sample by electrons without a radiator). The incident source code VPH is applied under the keyword INC-SOURCE. The particle code G is coded in REACTION SF2 with the electron energy under the heading EN-MAX.

The factor $E/E_{\max}$ in the denominator of the definition is due to normalization by the number of **equivalent quanta** (instead of number of incident photons) determined by the Wilson quantameter, and the cross section is sometimes referred to as the **cross section per equivalent quantum**. For more background, see [1].

Average over "Good Resolution" Bremsstrahlung Spectrum
REACTION coding: BRS in SF8.

The energy quoted will be, typically, EN with EN-RSL. The quantity is usually derived from the Bremsstrahlung spectrum averaged quantities by using an unfolding procedure coded under the keyword ANALAYSIS (*e.g.*, LEAST, PHDIF, PLA). The same modifier BRS is also applied to quantities obtained by unfolding of quantities measured by a virtual photon source.

Slowing-Down Time Spectrum Average

Slowing-down time spectrum averaged cross section is defined as

$$\sigma_{\text{SDT}}(<E>) = \frac{\displaystyle\int_0^\infty \sigma(E)\varphi(E)\mathrm{d}E}{\displaystyle\int_0^\infty \varphi(E)\mathrm{d}E}$$

For a given slowing-down time t, the corresponding average neutron energy E is expressed by $<E> = K / (t_0 + t)^2$, where K is the slowing-down constant and t_0 is a correction factor to account for the time it takes neutrons to slow down from source energies. The flux distribution $\varphi(E)$ is typically approximated by the Gaussian distribution centred at $<E>$ with its standard deviation $\sigma(<E>)$. The average energy quoted will be, typically, EN. The width information (*e.g.*, FWHM) is essential for comparison with better resolution data sets, and must be given under the keyword INC-SPECT. See [2] for compilation of some FWHM values determined by experimentalists.

REACTION coding: SDT in SF8.

Spectrum Average (Unspecified Spectrum)
REACTION coding: SPA in SF8.

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**.

Characteristic Energy of Spectra
The characteristic energy of spectra should be entered into the data table using one of the following data headings:

KT	spectrum temperature in units of energy
KT-K	spectrum temperature in units of temperature
KT-DUMMY	spectrum temperature (energy units) assumed by compiler
1.32 MeV	^{235}U thermal neutron induced fission prompt fission-neutron spectrum
1.42 MeV	^{252}Cf spontaneous fission prompt fission-neutron spectrum
EN-MEAN	mean energy
EN-DUMMY	dummy energy (characteristic of spectrum)
0.0005 eV	cold neutrons (if nothing else is specified by authors)
0.0253 eV	thermal Maxwellian and thermal reactor spectra
1.5 MeV	fission-neutron spectra (if nothing else is specified by authors)
4.5 MeV	decay α-Be neutron sources

Note:

For Maxwellian spectra: $E_{mean} = (3/2) \, kT$. However, compilers must give the spectrum temperature (~0.0253 eV for thermal reactor neutrons, ~30 keV for neutrons relevant to stellar environments) under the heading KT without conversion to the corresponding mean energy when the authors give the spectrum temperature value. The *kT* value corresponds to the most probable velocity of the Maxwell distribution.

References

[1] F. Carbonara et al., Nucl. Phys. **73** (1965) 385

[2] T. Nakagawa, O. Iwamoto, Report JAERI-Data/Code 2002-025 p.101 (2002).

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 Formats Manual Chapter 7: **MONITOR**, for coding rules). Only that standard data to which the data given are proportional should be coded. Other information should be entered under the 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 that 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 is coded using the information-identifier keyword MONIT-REF (see EXFOR Formats Manual Chapter 7: **MONIT-REF**, for coding rules).

Decay data for the standard(s) used is coded using the information-identifier keyword DECAY-MON (see EXFOR Formats Manual Chapter 7: **DECAY-MON**, 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.

1. 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 Formats Manual Chapter 7: **MONITOR**, for coding rules.

Numerical values for the uncertainty are entered using the data heading MONIT-ERR. The absolute uncertainty (*i.e.*, not in %) is coded only when the standard value is coded under the heading MONIT. Further information can be entered under the keyword ERR-ANALYS, see EXFOR Formats Manual Chapter 7: **ERR-ANALYS**.

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,T)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:

Use of data heading to link BIB and DATA

```
BIB
MONITOR    ((MONIT1)...)
           ((MONIT2)...)
MONIT-REF  ((MONIT1)...
           ((MONIT2)...
DECAY-MON  ((MONIT1)...
           ((MONIT2)...
...
ENDBIB
NOCOMMON
DATA
EN         DATA      MONIT1     MONIT2
MEV        B         B          B
 1.        ...       ...        ...
 2.        ...       ...        ...
 3.        ...       ...        ...
ENDDATA
```

Normalization information given in COMMON

```
COMMON
EN-NRM     E-LVL-NRM  MONIT
MEV        MEV        MB
 ...       ...        ...
ENDCOMMON
```

