International Atomic Energy Agency

Summary of Manual Updates

IAEA Nuclear Data Section
N. Otsuka

~150 slides until dinner

International Atomic Energy Agency

Summary of Manual Updates

1. Introduction

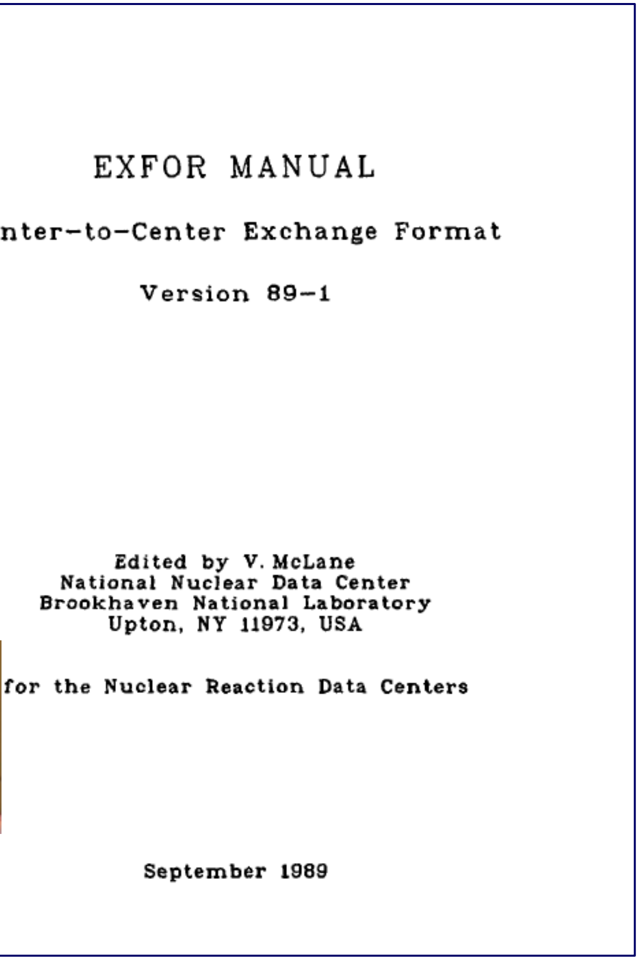
IAEA Nuclear Data Section
N. Otsuka

3

Brief History

EXFOR Manual
(Protocol + System + LEXFOR)

- Originally written by H. Lemmel (NDS) and V. McLane (NNDC).
- then maintained by McLane until her retirement.
- then maintained by O. Schwerer (NDS) until his retirement (+ δ).
- then maintained by me (until ?)



EXFOR MANUAL

Center-to-Center Exchange Format

Version 89-1

Edited by V. McLane
National Nuclear Data Center
Brookhaven National Laboratory
Upton, NY 11973, USA

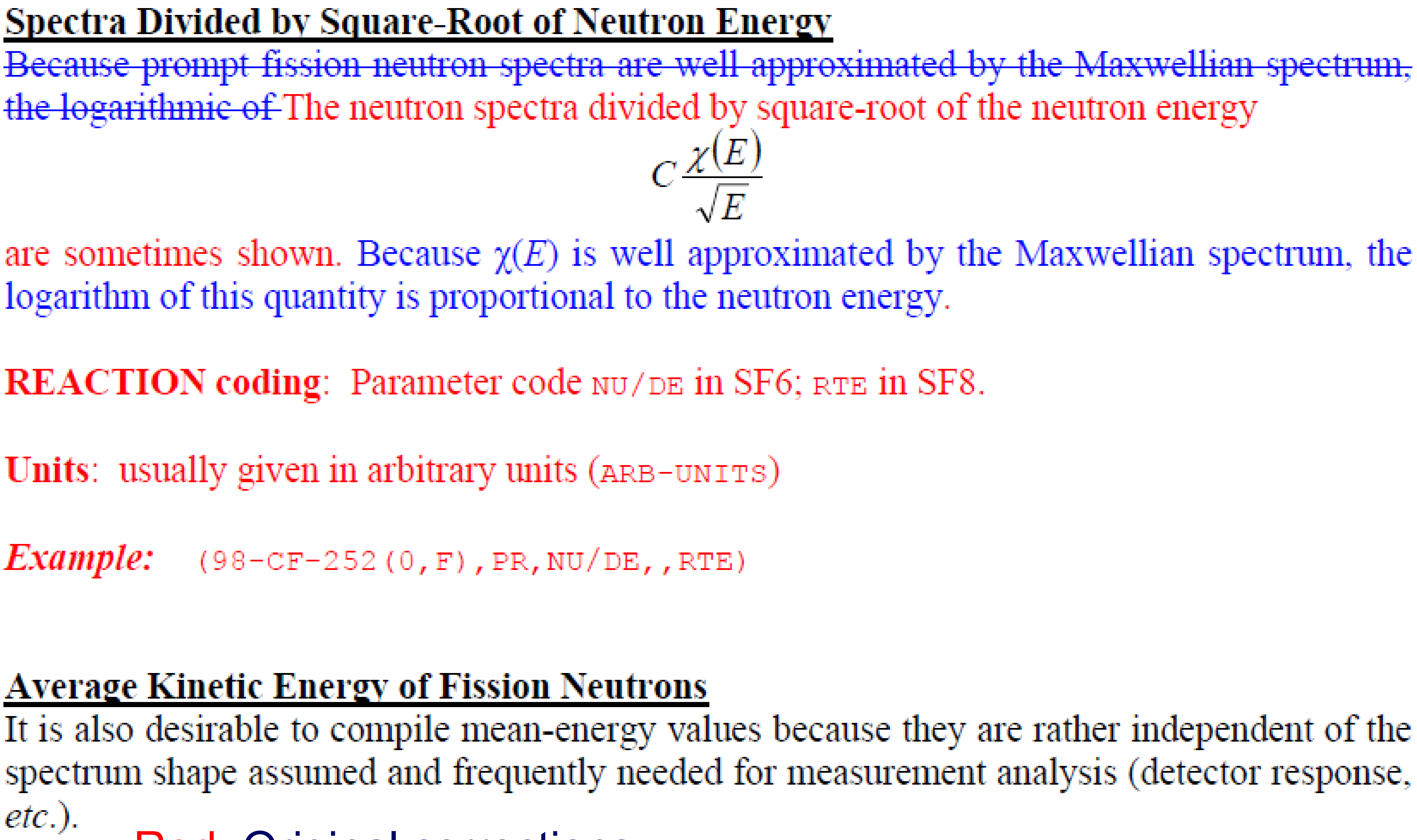
for the Nuclear Reaction Data Centers

September 1989

NRDC Manuals (maintained by NDS)

- EXFOR (Exchange) Formats Manual (September 2010)
- LEXFOR - EXFOR Compiler's Manual – (September 2010)
- NRDC Protocol (September 2010)
- NRDC Network Document (September 2010)
- EXFOR/CINDA Dictionary Manual (February 2008)
- EXFOR Basics (June 2008). HTML version is also available.
- CINDA Compiler's Manual (May 2008)

Indication of Altered Parts



Spectra Divided by Square-Root of Neutron Energy

~~Because prompt fission neutron spectra are well approximated by the Maxwellian spectrum, the logarithmic of~~ The neutron spectra divided by square-root of the neutron energy

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

are sometimes shown. Because $\chi(E)$ 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; `RTE` in SF8.

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

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

Average Kinetic Energy of Fission Neutrons

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*.).

Red: Original corrections

Blue: Further corrections after comments from participants

NRDC Protocol, Network Document

These two manuals will be also updated soon. We will <u>not</u> treat these manuals in the workshop.

Protocol:

- Scope of EXFOR/CINDA compilation
- EXFOR/CINDA compilation responsibility
- Procedure of EXFOR and CINDA data exchange
- Maintenance and revision of dictionary

Network document:

- Responsibility of each NRDC centre (signed by centre heads)

Maybe you will find a new duty…

EXFOR Compilation: Main steps

- **Prepared by M. Mikhaylyukova and V. Pronyaev (CJD, Obninsk)**

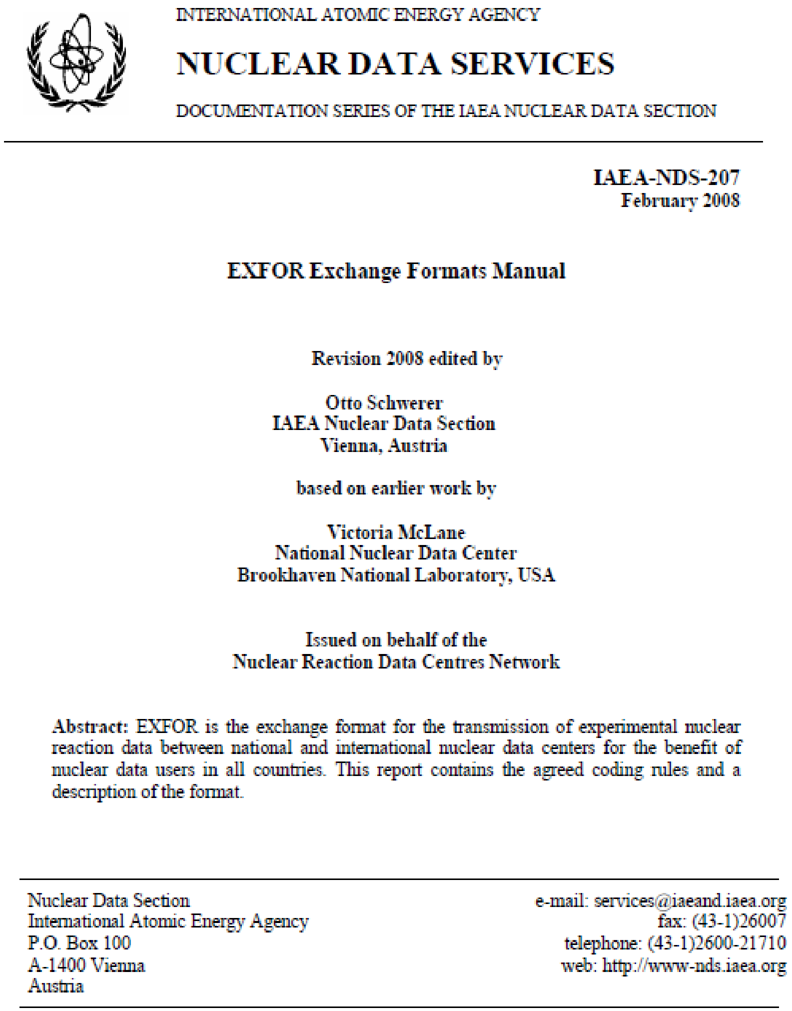
- **Main steps of compilation**
  - Main important steps of compilation;
  - Check list for compilation of new or correction of old entries;
  - Manuals to be used;
  - Main Web-sites with information for compilers' access;
  - Main codes to be used;

- **To be presented tomorrow.**

EXFOR (Exchange) Formats Manual

Description of the EXFOR Formats.

Not only for compilers, but also for programmers who read and process information in EXFOR.



INTERNATIONAL ATOMIC ENERGY AGENCY

NUCLEAR DATA SERVICES

DOCUMENTATION SERIES OF THE IAEA NUCLEAR DATA SECTION

IAEA-NDS-207
February 2008

EXFOR Exchange Formats Manual

Revision 2008 edited by

Otto Schwerer
IAEA Nuclear Data Section
Vienna, Austria

based on earlier work by

Victoria McLane
National Nuclear Data Center
Brookhaven National Laboratory, USA

Issued on behalf of the
Nuclear Reaction Data Centres Network

Abstract: EXFOR is the exchange format for the transmission of experimental nuclear reaction data between national and international nuclear data centers for the benefit of nuclear data users in all countries. This report contains the agreed coding rules and a description of the format.

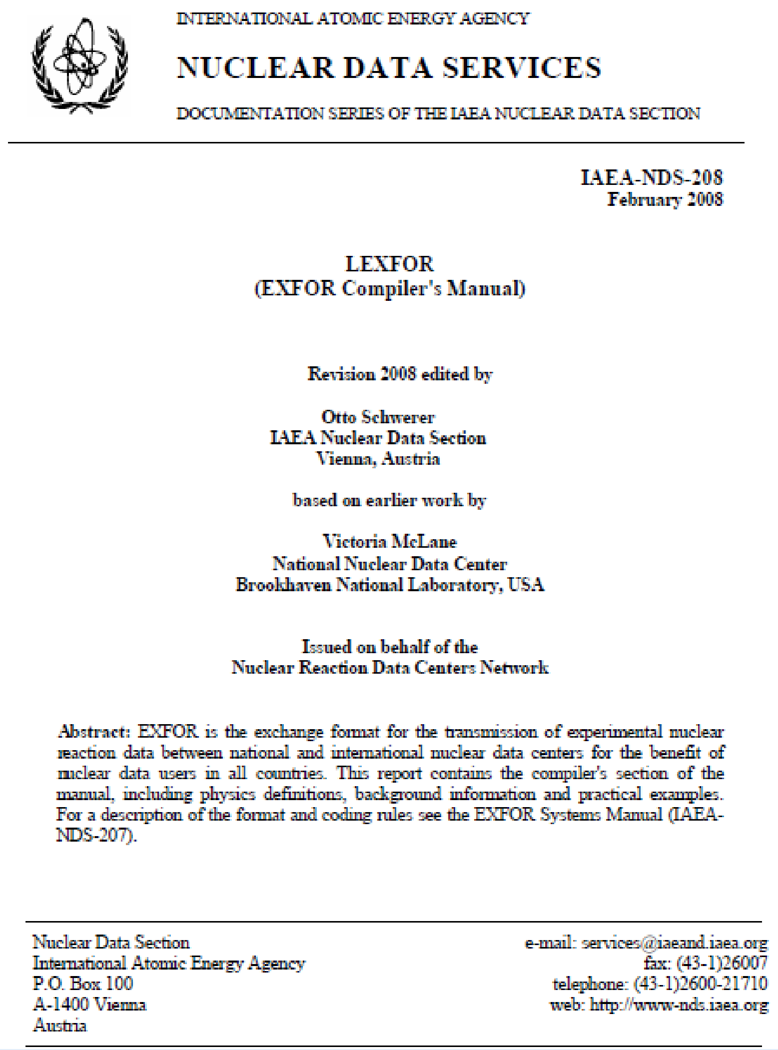
Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail: services@iaeand.iaea.org
fax: (43-1)26007
telephone: (43-1)2600-21710
web: http://www-nds.iaea.org

LEXFOR (EXFOR Compiler's Manual)

Description of
Quantity (REACTION) determination
and
compilation guideline.

You should be familiar with EXFOR chapters which are relevant to your compilation. **Formats Manual is not enough for determination of REACTION code.**



INTERNATIONAL ATOMIC ENERGY AGENCY

NUCLEAR DATA SERVICES

DOCUMENTATION SERIES OF THE IAEA NUCLEAR DATA SECTION

IAEA-NDS-208
February 2008

LEXFOR
(EXFOR Compiler's Manual)

Revision 2008 edited by

Otto Schwerer
IAEA Nuclear Data Section
Vienna, Austria

based on earlier work by

Victoria McLane
National Nuclear Data Center
Brookhaven National Laboratory, USA

Issued on behalf of the
Nuclear Reaction Data Centers Network

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

Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail: services@iaeand.iaea.org
fax: (43-1)26007
telephone: (43-1)2600-21710
web: http://www-nds.iaea.org

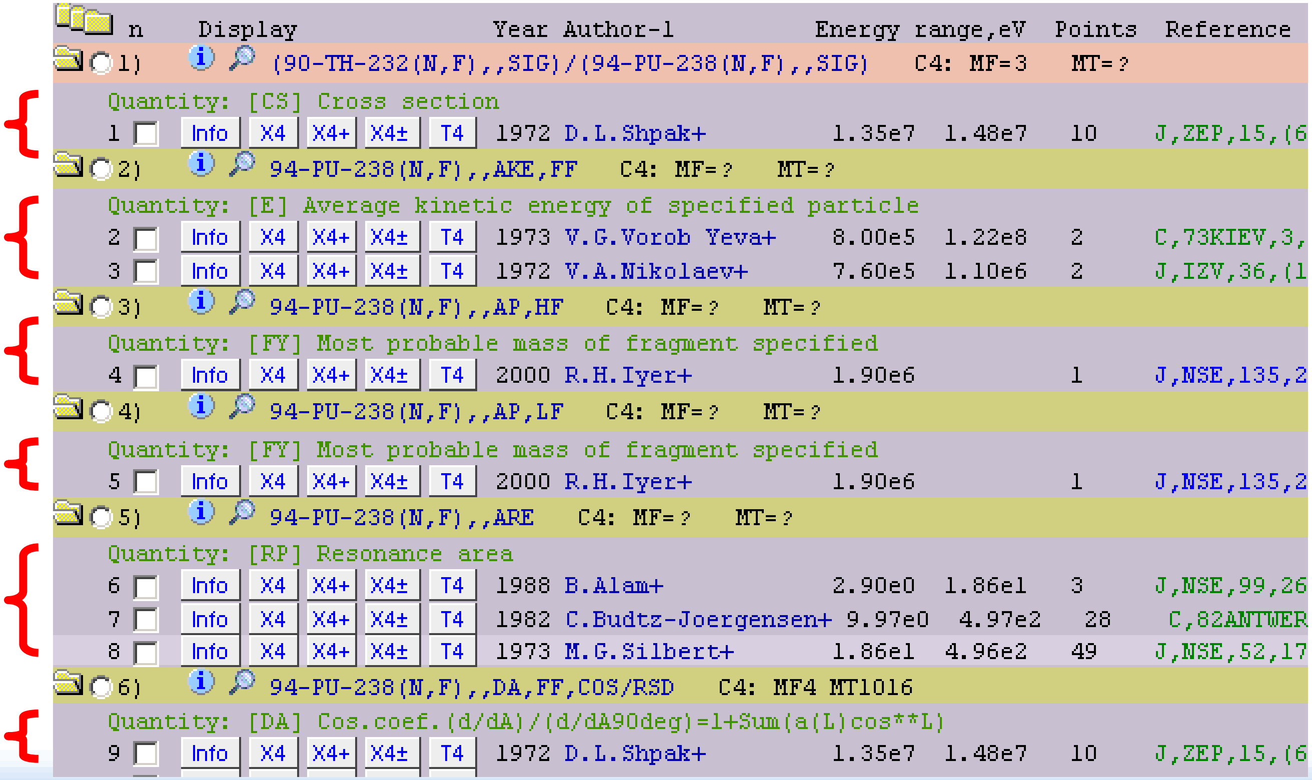
Data Libraries and Coding Rules

Important to obtain <u>necessary and enough sets of data</u> under a given condition

Example

EXFOR search results for ^{238}Pu(n,f) data, classified by REACTION codes.

All subentries belonging to one REACTION code must show a meaningful plot.



```
    n   Display                  Year Author-1              Energy range,eV  Points  Reference
    1)      (90-TH-232(N,F),,SIG)/(94-PU-238(N,F),,SIG)   C4: MF=3   MT=?
        Quantity: [CS] Cross section
        1 ☐  Info  X4  X4+  X4±  T4  1972 D.L.Shpak+            1.35e7  1.48e7   10    J,ZEP,15,(6
    2)      94-PU-238(N,F),,AKE,FF   C4: MF=?   MT=?
        Quantity: [E] Average kinetic energy of specified particle
        2 ☐  Info  X4  X4+  X4±  T4  1973 V.G.Vorob Yeva+       8.00e5  1.22e8   2     C,73KIEV,3,
        3 ☐  Info  X4  X4+  X4±  T4  1972 V.A.Nikolaev+         7.60e5  1.10e6   2     J,IZV,36,(1
    3)      94-PU-238(N,F),,AP,HF   C4: MF=?   MT=?
        Quantity: [FY] Most probable mass of fragment specified
        4 ☐  Info  X4  X4+  X4±  T4  2000 R.H.Iyer+             1.90e6           1     J,NSE,135,2
    4)      94-PU-238(N,F),,AP,LF   C4: MF=?   MT=?
        Quantity: [FY] Most probable mass of fragment specified
        5 ☐  Info  X4  X4+  X4±  T4  2000 R.H.Iyer+             1.90e6           1     J,NSE,135,2
    5)      94-PU-238(N,F),,ARE   C4: MF=?   MT=?
        Quantity: [RP] Resonance area
        6 ☐  Info  X4  X4+  X4±  T4  1988 B.Alam+               2.90e0  1.86e1   3     J,NSE,99,26
        7 ☐  Info  X4  X4+  X4±  T4  1982 C.Budtz-Joergensen+ 9.97e0   4.97e2   28     C,82ANTWER
        8 ☐  Info  X4  X4+  X4±  T4  1973 M.G.Silbert+          1.86e1  4.96e2   49    J,NSE,52,17
    6)      94-PU-238(N,F),,DA,FF,COS/RSD   C4: MF4 MT1016
        Quantity: [DA] Cos.coef.(d/dA)/(d/dA90deg)=1+Sum(a(L)cos**L)
        9 ☐  Info  X4  X4+  X4±  T4  1972 D.L.Shpak+            1.35e7  1.48e7   10    J,ZEP,15,(6
```

Data Libraries and Coding Rules (cont)

- **For programmers:**

  Important to create an algorithm to process the data library for a certain purpose

Data Libraries and Coding Rules (cont)

Same quantity? Different quantity?

Well known synonyms:

Capture kernel (neutron data) =
resonance strength (charged-particle data)

Non-elastic scattering cross section (nuclear data)=
reaction cross section (nuclear physics)

Do not rely upon author's terminology too much.
Check definition in LEXFOR.

Contents of My Presentation

1. Introduction

2. BIB section
- DOI coding under REFERENCE
- STATUS – Data source indication
- MONIT-REF for data libraries
- ERR-ANALYS for ranged uncertainty

3. REACTION: General
- General Quantity Modifier (MXW,SPA,REL,...)
- Independent variable for REACTION combination
- Frequently occurring reaction combination

4. Activation
- New modifier RAB
- Isotopic abundance as coded information

Contents of My Presentation (cont)

5. Fission

- Particle considered in fission
- Average kinetic energy – KE, AKE
- Prompt fission neutron spectrum - NU/DE

6. Low-energy data

- Cross section for eV neutrons
- Scope of resonance parameter in EXFOR
- KT rather than EN-MEAN - MACS

7. Photo-nuclear reaction

- Absorption for γ-induced reaction (excl. atomic process)

Contents of My Presentation (cont)

8. Reaction involving unstable nucleus

- REACTION for inverse kinematics experiments
- Nuclide unstable against prompt particle emission

9. Miscellaneous

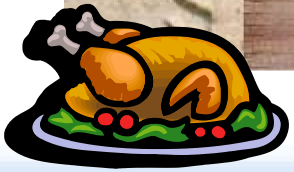
- Unit of multiplicity/field: PRT and PRD
- Various notation of spin observables

10. Conclusions

+...

Contents of Presentation (cont)

Dinner (~19:00) – Strandcafe (~15 min walk from U1 Alte Donau)



International Atomic Energy Agency

Summary of Manual Updates
2. BIB section

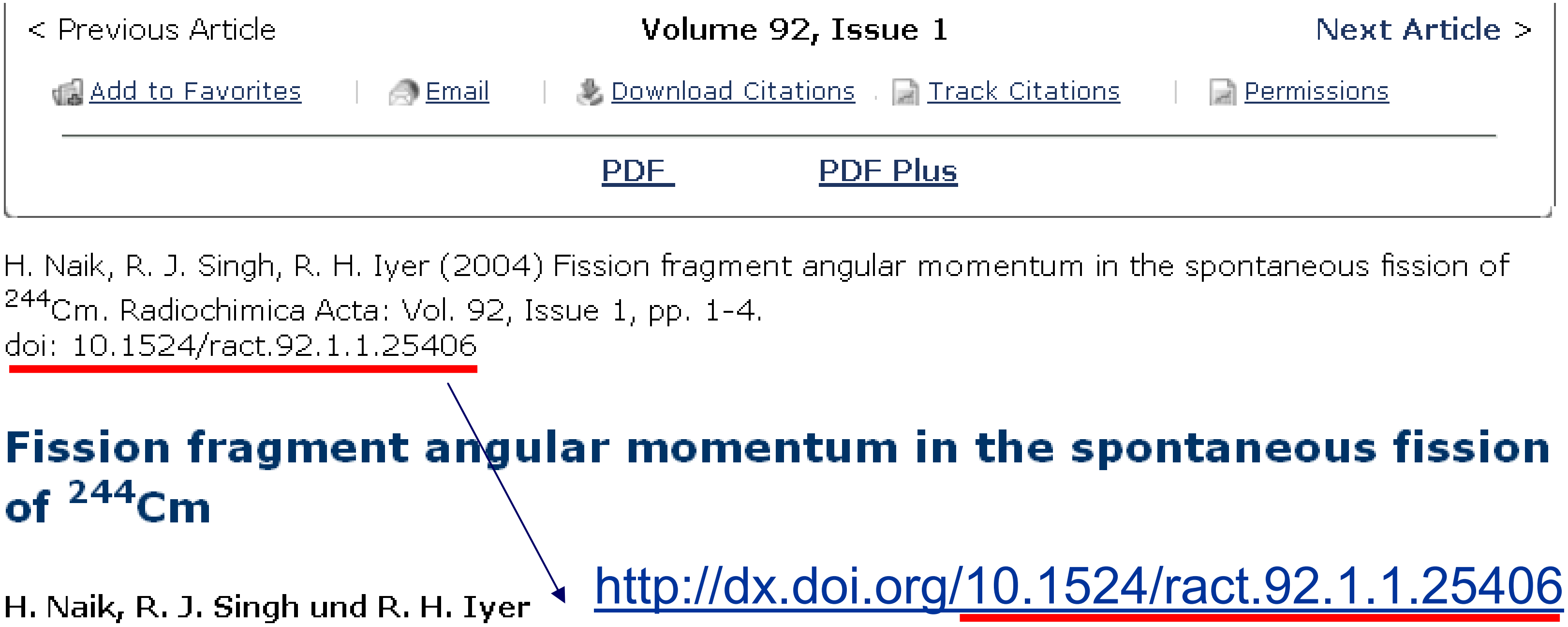
IAEA Nuclear Data Section
N. Otsuka

18

DOI Coding under REFERENCE

DOI: Digital Object Identifier

A character strings used to uniquely identify an electronic document



H. Naik, R. J. Singh, R. H. Iyer (2004) Fission fragment angular momentum in the spontaneous fission of ^{244}Cm. Radiochimica Acta: Vol. 92, Issue 1, pp. 1-4.
doi: 10.1524/ract.92.1.1.25406

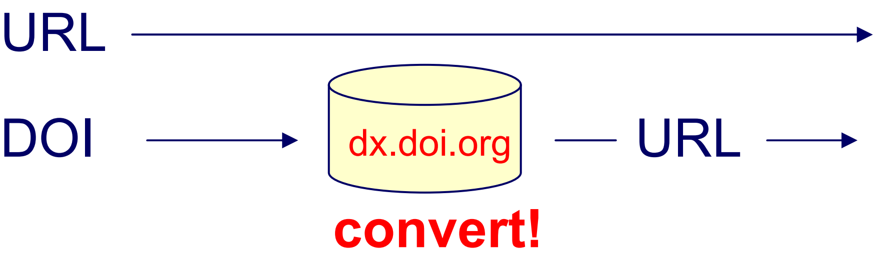
Fission fragment angular momentum in the spontaneous fission of ^{244}Cm

H. Naik, R. J. Singh und R. H. Iyer

http://dx.doi.org/10.1524/ract.92.1.1.25406 is a hyperlink to the abstract of this article.

DOI Coding under REFERENCE (cont)

URL= www.oldenbourg-link.com/doi/abs/10.1524/ract.92.1.1.25406
DOI = 10.1524/ract.1.1.25406



convert!

H. Naik, R. J. Singh, R. H. Iyer (2004) Fission fragment angular momentum in the spontaneous fission of ^{244}Cm. Radiochimica Acta: Vol. 92, Issue 1, pp. 1-4.
doi: 10.1524/ract.92.1.1.25406

Fission fragment angular momentum in the spontaneous fission of ^{244}Cm

H. Naik, R. J. Singh und R. H. Iyer

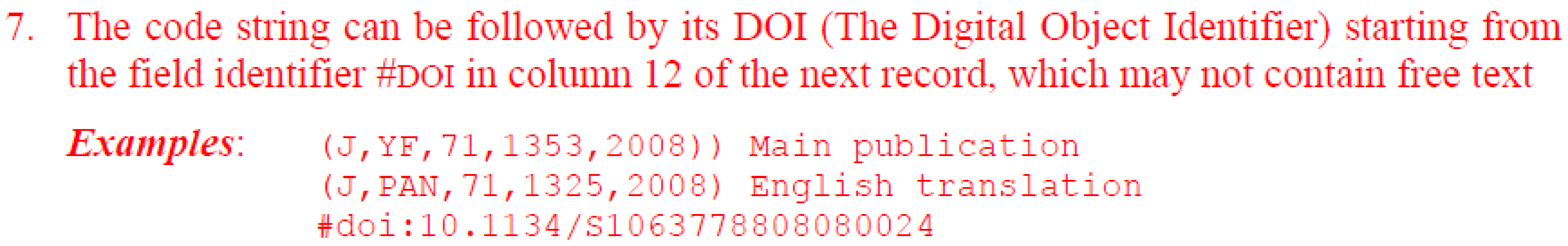
Summary

Independent isomeric yield ratios (IYR) of ^{128}Sb, ^{130}Sb, ^{132}Sb, ^{131}Te, ^{133}Te, ^{132}I, ^{134}I, ^{135}Xe and ^{138}Cs have been determined in the spontaneous fission of ^{244}Cm using off-line gamma ray spectrometric technique. From the IYR, fragment angular momenta (J_{rms}) have been deduced using spin dependent statistical model analysis. It was observed that: (i) J_{rms} of fragments having spherical 82*n* shell and even-*Z* products are lower than the fragments away from spherical neutron shell and odd-*Z* products which indicates the effect of nuclear structure. (ii) The yield-weighted

URL might be changed in future (e.g. when the publisher is changed), however, DOI is guaranteed to be converted to the valid URL even if the URL is changed.
→ **More useful for web service from data centres**

DOI Coding under REFERENCE (cont)

EXFOR Formats: 7.24



7. The code string can be followed by its DOI (The Digital Object Identifier) starting from the field identifier #DOI in column 12 of the next record, which may not contain free text

Examples:

```
(J,YF,71,1353,2008)) Main publication
(J,PAN,71,1325,2008) English translation
#doi:10.1134/S1063778808080024
```

```
----+----1----+----2----+----3----+----4-
REFERENCE  ....
           (J,PAN,71,1325,2008)
           #doi:10.1134/....
```

12th column

Note: After input the DOI, you should check if the DOI works properly by access to http://dx.doi.org/***DOI*** (e.g. http://dx.doi.org/10.1134/....).