Use of pointers to link BIB and DATA.

```
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 keyword STATUS. See EXFOR Formats Manual Chapter 7, **STATUS**, 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 labelled as superseded with a cross-reference to the data set which supersedes it. If the earlier set has the status code prelim, it is removed. (The codes prelim 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
For all compilations of new literature, a proof copy should be sent to the corresponding author. After the proof copy of a data set has been approved by the author, the code APRVD is entered under status. If no reply on the proof copy has been received from the author, this should be mentioned in free text ("no reply to author proof").

Example: STATUS   (APRVD) Approved by J. Doe, 7 January 2004

Note:
The status codes APRVD must be distinguished form TABLE. The code APRVD is used when the entry was proofread and approved by authors. The code TABLE is used when the numerical data presented by authors are compiled.

Source of the Data
The actual source from which the numerical values given in the data set were taken must be entered with a clear citation 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 labelled with the status code CURVE.

The table or figure number in free text must be followed by the reference information (*e.g.*, J. Nucl. Phys. 12(2021)345) when there are two or more reference under REFERENCE. This is also preferably done when there is only one reference.

Example:
```
STATUS      (CURVE) Scanned from Fig. 1 of Yad.Fiz.12(1951)345
STATUS      (TABLE) Taken from Table 1 of Phys.Atom.Nucl.12(1951)678
```

The information must be indicated under STATUS of each data subentry when the numerical values of the entry are from several tables or figures.

Note:
Older entries may have been labelled only under the keyword COMMENT or HISTORY.

Correction and Reassessment
If the codes RNORM and CRCTD are absent, the data are compiled as resulting from the author's corrections and normalizations.

A data set that is corrected or reassessed by other than the author is labelled with the status code CRCTD. The older data set that is superseded by the later correction or reassessment must be kept but labelled with the status code OUTDT. Both must give a cross reference to the other data set as follows:

Examples:
```
STATUS      (OUTDT,19231002)
STATUS      (CRCTD,10231003)
```

All such data sets must be also indicated by the data type code CRCTD in the REACTION SF9. See LEXFOR **Data type**.

Interdependent Data and Complemental Results
Interdependent data (*e.g.*, cross section and Legendre coefficients derived from the same angular distribution data) and complemental results (e.g., two activation cross sections from detection of two radiations) may be coded in the same subentry, see EXFOR Formats Manual Chapter 5.

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 Formats Manual Chapter 7: STATUS, for coding details).

Example: `STATUS      (COREL,X0001002)`

Unobtainable Data

In the case where a centre is aware that data exist, but the centre is unable to obtain the data, an entry may be made in EXFOR to inform the other centres (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 Formats Manual, page 7.2). 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.

The status code CURVE replaces UNOBT when the unobtainable dataset was digitized and compiled.

At least one data subentry should be included containing, at minimum the reaction; the system identifier NODATA replaces the DATA section (see EXFOR Formats Manual Chapter 2).

Translation from Older Libraries

Data that 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.

The status code TABLE replaces the status code indicating the library when the data set was confirmed in a table prepared by the experimentalist.

Compilation of data presented by other than the author (e.g., review, compilation) is no longer allowed. Only the data tabulated or plotted by the experimentalist can be newly compiled.

Sums

Sums of 2 or more reactions can be expressed as a reaction combination using the separator `+´ (see EXFOR Formats Manual Chapter 6).

Sum reactions such as absorption or nuclide production, where the individual competing reactions may not be known, are not coded using the form above.

Frequently Occurring REACTION Sum

The reaction sum formalism is not used for certain frequently occurring sums for which specific quantity codes have been introduced.

Examples:

Data for natural target = Sum data for all contributing target nuclides
```
(46-PD-106(P,2P)45-RH-105-G,CUM,SIG,,A)+
(46-PD-108(P,X)45-RH-105-G,CUM,SIG,,A)+
(46-PD-110(P,X)45-RH-105-G,CUM,SIG,,A)
→(46-PD-0(P,X)45-RH-105-G,CUM,SIG)
```

Production = Sum of processes
```
(46-PD-102(P,D)46-PD-101,CUM,SIG)+
(46-PD-102(P,N+P)46-PD-101,CUM,SIG)
→ (46-PD-102(P,X)46-PD-101,CUM,SIG)
```

Scattering = Elastic scattering + inelastic scattering
```
(3-LI-7(N,EL)3-LI-7,,SIG)+
(3-LI-7(N,INL)3-LI-7,PAR,SIG)
→ (3-LI-7(N,SCT)3-LI-7,PAR,SIG)
```

Production from Several Contributing Target Nuclides

When several target nuclides of the element may contribute to formation of a product, the author may express it by a sum of isotopic cross sections. In the following examples,

- $a(A)$ is the isotopic abundance of the target nuclide A,

- $\sigma(A)$ is the isotopic cross section for the target nuclide A,

- $\sigma(0)$ is the elemental cross section (*i.e.*, production cross section for a natural sample).

Summation is taken over all energetically possible production channels:

1. **$\sigma(0)=a(A)\sigma(A) + a(B)\sigma(B) +...$**

This is nothing other than the elemental cross section, and should not be coded by the sum reactions.

Example:

```
(22-TI-0(N,X)21-SC-47,,SIG)
```

Forbidden:

```
((22-TI-47(N,P)21-SC-47,,SIG,,A)+(22-TI-48(N,X)21-SC-47,,SIG,,A))
```

2. σ(0)/a(A)=σ(A) + [a(B)/a(A)]σ(B) + ...

This is coded with a modifier RAB (multiplied by the natural isotopic abundance of the target nuclide divided by the natural isotopic abundance of the target nuclide of the first term). The isotopic abundance a(A) adopted by the author must be given under SAMPLE if known.

Example:

```
((22-TI-47(N,P)21-SC-47,,SIG)+(22-TI-48(N,X)21-SC-47,,SIG,,RAB))
```

3. σ(0)/[a(A)+a(B)+...]=[a(A)σ(A) + b(B)σ(B) + ...] / [a(A) + a(B) + ...]

This is coded with a general quantity modifier FCT with free text explanation about the multiplier. The isotopic abundances such a(A) and a(B) adopted by the author must be given under SAMPLE if known.

Example:

```
((22-TI-47(N,P)21-SC-47,,SIG,,FCT)+(22-TI-48(N,X)21-SC-47,,SIG,,FCT))
```

Elemental cross section divided by the sum of isotopic abundances of ^{47}Ti and ^{48}Ti.

Sum of Unresolved Partial Quantities

When the quantity is a sum of partial quantities whose secondary energies are unresolved (*e.g.,* due to detection resolution), it is coded as an inclusive reaction quantity (*i.e.*, SF3=X).

Example:

412 keV prompt gamma production from n+^{nat}Fe reaction originated from production of two unresolved gammas, ^{54}Fe(n,n')^{54}Fe (411.5 keV) and ^{56}Fe(n,2n)^{55}Fe (411.7 keV), is coded by

```
(26-FE-0(N,X)0-G-0,PAR,SIG)
```

rather than

```
(26-FE-54(N,INL)26-FE-54,PAR,SIG,G,A)+(26-FE-56(N,2N)26-FE-55,PAR,SIG,G,A)
```

The contributing process is explained under EN-SEC.

Example:

```
EN-SEC   (E,G)   411.5 keV gamma of 54Fe and 411.7 keV gamma of 55Fe
```

Reactions to Sums of Isomeric States

Reactions to sums of isomeric states are coded using the separator "+" in the isomer field of the reaction product; see **Isomeric States**.

Example: `(…(P,X)39-Y-102-M1+M2,,SIG)`

Note: If the sum of all isomeric reactions is equal to the cross section for the given nuclide, it is coded without the isomer field.

Example: `(…(P,X)47-AG-109,,SIG)`

Forbidden: `(…(P,X)47-AG-109-G+M,,SIG))`

Supplemental Information

Supplemental information that is required to make the data set well-defined may be provided under SUPPL-INF. This is a useful option when the supplemental information is voluminous, and not suitable to keep it with other information in a BIB section. See also EXFOR Formats Chapter 7: **SUPPL-INF**.

Use of this keyword is currently limited to store (1) incident neutron spectra, or (2) resolution or response function.

Example