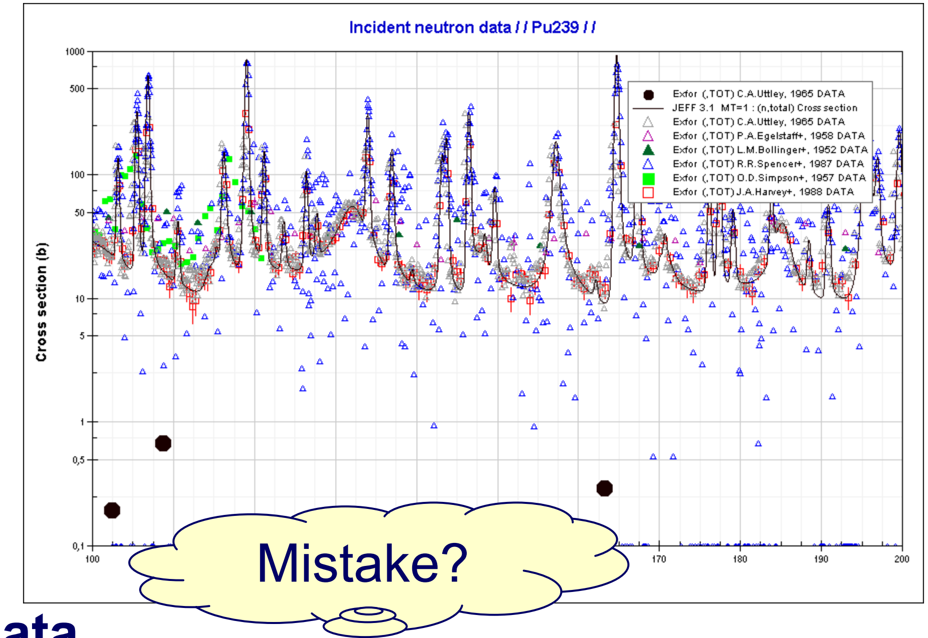
STATUS – Data Source Information

We should be able to go to the source of the numerical data even after compilation.

For examples,

- A data point is far from other data sets (outlier). Compilation mistake?
- Several versions of data sets from one experiment exist Which one is the latest data set.

Outlier in $^{239}Pu(n,\gamma)$ found by E. Dupont



We should check the source of data.
(Not compilation made by other people/group).

STATUS – Data Source Indication (cont)

For old entries, it is often difficult to get enough information about source of data (publication, date of receipt).

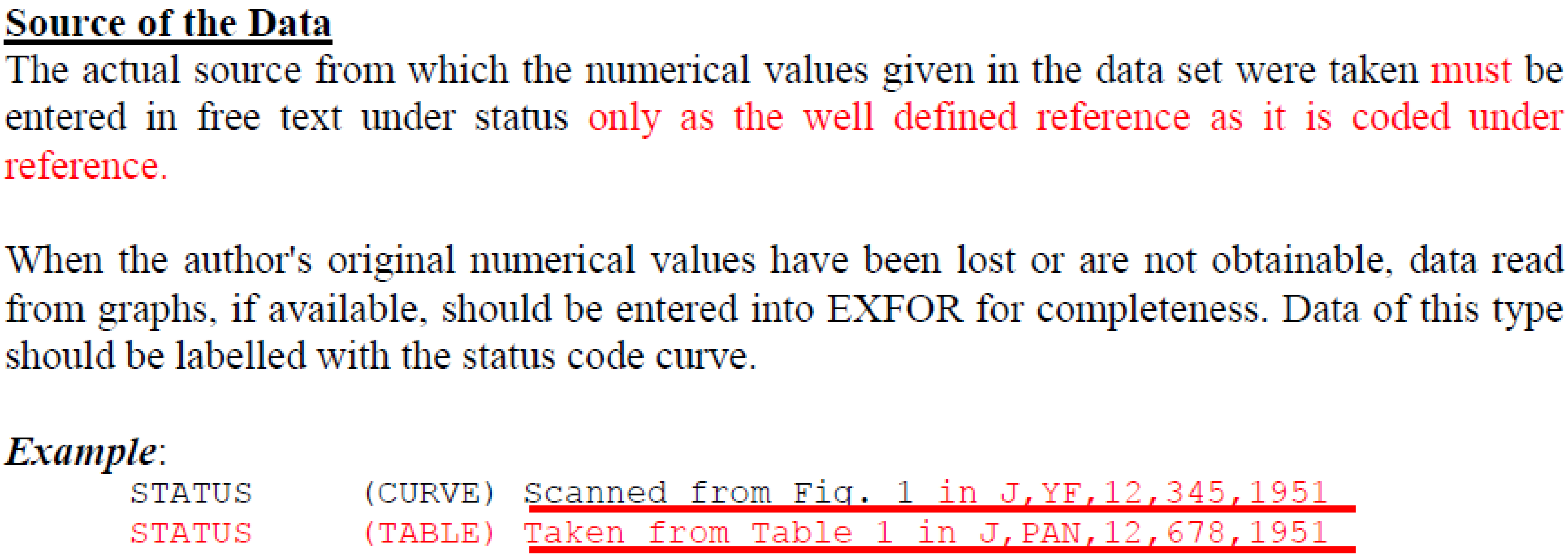
- Some EXFOR entries were converted from other data libraries
  (e.g., conversion from old neutron experimental data libraries
  - SCISRS, NEUDADA, DASTAR).

- Some compilers did not provide enough information about versions of numerical data.
  (e.g., various versions of prompt fission neutron spectra measured
  at NIIAR Dimitrovgrad by B. I. Starostov et al. in 1970s-1985.
  See V. Pronyaev's report in INDC(NDS)-541.

Now we should keep data source information clearly!

STATUS – Data Source Indication (cont)

LEXFOR: S.20 (Status)



Source of the Data

The actual source from which the numerical values given in the data set were taken must be entered in free text under status only as the well defined reference as it is coded under reference.

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.

Example:

```
STATUS      (CURVE)  Scanned from Fig. 1 in J,YF,12,345,1951
STATUS      (TABLE)  Taken from Table 1 in J,PAN,12,678,1951
```

STATUS – Data Source Indication (cont)

- **When you receive numerical data from authors, it must be indicated under STATUS with TABLE:**

```
STATUS     (TABLE) Data received by e-mail from K.Beata
```

The date can be indicated under HISTORY

```
HISTORY    (20100715R) M.M. E-mail from S.Simakov
```

(Not mandatory, but probably better than free text under STATUS…)

- **Some times compilers use APRVD when they receive data from authors:**

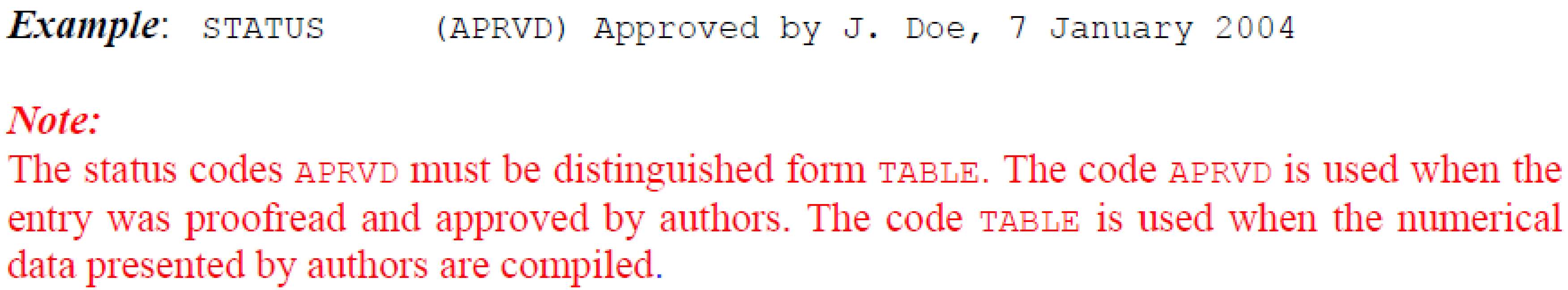
```
STATUS     (TABLE,APRVD) Data received from V.Semkova.
```

This is not right. APRVD must be used when an EXFOR file was sent to authors and approved by them. Must be

```
STATUS     (APRVD) Approved by V.Semkova (2010-08-30)
```

STATUS – Data Source Indication (cont)

LEXFOR: S.19 (Status)



Example: `STATUS      (APRVD) Approved by J. Doe, 7 January 2004`

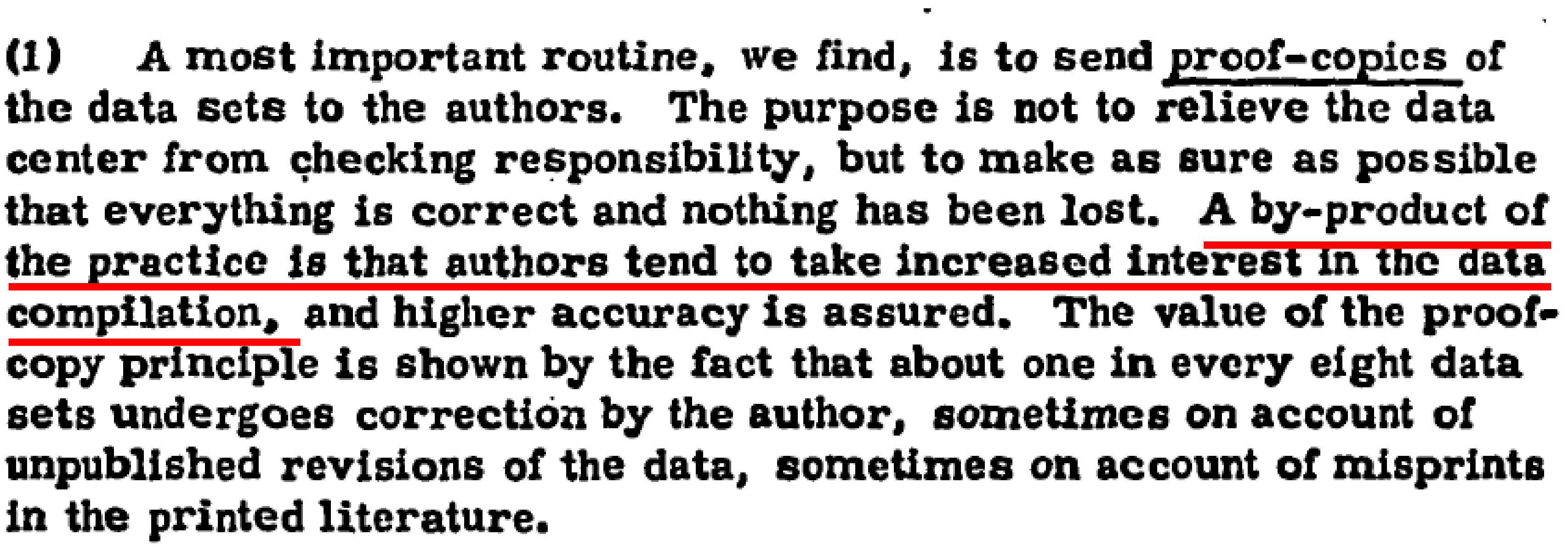
Note:

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.

- **Compiler should send your draft of compilation to authors for their proof-read and approval.**
- **We should not expect authors can understand our EXFOR format very well, and found all important mistake. We know some authors pay attention to free text information rather than coded information.**

STATUS – Data Source Indication (cont)

H.D. Lemmel et al., INDC(NDS)-001 (1968):



(1) A most important routine, we find, is to send proof-copies of the data sets to the authors. The purpose is not to relieve the data center from checking responsibility, but to make as sure as possible that everything is correct and nothing has been lost. A by-product of the practice is that authors tend to take increased interest in the data compilation, and higher accuracy is assured. The value of the proof-copy principle is shown by the fact that about one in every eight data sets undergoes correction by the author, sometimes on account of unpublished revisions of the data, sometimes on account of misprints in the printed literature.

MONIT-REF for Data Libraries

Absolute experimental values are often normalized by using a monitor (standard) values.

Examples:

- Fission cross sections $\sigma(E)$ normalized to 235U(n,f) cross section $\sigma_s(E)$ for several E.
- Activation cross section $\sigma(E)$ normalized to ^{27}Al(p,x)^{24}Na cross section $\sigma_s(E)$.
- Angular distribution $\sigma(E,\theta)$ normalized to its Coulomb scattering (Rutherford scattering) cross section at forwarded angle $\sigma_s(E,\theta=0)$.

MONIT-REF for Data Libraries (cont)

Absolute values σ are sensitive monitor values σ_s. If monitor values are revised based on our best knowledge, all measured values σ are also affected, and must be revised.

$$\sigma_{old}(E)=(n/n_s)\sigma_{s,old}(E)$$

$$\Downarrow$$

$$\sigma_{new}(E) = (n/n_s)\sigma_{s,new}(E) = \sigma_{old}(E) \times [\sigma_{s,new}(E) / \sigma_{s,old}(E)]$$

MONIT-REF for Data Libraries (cont)

Examples of revisions:
(p,t+x) cross section at 2.05 GeV normalized by $\sigma_s(^{27}Al(p,x)^{24}Na)$

Target	Currie+ (1956) [1] (mb)	Currie (1959)[2] (mb)	Ratio (1959/1956)
σ_s	**9.0**	**10.8**	**1.2**
C	14	17	1.21
N	25	30	1.20
O	30	36	1.20
Mg	30	36	1.20
Al	37	44	1.19
Fe	53	64	1.21
Ni	75	90	1.20
Ag	136	160	1.18
Pb	510	610	1.20

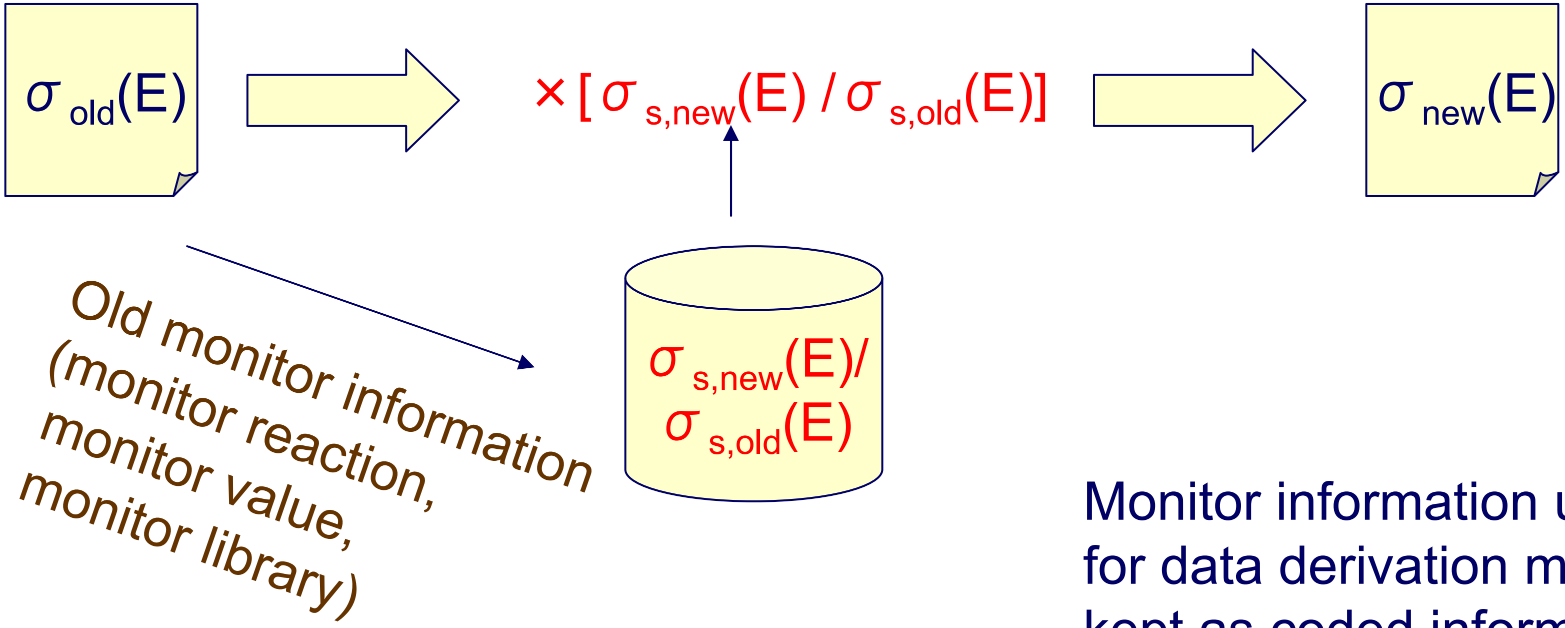
← Monitor cross section

[1] L.A.Currie et al., Phys.Rev.101(1956)1557
[2] L.A.Currie, Phys.Rev.114(1959)878

MONIT-REF for Data Libraries (cont)

Some EXFOR users have desired a correction system which renormalize EXFOR values with the latest standard value.

(V. Zerkin is working for construction of such a system.)



$\sigma_{old}(E)$

$\times [\sigma_{s,new}(E) / \sigma_{s,old}(E)]$

$\sigma_{new}(E)$

$\sigma_{s,new}(E)/\sigma_{s,old}(E)$

Old monitor information
(monitor reaction,
monitor value,
monitor library)

Monitor information used for data derivation must be kept as coded information for further process.

MONIT-REF for Data Libraries (cont)

1. MONIT values are given and computer readable.

```
REACTION    (6-C-0(P,X)1-H-3,,SIG,,,EXP)
MONITOR     ((MONIT)13-AL-27(P,X)9-F-18,,SIG)
MONIT-REF   (C0286001,A.CARETTO+,J,PR,110,1130,58)
…
EN          DATA        THICKNESS   MONIT       FLAG
GEV         MB          G/CM-SQ     MB          NO-DIM
       2.05        17.                                   1.
        5.7        18.        0.75        7.4
        6.2        20.        0.45        7.4
ENDDATA                  5
```

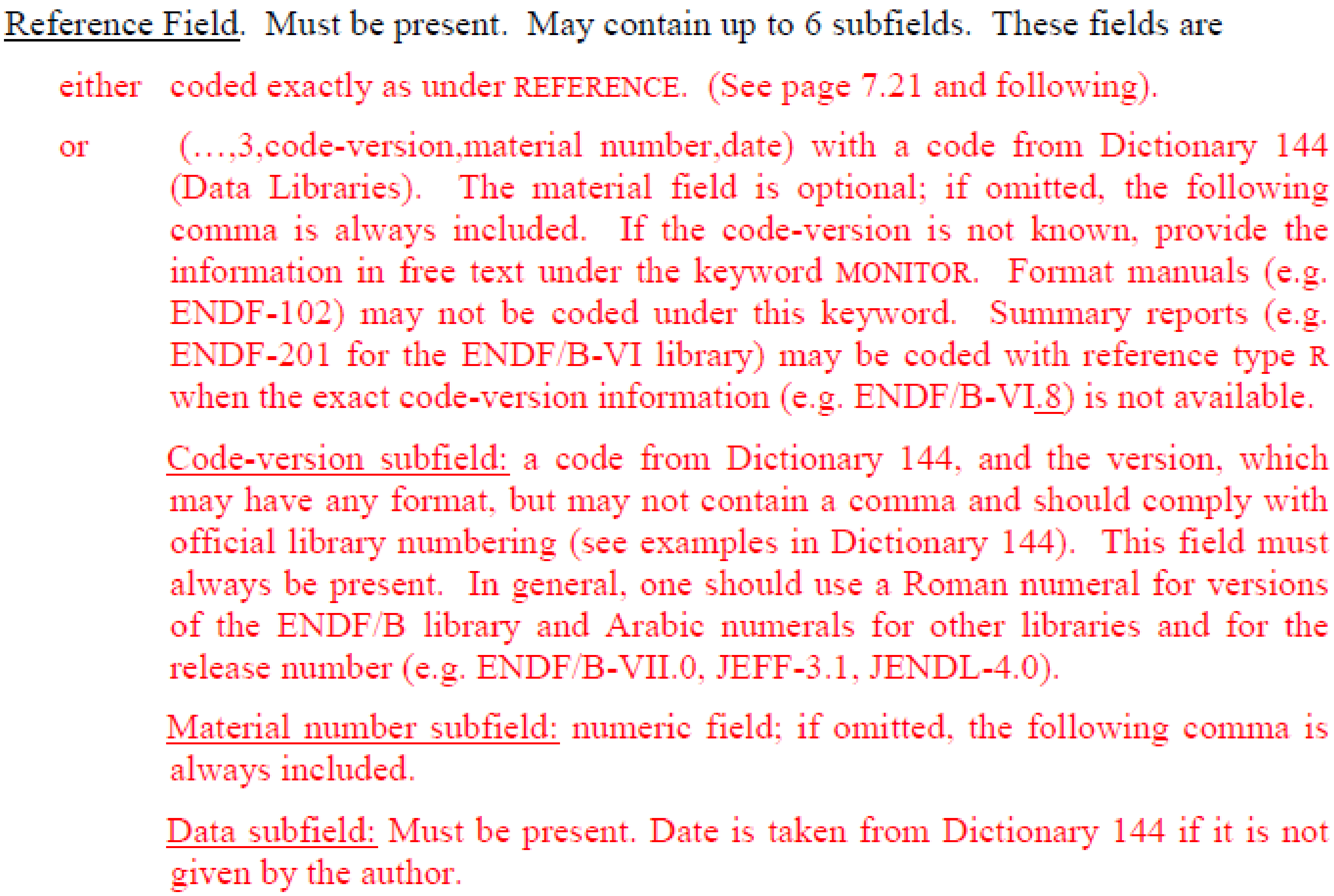
2. MONIT values are not given. Library name is also not computer readable..

```
REACTION    (92-U-236(N,F),,SIG)
MONITOR     (92-U-233(N,F),,SIG) ENDF-B/VII.0 library
....
EN          DATA
MEV         B
20.990      1.6503
20.870      1.6149
20.750      1.5331
20.630      1.5275
20.510      1.5841
```

Library name as coded information under MONIT-REF could help future automatic correction.

MONIT-REF for Data Libraries (cont)

EXFOR Formats 7.19 (New format for data library in MONIT-REF)



Reference Field. Must be present. May contain up to 6 subfields. These fields are

either coded exactly as under REFERENCE. (See page 7.21 and following).

or (…,3,code-version,material number,date) with a code from Dictionary 144 (Data Libraries). The material field is optional; if omitted, the following comma is always included. If the code-version is not known, provide the information in free text under the keyword MONITOR. Format manuals (e.g. ENDF-102) may not be coded under this keyword. Summary reports (e.g. ENDF-201 for the ENDF/B-VI library) may be coded with reference type R when the exact code-version information (e.g. ENDF/B-VI.8) is not available.

Code-version subfield: a code from Dictionary 144, and the version, which may have any format, but may not contain a comma and should comply with official library numbering (see examples in Dictionary 144). This field must always be present. In general, one should use a Roman numeral for versions of the ENDF/B library and Arabic numerals for other libraries and for the release number (e.g. ENDF/B-VII.0, JEFF-3.1, JENDL-4.0).

Material number subfield: numeric field; if omitted, the following comma is always included.

Data subfield: Must be present. Date is taken from Dictionary 144 if it is not given by the author.

MONIT-REF for Data Libraries (cont)

Format

```
  MONIT-REF  (,,3,$library, $mat, $year)
```

$mat **(MAT number):**

4 digits number to express target isotopes.

(First two digits for Z number, the last two digits depend on library.)

$year **must be taken from dictionary 144 if it is not given in the article.**

Example

```
  MONIT      (92-U-235(N,F),,SIG)
  MONIT-REF  (,,3,ENDF/B-VII.0,9228,2006)
```

We can construct monitor cross sections used by authors by these two lines.

MONIT-REF for Data Libraries (cont)

Several lines from Dictionary 144

```
IRDF-         International Reactor Dosimetry File (IRDF) in
              ENDF/B-5 format
               2005 IRDF-2002
               1993 IRDF-90.2
               1990 IRDF-90.1
JEF-          Joint Evaluated File (JEF)
              compiled at the OECD Nuclear Energy Agency Data Bank
              Last version: JEF-2.2 (1992)
               1993 JEF-2.2
               1991 JEF-2.1
               1990 JEF-2.0
               1985 JEF-1
JEFF-         Joint Evaluated Fission and Fusion (JEFF) Library,
              compiled at the OECD Nuclear Energy Agency Data Bank
               2009 JEFF-3.1.1/GP (update of neutron data)
               2009 JEFF-3.1.1/FY (update of fission yields)
```

ERR-ANALYS for Ranged Uncertainty

Experimental covariance matrix V helps us to perform reliable evaluation.

Example: Least squares fitting:

Evaluated values: x=(x1,x2,…) and experimental values y=(y1,y2,…).

Measurement equation: y=Cx+e (C: Design matrix, e: error)

The least square solution satisfies $x=(C^tV^{-1}C)^{-1}C^tV^{-1}y$

Non-diagonal elements of V is often approximated by $\Delta_{cor,i}\ \Delta_{cor,j}$ (products of correlated uncertainties).

It is important to extract $\Delta_{cor,i}$ uncertainties from EXFOR.

ERR-ANALYS for Ranged Uncertainty (cont)

Experimental covariance matrix V helps us to perform reliable evaluation.

Example: Least squares fitting:

Evaluated values: $x=(x1,x2,\ldots)$ and experimental values $y=(y1,y2,\ldots)$.

Measurement equation: $y=Cx+e$ (C: Design matrix, e: error)

The least square solution is obtained as $x=(C^t V^{-1} C)^{-1} C^t V^{-1} y$

- Diagonal elements of V is $\Delta_{tot,i}\Delta_{tot,j}$.

- Non-diagonal elements of V is often approximated by $\Delta_{cor,i}\Delta_{cor,j}$ (products of correlated uncertainties).

It is important to extract $\Delta_{tot,i}$ and $\Delta_{cor,i}$ uncertainties from EXFOR.

ERR-ANALYS for Ranged Uncertainty (cont)

How can we extract $\Delta_{tot,i}$ and $\Delta_{cor,i}$ uncertainties from EXFOR?

Headings of uncertainties in EXFOR:

(1) ERR-T: Total uncertainty
(2) ERR-S: Statistical uncertainty
(3) ERR-SYS: Total systematic uncertainty
(4) ERR-1, -2,…: Systematic uncertainty

Two of them are required.
If one of (2)-(4) is available, "*total uncertainty*" should be coded under ERR-T!
(my opinion)

Total uncertainties can be derived as

$\Delta_{tot,i} \sim (\text{ERR-T})_i$ or $\Delta_{cor,i} \sim \text{sqrt}\,[(\text{ERR-S})_i^2+(\text{ERR-SYS})_i^2]$

or $\Delta_{cor,i} \sim \text{sqrt}[(\text{ERR-S})_i^2+(\text{ERR-1})_i^2+(\text{ERR-2})_i^2+\ldots.]$

Total systematic uncertainties can be derived as

$\Delta_{cor,i} \sim (\text{ERR-SYS})_i$ or $\Delta_{cor,I} \sim \text{sqrt}\,[(\text{ERR-T})_i^2-(\text{ERR-S})_i^2]$

or $\Delta_{cor,I} \sim \text{sqrt}\,[(\text{ERR-1})_i^2+(\text{ERR-2})_i^2+\ldots.]$

ERR-ANALYS for Ranged Uncertainty (cont)

Example of uncertainty coding which disturbing evaluator's code:

```
ERR-ANALYS (ERR-T) Total uncertainty
           (ERR-1) Maximum uncertainty due to number of target
                   nuclei (<1%)
           (ERR-2) Uncertainty due to standard capture cross
                   sections of 197Au
           (ERR-3) Uncertainty due to weighting function of
                   gamma-ray spectrometer
           (ERR-4) Uncertainty due to extrapolation of
                   pulse-height spectrum below the discrimination
                   level
           (ERR-5) Maximum uncertainty due to correction for
                   self-shielding and multiple scattering (1-3%)
           (ERR-S) Maximum statistical uncertainty (2-3%)
…
COMMON                6          3
ERR-1      ERR-2      ERR-3      ERR-4      ERR-5      ERR-S
PER-CENT   PER-CENT   PER-CENT   PER-CENT   PER-CENT   PER-CENT
 1.         3.         1.         2.         3.         3.
```

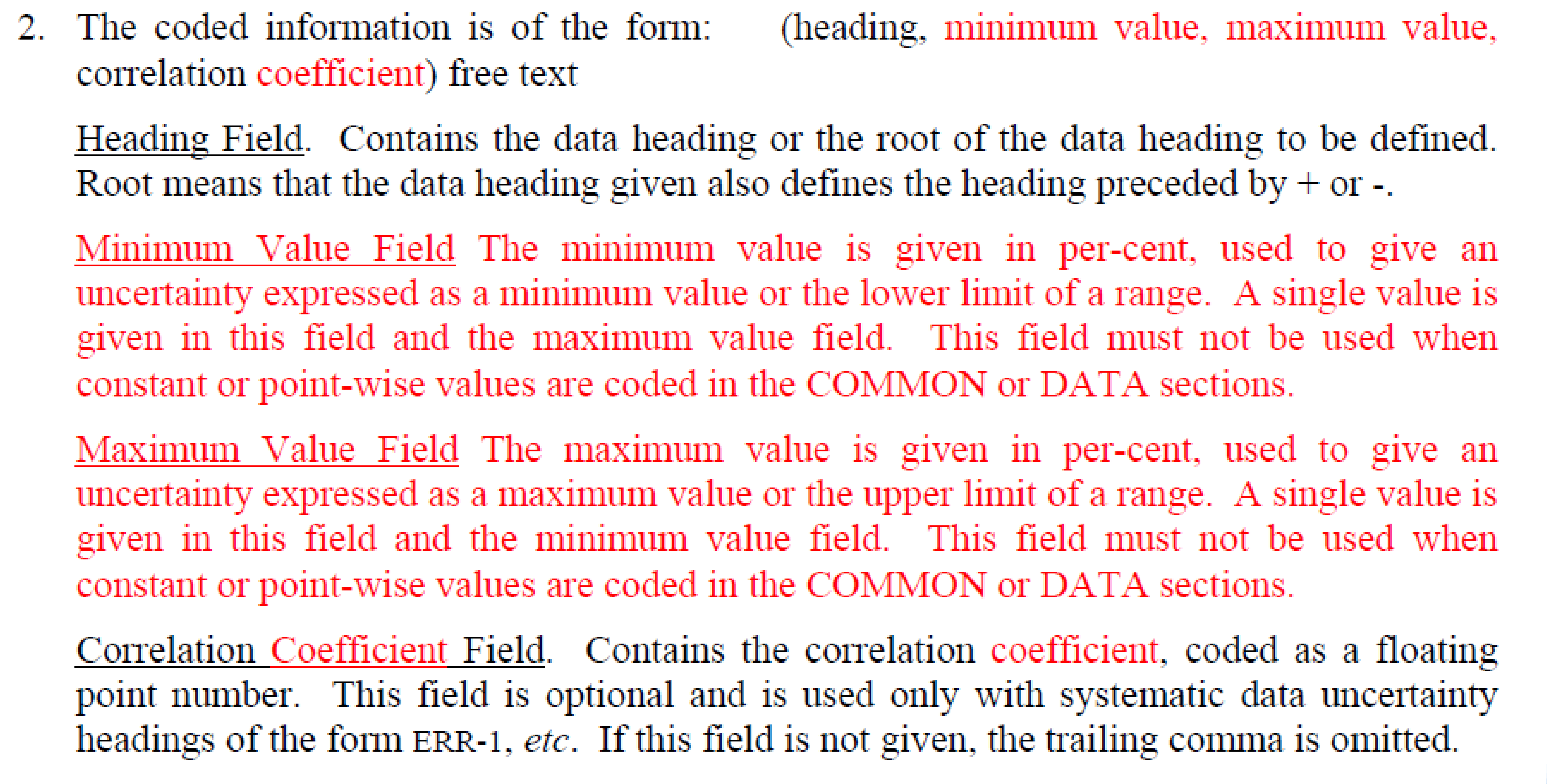
Given in DATA section.

ERR-1, ERR-5, ERR-S:

Ranged uncertainty treated as constant uncertainties!!!

ERR-ANALYS for Ranged Uncertainty (cont)

EXFOR Formats 7.10



2. The coded information is of the form: (heading, minimum value, maximum value, correlation coefficient) free text

Heading Field. Contains the data heading or the root of the data heading to be defined. Root means that the data heading given also defines the heading preceded by + or -.

Minimum Value Field The minimum value is given in per-cent, used to give an uncertainty expressed as a minimum value or the lower limit of a range. A single value is given in this field and the maximum value field. This field must not be used when constant or point-wise values are coded in the COMMON or DATA sections.

Maximum Value Field The maximum value is given in per-cent, used to give an uncertainty expressed as a maximum value or the upper limit of a range. A single value is given in this field and the minimum value field. This field must not be used when constant or point-wise values are coded in the COMMON or DATA sections.

Correlation Coefficient Field. Contains the correlation coefficient, coded as a floating point number. This field is optional and is used only with systematic data uncertainty headings of the form ERR-1, *etc*. If this field is not given, the trailing comma is omitted.

ERR-ANALYS for Ranged Uncertainty (cont)

Example

Correction of the previous examples with the new format

```
ERR-ANALYS (ERR-T) Total uncertainty
           (ERR-1,,1) Maximum uncertainty due to number of target
                   nuclei (<1%)
           (ERR-2) Uncertainty due to standard capture cross
                   sections of 197Au
           (ERR-3) Uncertainty due to weighting function of
                   gamma-ray spectrometer
           (ERR-4) Uncertainty due to extrapolation of
                   pulse-height spectrum below the discrimination
                   level
           (ERR-5,1,3) Maximum uncertainty due to correction for
                   self-shielding and multiple scattering (1-3%)
           (ERR-S,2,3) Maximum statistical uncertainty (2-3%)
…
COMMON                 6          3
ERR-2      ERR-3      ERR-4
PER-CENT   PER-CENT   PER-CENT
 3.         1.         2.
```

← Given in DATA section

ERR-ANALYS for Ranged Uncertainty (cont)

Note:
Try to classify systematic uncertainties to "correlated" and "uncorrelated" systematic uncertainties when authors do it !

Uncorrelated systematic uncertainty must be treated as statistical uncertainty in covariance analysis.

Example →

M. Bostan et al., Phys.Rev.C49(1994)266 (EXFOR 22292.006)

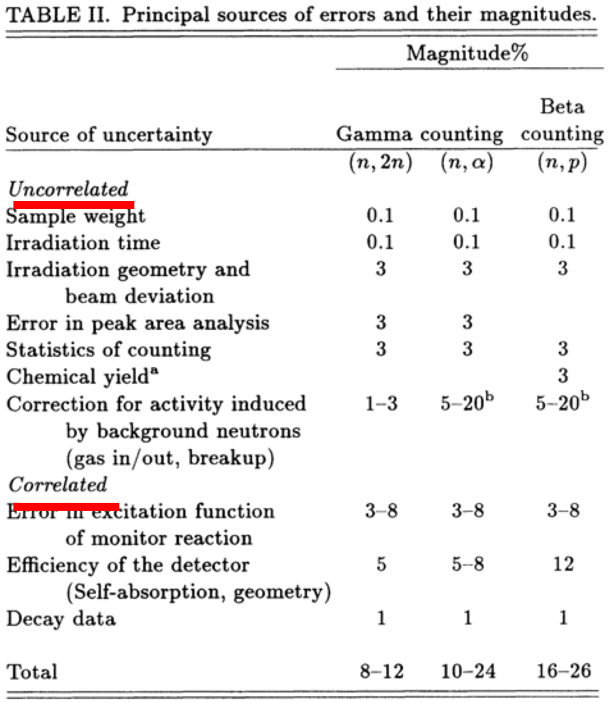


TABLE II. Principal sources of errors and their magnitudes.

	Magnitude%		
Source of uncertainty	Gamma counting		Beta counting
	$(n,2n)$	(n,α)	(n,p)
Uncorrelated			
Sample weight	0.1	0.1	0.1
Irradiation time	0.1	0.1	0.1
Irradiation geometry and beam deviation	3	3	3
Error in peak area analysis	3	3	
Statistics of counting	3	3	3
Chemical yield[a]			3
Correction for activity induced by background neutrons (gas in/out, breakup)	1–3	5–20[b]	5–20[b]
Correlated			
Error in excitation function of monitor reaction	3–8	3–8	3–8
Efficiency of the detector (Self-absorption, geometry)	5	5–8	12
Decay data	1	1	1
Total	8–12	10–24	16–26

ERR-ANALYS for Ranged Uncertainty (cont)

Try to express "uncorrelated" by correlation factor=0!

Example:

The current 22292.006

(No any detail of uncertainty…)

```
ERR-ANALYS (DATA-ERR) TOTAL ERRORS.
…
REACTION   (25-MN-55(N,2N)25-MN-54,,SIG)
DECAY-DATA (25-MN-54,312.2D,DG,834.8,.9998)
STATUS     .DATA TAKEN FROM TABLE IV OF MAIN REF.
HISTORY    (960204C) J.B.
           (961220E)
ENDBIB               5
NOCOMMON             0          0
DATA                 4          3
EN         EN-ERR     DATA       DATA-ERR
MEV        MEV        MB         MB
 1.1140E+01 1.6000E-01 1.5000E+02 1.2000E+01
 1.1970E+01 1.8000E-01 4.0000E+02 3.3000E+01
 1.2850E+01 2.0000E-01 6.1000E+02 5.2000E+01
ENDDATA              5
```

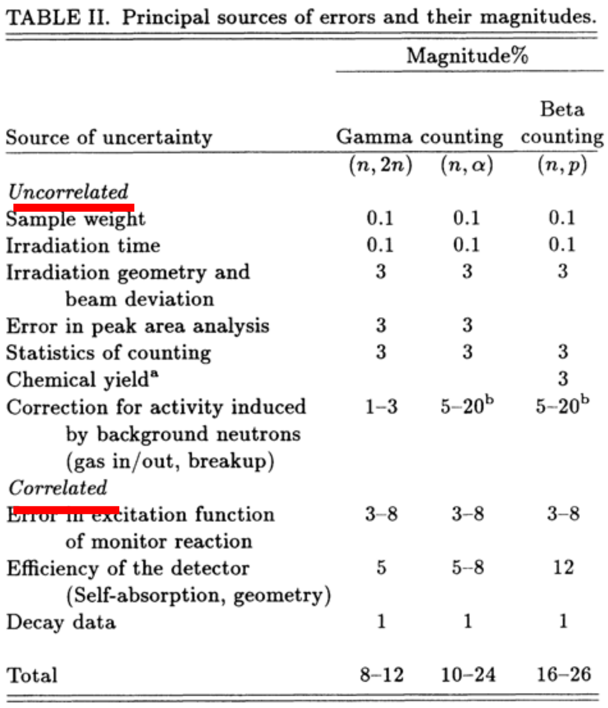


TABLE II. Principal sources of errors and their magnitudes.

Source of uncertainty	Magnitude% Gamma counting $(n,2n)$	Gamma counting (n,α)	Beta counting (n,p)
Uncorrelated			
Sample weight	0.1	0.1	0.1
Irradiation time	0.1	0.1	0.1
Irradiation geometry and beam deviation	3	3	3
Error in peak area analysis	3	3	
Statistics of counting	3	3	3
Chemical yield[a]			3
Correction for activity induced by background neutrons (gas in/out, breakup)	1–3	5–20[b]	5–20[b]
Correlated			
Error in excitation function of monitor reaction	3–8	3–8	3–8
Efficiency of the detector (Self-absorption, geometry)	5	5–8	12
Decay data	1	1	1
Total	8–12	10–24	16–26

ERR-ANALYS for Ranged Uncertainty (cont)

Example of 22292.006 correction:

```
…
ERR-ANALYS (ERR-T) Total uncertainty
           (ERR-1,,,0.) Sample weight
           (ERR-2,,,0.) Irradiation time
…
ERR-1     ERR-2      …
PER-CENT  PER-CENT   …
 0.1        0.1      …
ENDCOMMON
DATA                 4          3
EN         EN-ERR     DATA        ERR-T
MEV        MEV        MB          MB
 1.1140E+01 1.6000E-01 1.5000E+02 1.2000E+01
 1.1970E+01 1.8000E-01 4.0000E+02 3.3000E+01
 1.2850E+01 2.0000E-01 6.1000E+02 5.2000E+01
ENDDATA              5
```

Correlation coefficient = 0

→

An indication that it should not be considered in the off-diagonal components of the covariance matrix.

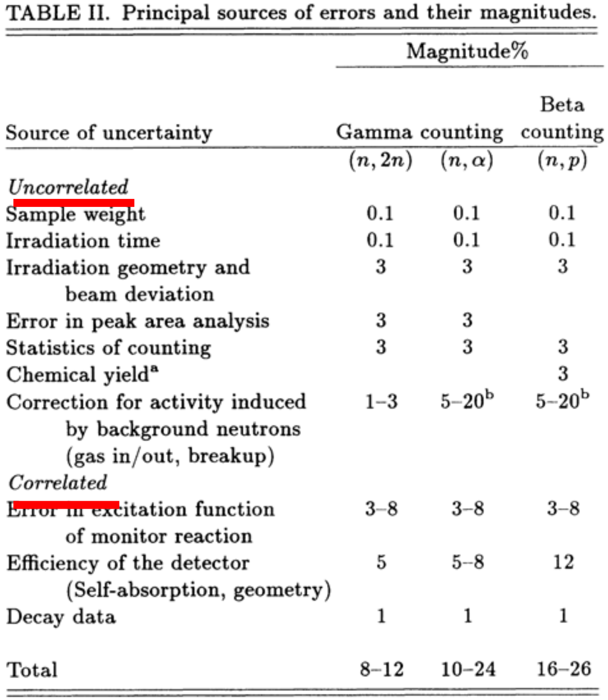


TABLE II. Principal sources of errors and their magnitudes.

	Magnitude%		
Source of uncertainty	Gamma counting		Beta counting
	$(n,2n)$	(n,α)	(n,p)
Uncorrelated			
Sample weight	0.1	0.1	0.1
Irradiation time	0.1	0.1	0.1
Irradiation geometry and beam deviation	3	3	3
Error in peak area analysis	3	3	
Statistics of counting	3	3	3
Chemical yield[a]			3
Correction for activity induced by background neutrons (gas in/out, breakup)	1–3	5–20[b]	5–20[b]
Correlated			
Error in excitation function of monitor reaction	3–8	3–8	3–8
Efficiency of the detector (Self-absorption, geometry)	5	5–8	12
Decay data	1	1	1
Total	8–12	10–24	16–26

International Atomic Energy Agency

Summary of Manual Updates

3. REACTION: General

IAEA Nuclear Data Section

N. Otsuka

45

General Quantity Modifier

There are 3 major groups of General Quantity Modifier (GENQ):

1. Relation with absolute values

A : multiplied by isotopic abundance
FCT: multiplied by a defined constant (e.g. branching ratio)
REL: multiplied by a unknown constant (e.g. counts)

2. Quality of the value

RAW: Raw data (e.g. uncorrected for major effects)
MSC: Miscellaneous data (data is not well defined by REACTION code)

3. Spectrum average

BRA: Averaged for Bremsstrahlung spectrum
MXW: Averaged for Maxwellian spectrum
FIS: Averaged for fission neutron spectrum
etc.

General Quantity Modifier (cont)

Example of REACTION with general quantity modifiers

`(28-NI-58(N,P)27-CO-58,,SIG,,A)`

^{58}Ni(n,p)^{58}Co cross section multiplied by 0.68

(68%: Isotopic abundance of ^{58}Ni in natural environment.)

`(22-TI-44(N,P)21-SC-44,,SIG,,MXW)`

^{44}Ti(n,p)^{44}Sc cross section for neutron equilibrated to Maxwell distribution

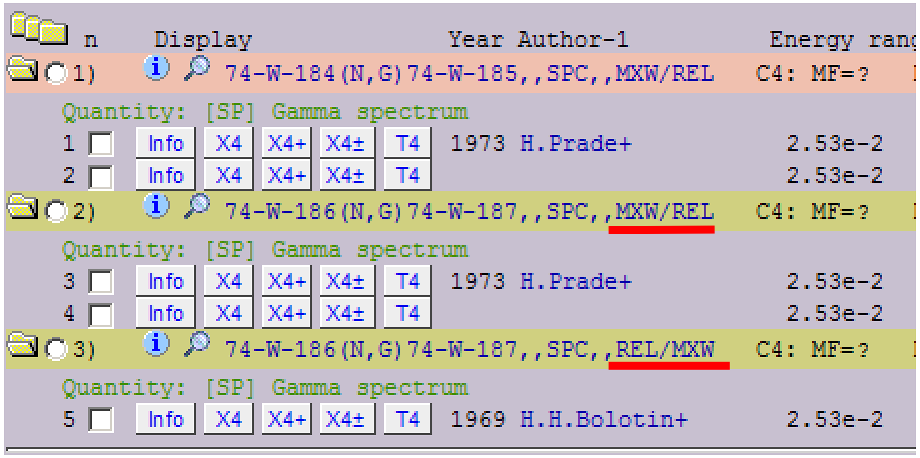
`(74-W-186(N,G)74-W-187,,SPC,,MXW/REL)`

^{186}W(n, γ)^{185}W cross section for neutron equilibrated to Maxwell distribution in arbitrary unit

So far, we do not have any rule for the order of two general quantity modifiers. (e.g. both MXW/REL and REL/MXW were acceptable.)

General Quantity Modifier (cont)

Use of several general quantity modifiers without the rule for their ordering would make a problem to users.



```
   n    Display                    Year Author-1         Energy rang
 ○ 1)     74-W-184(N,G)74-W-185,,SPC,,MXW/REL      C4: MF=?
     Quantity: [SP] Gamma spectrum
     1 ☐  Info  X4  X4+  X4±  T4  1973 H.Prade+          2.53e-2
     2 ☐  Info  X4  X4+  X4±  T4                         2.53e-2
 ○ 2)     74-W-186(N,G)74-W-187,,SPC,,MXW/REL      C4: MF=?
     Quantity: [SP] Gamma spectrum
     3 ☐  Info  X4  X4+  X4±  T4  1973 H.Prade+          2.53e-2
     4 ☐  Info  X4  X4+  X4±  T4                         2.53e-2
 ○ 3)     74-W-186(N,G)74-W-187,,SPC,,REL/MXW      C4: MF=?
     Quantity: [SP] Gamma spectrum
     5 ☐  Info  X4  X4+  X4±  T4  1969 H.H.Bolotin+       2.53e-2
```

Same quantity is divided to two parts in this search result.

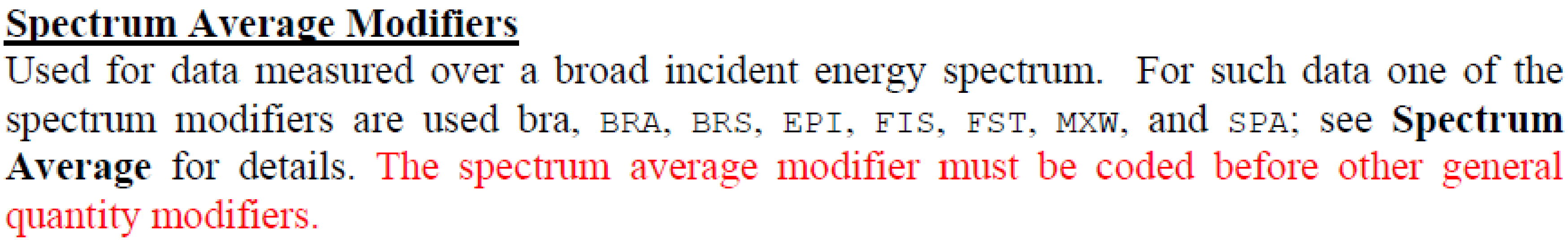
We have introduced a rule for order of general quantity modifier.

Spectrum Average Modifiers

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

General Quantity Modifier (cont)

LEXFOR G.3 (General Quantity Modifier)



Spectrum Average Modifiers

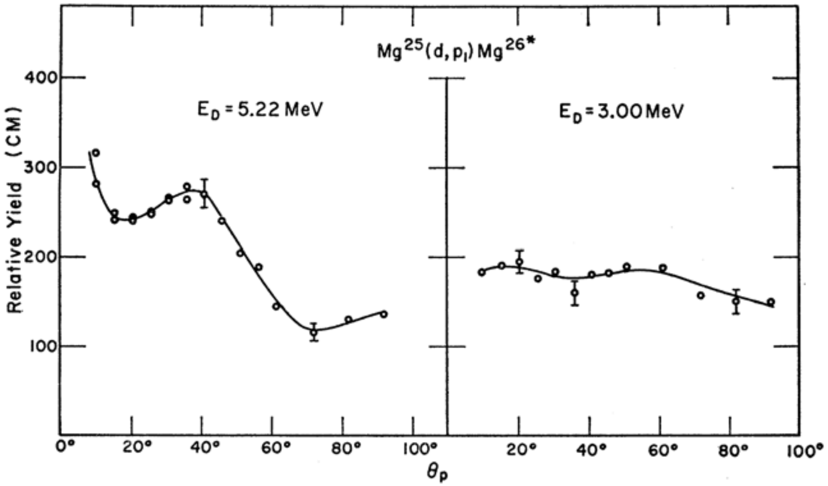
Used for data measured over a broad incident energy spectrum. For such data one of the spectrum modifiers are used bra, `BRA`, `BRS`, `EPI`, `FIS`, `FST`, `MXW`, and `SPA`; see **Spectrum Average** for details. The spectrum average modifier must be coded before other general quantity modifiers.

(74-W-186(N,G)74-W-187,,SPC,,REL/MXW)

→(74-W-186(N,G)74-W-187,,SPC,,MXW/REL)

General Quantity Modifier (cont)

Arbitrary unit data digitized from two panels



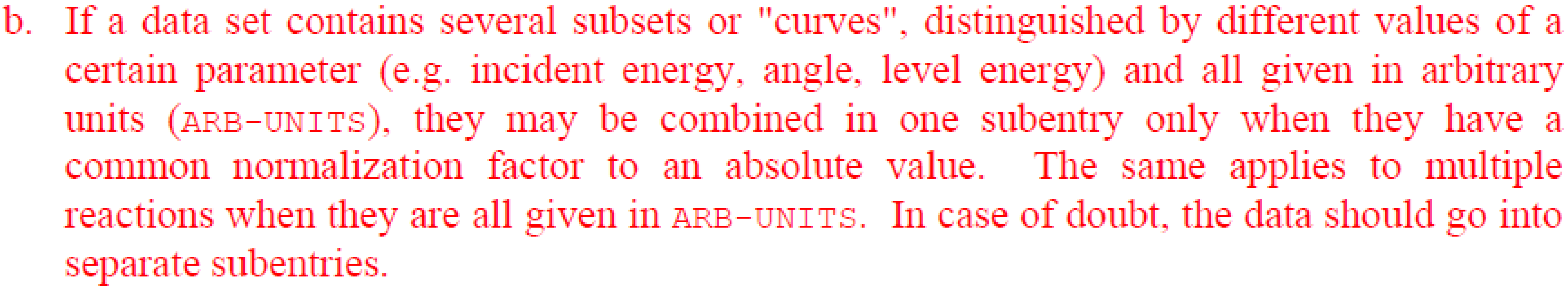
Can we keep these data in one subentry? No!

```
REACTION   (12-MG-25(D,P)12-MG-26,PAR,DA,,REL)
...
EN         ANG        DATA-CM    DATA-ERR
MEV        ADEG       ARB-UNITS  ARB-UNITS
       3.00      9.766     184.14
       3.00     15.547     191.31
       3.00     20.423     195.61     14.388
...
       5.22     10.638     316.63
       5.22       10.8     281.38
       5.22     15.457     250.48
       5.22     15.583     241.85
...
```

We are not sure these two parts have a common normalization factor to their absolute values.

General Quantity Modifier (cont)

LEXFOR G.3 (General Quantity Modifier)



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.

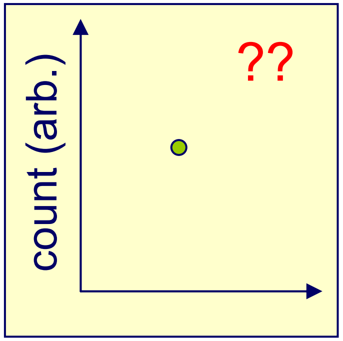
It may creates a lot of subentries when a differential data are given for various constants (e.g. incident energies, excitation energies etc.). Compiler must examine whether they are really useful for compilation….

General Quantity Modifier (cont)

Data table containing one data point in arbitrary unit?

Data points in arbitrary unit can be useful as “shape data”. Users multiply a factor (e.g. a factor which can reproduce their theoretical values well.)

That means at least two data points must be included in one data set in arbitrary nit.



LEXFOR G.3 (General Quantity Modifier)

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

Frequently Occurring REACTION Combination

We can make a combination of REACTION:

Example:

`(94-PU-239(N,F),,SIG)`

^{239}Pu(n,f) cross section

`(94-PU-239(N,F),,SIG)/(92-U-235(N,F),,SIG)`

^{239}Pu(n,f) cross section relative to ^{235}U(n,f) cross section

However,...

Frequently Occurring REACTION Combination

REACTION combination must NOT be used when a specialized code exists for the combination. Do not need to be “as written by authors”.

This is to avoid variety of REACTION codes for a given quantity in the database.

Example:

Elastic scattering + inelastic scattering = **Scattering**

`(90-TH-232(N,EL)90-TH-232,,SIG)+`

`(90-TH-232(N,INL)90-TH-232,PAR,SIG)`

→ `(90-TH-232(N,SCT)90-TH-232,PAR,SIG)`

Note:

The elastic scattering cannot be free from inelastic scattering to the 1st level for high energy neutron (above ~1 MeV). There are some suspicious coding in EXFOR now, and we have to correct it!

Frequently Occurring REACTION Combination (cont)

More examples:

Capture cross section / fission cross section= **Alpha value**

`(92-U-235(N,G)92-U-236,,SIG)/(92-U-235(N,F),,SIG)`

→ **`(92-U-235(N,ABS),,ALF)`**

(Useful quantity for ^{235}U capture cross section evaluation)

$g \Gamma_n \Gamma_\gamma / \Gamma_{tot}$= **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)82-PB-209,,WID/STR)`**

Frequently Occurring REACTION Combination (cont)

More examples:

Sum data for all contributing target nuclide= **Data for natural target**

```
(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)
```

(0: natural target, A: times the natural isotopic abundance)

Frequently Occurring REACTION Combination (cont)

Sum of exclusive cross section= **Inclusive cross section**

(40-ZR-91(P,N)41-NB-91,,SIG)+

(40-ZR-91(P,N+P)40-ZR-90,,SIG)+

(40-ZR-91(P,N+A)39-Y-87,,SIG)

→ **(40-ZR-91(P,X)0-NN-1,,SIG)**

Sum of processes resulting same residual = (inclusive) **Production**

(46-PD-102(P,D)46-PD-101,CUM,SIG)+

(46-PD-102(P,N+P)46-PD-101,CUM,SIG)

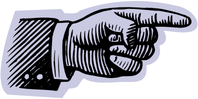
→ **(46-PD-102(P,X)46-PD-101,CUM,SIG)**

Note: An open question for data above thresholds:

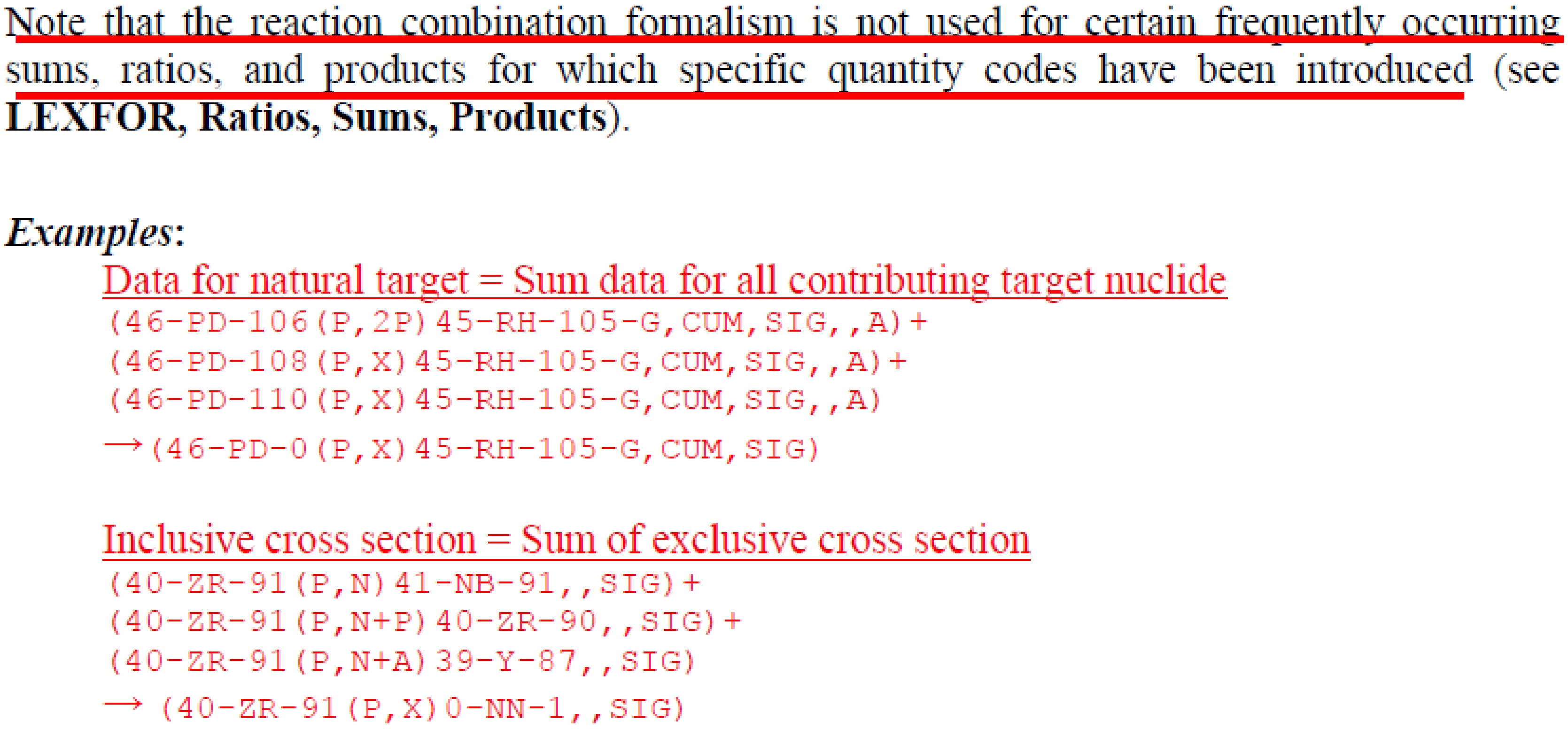
Should we use **(P,X)** rather than **(P,N+P)**?

Should we use **(P,X)** rather than **(P,A)** ?

Frequently Occurring REACTION Combination (cont)



EXFOR Formats 6.7



Note that the reaction combination formalism is not used for certain frequently occurring sums, ratios, and products for which specific quantity codes have been introduced (see **LEXFOR, Ratios, Sums, Products**).

Examples:

Data for natural target = Sum data for all contributing target nuclide

```
(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)
```

Inclusive cross section = Sum of exclusive cross section

```
(40-ZR-91(P,N)41-NB-91,,SIG)+
(40-ZR-91(P,N+P)40-ZR-90,,SIG)+
(40-ZR-91(P,N+A)39-Y-87,,SIG)
→ (40-ZR-91(P,X)0-NN-1,,SIG)
```

Not a new rule. Just addition of examples.

Independent Variable for REACTION Ratio

Some “typical” REACTION ratios

```
REACTION   (91-PA-233(N,F),,SIG)/
           (92-U-235(N,F),,SIG))
....
EN         DATA
MEV        NO-DIM
 14.8        ...
```

^{233}Pa(n,f) / ^{235}U(n,f) cross section ratio

```
REACTION   ((92-U-232(N,F)53-I-133,CUM,FY)/
           (92-U-232(N,F)MASS,CUM,FY))
…
EN-DUMMY   MASS      DATA
EV         NO-DIM    NO-DIM
 0.0253     128.       ...
```

^{232}U(n,f) ^{133}I cumulative yield relative to A=133 ^{232}U(n,f) cumulative yield

Is it possible to make a ratio for the same REACTION?

Independent Variable for REACTION Ratio (cont)

REACTION ratios of the same “reaction”

^{10}B(n, α)^{7}Li (g.s.) / ^{10}B(n, α)^{7}Li (total)   (=*branching ratio* to g.s.)

`(5-B-10(N,A)3-LI-7,PAR,SIG)/(5-B-10(N,A)3-LI-7,,SIG)`

“g.s.” is expressed by **`E-LVL=0.0MEV.`**

^{10}B(n, α)^{7}Li (total) / ^{10}B(n, α)^{7}Li (g.s.)

`(5-B-10(N,A)3-LI-7,,SIG)/(5-B-10(N,A)3-LI-7,PAR,SIG)`

“g.s.” is expressed by **`E-LVL=0.0MEV.`**

^{10}B(n, α)^{7}Li (1st) / ^{10}B(n, α)^{7}Li (g.s.)

`(5-B-10(N,A)3-LI-7,PAR,SIG)//(5-B-10(N,A)3-LI-7,,SIG)`

“1st” “g.s.” are expressed by

`E-LVL-NM=0.48MEV;`
`E-LVL-DN=0.0MEV.`

(// is an indication numerator and denominator refer to different values of an independent variable, e.g., level energy.)