```
SUBENT        22850002    20101208                               2285000200001
…
REACTION    (43-TC-99(N,G)43-TC-100,,SIG,,SPA)                   2285000200003
…
STATUS      (TABLE) Table 4 of Nucl.Sci.Technol.40(2003)61       2285000200014
            (SUPPL,22850010) Neutron source spectrum
…
SUBENT        22850010    20101208                               2285001000001
BIB                 1          997                               2285000200002
SUPPL-INF   (INCSP) Neutron flux (spectrum) normalized to 1      2285001000003
              Col. 1: Incident neutron energy (MeV)              2285001000004
              Col. 2: Neutron flux (1/MeV)                       2285001000005
              -------------------------                          2285001000006
                0.0000E+00    0.0100E+00                         2285001000007
                1.0000E+00    0.0100E+00                         2285001000008
                2.0000E+00    0.0100E+00                         2285001000009
…
STATUS      (TABLE) Fig.2 data set received from the authors     2285001000998
HISTORY     (20102108R) Data received from the authors           2285001000999
ENDBIB              997          0                               2285001001000
NOCOMMON              0          0                               2285001001001
NODATA                0          0                               2285001001002
ENDSUBENT          1001          0                               2285001099999
```

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.

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, if corrections for isotopic abundance have not been or cannot be applied, one of the following modifiers is given with the quantity code (see Dictionary 34 for definition of codes):

A   - data times isotopic abundance of target, where target is a natural isotopic mixture.

(A)   - used as above when it is not clear whether the data were corrected for abundance.

FCT   - used for an enriched target, where enrichment << 100%. (In this case, a free text explanation is necessary.)

In these cases the target description must be entered under the keyword sample.

If a light target, such as ^{1}H, is bombarded with a heavy projectile, such as ^{12}C, the data are considered to be equivalent to a ^{12}C(p,...) reaction. In the REACTION code, the target and projectile are always coded according to the actual experimental arrangement. To retrieve in one go also the reaction with target and projectile exchanged, special retrieval options may be foreseen. If the numerical values are actually identical for both representations without any kinematics conversion, the Tautology formalism may be used (see page T.2).

The neutron as target nucleus, (*e.g.*, for neutron-neutron interactions) is coded as 0-NN-1.

For elemental targets, see also **Elements**.

For compounds as targets, see also **Chemical Compounds**.

The isomeric state code -G is never used for a target nucleus. See also, **Isomeric States**.

For coding rules see EXFOR Formats Manual Chapter 6.

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 Formats Manual Chapter 6). Its use is optional, *i.e.*, at the discretion of the compiler.

Examples of tautologies that may be entered:

1. <u>For data below thresholds</u>. For example, total scattering equals elastic scattering below the inelastic threshold.

2. <u>Emission cross sections, for certain secondary energies</u>. For example, the γ-ray emission cross section equals the inelastic γ cross section for some γ-ray energies.

3. <u>Data measured by inverse kinematics technique</u>. For example, heavy-ion induced reaction on a light target nucleus which data are unchanged under exchange of incident particle and target. See also **Centre-of-mass system**.

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 favour 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 293 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: $\hat{\sigma} = \sigma_0 (g + rs)$

where σ_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 the chemical binding energy, and not close to resonance region, typically less than a few eV), with matter depends on the <u>atomic structure</u> of the material (because the wavelength of slow neutrons is of the order of inter-atomic distances) and on the <u>atomic dynamics</u> in the scattering medium (because the energy of slow neutrons is of the same order as the energy of thermal motion of atoms in crystals and solids). Van Hove formulated the double differential cross sections considering the structure and dynamics as

$$d^2\sigma/d\Omega dE' = (1/2\pi\hbar)\ (k'/k)\ \Sigma_{ij}\ b_i b_j \int_{-\infty}^{+\infty} dt < \exp(-i\mathbf{q}\cdot\mathbf{r}_j(0))\exp(-i\mathbf{q}\cdot\mathbf{r}_i(t)) >_T \exp(-i\omega t)$$

where k and k' are the initial and final wave numbers of the neutron, b_i is the scattering length of the nucleus i which is at position $\mathbf{r}_i$ at time t, $\mathbf{q}=\mathbf{k'}-\mathbf{k}$ is the momentum transfer of neutron, and $\hbar\omega=E'-E$ is the energy transfer of neutron. $<...>_T$ denotes averaging over the canonical ensemble characterized by the temperature T. If we denotes the integral by $S_{ij}(\mathbf{q},\omega)$, and decompose the differential cross section to the i≠j and i=j part:

$$d\sigma/d\Omega dE' = (1/2\pi\hbar)\ (k'/k)\ [<b>^2\Sigma_{i\neq j}\ S_{ij}(\mathbf{q},\omega) + <b^2>\Sigma_{i=j}\ S_{ij}(\mathbf{q},\omega)]$$

$$= (1/2\pi\hbar)\ (k'/k)\ [<b>^2\Sigma_{i,j}\ S_{ij}\ (\mathbf{q},\omega)+ (<b^2>-<b>^2)\Sigma_{i=j}\ S_{ij}(\mathbf{q},\omega)]$$

where $<b>^2$ is $<b_i b_j>$ with i≠j and $<b^2>=<b_i b_j>$ with i=j. The first term of the second equation involving all nuclear states (isotopes and spin states of the compound) describes **coherent scattering** while the second term involving a single nuclear state describes **incoherent scattering**.

Coding
- For all scattering processes where molecular and crystalline forces are involved the code THS is used in REACTION SF3.

- The sample temperature is given under the heading TEMP and the modifier TMP should be in REACTION SF8 when the sample temperature is different from room temperature (~300 K).

- The crystal structure of the sample is given under the keyword SAMPLE.

- When the compiler is aware that the quantity depends on the orientation of the sample (e.g., transmission for a single crystal), it must be indicated by SF8=MSC with free text.

- The scattering <u>length</u> is compiled with AMP in REACTION SF6. This parameter code is combined with MSC in REACTION SF8 when the scattering <u>amplitude</u> is compiled.

Coherent and incoherent scattering length
The quantities $b_{coh}=<b>$ and $b_{inc}= (<b^2>-<b>^2)^{1/2}$ are known as the coherent and incoherent scattering length.

The scattering length for a **free atom** (mass number A) is a factor A/(A+1) smaller than that for a **bound atom**. Their distinction is important for light nuclides.

Some strong neutron absorbers (e.g., ^{113}Cd, ^{157}Gd) may have an imaginary part of the scattering length. The imaginary part of <b> is related with the absorption cross section by Im(<b>)=$k\sigma_{abs}(E)/4\pi$ (optical theorem) at E→0.

The scattering length b is related with the **scattering amplitude** f(E) by b=-lim$_{E\to0}$f(E). (Sometimes scattering length is called as scattering amplitude.)

REACTION Coding: COH or INC in SF5 and AMP in SF6. IM in SF5 for imaginary part.

Examples:

```
(6-C-12(N,THS)6-C-12,BA/COH,AMP)
```
        Bound atom coherent scattering length of ^{12}C

```
(23-V-51(N,THS)23-V-51,FA/INC,AMP)
```
        Free atom incoherent scattering length of ^{51}V