Independent Variable for REACTION Combination (cont)

```
REACTION   ((3-LI-7(P,N)4-BE-7,PAR,SIG)/
           (3-LI-7(P,N)4-BE-7,,SIG))
....
EN         E-LVL      DATA
MEV        MEV        MB
 14.8       0.0        ...
```

$^{10}B(n,\alpha)^{7}Li$ (g.s.) / $^{10}B(n,\alpha)^{7}Li$ (tot.)

```
REACTION   ((3-LI-7(P,N)4-BE-7,,SIG)/
           (3-LI-7(P,N)4-BE-7,PAR,SIG))
....
EN         E-LVL      DATA
MEV        MEV        MB
 14.8       0.0        ...
```

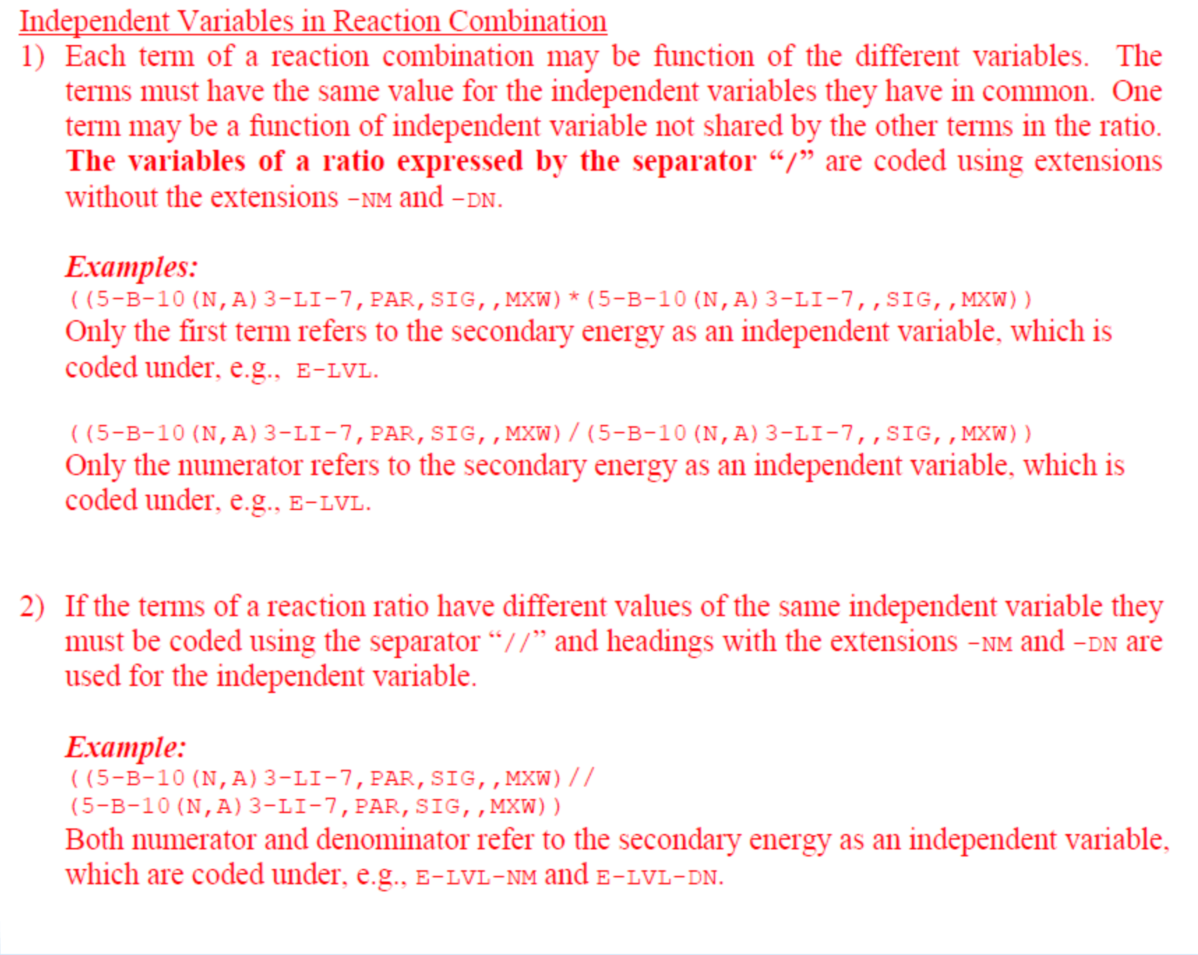
$^{10}B(n,\alpha)^{7}Li$ (tot.) / $^{10}B(n,\alpha)^{7}Li$ (g.s.)

```
REACTION   ((3-LI-7(P,N)4-BE-7,PAR,SIG)//
           (3-LI-7(P,N)4-BE-7,PAR,SIG))
....
EN         E-LVL-NM   E-LVL-DN     DATA
MEV        MEV        MEV          MB
 14.8       0.48       0.0          ...
```

$^{10}B(n,\alpha)^{7}Li$ (1st.) / $^{10}B(n,\alpha)^{7}Li$ (g.s.)

Independent Variable for REACTION Combination (cont)

LEXFOR I.7 (Independent Variables)



Independent Variables in Reaction Combination

1) Each term of a reaction combination may be function of the 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.

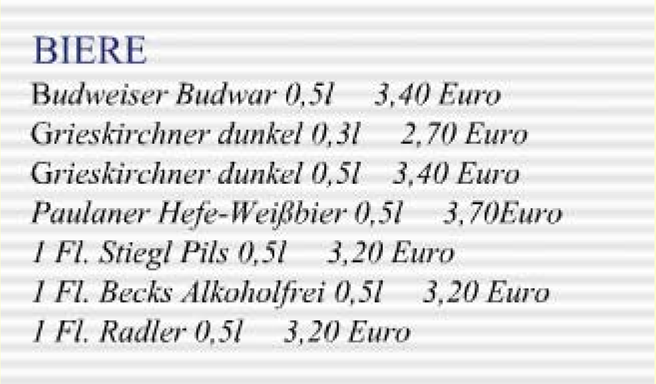
   Example:

   `((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`.

Break Point (63)

2009-05-25 NRDC meeting



BIERE

Budweiser Budwar 0,5l	3,40 Euro
Grieskirchner dunkel 0,3l	2,70 Euro
Grieskirchner dunkel 0,5l	3,40 Euro
Paulaner Hefe-Weißbier 0,5l	3,70Euro
1 Fl. Stiegl Pils 0,5l	3,20 Euro
1 Fl. Becks Alkoholfrei 0,5l	3,20 Euro
1 Fl. Radler 0,5l	3,20 Euro

Dinner (19:00~)
(~15 min walk from U1 Alte Donau)

International Atomic Energy Agency

Summary of Manual Updates
4. Activation

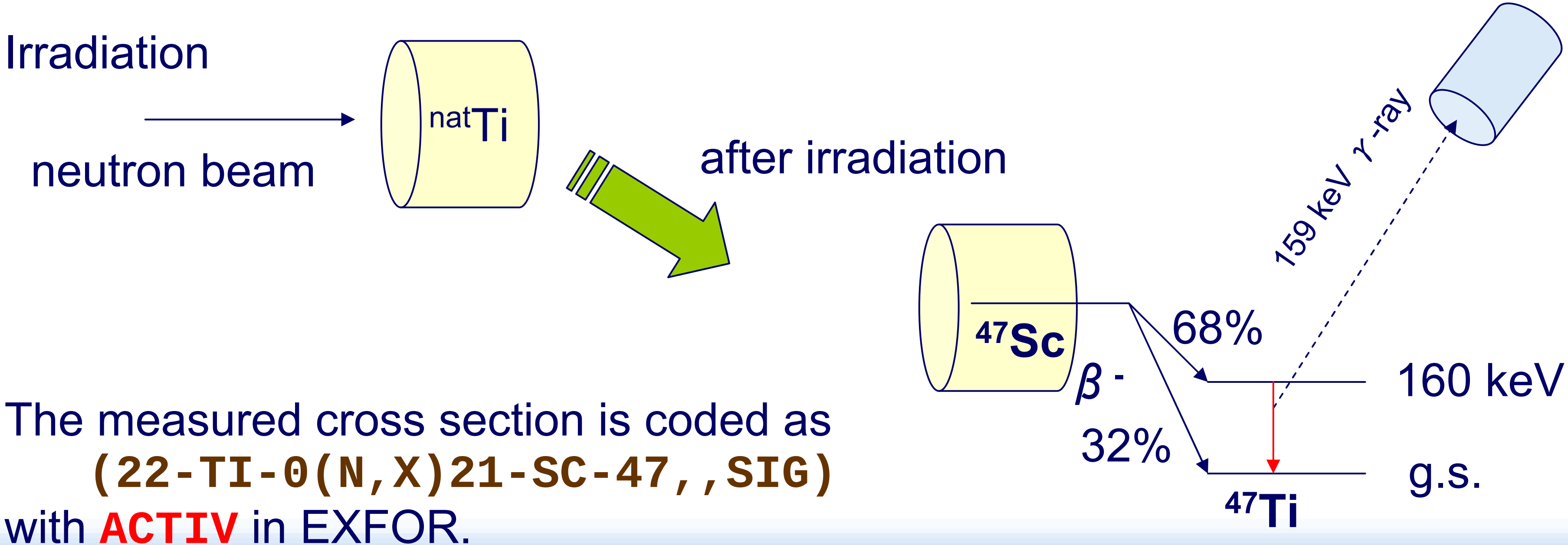
IAEA Nuclear Data Section
N. Otsuka

New Modifier RAB

Activation cross section:

Cross section derived from measurement of decay of reaction product

Example: ^{47}**Sc** production from ^{nat}Ti by neutron irradiation



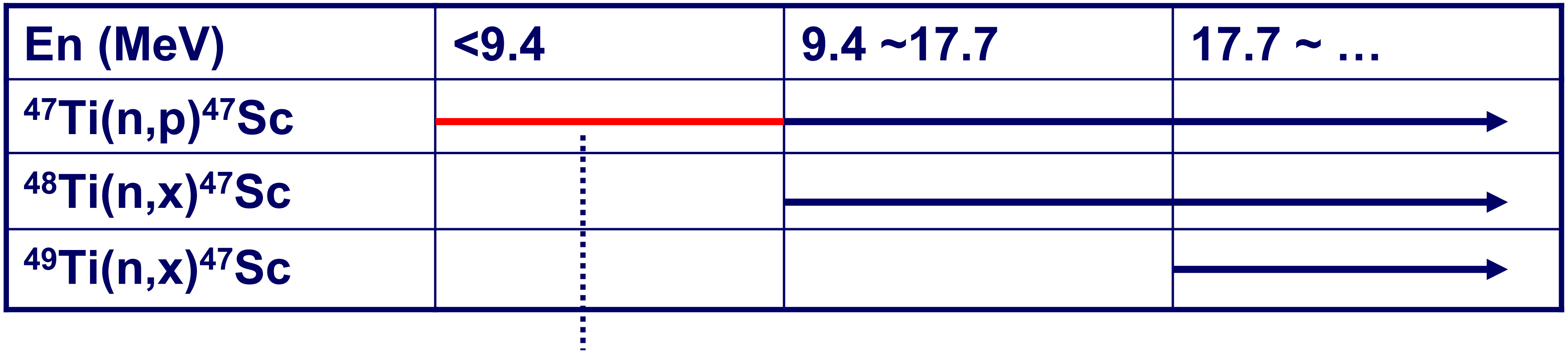
The measured cross section is coded as

`(22-TI-0(N,X)21-SC-47,,SIG)`

with **`ACTIV`** in EXFOR.

New Modifier RAB (cont)

Contribution of Ti isotopes to ^{47}Sc production



En (MeV)	**<9.4**	**9.4 ~17.7**	**17.7 ~ …**
^{47}Ti(n,p)^{47}Sc	—	—	→
^{48}Ti(n,x)^{47}Sc		—	→
^{49}Ti(n,x)^{47}Sc			→

En < 9.4 MeV: Only ^{47}Ti(n,p)^{47}Sc contributes to ^{47}Sc production.

Isotopic cross section can be derived from elemental cross section:

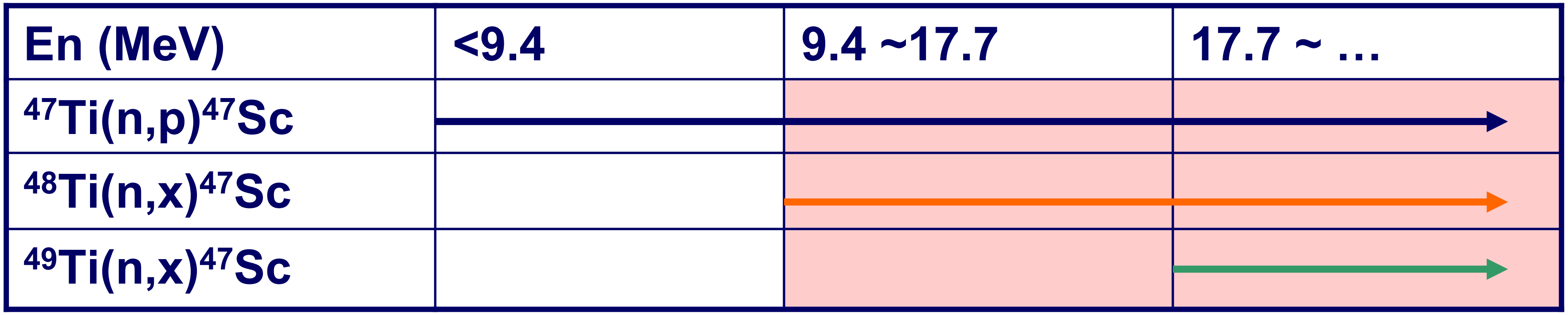
$$\sigma(^{47}\mathrm{Ti(n,p)}^{47}\mathrm{Sc}) = \sigma(^{nat}\mathrm{Ti(n,p)}^{47}\mathrm{Sc}) / a(^{47}\mathrm{Ti})$$

This isotopic cross section is coded as

```
(22-TI-47(N,P)21-SC-47,,SIG)
```

New Modifier RAB (cont)

Elemental cross sections cannot be converted to isotopic cross sections when two or more contributing reactions exist.

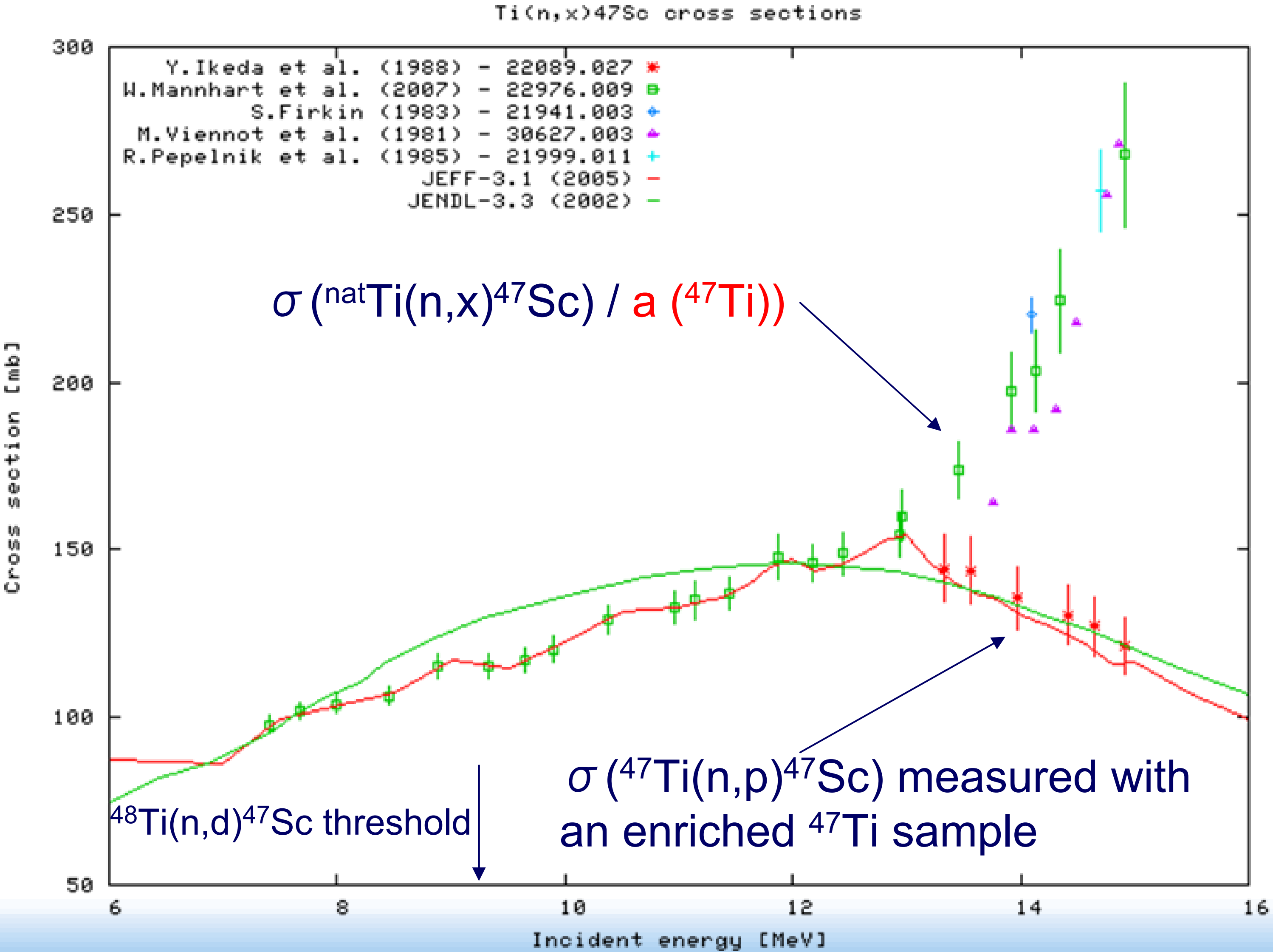


En (MeV)	<9.4	9.4 ~17.7	17.7 ~ …
^{47}Ti(n,p)^{47}Sc	→	→	→
^{48}Ti(n,x)^{47}Sc		→	→
^{49}Ti(n,x)^{47}Sc			→

However some authors prefer to divide elemental cross section by isotopic abundance even some data points are above the threshold.

$$? = \sigma\,(^{nat}\mathrm{Ti(n,p)}^{47}\mathrm{Sc})\ /\ a\ (^{47}\mathrm{Ti})$$

New Modifier RAB (cont)



σ (^{nat}Ti(n,x)^{47}Sc) / a (^{47}Ti))

σ (^{47}Ti(n,p)^{47}Sc) measured with an enriched ^{47}Ti sample

^{48}Ti(n,d)^{47}Sc threshold

New Modifier RAB (cont)

E_n < 9.4 MeV

σ (^{nat}Ti(n,p)^{47}Sc) / a (^{47}Ti) = σ (^{47}Ti(n,p)^{47}Sc)

```
(22-TI-47(N,P)21-SC-47,,SIG)          (1)
```

9.4 MeV < E_n < 17.7 MeV

σ (^{nat}Ti(n,p)^{47}Sc) / *a* (^{47}Ti)

= σ (^{47}Ti(n,p)^{47}Sc) + σ (^{48}Ti(n,x)^{47}Sc)[a (^{48}Ti)/a (^{47}Ti)]

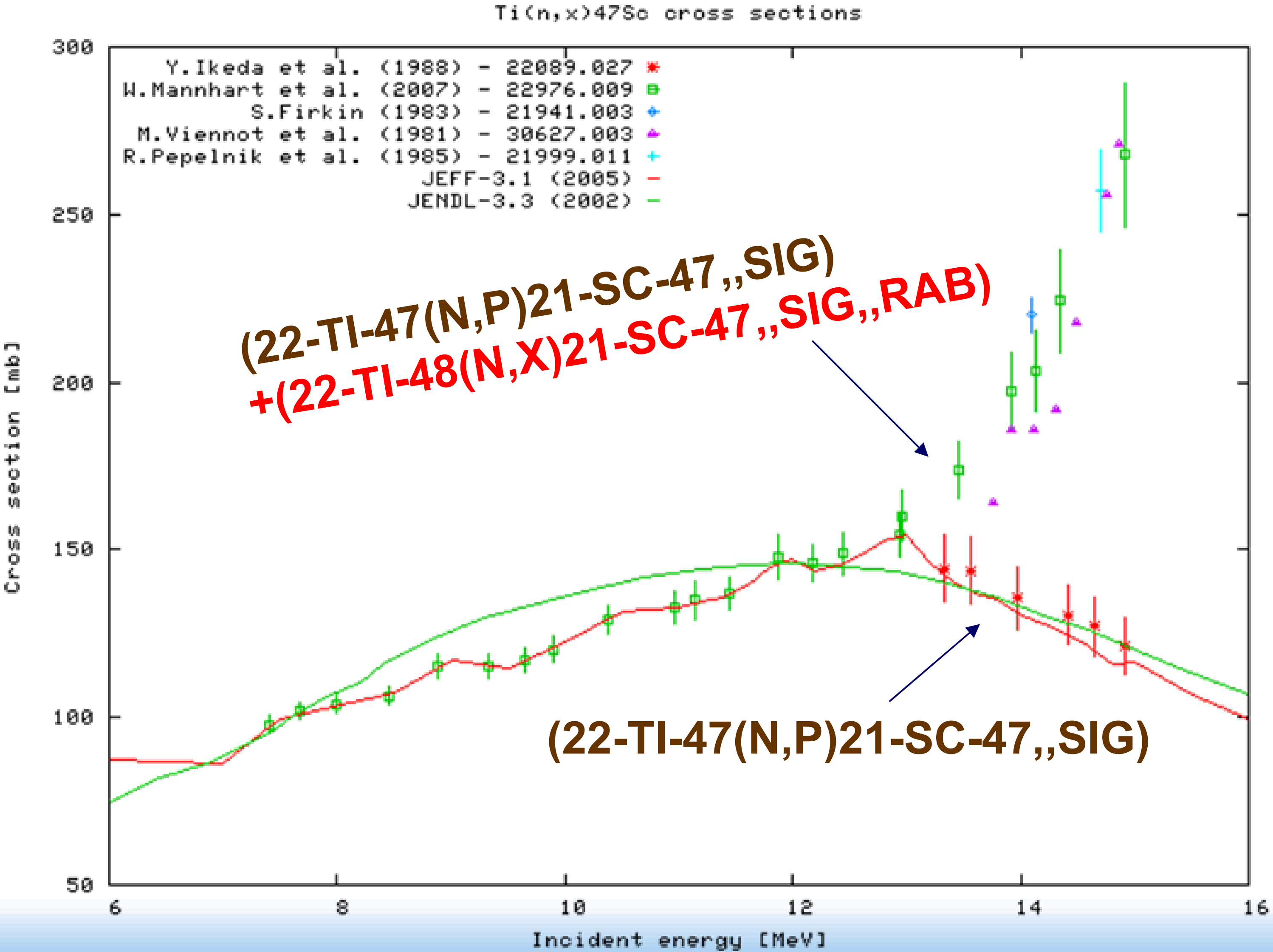
```
 (22-TI-47(N,P)21-SC-47,,SIG)
+(22-TI-48(N,X)21-SC-47,,SIG,,FCT)
```

This will be coded with a new modifier **RAB**:

```
 (22-TI-47(N,P)21-SC-47,,SIG)
+(22-TI-48(N,P)21-SC-47,,SIG,,RAB)   (2)
```

Note: (1)=(2) below 9.4 MeV.

New Modifier RAB (cont)



(22-TI-47(N,P)21-SC-47,,SIG)
+(22-TI-48(N,X)21-SC-47,,SIG,,RAB)

(22-TI-47(N,P)21-SC-47,,SIG)

New Modifier RAB (cont)

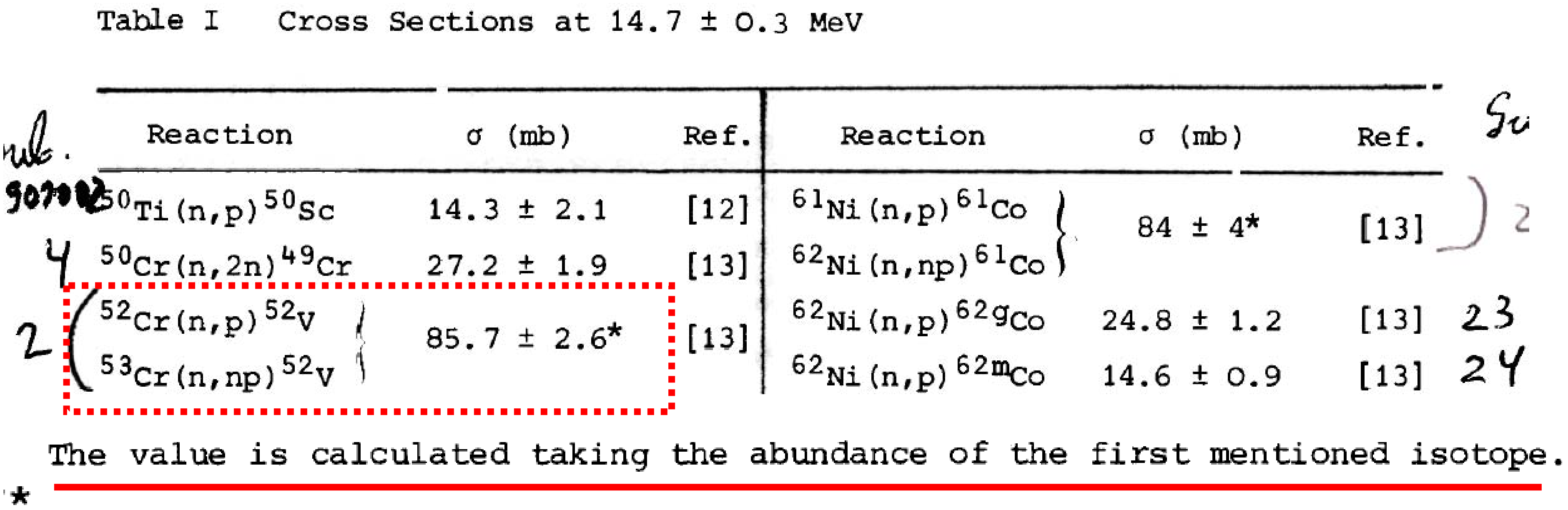


Table I Cross Sections at 14.7 ± 0.3 MeV

ub.	Reaction	σ (mb)	Ref.	Reaction	σ (mb)	Ref.	Su
9070	^{50}Ti(n,p)^{50}Sc	14.3 ± 2.1	[12]	^{61}Ni(n,p)^{61}Co ^{62}Ni(n,np)^{61}Co	84 ± 4*	[13]	2
4	^{50}Cr(n,2n)^{49}Cr	27.2 ± 1.9	[13]				
2	^{52}Cr(n,p)^{52}V ^{53}Cr(n,np)^{52}V	85.7 ± 2.6*	[13]	^{62}Ni(n,p)^{62g}Co	24.8 ± 1.2	[13]	23
				^{62}Ni(n,p)^{62m}Co	14.6 ± 0.9	[13]	24

* The value is calculated taking the abundance of the first mentioned isotope.

should be coded as

(24-CR-52(N,P)23-V-52,,SIG)+
(24-CR-53(N,X)23-V-52,,SIG,,RAB)

Note:

(24-CR-52(N,P)23-V-52,,SIG)+
(24-CR-53(N,X)23-V-52,,SIG)

is has no physical meaning.

R. Pepelnik et al.,
Conf. Proc. 85SANTA
(EXFOR 21976.018)

Isotopic Abundance as Coded Information

Again σ (^{nat}Ti(n,p)^{47}Sc) / a(^{47}Ti):

E_n < 9.4 MeV

```
    (22-TI-47(N,P)21-SC-47,,SIG)
```

9.4 MeV < E_n < 17.7 MeV

```
    (22-TI-47(N,P)21-SC-47,,SIG)
   +(22-TI-48(N,P)21-SC-47,,SIG,,RAB)
```

Data are sensitive to a(^{47}Ti) adopted by authors
(similar to gamma intensity used in derivation of activation cross sections).

Should we keep the isotopic abundance as computer readable information for future renormalization ??

Isotopic Abundance as Coded Information (cont)

An answer from W. Mannhart (2009-02-06):

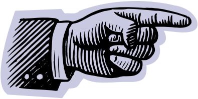
I agree completely with you in the following. *In the experiments the isotopic abundance is of similar importance as the monitor cross section and the decay data used.* All three data are needed to allow a proper renormalization of the EXFOR cross sections with the latest values of the mentioned quantities. I support strongly your proposal to introduce a new format in the future:

We will code the isotopic abundance as coded information:

`SAMPLE    (22-TI-47,ENR=0.90)` Enriched sample

`SAMPLE    (22-TI-47,NAT=0.0744)` Natural sample

Isotopic Abundance as Coded Information (cont)



EXFOR Formats 7.28

SAMPLE. Used to give information on the structure, composition, shape, *etc.*, of the measurement sample.

1. Must be present and must contain coded information when the data modifier RAB is coded under the keyword REACTION. Otherwise, its presence is optional and free text or coded information, with or without free text, may be given.

2. The general format of the code is : (nuclide, abundance)

   Nuclide field: The general format of the code is *Z-S-A-X*.

   Abundance field: The field identifier NAT= or ENR= followed by the isotopic abundance of the natural or enriched sample, respectively. Only the values assumed by the author for obtaining the data are given.

   Example:

```
SAMPLE    (22-TI-47,NAT=0.0744)
           Normalized to the number of Ti-47 nuclei

SAMPLE    (22-TI-46,ENR=0.955)
           Enriched sample, 95.5% Ti-46, 3.5% Ti-48
          (22-TI-48,ENR=0.035)
```

International Atomic Energy Agency

Summary of Manual Updates

5. Fission

IAEA Nuclear Data Section
N. Otsuka

75

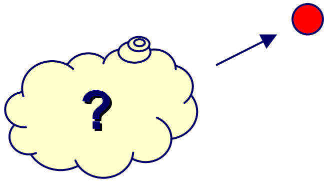
Particle Considered in Fission

Usually particle considered in inclusive measurement is coded in SF4.