```
(64-GD-157(N,THS)64-GD-157,COH/IM,AMP)
```
        Imaginary part of coherent scattering length of ^{157}Gd

Contribution of potential scattering and resonance scattering
The bound atom scattering length is the sum of the contribution from potential scattering and all s-wave resonances:

$$[A/(A+1)]|b_{\pm}| = R' - [(A+1)/A] [\hbar/(8m)^{1/2}] \Sigma_{i\pm} [(\Gamma_{n,i}/E_{0,i}^{3/2}) - i (\Gamma_{n,i}\Gamma_n/2E_{0,i}^{5/2})],$$

where m is the neutron mass and $\hbar c/(8m)^{1/2}$~2277 fm eV$^{1/2}$. R' is the **potential scattering radius**, A is the mass number of the nuclei, $\Gamma_{n,i}$ and Γ_i are the neutron and total width of the i-th resonance at the resonance energy $E_{0,i}$. $\Sigma_{\pm}$ means summation for all resonance having the same spin $J_+=I+1/2$ or $J_-=I-1/2$. Their weighted mean gives <b>=$g_+b_++g_-b_-$ with $g_{\pm}=[2(I\pm1/2)+1]/[(2I+1)2]$, where I is the spin of the target nucleus

Note that only J=I+1/2 is possible for spin zero nuclei, and $b_{coh}=b_+$ and $b_{inc}=0$ for them. For example, thorium gives no incoherent scattering because it is enriched to thorium-232 and its ground state spin is zero.

Coherent and incoherent scattering cross section
The quantities $\sigma_{coh}=4\pi b_{coh}^2$ and $\sigma_{inc}=4\pi b_{inc}^2$ are known as the coherent and incoherent scattering cross section. Their values for bound and free atom are related by the factor A/(A+1). Their sum $4\pi(b_{coh}^2+b_{inc}^2)$ gives the total scattering cross section of fixed nuclei.

Examples:

```
(6-C-12(N,THS)6-C-12,BA/COH,SIG)
```
        Bound atom coherent cross section of ^{12}C