Some example:

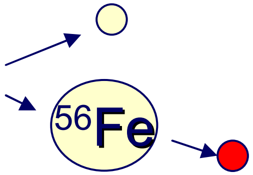
1. Inclusive proton spectrum (n,p+x)
   `(82-PB-208(N,X)1-H-1,,DA/DE)`

2. Inclusive gamma multiplicity (α, γ+x)
   `(79-AU-197(A,X)0-G-0,,PY,,TT)`

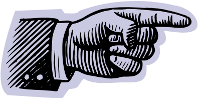


SF7 is used when the yield is exclusively measured in a reaction channel:

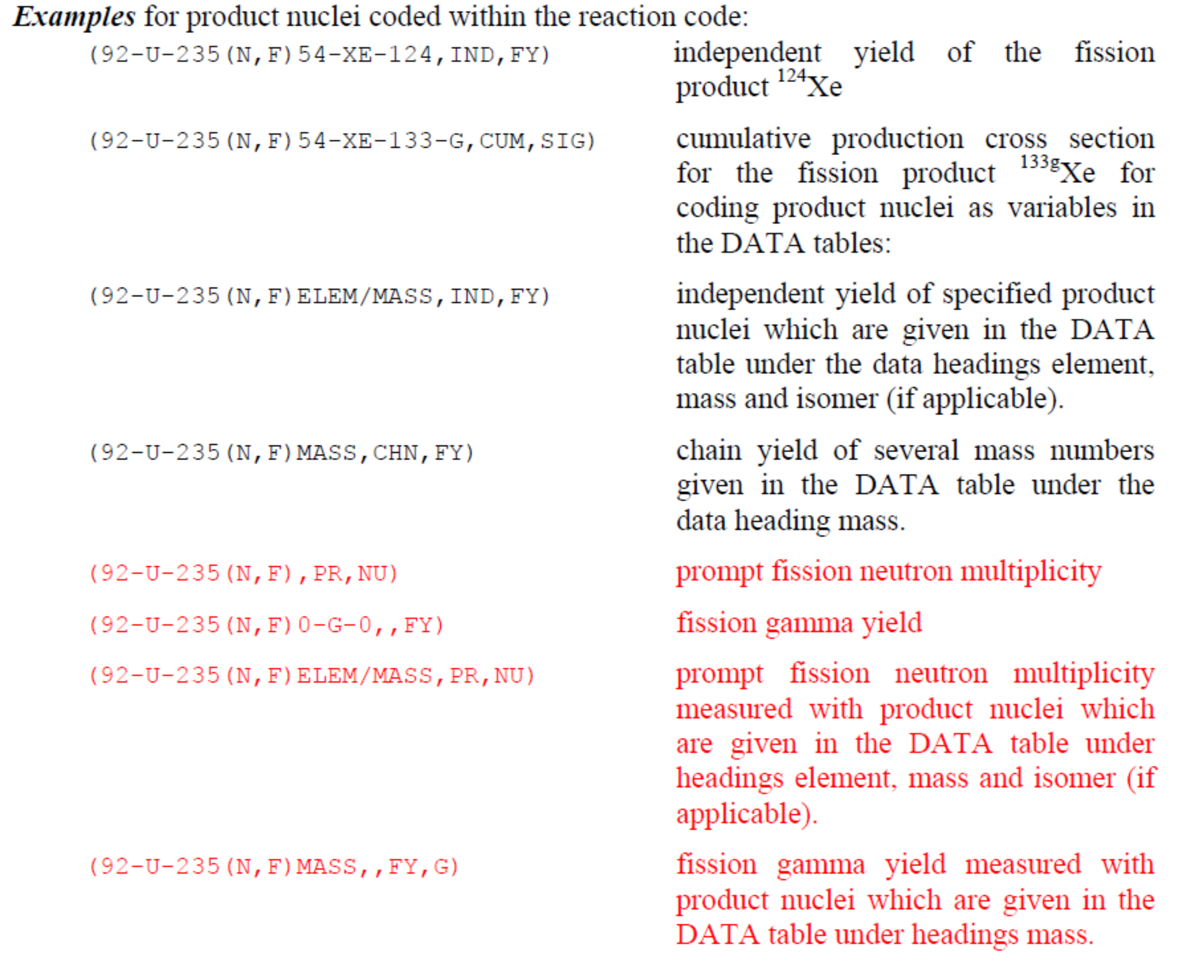
3. Inelastic gamma yield (n,n'+γ)
   `(26-FE-56(N,INL)26-FE-56,PAR,SIG,G)`



Particle Considered in Fission (cont)



LEXFOR F.7 (Fission Yield)



Examples for product nuclei coded within the reaction code:

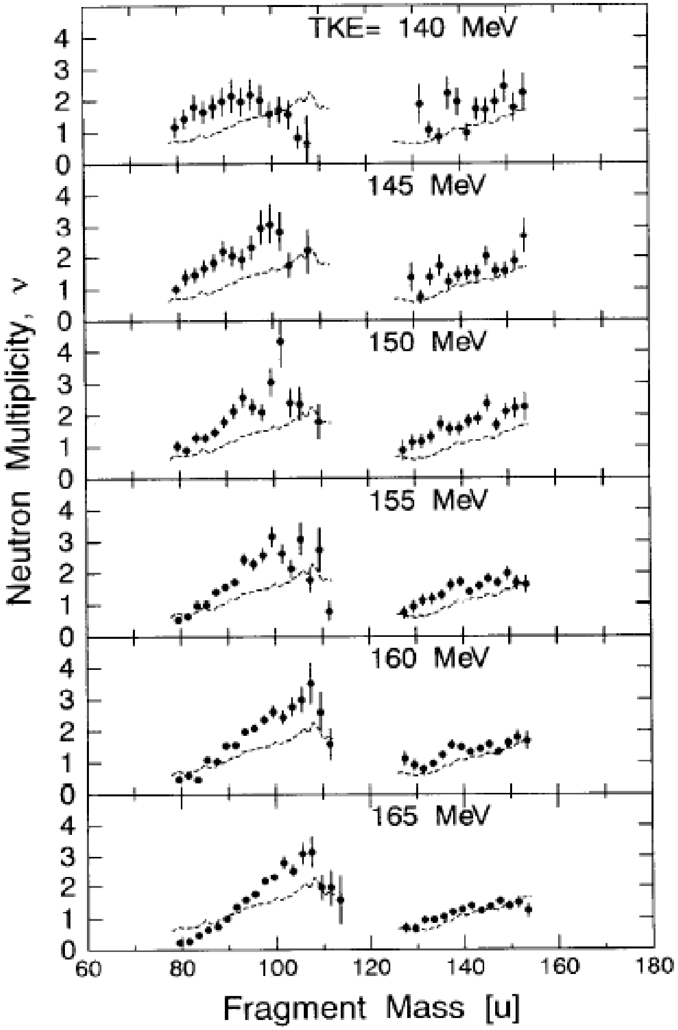
`(92-U-235(N,F)54-XE-124,IND,FY)`	independent yield of the fission product ^{124}Xe
`(92-U-235(N,F)54-XE-133-G,CUM,SIG)`	cumulative production cross section for the fission product ^{133g}Xe for coding product nuclei as variables in the DATA tables:
`(92-U-235(N,F)ELEM/MASS,IND,FY)`	independent yield 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.

Particle Considered in Fission (cont)

- We do not need to compile data which are not clearly defined in the EXFOR format. Do not try to compile all.

- However, we have to try it when there are users.

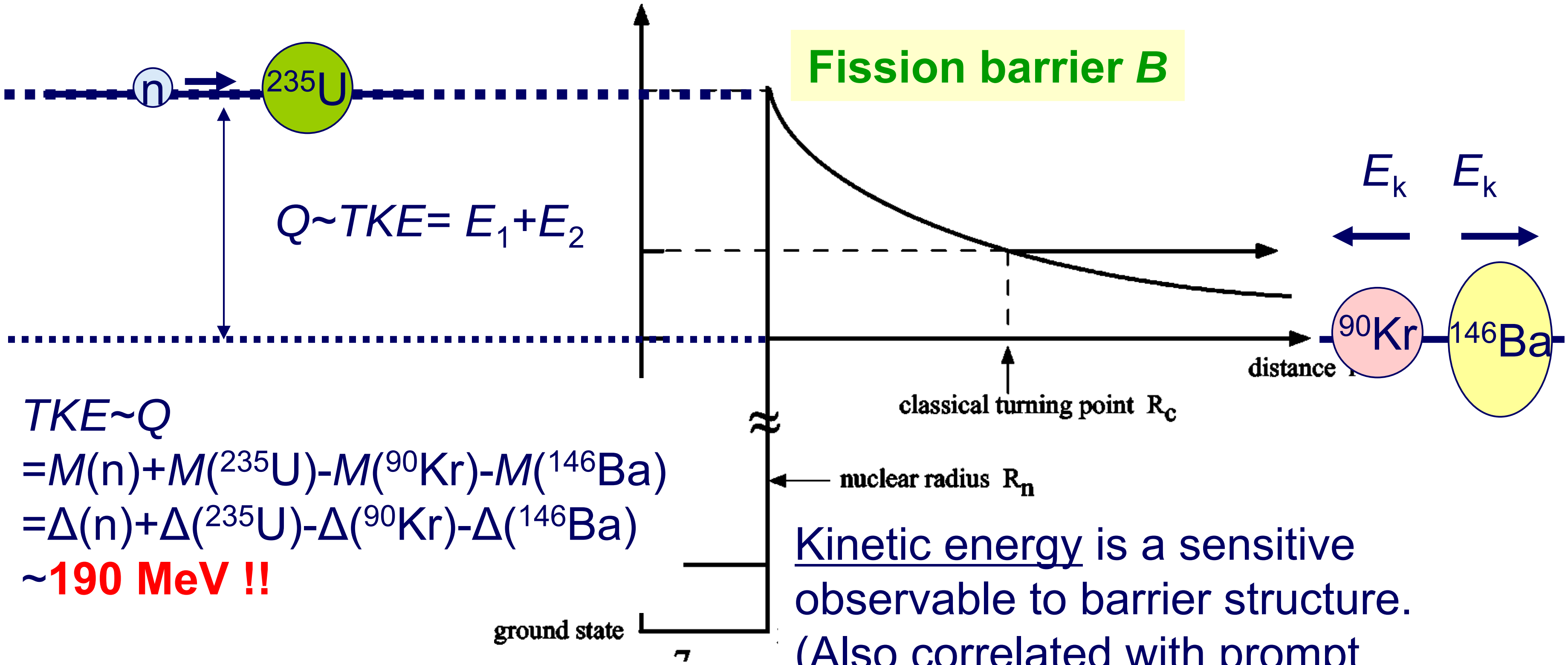
Example (under discussion):
Neutron multiplicity from a fragment *A* in a given TKE window.
(K. Nishio et al., Nucl.Phys.A632(1998)540)



Average Kinetic Energy – KE, AKE

Problem

Roughly estimate the total kinetic energy $E_k(^{90}\text{Kr})+E_k(^{146}\text{Ba})$ in $^{235}\text{U}(n_{th},f)$



TKE~*Q*

$=M(\text{n})+M(^{235}\text{U})-M(^{90}\text{Kr})-M(^{146}\text{Ba})$

$=\Delta(\text{n})+\Delta(^{235}\text{U})-\Delta(^{90}\text{Kr})-\Delta(^{146}\text{Ba})$

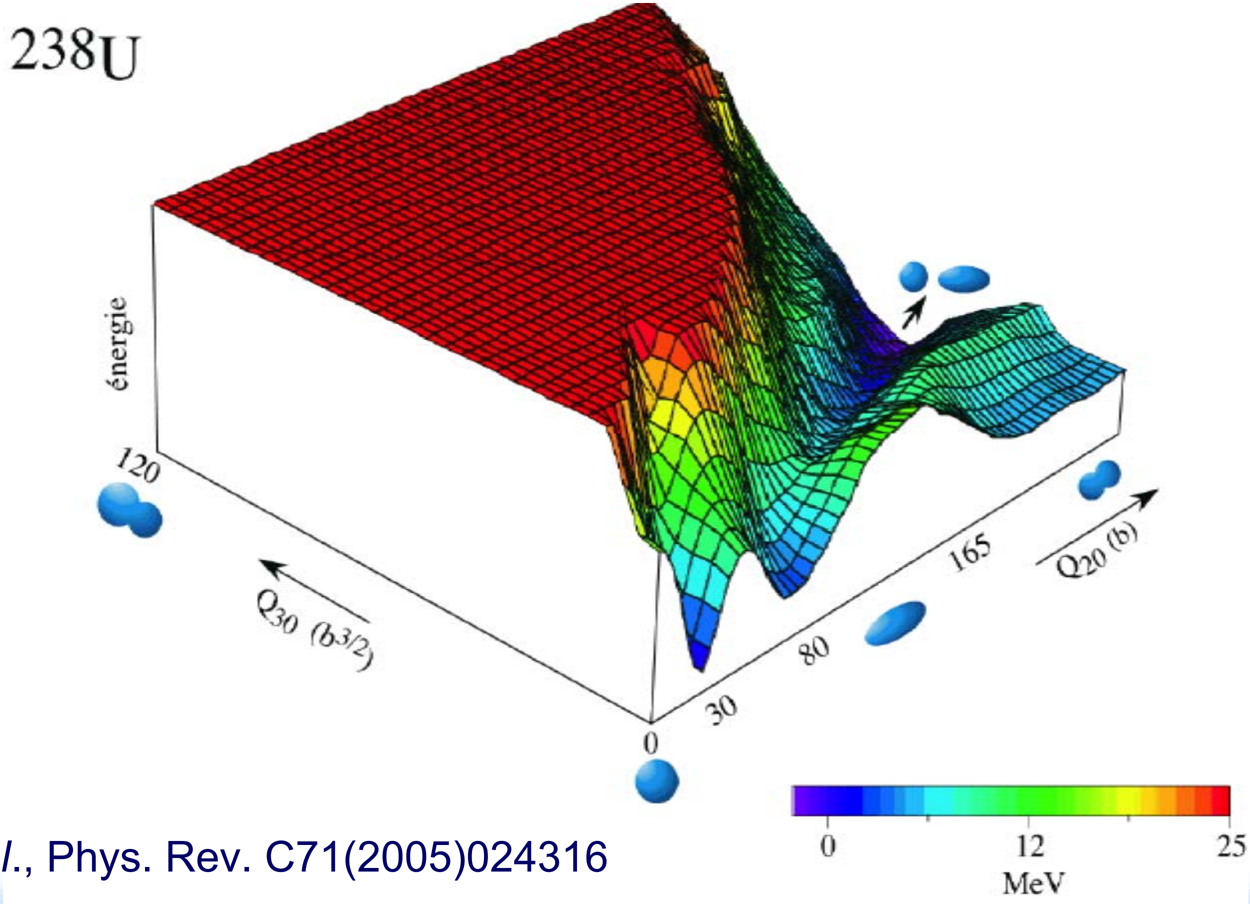
~**190 MeV !!**

Kinetic energy is a sensitive observable to barrier structure. (Also correlated with prompt fission neutron energy.)

Average Kinetic Energy – KE, AKE

Note:

Real barrier structure is more complicated due to deformation



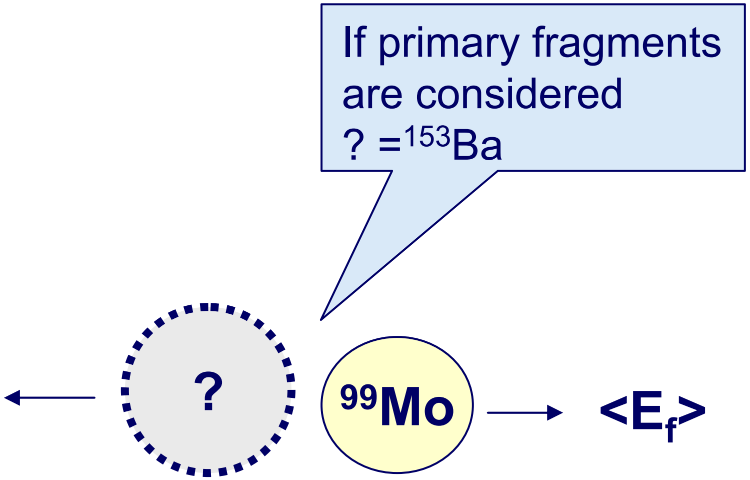
H. Goutte *et al*., Phys. Rev. C71(2005)024316

Average Kinetic Energy – KE, AKE (cont)

Various "average" kinetic energy

1. Average for single fragment
   having a specific (Z,A)=(Z_0,A_0)

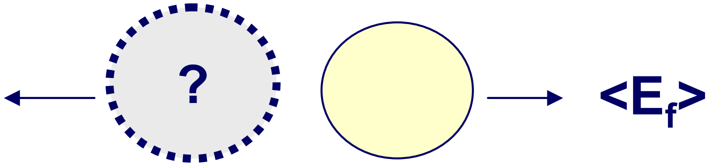
   Coding sample:
   `(98-CF-252(0,F)42-MO-99,,KE)`



If primary fragments are considered
? =^{153}Ba

2. Average for single fragment for all (Z,A)

   Coding sample:
   `(98-CF-252(0,F),,AKE,FF)`



In EXFOR dictionary, **KE** and **AKE** have been defined as

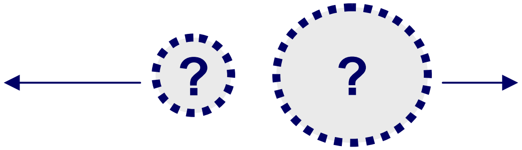
KE: Kinetic energy
AKE: "Average" kinetic energy

Average Kinetic Energy – KE, AKE (cont)

More examples of “average” kinetic energy

3. Average for total kinetic energy

$\langle TKE\rangle=\langle E_L+E_F\rangle \sim 200$ MeV

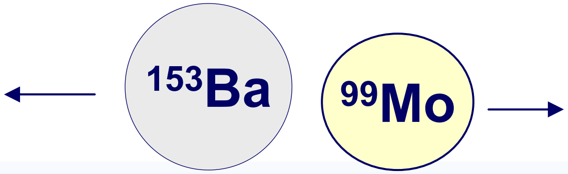


Coding sample:
`(98-CF-252(0,F),,AKE,LF+HF)`

4. Average for total kinetic energy of a specific pair

Coding sample:
`(98-CF-252(0,F)42-MO-99,PRE,KE,LF+HF)`
or
`(98-CF-252(0,F)53-BA-153,PRE,KE,LF+HF)`

$\langle TKE\rangle=\langle E_L+E_F\rangle$

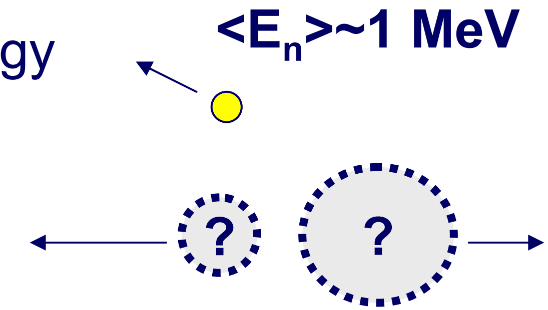


Average Kinetic Energy – KE, AKE (cont)

More examples of “average” kinetic energy

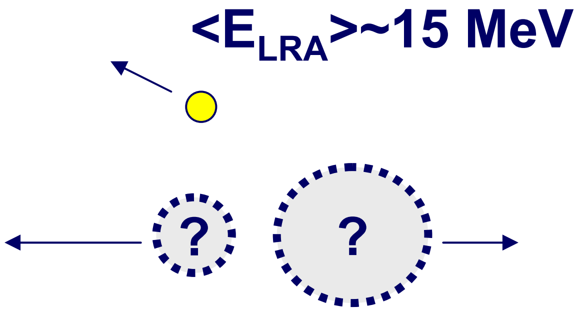
5. Average for prompt neutron kinetic energy

Coding sample:
`(98-CF-252(0,F)0-NN-1,PR,KE)`



6. Average for alpha (LRA) kinetic energy

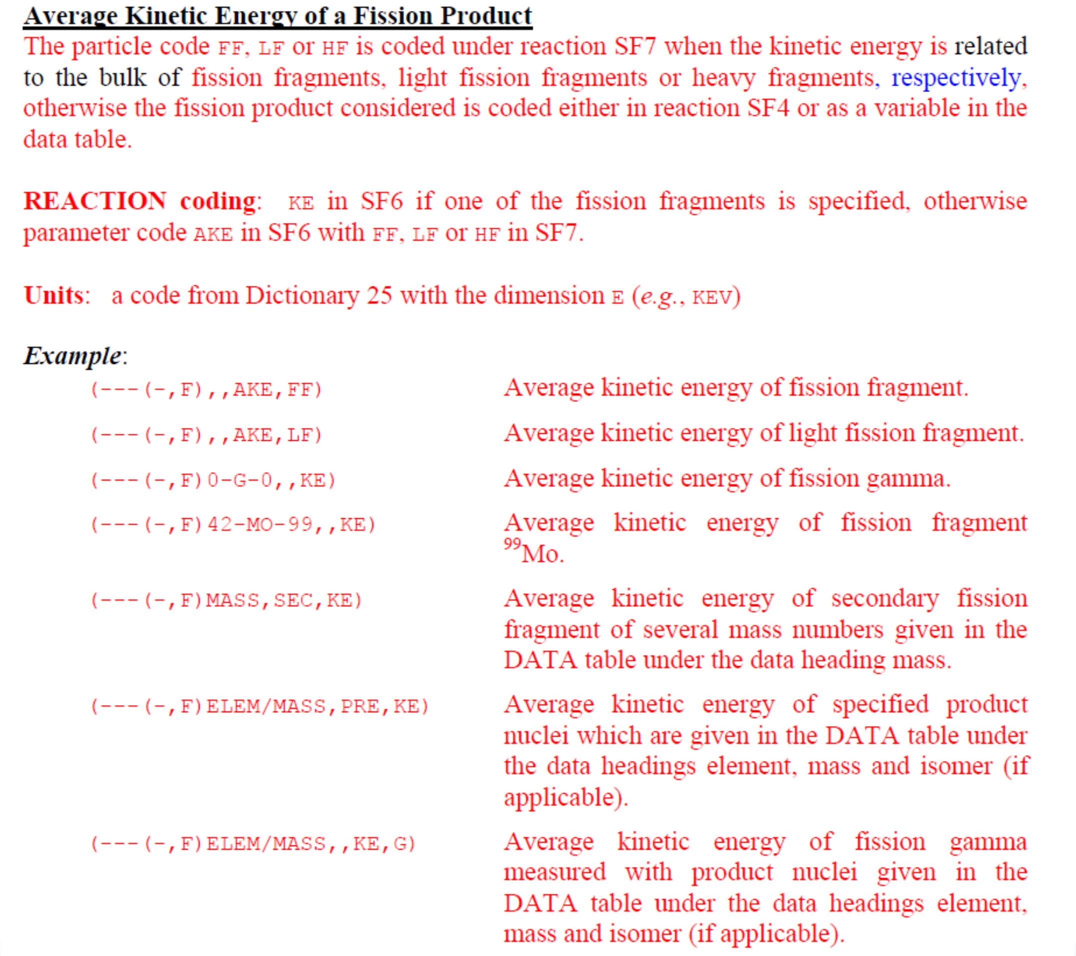
Coding sample:
`(98-CF-252(0,F)2-HE-4,TER,KE)`



(, but probably we do not need TER, because it is equivalent to
`(98-CF-252(0,F)2-HE-4,,KE)`
)

Average Kinetic Energy – KE, AKE (cont)

LEXFOR F.13 (Fission Yield)



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.

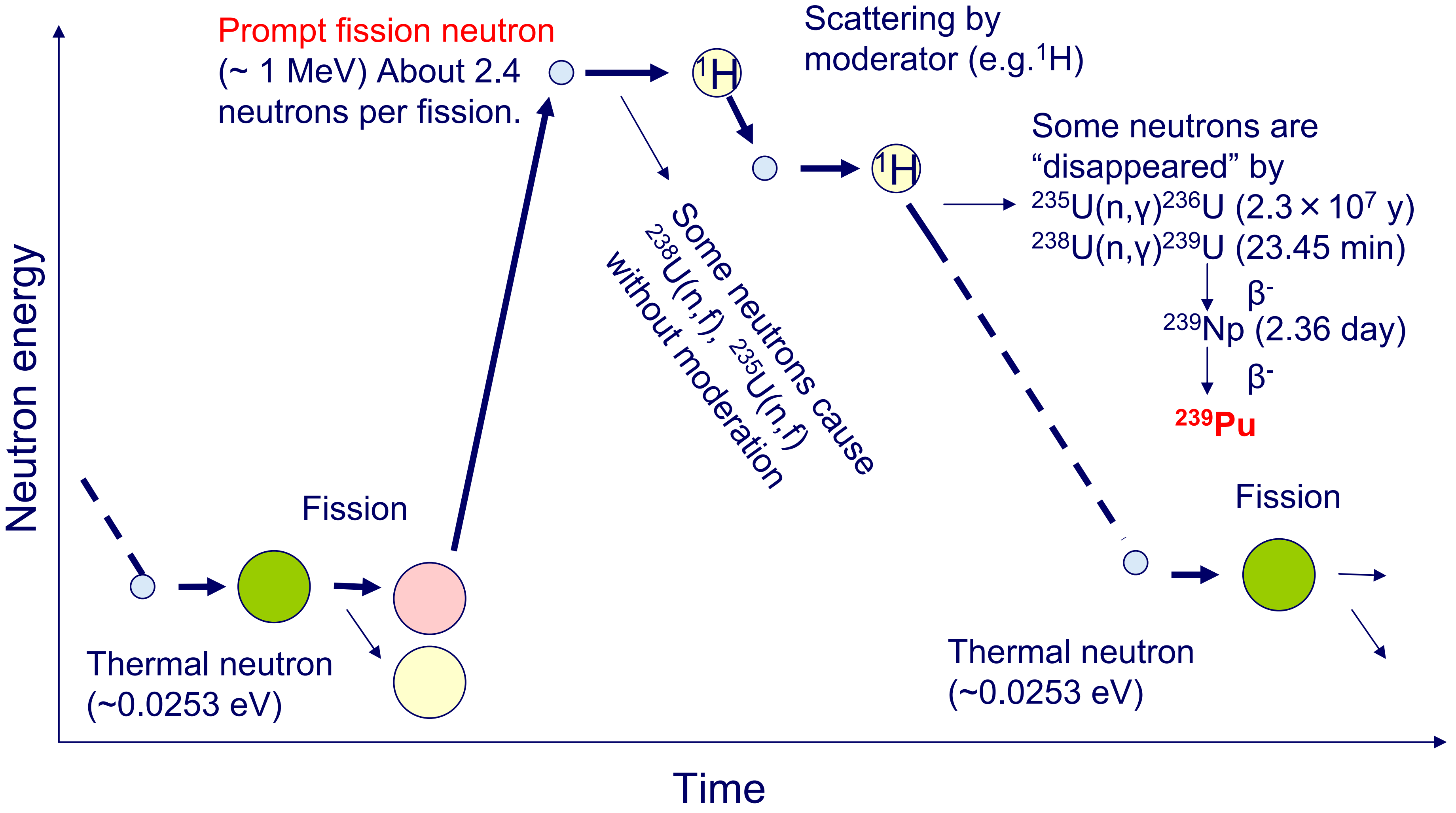
REACTION coding: `KE` in SF6 if one of the fission fragments is specified, otherwise parameter code `AKE` in SF6 with `FF`, `LF` or `HF` in SF7.

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).

Prompt Fission Neutron Spectrum



Prompt fission neutron (~ 1 MeV) About 2.4 neutrons per fission.

Scattering by moderator (e.g.^{1}H)

Some neutrons are "disappeared" by

$^{235}\mathrm{U}(n,\gamma)^{236}\mathrm{U}$ (2.3 × 10^{7} y)

$^{238}\mathrm{U}(n,\gamma)^{239}\mathrm{U}$ (23.45 min)

$\downarrow \beta^{-}$

$^{239}\mathrm{Np}$ (2.36 day)

$\downarrow \beta^{-}$

$^{239}\mathrm{Pu}$

Some neutrons cause $^{238}\mathrm{U}(n,f)$, $^{235}\mathrm{U}(n,f)$ without moderation

Fission

Fission

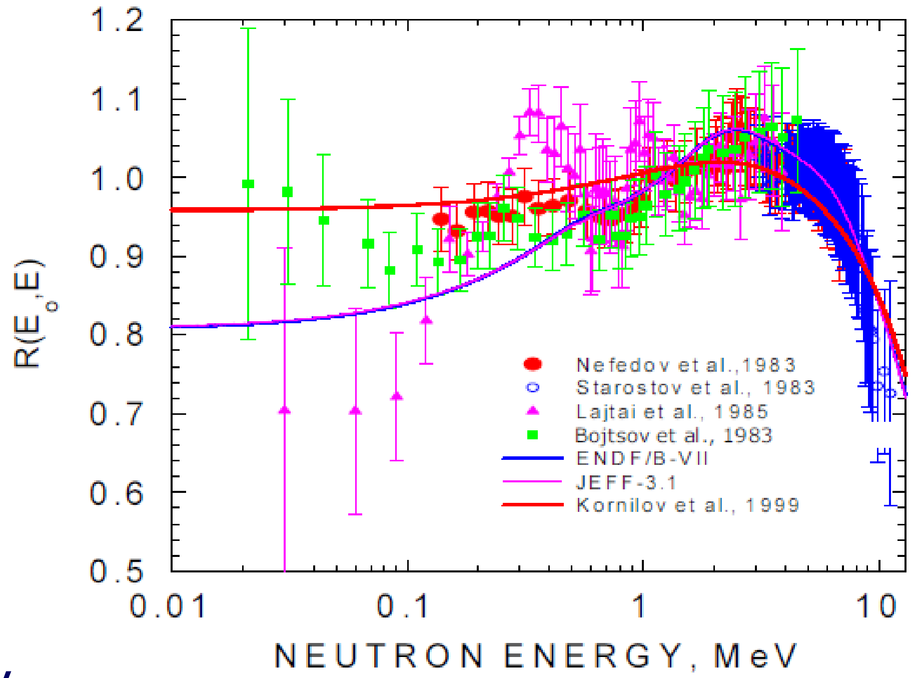
Thermal neutron (~0.0253 eV)

Thermal neutron (~0.0253 eV)

Prompt Fission Neutron Spectrum

M. Chadwick, INDC-NDC-0541 Annex E (2009)

- Many labs have determined that current uncertainties in the fission spectrum **represent one of the biggest source of uncertainty in *k*$_{\mathbf{eff}}$** predictions
- For ^{239}Pu and ^{235,8}U, few precise measurements exist below ~ 1MeV emission energy, and above ~7 MeV emission energy. We presently rely on old models that are calibrated to the few measured data.



^{239}Pu(n$_{th}$,f) PFNS relative to Maxwellian

R. Capote Noy et al., INDC-NDC-0541(2009)

Prompt Fission Neutron Spectrum (cont)

Year	TH232	U233	U235	U238	NP237	PU239	PU240	PU242 (s.f.)	CM244 (s.f.)	CM248 (s.f.)	CF252 (s.f.)
1950-			3								
1960-			2			2		1	1		7
1970-			9	1		5					19
1980-	2	7	11	6	2	9	1(n,f)				13
1990-	2	1	3	3	1					1	13
2000-	1	1	10	2		4	1(s.f.)	1			
Total	**5**	**9**	**38**	**12**	**3**	**20**	**2**	**2**	**1**	**1**	**52**

Total = 145 subentries (52 for ^{252}Cf(s.f.))

Prompt Fission Neutron Spectrum (cont)

(1) **Absolute PFNS** (neutrons/MeV/fission)

$\chi(E)$; Normalization: $\int \chi(E)dE = \bar{\nu}$

(92-U-235(N,F),,NU/DE)

(2) **PFNS relative to the ^{252}Cf spontaneous PFNS** (no dimension)

$\chi(E) / \chi_{252}(E)$; Normalization: $\int \chi(E)dE = \bar{\nu}$ $\int \chi_{252}(E)dE = \bar{\nu}_{252} \sim 3.76$

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

(3) **PFNS relative to Maxwell distribution** (no dimension)

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

(92-U-235(N,F),,NU/DE,,MXD)

Prompt Fission Neutron Spectrum (cont)

(4) **“Normalized” PFNS** (1/MeV/fission)

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

`(92-U-235(N,F),,NU/DE,,NPD)`

(5) **“Normalized” PFNS <u>relative to the “normalized” 252Cf spontaneous PFNS</u>** (no dimension)

$X(E) / X_{252}(E)$; Normalization $\int X(E)dE = 1 \quad \int X_{252}(E)dE = 1$

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

(6) **PFNS <u>relative to √E</u>**

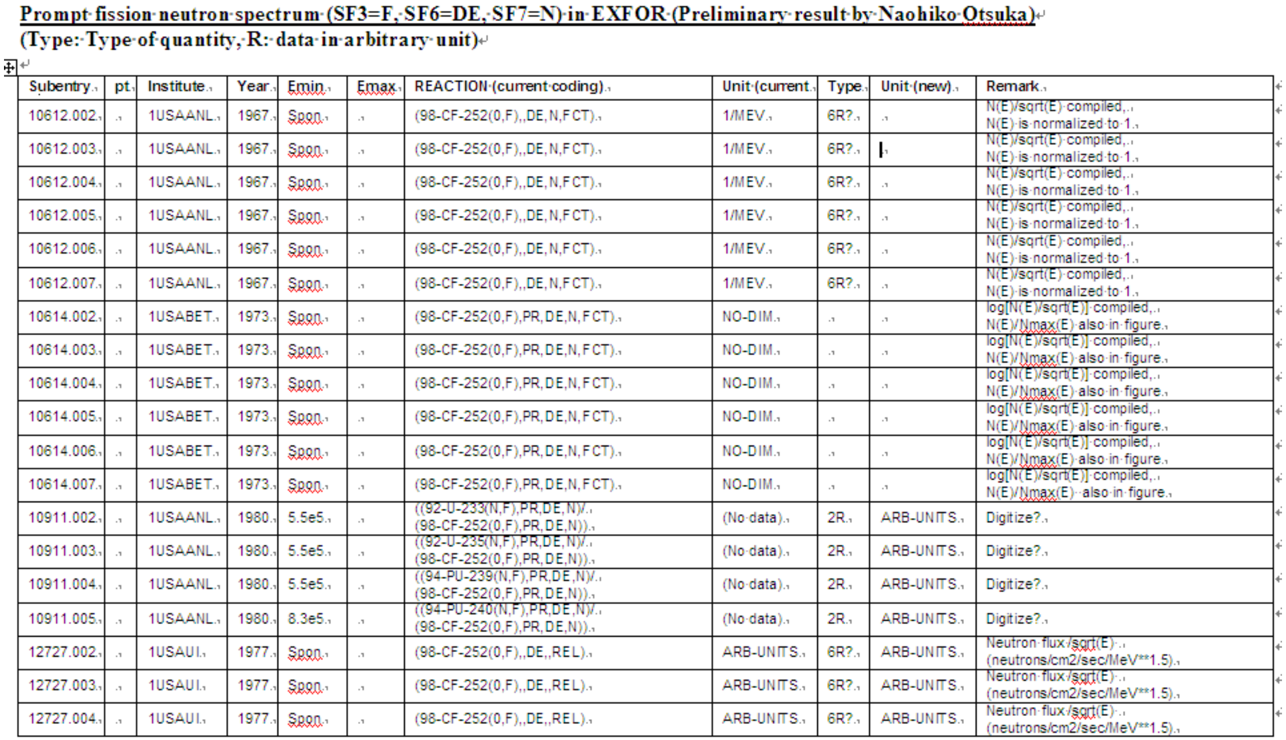
$$C\frac{\chi(E)}{\sqrt{E}}$$

Prompt Fission Neutron Spectrum (cont)

Absolute data, shape data, absolute ratio, shape ratio …

Many corrections are required.

See Memo CP-D/635 (not registered into the web error list)



Prompt fission neutron spectrum (SF3=F, SF6=DE, SF7=N) in EXFOR (Preliminary result by Naohiko Otsuka)

(Type: Type of quantity, R: data in arbitrary unit)

Subentry	pt	Institute	Year	Emin	Emax	REACTION (current coding)	Unit (current	Type	Unit (new)	Remark
10612.002		1USAANL	1967	Spon		(98-CF-252(0,F),,DE,N,FCT)	1/MEV	6R?		N(E)/sqrt(E) compiled, N(E) is normalized to 1
10612.003		1USAANL	1967	Spon		(98-CF-252(0,F),,DE,N,FCT)	1/MEV	6R?		N(E)/sqrt(E) compiled, N(E) is normalized to 1
10612.004		1USAANL	1967	Spon		(98-CF-252(0,F),,DE,N,FCT)	1/MEV	6R?		N(E)/sqrt(E) compiled, N(E) is normalized to 1
10612.005		1USAANL	1967	Spon		(98-CF-252(0,F),,DE,N,FCT)	1/MEV	6R?		N(E)/sqrt(E) compiled, N(E) is normalized to 1
10612.006		1USAANL	1967	Spon		(98-CF-252(0,F),,DE,N,FCT)	1/MEV	6R?		N(E)/sqrt(E) compiled, N(E) is normalized to 1
10612.007		1USAANL	1967	Spon		(98-CF-252(0,F),,DE,N,FCT)	1/MEV	6R?		N(E)/sqrt(E) compiled, N(E) is normalized to 1
10614.002		1USABET	1973	Spon		(98-CF-252(0,F),PR,DE,N,FCT)	NO-DIM			log[N(E)/sqrt(E)] compiled, N(E)/Nmax(E) also in figure
10614.003		1USABET	1973	Spon		(98-CF-252(0,F),PR,DE,N,FCT)	NO-DIM			log[N(E)/sqrt(E)] compiled, N(E)/Nmax(E) also in figure
10614.004		1USABET	1973	Spon		(98-CF-252(0,F),PR,DE,N,FCT)	NO-DIM			log[N(E)/sqrt(E)] compiled, N(E)/Nmax(E) also in figure
10614.005		1USABET	1973	Spon		(98-CF-252(0,F),PR,DE,N,FCT)	NO-DIM			log[N(E)/sqrt(E)] compiled, N(E)/Nmax(E) also in figure
10614.006		1USABET	1973	Spon		(98-CF-252(0,F),PR,DE,N,FCT)	NO-DIM			log[N(E)/sqrt(E)] compiled, N(E)/Nmax(E) also in figure
10614.007		1USABET	1973	Spon		(98-CF-252(0,F),PR,DE,N,FCT)	NO-DIM			log[N(E)/sqrt(E)] compiled, N(E)/Nmax(E) also in figure
10911.002		1USAANL	1980	5.5e5		((92-U-233(N,F),PR,DE,N)/ (98-CF-252(0,F),PR,DE,N))	(No data)	2R	ARB-UNITS	Digitize?
10911.003		1USAANL	1980	5.5e5		((92-U-235(N,F),PR,DE,N)/ (98-CF-252(0,F),PR,DE,N))	(No data)	2R	ARB-UNITS	Digitize?
10911.004		1USAANL	1980	5.5e5		((94-PU-239(N,F),PR,DE,N)/ (98-CF-252(0,F),PR,DE,N))	(No data)	2R	ARB-UNITS	Digitize?
10911.005		1USAANL	1980	8.3e5		((94-PU-240(N,F),PR,DE,N)/ (98-CF-252(0,F),PR,DE,N))	(No data)	2R	ARB-UNITS	Digitize?
12727.002		1USAUI	1977	Spon		(98-CF-252(0,F),,DE,,REL)	ARB-UNITS	6R?	ARB-UNITS	Neutron flux/sqrt(E) (neutrons/cm2/sec/MeV**1.5)
12727.003		1USAUI	1977	Spon		(98-CF-252(0,F),,DE,,REL)	ARB-UNITS	6R?	ARB-UNITS	Neutron flux/sqrt(E) (neutrons/cm2/sec/MeV**1.5)
12727.004		1USAUI	1977	Spon		(98-CF-252(0,F),,DE,,REL)	ARB-UNITS	6R?	ARB-UNITS	Neutron flux/sqrt(E) (neutrons/cm2/sec/MeV**1.5)

Prompt Fission Neutron Spectrum (cont)

REACTION: **Variety in PFNS relative to Maxwell spectrum**

```
(98-CF-252(0,F),PR,DE,N,MXD)
(98-CF-252(0,F),PR,DE,N,REL)
((98-CF-252(0,F),PR,DE,N,,EXP)/(98-CF252(0,F),PR,DE,N,,CALC))
((98-CF-252(0,F),PR,DE,N)/(98-CF-252(0,F),PR,DE,N))
```

REACTON: **Strange quantity code defined in the dictionary**

`PR,DE,N,RTE` - Energy spectrum of prompt fission neutron × square root(E)) ***!?***

Variety in unit

`1/MEV` (should not be used for any type of PFNS)

`PT/FIS/MEV` (should be used for absolute PFNS)

`NO-DIM` (should be used for absolute PFNS ratio)

`ARB-UNITS` (should be used for shape data)

etc..

Prompt Fission Neutron Spectrum (cont)

Example of REACTION and unit decision

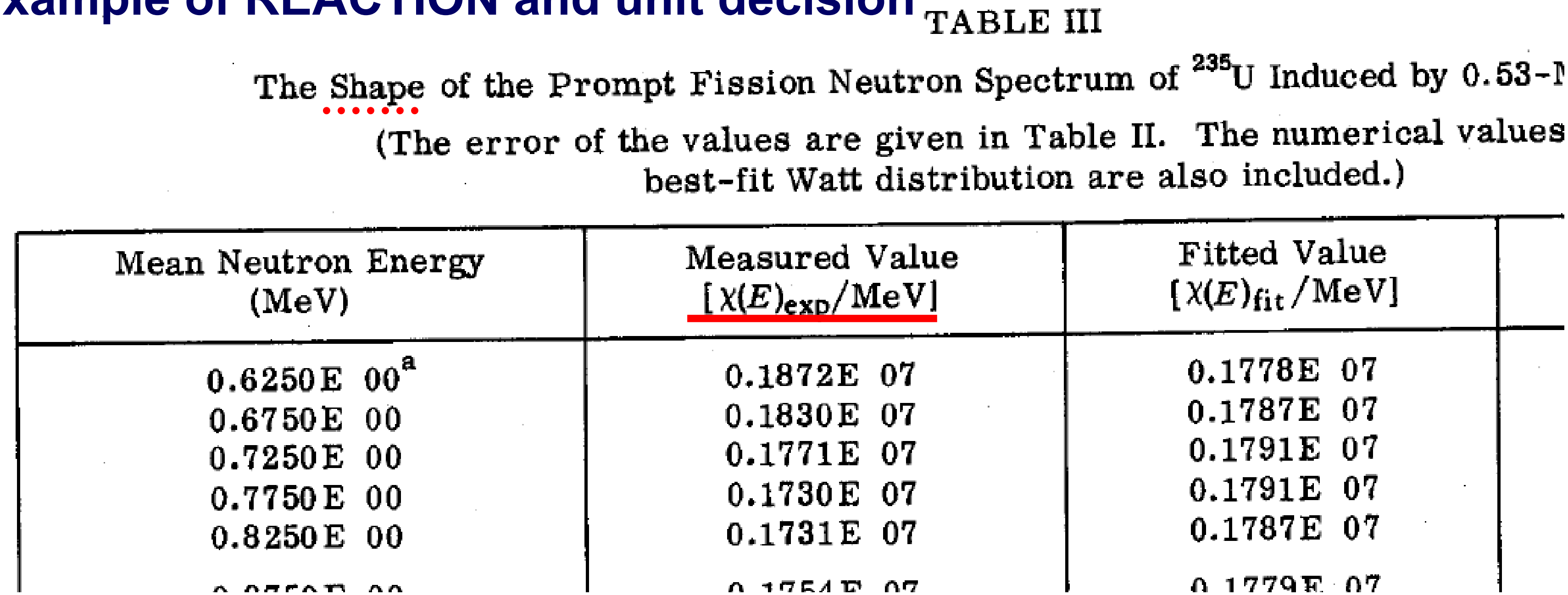


TABLE III

The Shape of the Prompt Fission Neutron Spectrum of ^{235}U Induced by 0.53-

(The error of the values are given in Table II. The numerical values best-fit Watt distribution are also included.)

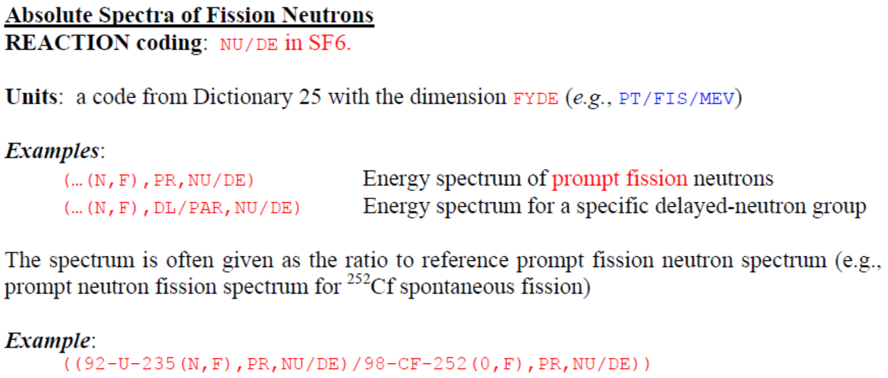
Mean Neutron Energy (MeV)	Measured Value [$\chi(E)_{exp}$/MeV]	Fitted Value [$\chi(E)_{fit}$/MeV]
0.6250E 00[a]	0.1872E 07	0.1778E 07
0.6750E 00	0.1830E 07	0.1787E 07
0.7250E 00	0.1771E 07	0.1791E 07
0.7750E 00	0.1730E 07	0.1791E 07
0.8250E 00	0.1731E 07	0.1787E 07
0.8750E 00	0.1754E 07	0.1779E 07

Relative data (arbitrary unit)?
Absolute data (neutrons per MeV per fission)?

Because I am not an expert,
I plot data to decide their quantity code and unit.

Prompt Fission Neutron Spectrum (cont)

LEXFOR F.4
(Fission Neutron Spectrum)



Absolute Spectra of Fission Neutrons
REACTION coding: `NU/DE` in SF6.

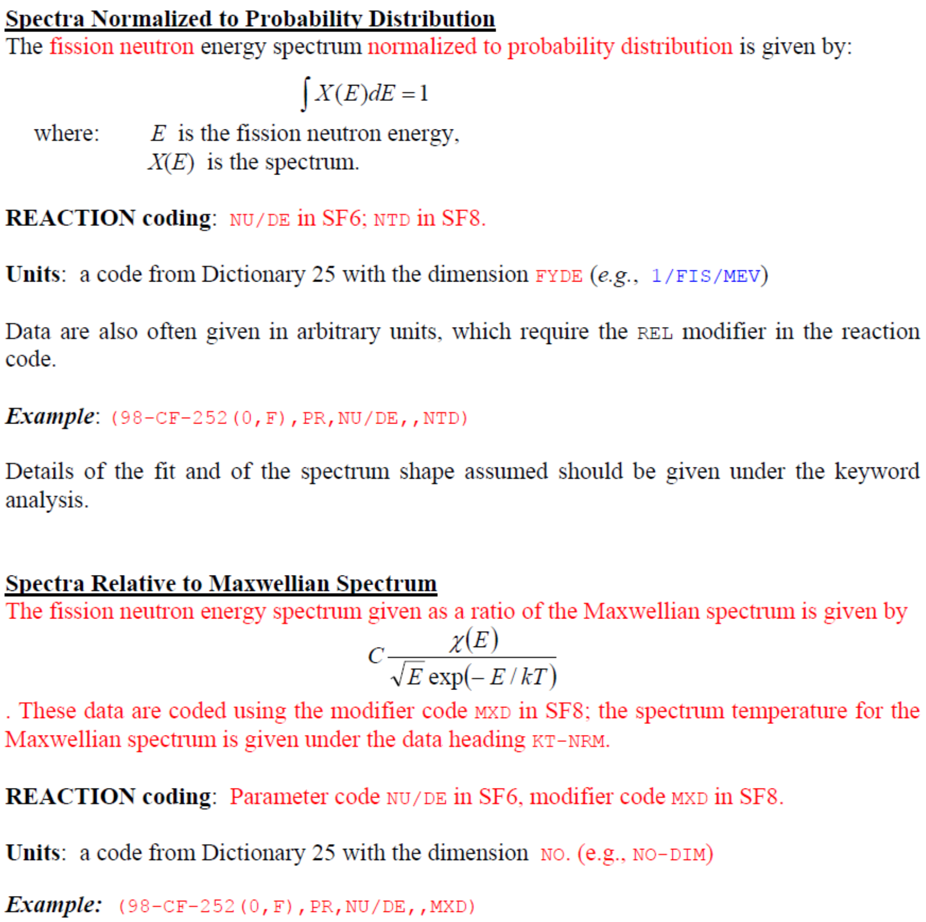
Units: a code from Dictionary 25 with the dimension `FYDE` (*e.g.*, `PT/FIS/MEV`)

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; `NTD` 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,,NTD)`

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)`

Break Point (94)

2009-05-25 NRDC meeting

GRILLSPEZIALITÄTEN

Spare Ribs mit Bratkartoffel, 2 Saucen, Zwiebel und milden Pfefferoni	*13,40 Euro*
Filetspiess mit Sauce	*9,60 Euro*
Grillkotlette (2 Stk.)	*8,10 Euro*
Hühnerflügerl (6 Stk)	*6,50 Euro*
Steckerlfisch mit Knoblauchbutter und Brot	*9,00 Euro*

STRANDCAFE

Dinner (19:00~)
(~15 min walk from U1 Alte Donau)

International Atomic Energy Agency

Summary of Manual Updates
6. Low-Energy Data

IAEA Nuclear Data Section
N. Otsuka

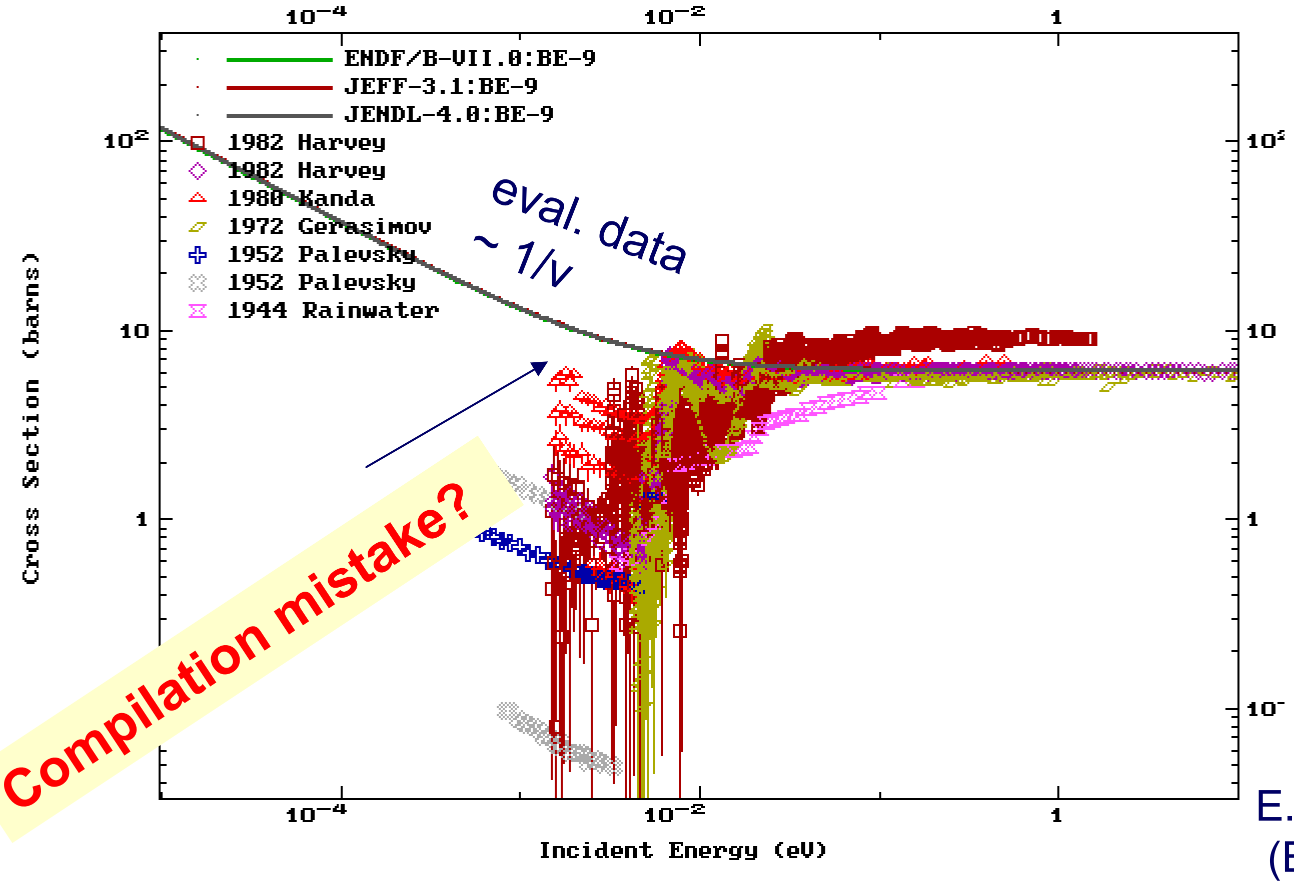
94

Cross Section for eV Neutrons

Sorry, I do not know physics of thermal scattering…

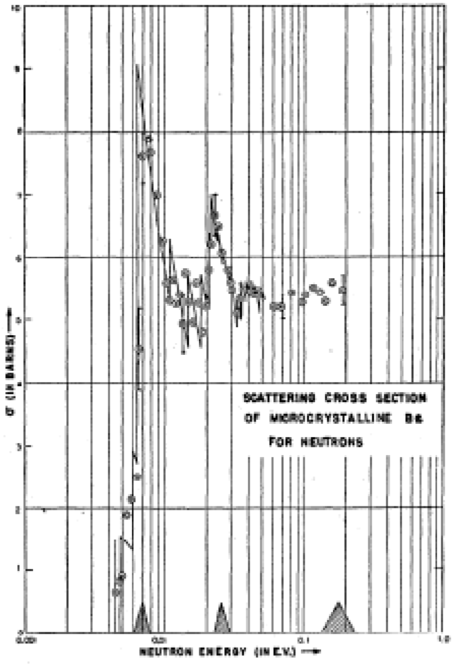
Cross Section for eV Neutrons (cont)

^{9}Be(n,tot)below 10 eV



eval. data
~ 1/v

Compilation mistake?



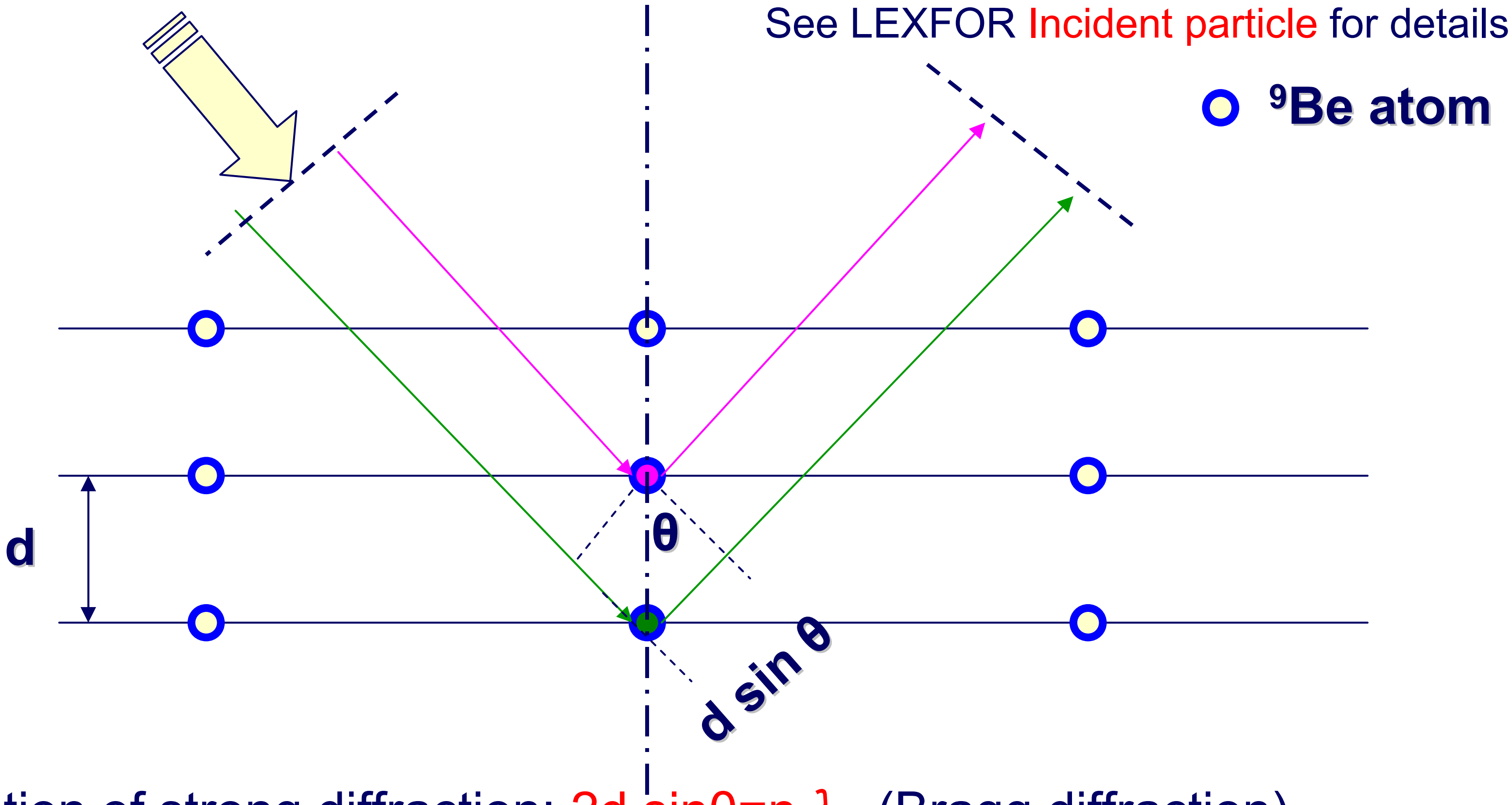
E.Fermi et al., 71(1947)589
(EXFOR 11248, but
monocrystal data is missing.)

Cross Section for eV Neutrons (cont)

Neutron scattering by Be crystal

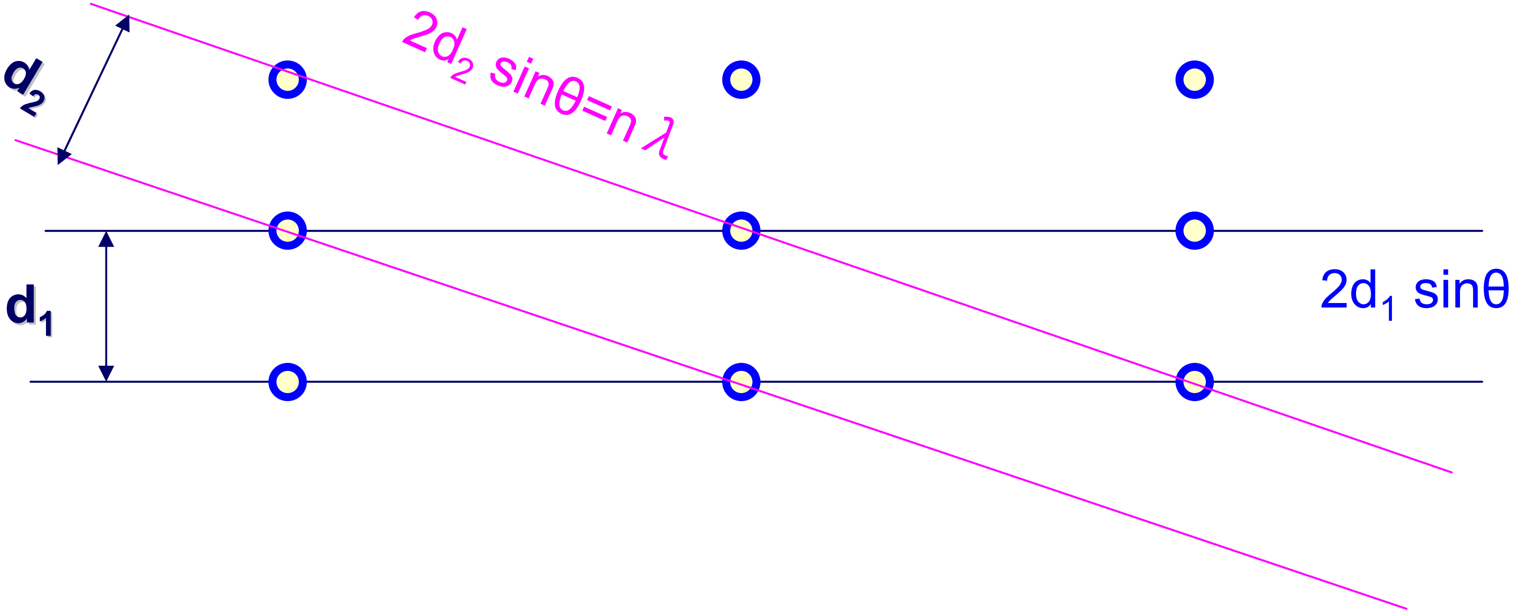
Neutron flux $\lambda = h/(2mE)^{1/2}$ (~1.8 Å for thermal neutron)

See LEXFOR Incident particle for details.