```
(23-V-51(N,THS)23-V-51,INC,SIG)
```
        Incoherent cross section of ^{51}V

Cross section of hydrogen in hydride molecule

Cross sections of hydride molecule are often reported as "cross section per hydrogen (proton)". It means the free atom (gas) cross sections of the elements other than hydrogen are subtracted and then divided by the number of hydrogen atoms in the molecule. The cross section should approach to the free hydrogen cross section (~20.5 b) at the asymptotic region (~1 eV). Above this energy, cross sections should be compiled as those for free hydrogen atoms. The unit code B is used even if the authors give the cross section in b/atom.

REACTION coding: HYD in SF8.

References

[1.] S. Mughabghab, Atlas of neutron resonances: Resonance parameters and thermal cross sections Z=1-100 (Elsevier, 2006).

[2.] B.T.M. Willis and C.J.Carlile, Experimental neutron scattering (Oxford University Press, London, 2009).

[3] ILL Neutron Data Booklet, Editors Albert-José Dianoux and Gerry Lander (2003 Institute Laue-Langevin, France)

[4] J.I. Marquez Damian and V. Semkova (eds.), Summary report of the Consultants' Meeting on compilation of thermal neutron scattering data for experimental nuclear reaction data library (EXFOR). Report INDC(NDS)-0697, International Atomic Energy Agency, 2016.

Thermonuclear Reaction Rate

<u>Definition</u>
The thermonuclear reaction rate (often denoted by$<\sigma\cdot v>$ symbolically) is at temperature T is defined by

$$<\sigma\cdot v> = \int \sigma(v)\, v \exp(-\mu v^2/2kT)\, v^2\, dv \;/\; \int \exp(-\mu v^2/2kT)\, v^2\, dv$$

$$= (2/\mu)^{1/2} \int E\, \sigma(E) \exp(-E/kT)\, dE \;/\; \int E^{1/2} \exp(-E/kT)\, dE,$$

where v is the relative velocity between the projectile and target, E is the centre-of-mass energy, k is the Boltzmann constant, μ is the reduced mass of the projectile and target. In astrophysics application it is often multiplied by the Avogadro constant.

REACTION Coding: SGV in SF6.

Units: a code from Dictionary 25 with the dimension B*V (*e.g.*, CM3/SEC/MOL).

The spectrum average modifier MXW is always omitted by definition of the quantity. The data type DERIV is also always omitted because typically the cross section from the measurement must be extrapolated to the energy not covered by the experiment (*e.g.*, by using a reaction model) to perform the energy integration. <u>However, the derivation of the reaction rate must be always explained under the keyword ANALYSIS.</u>

The compiler may indicate existence of the reaction rate data by RRATE under the keyword ADD-RES without their compilation.

If the authors provide a portion of the reaction rate corresponding to a specific reaction mechanism determined in their measurement, it can be compiled separately with the branch code DI.

***Example*:**

(…(P,G)…,DI,SGV)   Direct interaction portion of the proton capture reaction rate.

The thermonuclear reaction rate is coded with the projectile temperature under data headings such as KT and KT-K.

Note:

- The quantity $<\sigma\cdot v>/v_T$ with the thermal velocity $v_T=(2kT/\mu)^{1/2}$ is known as the Maxwellian-averaged cross section (,SIG,,MXW).

- The thermonuclear reaction rate can be generalized to any velocity distribution n(v) and $\varphi(v) = v\, n(v)$ such as $R= \int \varphi(v)\sigma(v)\, dv \;/\; \int n(v)\, dv$. Also the number of products per time per volume $N_b\cdot N_t\cdot R$ (N_b: number of projectiles per volume, N_t: number of target atoms per volume) is referred to as the reaction rate. However the reaction rates other than the thermonuclear reaction rates are not characterized by temperature, and *not* compiled in EXFOR in general. When necessary, its existence may be mentioned with the code RRAC under the keyword ADD-RES.

Thermonuclear S-factor
(See **Astrophysical S-factor**)

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. **A315**, 253 (1979).

[5.] C. A. Barnes, Advances in Nuclear Physics, Vol. 4 (Plenum, New York, 1971) p. 133

Thick- and Thin-Target Yields

Thick-target Yield is the yield of a product measured on a target whose thickness is such that the incident beam is degraded in energy to or below the threshold for producing the measured product.

Thin-target yield is the yield of a product measured on a target whose thickness is such that the incident beam is less significantly degraded in energy, and which is given as a function of incident beam current. The incident energy range must be given in the data table under the field headings EN-MIN and EN-MAX, or, if the final energy is not specified, the incident energy and target thickness must be given under EN and THICKNESS.

The distinction between the thick- and thin-target yields explained above is a typical one, but there is no common established boundary between them.

The data are sensitive to target thickness. The energy loss is a function of the stopping power of the target material.

The **thick target product yield** y is the number of the products per unit induced electric charge (e.g., μC, μA-h) is

$$y = \int_0^{E_0} dE \left[-(1/\rho)(dE/dx) \right]^{-1} \sigma(E)(1/Ze),$$

where
E_0: initial beam energy,
$\sigma(E)$: energy dependent cross section
ρ: target isotope number density,
x: sample thickness,
Z: beam particle electric charge,
e: elemental charge.

The quantity $[-(1/\rho)(dE/dx)]$ is known as the stopping power. The thick target product yield may be also expressed as the number of the product per beam particle.

The **end-of-bombardment thick target yield** a(t), the activity of the sample material per unit current at irradiation time t, is
$$a(t) = y(1 - e^{-\lambda t}),$$