Condition of strong diffraction: $2d \sin\theta = n\lambda$ (Bragg diffraction)

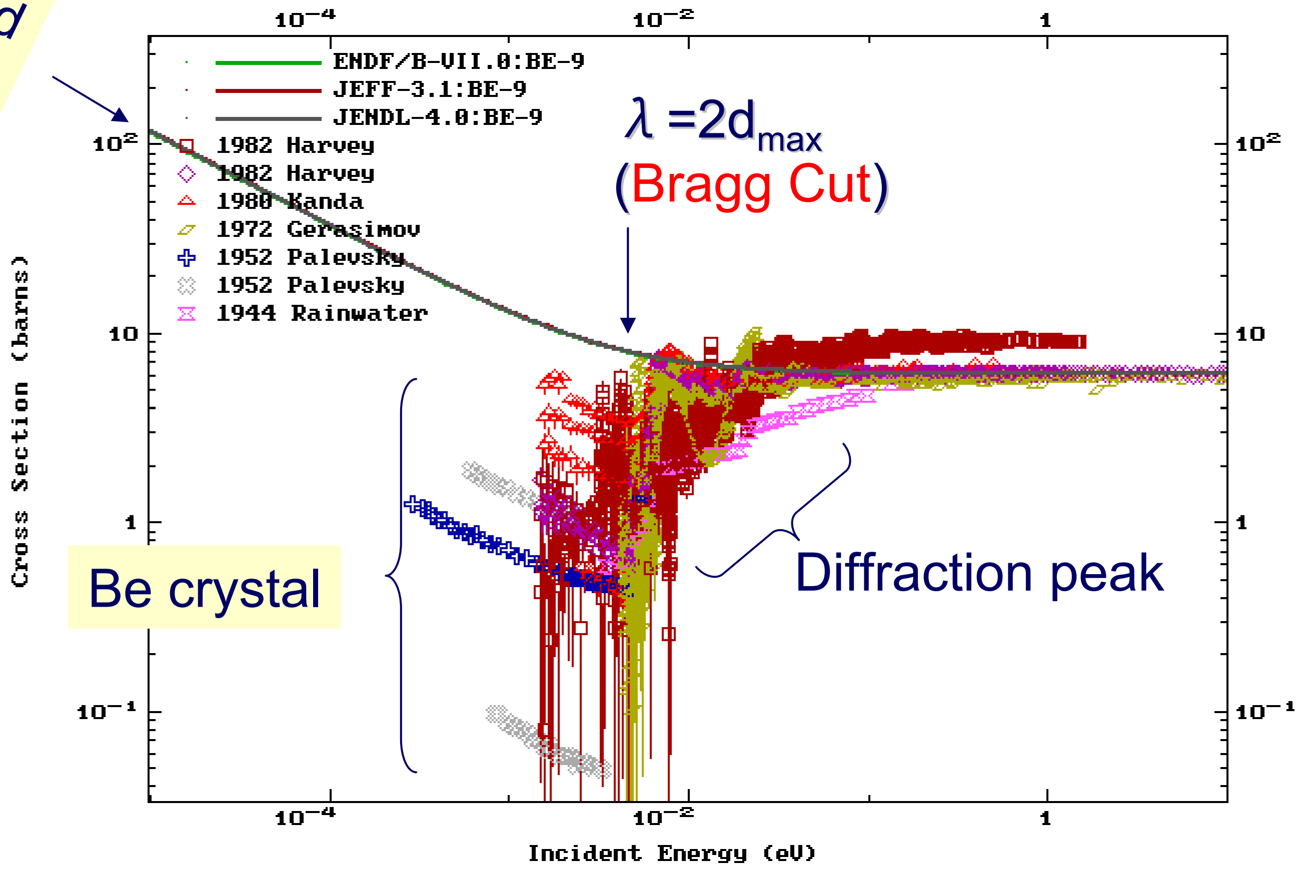
Cross Section for eV Neutrons (cont)



Maximum distance d_{max} gives the lowest neutron energy which satisfies Bragg diffraction condition: $\lambda_{min} = 2d \sin\theta / n < 2d_{max}$

Cross Section for eV Neutrons (cont)

^{9}Be(n,tot) below 10 eV



Isolated nucleus

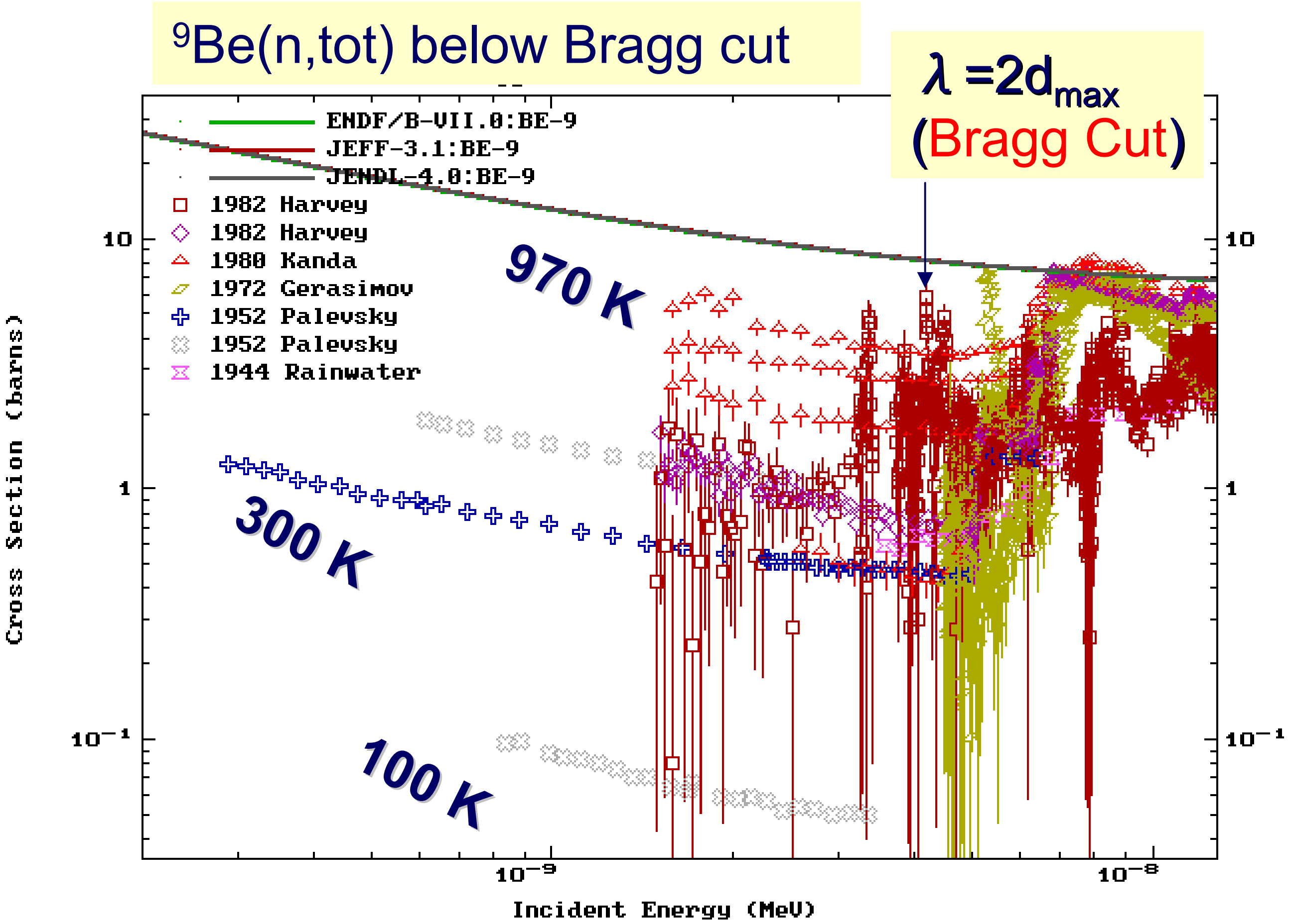
$\lambda = 2d_{max}$
(Bragg Cut)

Be crystal

Diffraction peak

Next question: What is factor ~100 times difference under Bragg Cut?

Cross Section for eV Neutrons (cont)



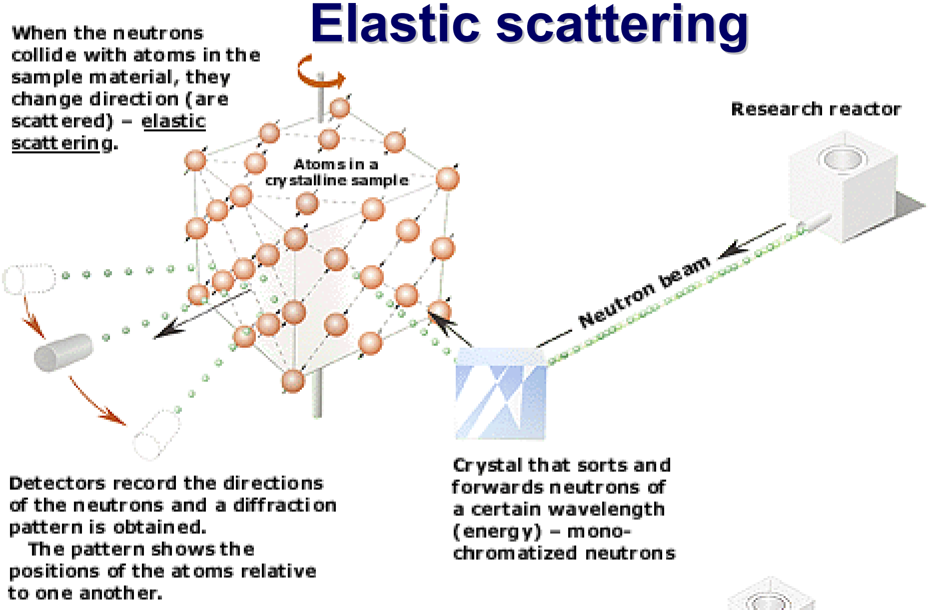
Inelastic scattering due to interaction with phonon oscillation (energy gain of neutron from oscillation)

$$\frac{d\sigma}{d\Omega dE} = \frac{\sigma_b}{4\pi}\frac{1}{T}\frac{k}{k_0}\exp\left(-\frac{E-E_0}{2T}\right)\underline{S(\alpha,\beta)}$$

Cross Section for eV Neutrons (cont)

The Nobel Prize in Physics (1994) – N.N.Brockhouse and C.G.Shull.

Elastic scattering



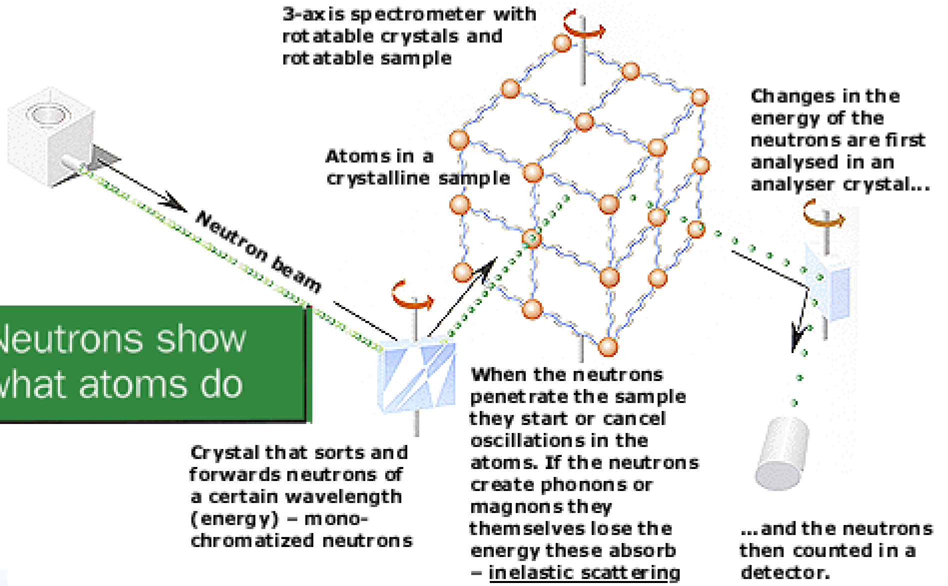
When the neutrons collide with atoms in the sample material, they change direction (are scattered) – elastic scattering.

Detectors record the directions of the neutrons and a diffraction pattern is obtained.
The pattern shows the positions of the atoms relative to one another.

Crystal that sorts and forwards neutrons of a certain wavelength (energy) – monochromatized neutrons

Neutrons show where atoms are

Inelastic scattering



3-axis spectrometer with rotatable crystals and rotatable sample

Changes in the energy of the neutrons are first analysed in an analyser crystal...

Crystal that sorts and forwards neutrons of a certain wavelength (energy) – monochromatized neutrons

When the neutrons penetrate the sample they start or cancel oscillations in the atoms. If the neutrons create phonons or magnons they themselves lose the energy these absorb – inelastic scattering

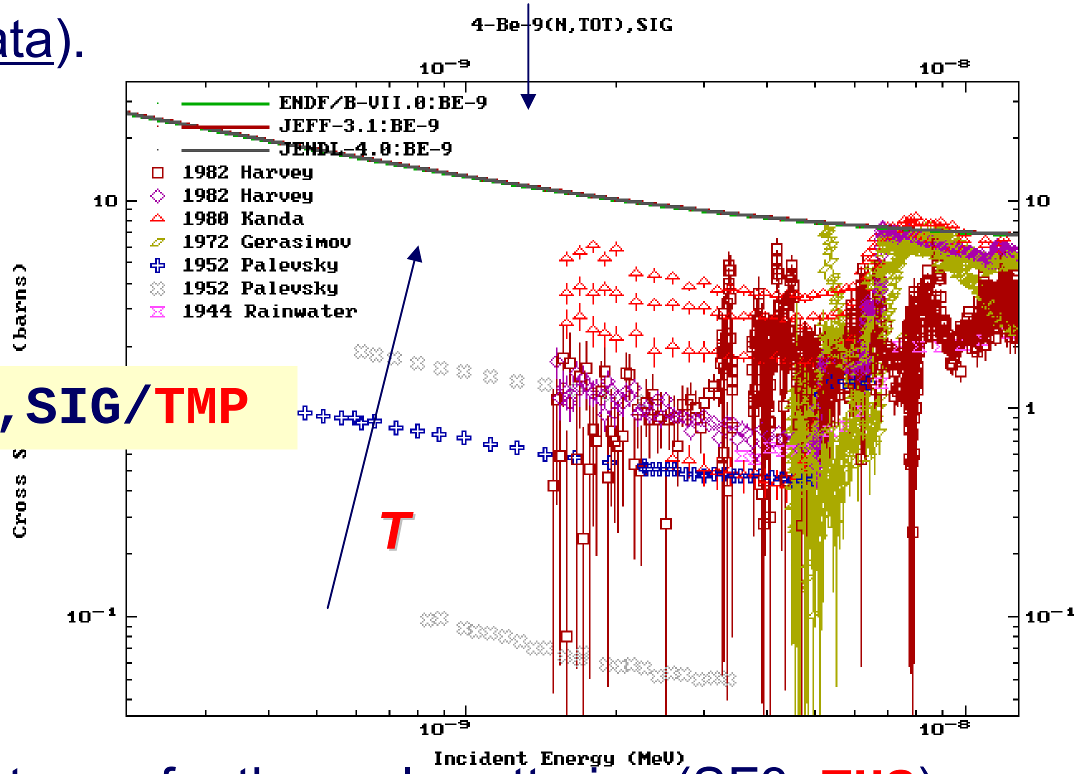
...and the neutrons then counted in a detector.

Neutrons show what atoms do

Images taken from nobelprize.org

Cross Section for eV Neutrons (cont)

Temperature dependent cross section:
→ TMP must be added in SF6 for all data sets
(except for ~300K data).



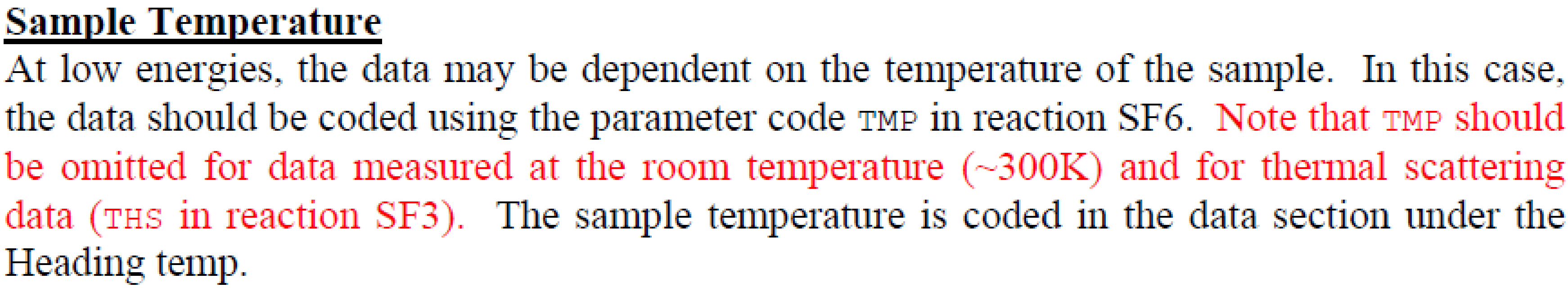
4-BE-9(N,TOT),,SIG/TMP

Note that

1. **TMP** is omitted when data are for thermal scattering (SF3=**THS**).
2. I am not sure we should use TMP for other temperature dependence.

Cross Section for eV Neutrons (cont)

LEXFOR S.1 (Sample)

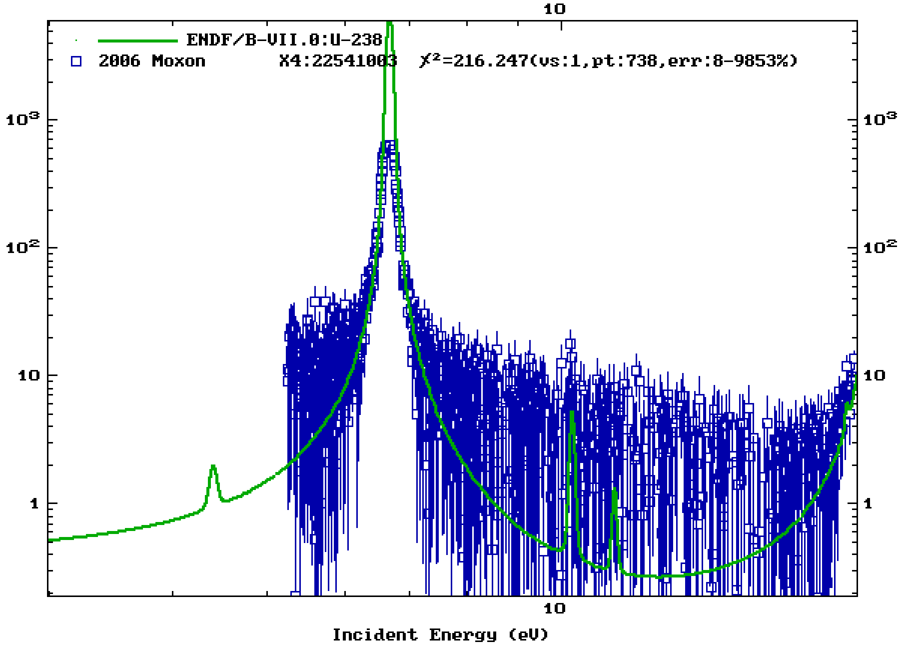


Sample Temperature

At low energies, the data may be dependent on the temperature of the sample. In this case, the data should be coded using the parameter code `TMP` in reaction SF6. Note that `TMP` should be omitted for data measured at the room temperature (~300K) and for thermal scattering data (`THS` in reaction SF3). The sample temperature is coded in the data section under the Heading temp.

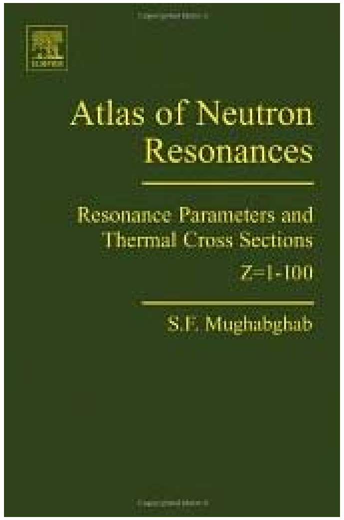
Scope of Resonance Parameter in EXFOR

A lot of neutron resonance parameters have been compiled in the EXFOR library and also evaluated. They have played an essential role in nuclear data for low energy neutron application.



The 1st 6.4 eV resonance of $^{238}U(n,\gamma)^{239}U$ ENDF/B-VII.0 compared with M.C.Moxon (2006)

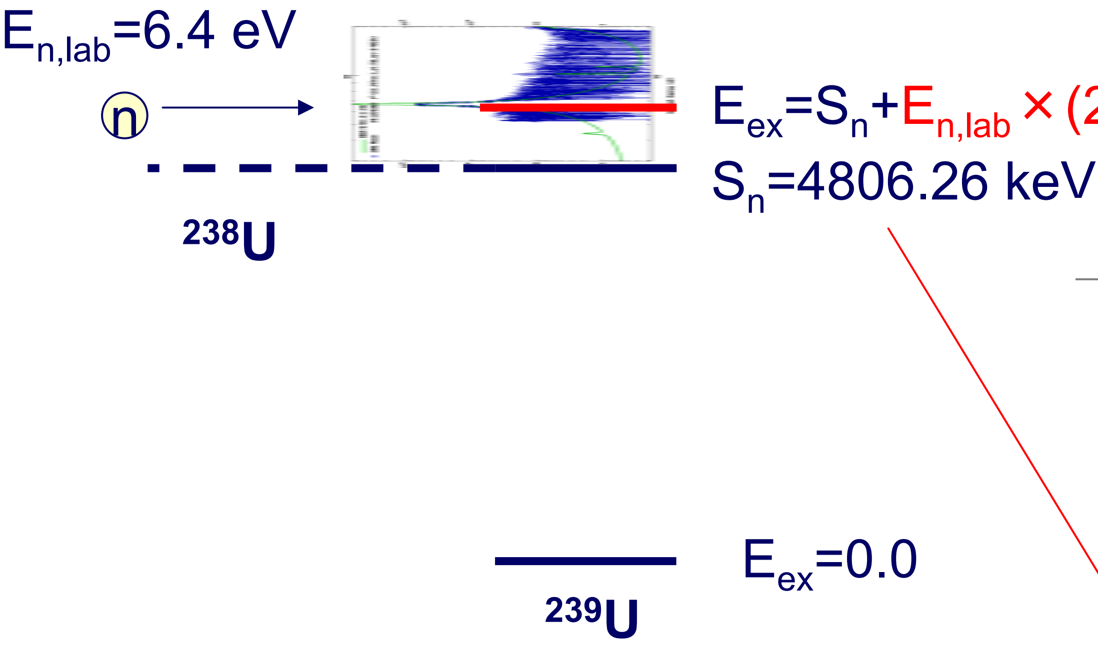
Resonance parameters compiled by S.F.Mughabghab (2006).



Scope of Resonance Parameter in EXFOR (cont)

- In **neutron reaction data**, level energies of resonances are expressed by incident laboratory energies of neutron.

Example: The 1st resonance of $^{238}U(n,\gamma)^{239}U$ at $E_{n,lab}=6.4$ eV.



$E_{n,lab}=6.4$ eV

n

^{238}U

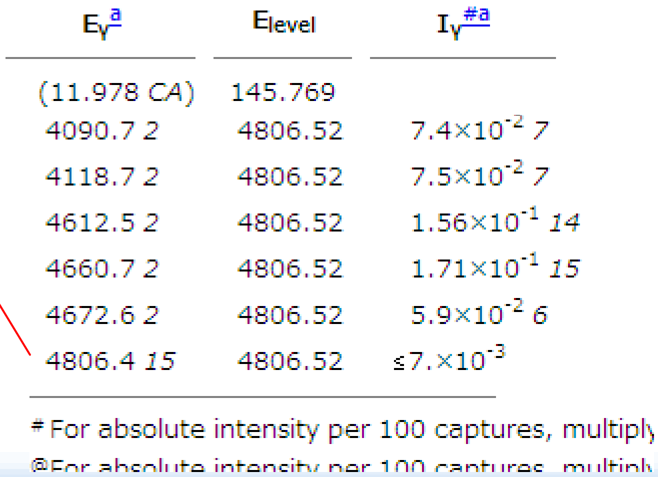
$E_{ex}=S_n+E_{n,lab}\times(238/239)$

$S_n=4806.26$ keV

$E_{ex}=0.0$

^{239}U

Resonance above S_n is not shown in ENSDF.



E_γ a	E_{level}	I_γ #a
(11.978 *CA*)	145.769	
4090.7 *2*	4806.52	7.4×10^{-2} *7*
4118.7 *2*	4806.52	7.5×10^{-2} *7*
4612.5 *2*	4806.52	1.56×10^{-1} *14*
4660.7 *2*	4806.52	1.71×10^{-1} *15*
4672.6 *2*	4806.52	5.9×10^{-2} *6*
4806.4 *15*	4806.52	$\leq7.\times10^{-3}$

\# For absolute intensity per 100 captures, multiply

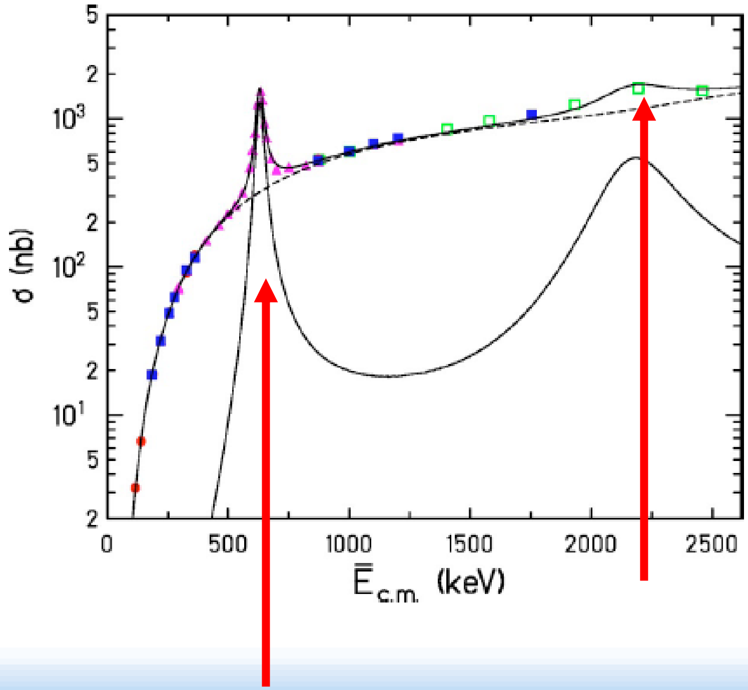
@For absolute intensity per 100 captures, multiply

Scope of Resonance Parameter in EXFOR (cont)

- Resonance physics is also important in **charged-particle induced reaction** (especially in the relation with astro-nuclear physics.)

  Usually $E_{p,c.m.}$ is preferred than $E_{p,lab}$ system.

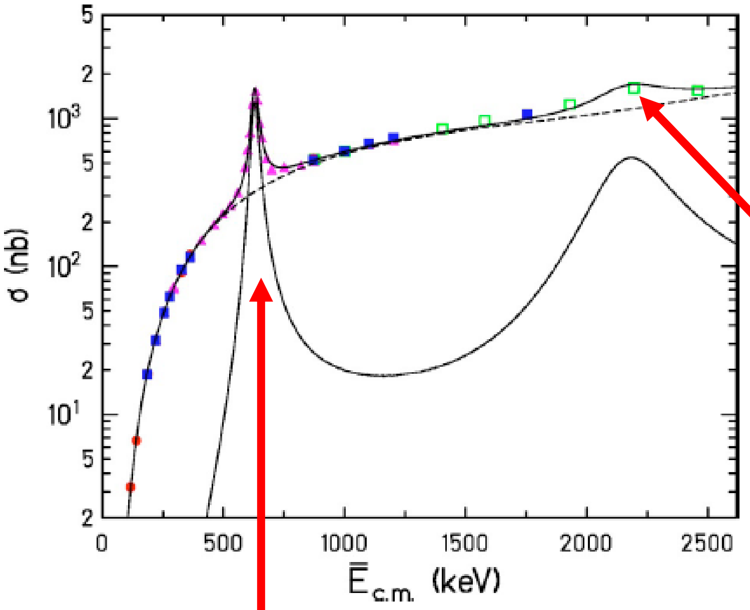
  Example: $^7Be(p,\gamma)^8B$ resonances at $E_{p,cm}$=630 keV and 2.2 MeV.



(^{8}B is a strong source of solar neutrino.)

A.R.Junghans et al.,
Phys.Rev.C68(2003)065803
(EXFOR C1004)

Scope of Resonance Parameter in EXFOR (cont)



A.R. Junghans et al.,
Phys.Rev.C68(2003)065803
(EXFOR C1004)

$$\sigma(E_{\rm c.m.}) = C_1\sigma_{DB}(E_{\rm c.m.}) + \frac{C_2}{E_{\rm c.m.}}\frac{\Gamma_p(E_{\rm c.m.})\Gamma_\gamma(E_{\rm c.m.})}{\underline{(E_{\rm c.m.}-E_0)}^2+\Gamma_p(E_{\rm c.m.})^2/4},$$

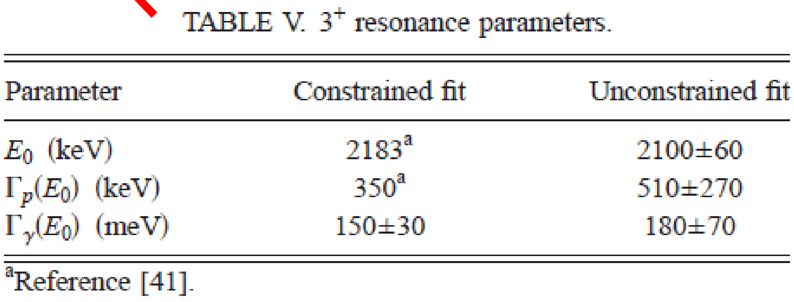
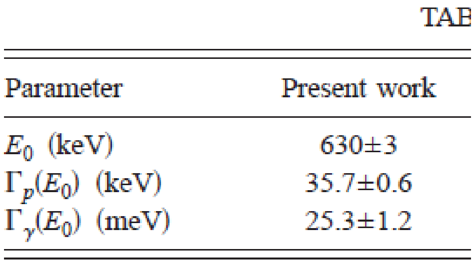


TABLE V. 3^+ resonance parameters.

Parameter	Constrained fit	Unconstrained fit
E_0 (keV)	2183^a	2100±60
$\Gamma_p(E_0)$ (keV)	350^a	510±270
$\Gamma_\gamma(E_0)$ (meV)	150±30	180±70

[a] Reference [41].