and its unit is the decay rate per unit current (e.g., MBq/μA). Especially this quantity for infinite irradiation $a_{sat} = a(t \rightarrow \infty) = y$ is defined as the **saturation thick target yield**.

The **physical thick target yield** α_{phys} is the time differential of the end-of-bombardment thick target yield at t=0:
$$\alpha_{phys} = da(t)/dt|_{t=0} = \lambda y.$$

The unit of the physical thick target yield is the decay rate per unit electric charge (e.g., MBq/C or MBq/μA-h).

See also Ref. [1] for the definitions and typical units of the above mentioned thick target yields.

By replacing the lower-boundary of the integral with the beam energy at the exit of the sample, we may also define these yields for thin targets.

Saturation Thick/Thin-Target Yield
Target yield measured after a long irradiation time (*i.e.*, longer than 3 half-lives of the product activity) and usually given as decay rate per unit of incident beam current.

REACTION Coding: `,TTY,,SAT`

Units: a code from Dictionary 25 with dimension `TTY` (decay rate per unit of beam current), *e.g.*, `MBQ/MUA` or `MCI/MUA`.

End-of-Bombardment Thick/Thin-Target Yield
(Irradiation time dependent) target yield measured after any irradiation time and given as decay rate per unit of incident beam current at the end-of-bombardment (EOB).

REACTION Coding: `,TTY,,EOB`

Units: a code from Dictionary 25 with dimension `TTY` (decay rate per unit of beam current), *e.g.*, `MBQ/MUA` or `MCI/MUA`.

Some authors use MBq/µA-h instead of MBq/µA for the 1-hour end-of-bombardment yield interpreting that "h" means "1-hour irradiation". The yield must be coded not with `MBQ/MUAHR` but with `MBQ/MUA`. The `(PHY)` modifier is used if the compiler is uncertain whether the yield given in MBq/µA-h, MBq/C etc. is physical yield.
The irradiation time is an essential variable for this quantity and is given under the heading `TIME-IRRD`.

Physical Thick/Thin-Target Yield
Target yield given as decay rate per unit of incident charge (or beam current ∗ time), which is equal to the time differential of the end-of-bombardment yield at the beginning of irradiation.

REACTION Coding: `,TTY,,PHY`

Units: a code from Dictionary 25 with dimension `TTT` (decay rate per unit of incident charge or beam current ∗ time), *e.g.*, `MBQ/COUL`, `MBQ/MUAHR`, `MCI/MUAHR` or `DPS/MUAHR`.

Thick Target Product Yields

Thick target yield of a reaction product coded in SF4 under keyword REACTION, where the value is given as the number of formed product per incident particle or charge.

REACTION Coding: ,PY,,TT (for number per incident particle) or ,PY,,TT/CH (for number per incident charge).

Units: a code from Dictionary 25 with dimension YLD, *e.g.*, PRD/INC (for number per incident particle) or dimension PYT, *e.g.*, PRD/MUAHR (for number per incident charge)

Thick Target Multiplicities

Thick target yield of a product coded in SF3 or SF7 under keyword REACTION, where the value is given as the number of formed product per incident particle or charge.

REACTION Coding: ,MLT,,TT (for number per incident particle) or ,MLT,,TT/CH (for number per incident charge).

Units: a code from Dictionary 25 with dimension YLD, *e.g.*, PRT/INC (for number per incident particle) or dimension PYT, *e.g.*, PRT/MUAHR (for number per incident charge)

Thick Target Discrete Gamma-Ray Yields

Discrete gamma spectrum, where the value is given as the number of particles per incident projectile as a function of gamma energy.

REACTION Coding: ,SPC,,TT

Units: a code from Dictionary 25 with dimension YLD, *e.g.*, PRT/INC

Physical Thick Target Yields Differential with Respect to Incident Energy
REACTION Coding: ,TTY/DEN,,PHY.

Units: a code from Dictionary 25 with dimension TTTE, *e.g.*, MBQ/C/MEV

Data not Corrected for Target Thickness

Thick Target Cross Sections: cross section measured on a thick target.

REACTION Coding: SIG in SF6; TT in SF8.

Units: a code from Dictionary 25 with dimension B, *e.g.*, MB

Similarly, all quantities may be given as angular distributions, excitation functions, *etc*. See Table following and Dictionary 236 for a complete list of quantities.

Unit Definitions

Saturated thick target yields are most often measured as observed decay rate per unit of beam current. Unsaturated thick target yields are most often measured as observed decay rate per unit of beam current per unit time.

Measures of beam current

Ampere: SI fundamental unit of current.
Coulomb: SI fundamental unit of charge; 1 C = 1 Ampere of current for 1 second.

Measures of decay rate

Becquerels SI fundamental unit of radioactivity; 1 Bq = 1 decay/second.
Curies[1]: unit of radioactivity; 1 Ci = 3.7×10^{10} decays/second.
1 Bq = 2.7×10^{-11} Ci

Table of data types versus unit types

Type of data compiled		Unit type for			
		type	d/dΩ	d/dE	d2/dΩ/dE
Saturation thick/thin-target yield End-of-bombardment thick/thin-target yield		TTY			
Physical thick/thin-target yield		TTT			
Production thick target yield per 1 MeV of target thickness		TTTE			
Thick target product yield and multiplicity	per incident charge	PYT	PYTA	PYTE	PYT2
	per incident particle	YLD	1/A	1/E	1/AE
Thick target cross section		B	DA	DE	DAE

Reference

[1.]   N. Otuka, S. Takács, Radiochim.Acta, **103** (2015) 1.

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[1] The Curie has been replaced in usage by the Becquerel.

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 **must not 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 that describes the experiment may be provided by the compiler.

See EXFOR Formats Manual Chapter 7: **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:

1.   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.

2.   Photo-atomic interaction contribution (e.g. Rayleigh scattering, Compton scattering, photo-ionization) is excluded from processes considered in photo-nuclear reaction data. $(\gamma,\text{tot}) = (\gamma,n) + (\gamma,p) + (\gamma,2n) + \ldots + (\gamma,f) + \text{nuclear scattering}$.

3.   Total cross section cannot be defined for charged-particle induced reaction because of Coulomb interaction.

    Forbidden: `(...(P,TOT)...,,SIG)`

Transmission
See **Transmission and Reaction Yield**

Self Indication
See **Transmission and Reaction Yield**

Total Reaction Cross Section
This is defined as all reactions except elastic scattering. Equivalent to Nonelastic, coded with `NON` in SF3. See also **Nonelastic**.

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 ν
`(N,F),PR,NU`	= prompt ν
`(N,INL),,SIG`	= total inelastic scattering cross section
`(N,INL),PAR,SIG`	= partial inelastic scattering cross section.

Transmission and Reaction Yield

Definition
Transmission $T(E)$ and reaction yield $Y_x(E)$ are defined by
$$T(E) = \exp\left[-n_T \sigma_T(E)\right]$$

$$Y_x(E) = \left[1 - \exp\left(-n_T \sigma_T(E)\right)\right]\frac{\sigma_x(E)}{\sigma_T(E)} \quad (x = \text{capture, fission etc.}),$$

where n_T is the sample thickness in nuclei/barn, $\sigma_T(E)$ and $\sigma_x(E)$ are the Doppler-broadened total cross section and cross section for the channel x.

REACTION coding: TRN (transmission) or RYL (reaction yield) in SF6.

Independent variables:
  Incident energy (e.g., EN)
  Sample thickness (THICKNESS)
  Sample temperature (TEMP)

Units: NO-DIM.

Examples:

(…(N,TOT),,TRN)	Transmission
(…(N,G)…,,RYL)	Capture yield

Usually these data are reduced from raw data as follows:
$$T = N_T \frac{C'_{in} - B'_{in}}{C'_{out} - B'_{out}} \qquad Y_x = N_x \frac{C'_x - B'_x}{C'_\varphi - B'_\varphi},$$

where in, out, x and φ stand for sample-in, sample-out, reaction channel and beam flux measurement, N_T and N_x are normalization factors, and C' and B' denote count and background count corrected for dead time, respectively. In addition, reaction yield from incident particles scattered before inducing the reaction of type x should be subtracted from Y_x. Corrections applied to compiled data should be described under the keyword CORRECTION. If appropriate corrections are not applied to data received by compilers, it should be indicated by RAW in SF8. (See **Raw Data**.).

In neutron time-of-flight measurements, the observed value broadened by resolution function is defined by
$$F(T) = \int R(T, E)\, f(E)\, dE \quad,$$

where T is the channel number (e.g. time-of-flight channel) and $R(T,E)$ is the resolution function (probability to find outgoing particle having E in T).

Transmission Ratio and Self-Indication Ratio

Transmission (ratio) T_g and self-indication (ratio) R_{gx} are defined as

$$T_g = \frac{\int_g \varepsilon_T(E)\exp\left[-n_T\sigma_T(E)\right]\varphi(E)dE}{\int_g \varepsilon_T(E)\varphi(E)\,dE} \sim \frac{\int_g \exp\left[-n_T\sigma_T(E)\right]dE\,/\,E}{\int_g dE\,/\,E}$$

$$R_{gx} = \frac{\int_g \varepsilon_x(E_\gamma)n_x\sigma_x(E)\exp\left[-n_T\sigma_T(E)\right]\varphi(E)dE}{\int_g \varepsilon_x(E_\gamma)n_x\sigma_x(E)\varphi(E)dE} \sim \frac{\int_g \sigma_x(E)\exp\left[-n_T\sigma_T(E)\right]dE\,/\,E}{\int_g \sigma_x(E)\,dE\,/\,E}$$

, where $\varepsilon_T(E)$ and $\varepsilon_x(E)$ give detection efficiencies for transmission and reaction yield measurements, n_x gives the sample thickness of the thin reaction target, $\varphi(E)$ gives spectrum of incoming particles. Integration is performed over a given energy range of the energy group g. The approximation $\sim$ is applied when the efficiencies are regarded as constants and the spectrum is proportional to $1/E$. These ratios can be used to derive self-shielding factors in reactor physics [1,2].

REACTION coding:
   Transmission (ratio): TRN in SF6; SPA in SF8
   Self-indication (ratio): SIF in SF6; SPA in SF8

Independent variables:
  Upper and lower boundary of incident energy (e.g., EN-MIN, EN-MAX)
  Sample thickness (THICKNESS)
  Sample temperature (TEMP)

Units: NO-DIM.

Examples:
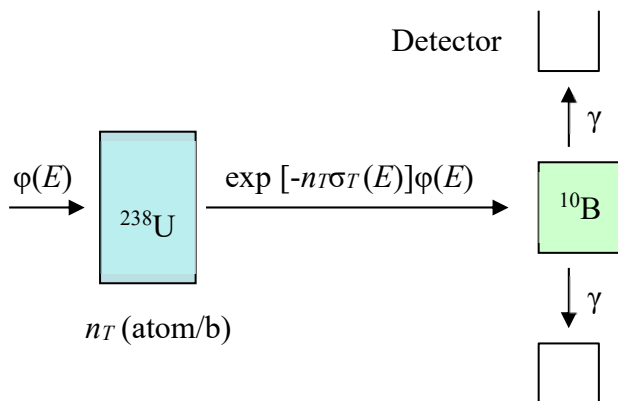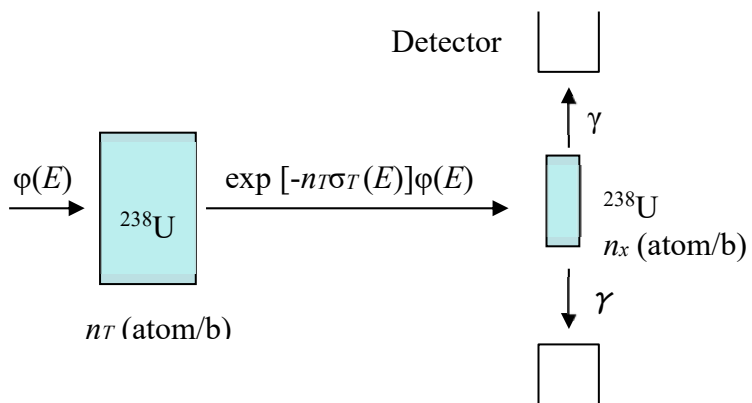   (…(N,TOT),,TRN,,SPA)   Transmission (ratio)
   (…(N,G)…,,SIF,,SPA)   Self-indication (ratio) for capture

Note: Older transmission data entries may be compiled with the code RAW in SF6.

Spectrum should be explained under INC-SPECT.

(a) Transmission measurement for ^{238}U

Detector

$\varphi(E)$ → ^{238}U → $\exp[-n_T \sigma_T(E)]\varphi(E)$ → ^{10}B

γ ↑

γ ↓

n_T (atom/b)

(b) Self-indication measurement for ^{238}U

Detector

$\varphi(E)$ → ^{238}U → $\exp[-n_T \sigma_T(E)]\varphi(E)$ → ^{238}U

n_x (atom/b)

γ ↑

γ ↓

n_T (atom/b)

References

[1] H. Oigawa *et al.*, J. Nucl. Sci. Technol. **28** (1991) 879

[2] T. Bakalov *et al.*, Proc. of Int. Conf. on Nuclear Cross Sections for Technology, Knoxville, Tennessee, 22 - 26 Oct 1979, p692.

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. The original data should also be entered using the data heading MISC-COL and the units SEE TEXT.

Unit Dimension Codes
In Dictionary 236 (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.

Unit Conversion Factors
In Dictionary 25, a conversion factor is given for each unit code, which allows computerized conversion between different units of the same dimension.

Special Cases (See also EXFOR Formats Manual Chapter 4).
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 code **PER-CENT** is used only for errors or resolutions and **must not be used under the data heading 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 code **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 $\hbar = 1$ as is usually done in high-energy physics.