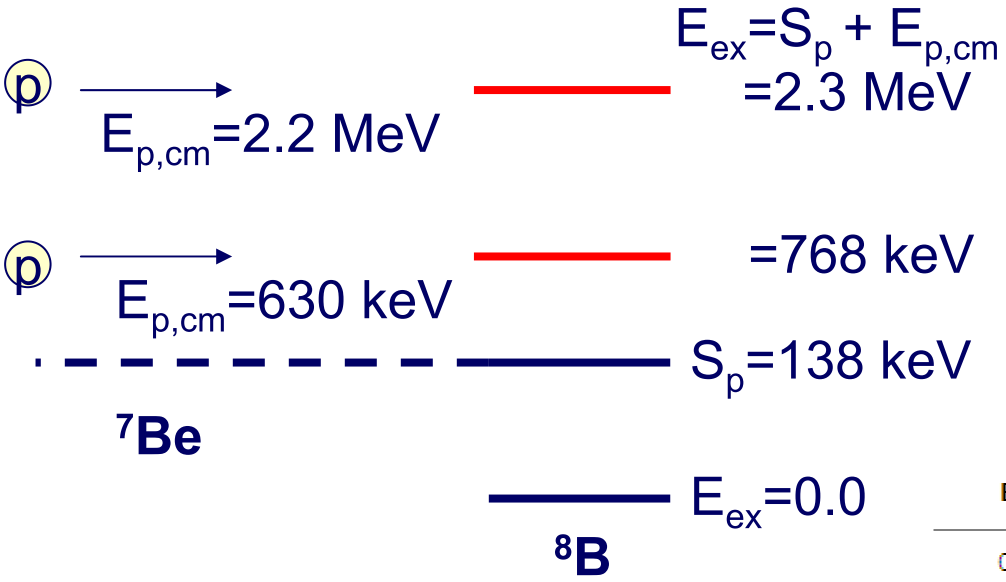


TAB

Parameter	Present work
E_0 (keV)	630±3
$\Gamma_p(E_0)$ (keV)	35.7±0.6
$\Gamma_\gamma(E_0)$ (meV)	25.3±1.2

These tables can be compiled as resonance parameters under c.m. system (**DATA-CM**) in ^{7}Be(p, γ)^{8}B reaction.
Note that $E_{0c.m.}$ =E_x-S_p

Scope of Resonance Parameter in EXFOR (cont)



p

$E_{p,cm}$=2.2 MeV

$E_{ex}=S_p + E_{p,cm}$

=2.3 MeV

p

$E_{p,cm}$=630 keV

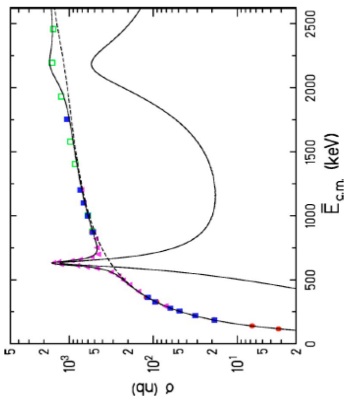
=768 keV

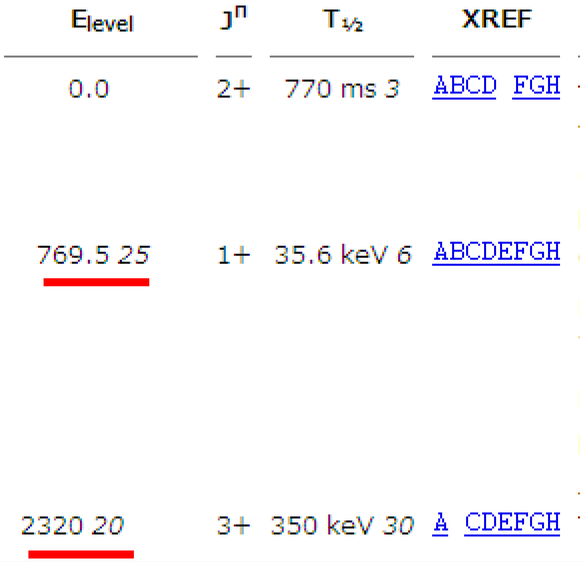
S_p=138 keV

^{7}**Be**

E_{ex}=0.0

^{8}**B**



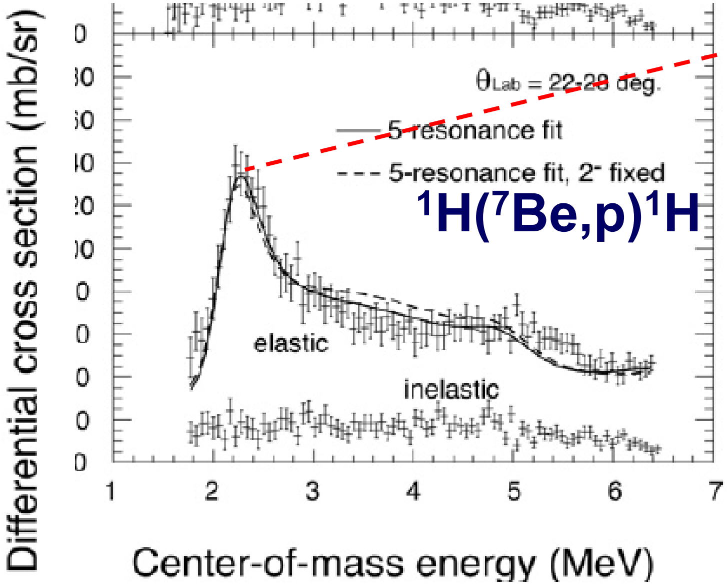


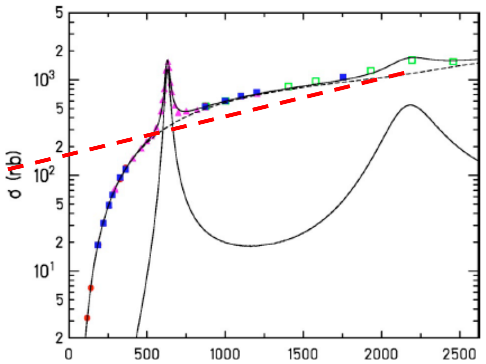
Elevel	Jπ	T½	XREF
0.0	2+	770 ms *3*	ABCD FGH
769.5 *25*	1+	35.6 keV *6*	ABCDEFGH
2320 *20*	3+	350 keV *30*	A CDEFGH

These resonances are also shown in ENSDF.

Scope of Resonance Parameter in EXFOR (cont)

^{7}Be+^{1}H compound resonance scattering by thick-target method.



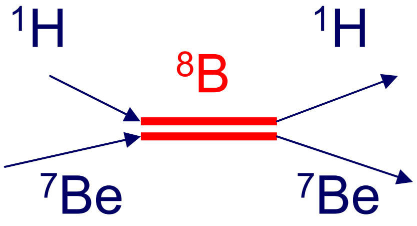


^{7}Be(p, γ)^{8}B

Table 1

Resonance parameters of ^{8}B determined by the present work and previous studies. *l* is the angular momentum used in the R-matrix calculation.

J^π	l	E_{ex} (MeV)	Γ (MeV)	Reference
1^+	1	0.7695 ± 0.0025	0.0356 ± 0.0006	[17]
3^+	1	2.32 ± 0.02	0.35 ± 0.03	[17]
2^-	0	$3.2^{+0.3}_{-0.2}$	$3.4^{+0.8}_{-0.5}$	present
$(2^-, 1^-)$	0	3	1–4	[18]
2^-	0	3.5 ± 0.5	8 ± 4	[17,19]
1^-	0 or 2	5.0 ± 0.4	0.15 ± 0.10	present
(3^+)	1	∼7	>2	present

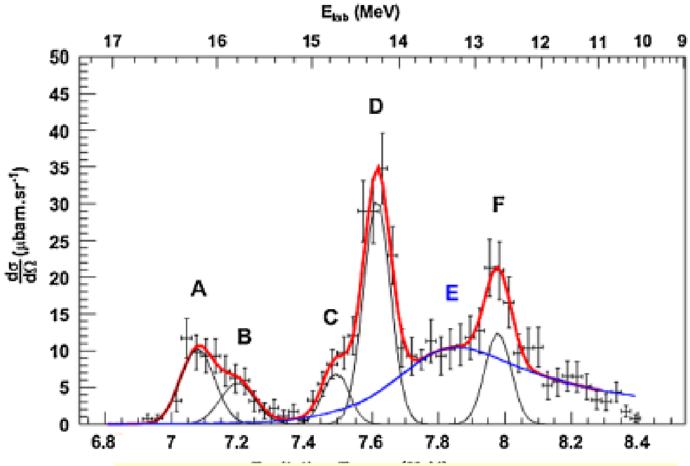


H.Yamaguchi et al., Phys.Lett.B672(2009)230 (EXFOR E2133)

Resonance energy is given as excitation energy E_x(= $E_{c.m.}$ -S_p). We do *not* have an appropriate heading for this case.

Scope of Resonance Parameter in EXFOR (cont)

Another example:



^{19}Ne excitation energy

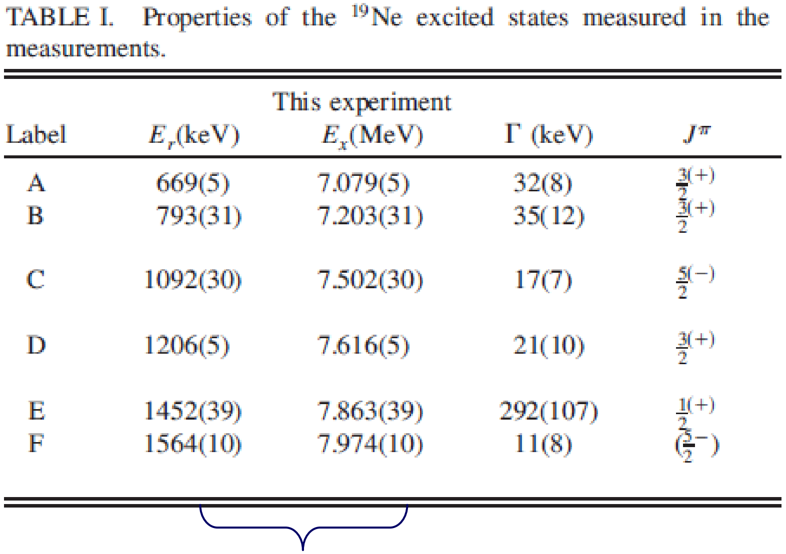


TABLE I. Properties of the ^{19}Ne excited states measured in the measurements.

	This experiment			
Label	E_r(keV)	E_x(MeV)	Γ (keV)	J^π
A	669(5)	7.079(5)	32(8)	$\frac{3}{2}(+)$
B	793(31)	7.203(31)	35(12)	$\frac{3}{2}(+)$
C	1092(30)	7.502(30)	17(7)	$\frac{5}{2}(-)$
D	1206(5)	7.616(5)	21(10)	$\frac{3}{2}(+)$
E	1452(39)	7.863(39)	292(107)	$\frac{1}{2}(+)$
F	1564(10)	7.974(10)	11(8)	$(\frac{5}{2}-)$

^{1}H(^{19}Ne,^{1}H)^{19}Ne*(→p+^{18}F) scattering
Phys.Rev.Lett.102(2009)162503
(EXFOR C1696)

Not only excitation energy, but also resonance energy is given. Can be compiled! Because $E_r=E_x-S_p$

Authors are interested ^{18}F(p, α)^{15}O reaction rate in novae.

`9-F-18(P,0),,EN`

(not `10-NE-19(P,0),,EN`)!!

Scope of Resonance Parameter in EXFOR (cont)

- Resonance parameters in charged-particle induced reaction derived from direct and various in-direct method can be compiled in EXFOR.

- However compilers have to understand the definition of quantities (e.g. E_{lab}?, E_{cm}?, E_x?) as well as the reaction which create the resonance as a compound.

- If there is no such a description about the reaction which forms the compound resonance, the data set must not be in EXFOR. It should go to experimental nuclear structure databases (e.g. XUNDL).

Scope of Resonance Parameter in EXFOR (cont)

LEXFOR S.8 (Single level resonance parameters)

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).

KT rather than EN-MEAN - MACS

Maxwellian averaged cross section (MACS)

$$\sigma_{\mathrm{MXW}}(kT) = \frac{2}{\sqrt{\pi}} \frac{\int_0^\infty \sigma(E) E_n \exp(-E/kT) dE}{\int_0^\infty E \exp(-E/kT) dE}$$

1) kT = 0.0253 eV MACS is measured in <u>thermal reactor</u> spectrum.
2) kT ~ 30 keV MACS is studied in the relation with <u>stellar evolution</u>.

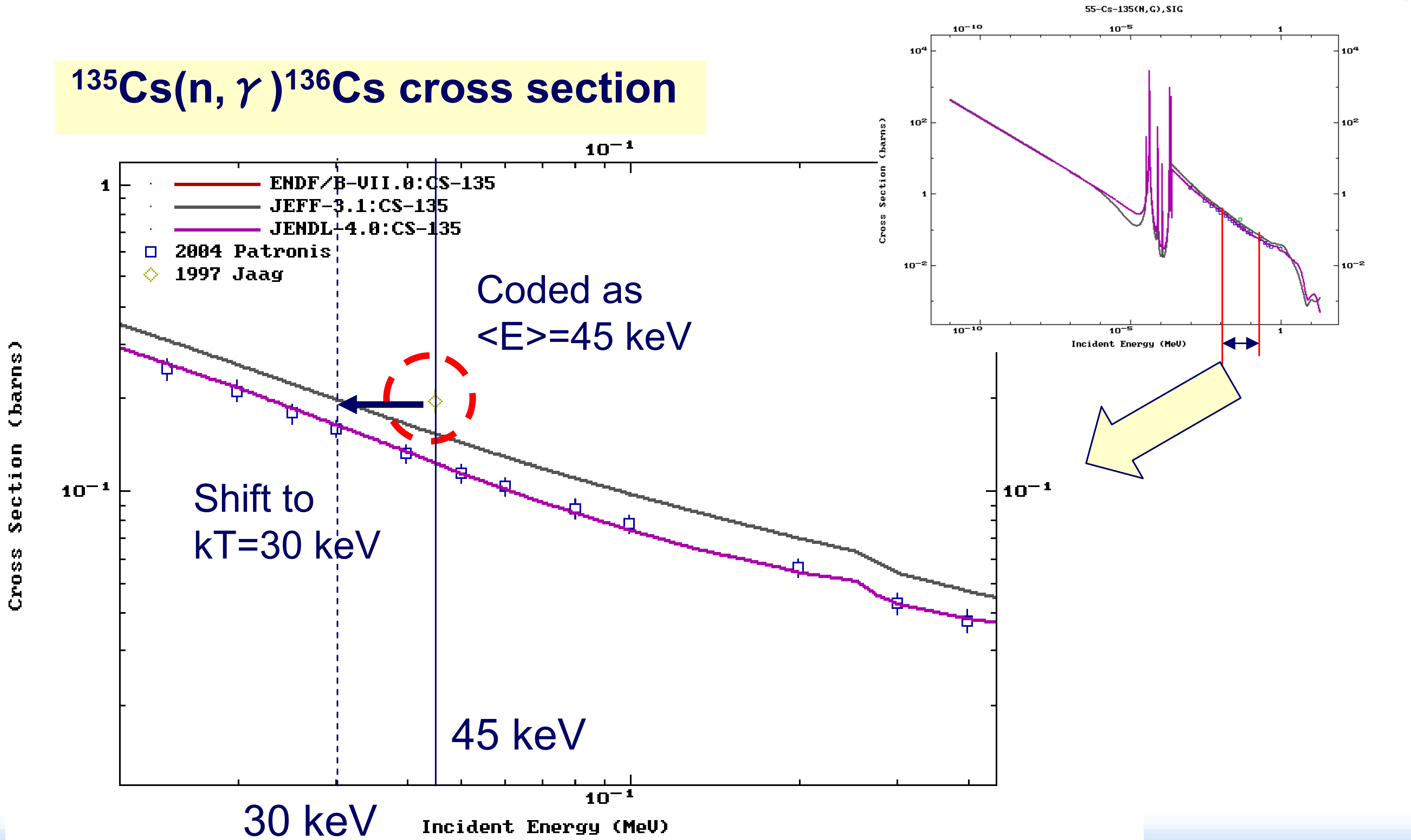
The <u>mean</u> incident energy (**`EN-MEAN`**) is (3/2)kT. Physically this can be used as an independent variable of MACS.

However, users prefer kT rather than <E>. Threfore MACS must be coded as a function of kT (**`KT`**) without conversion

Note that MACS at kT is more comparable with point cross section at E=kT. Especially, MACS (kT)=σ(E=kT) when σ~1/v.

KT rather than EN-MEAN – MACS (cont)

$^{135}Cs(n,\gamma)^{136}Cs$ cross section



Coded as <E>=45 keV

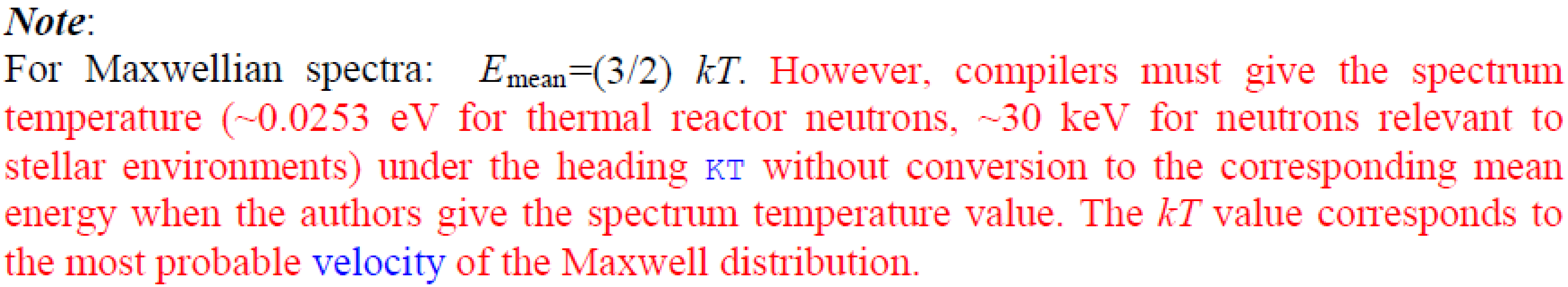
Shift to kT=30 keV

45 keV

30 keV

KT rather than EN-MEAN – MACS (cont)

LEXFOR S.15 (Spectrum average)



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.

 # Why we use `EN-DUMMY` instead of `KT` for room temperature (kT=0.0253 eV) for the thermal neutron?

I do not know…

International Atomic Energy Agency

Summary of Manual Updates
7. Photo-nuclear Reaction

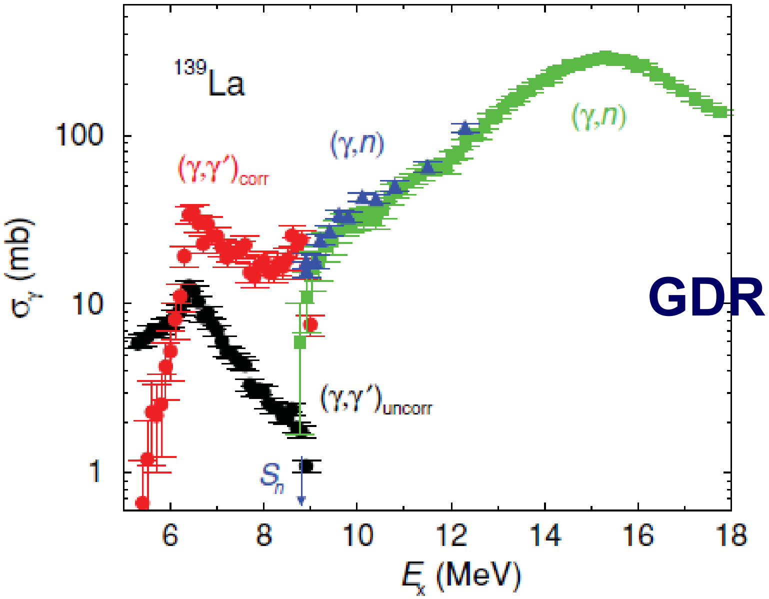
IAEA Nuclear Data Section
N. Otsuka

117

Absorption for γ -induced reaction

Definition of absorption
in EXFOR (ABS in SF3):

Total minus scattering



GDR

FIG. 7. (Color online) Uncorrected (black circles) and corrected (red circles) photoabsorption cross sections deduced from the present experiment in comparison with (γ,n) data from Ref. [19] (blue triangles) and Ref. [37] (green squares).

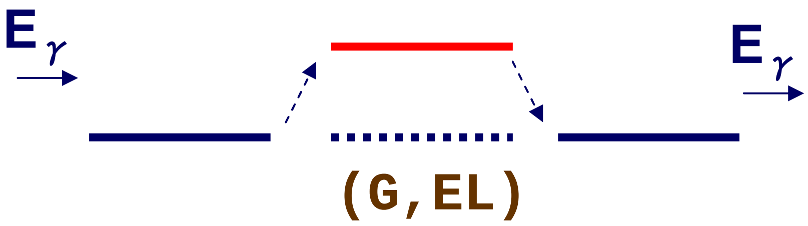
What is "photo-absorption"?
(G,ABS) in EXFOR??

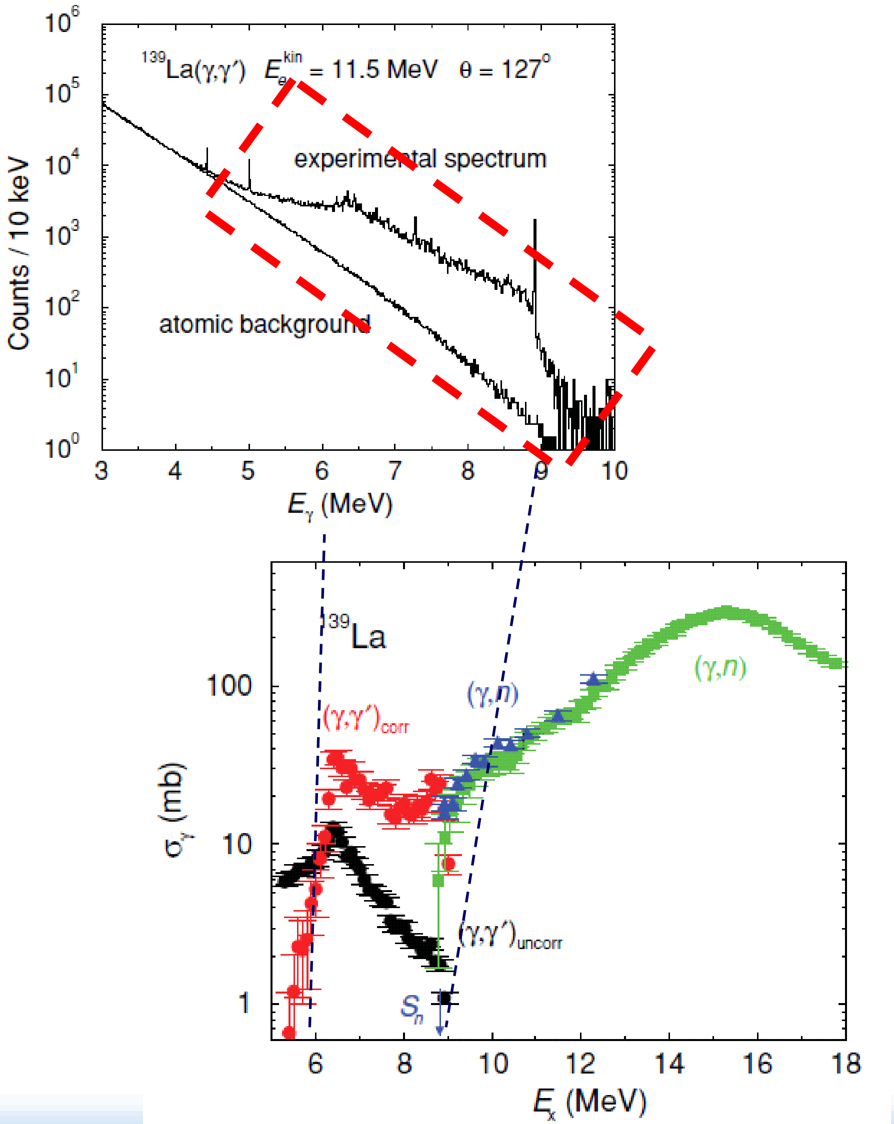
A. Makinaga et al., Phys.Rev.C82(2010)024314

Absorption for γ-induced reaction (cont)

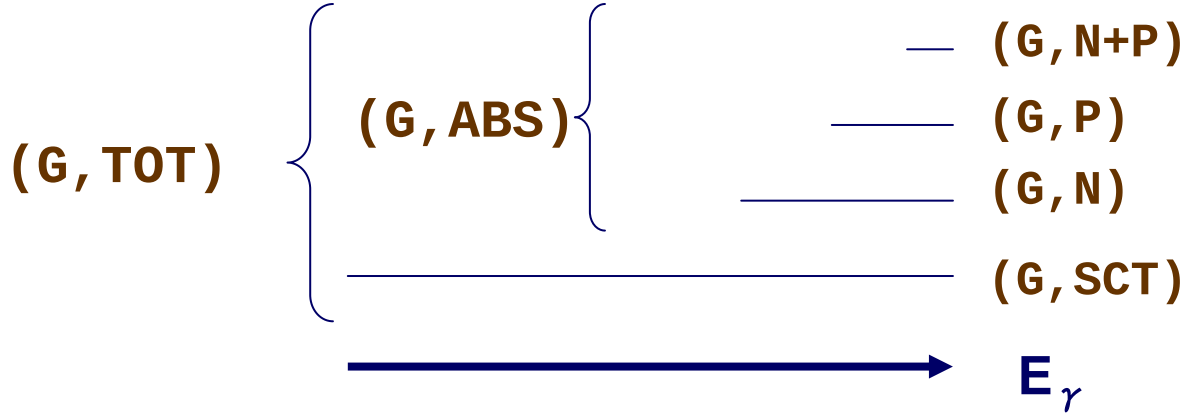
Below the (γ,n) threshold,
“photo-absorption” means “scattering”
process in EXFOR (SCT in SF3).
(Intensive measurement at FZD)

Excitation to
a nuclear state
(“nuclear fluoresce”)





Absorption for γ -induced reaction (cont)



Various coding of "photo-absorption"

(G,SCT) or **(G,EL)** : under the threshold of (γ ,n)

(G,ABS) : sum of particle emission is considered – nucleon detection

… consistent with Eq.(2.3) of IAEA-TECDOC 1178

$$\begin{aligned}\sigma(\gamma,abs) &= \sigma(\gamma,sn)+\sigma(\gamma,p)+\sigma(\gamma,2p)+\cdots+\\ &+ \sigma(\gamma,d)+\sigma(\gamma,dp)+\cdots+\sigma(\gamma,\alpha)+\cdots\end{aligned}$$

(G,TOT) : photon transmission above the threshold of (γ ,n) ~ **(G,ABS)**

Absorption for γ -induced reaction (cont)

LEXFOR A.1 (Absorption)

c.) The "photo-absorption cross section" below the nucleon emission threshold must be coded as (γ,sct), (γ,el) or (γ,inl). Above the threshold, photo-absorption (= total minus photo-scattering) $(\gamma,\text{abs}) = (\gamma,\text{n}) + (\gamma,\text{p}) + (\gamma,2\text{n}) + \ldots + (\gamma,\text{f})$ is coded with ABS in SF3.

LEXFOR T.13 (Total)

2. Photo-atomic interaction contribution (e.g. Rayleigh scattering, Compton scattering, photo-ionization) is excluded from processes considered in photo-nuclear reaction data. $(\gamma,\text{tot}) = (\gamma,\text{n}) + (\gamma,\text{p}) + (\gamma,2\text{n}) + \ldots + (\gamma,\text{f}) +$ nuclear scattering.

International Atomic Energy Agency

Summary of Manual Updates

8. Reaction Involving Unstable Nucleus

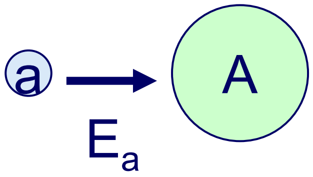
IAEA Nuclear Data Section

N. Otsuka

122

REACTION for Inverse Kinematics

A(a,b)B
Normal kinematics



$E_{cm}=E_aM_A/(m_a+M_A)$

a ↔ A

a(A,b)B
Inverse kinematics
(Heavy ion reaction)

$E_{cm}=E_Am_a(m_a+M_A)$

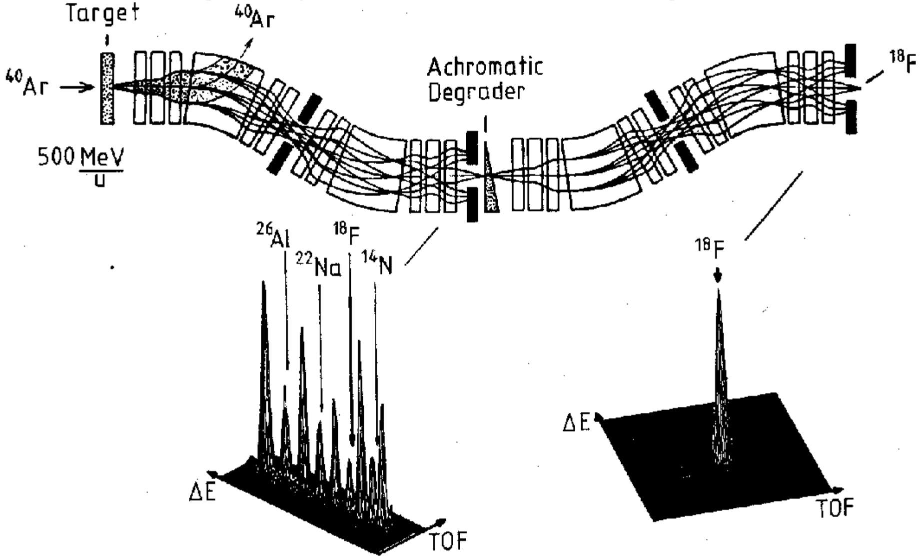
Physics of two reactions is same when E_{cm} of two reaction are same.

REACTION for Inverse Kinematics

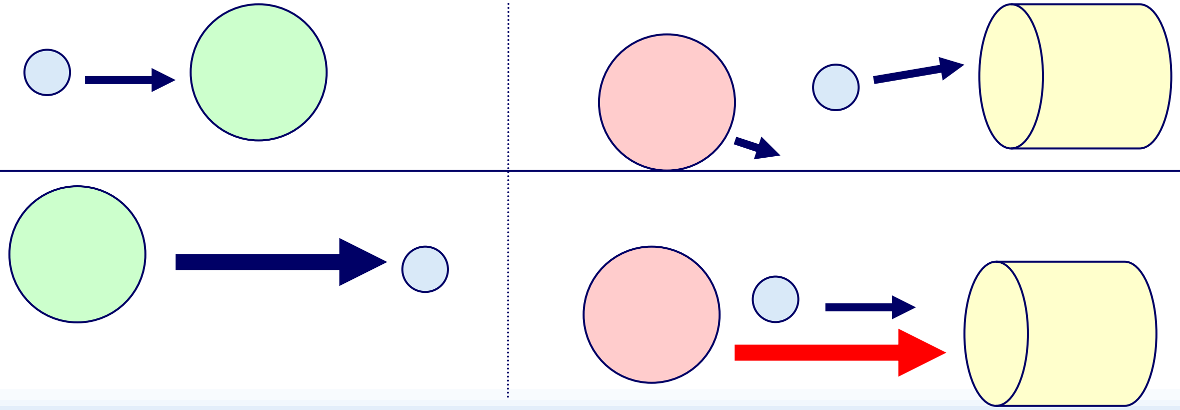
Advantage 1:
Residual nuclide moves to forward direction. Note only outgoing particles, residual also can be detected.

Flying residual can be used as beam of another reaction, too. (Secondary beam).

GSI FRS (Fragment Separator)



H.Geissel *et al*., Nucl.Instrum.Meth.B70(1992)286



A(a,b)B

Detector

a(A,b)B

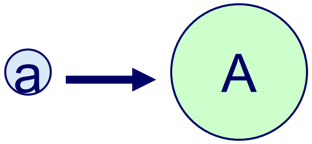
Detector

REACTION for Inverse Kinematics (cont)

Advantage 2

Not only stable nuclide, but also unstable nuclide can be considered as “target” (RI beam).

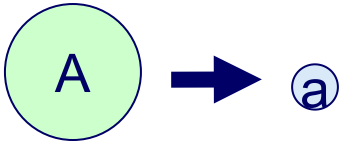
A(a,b)B



“*A*” must be a stable nuclide.

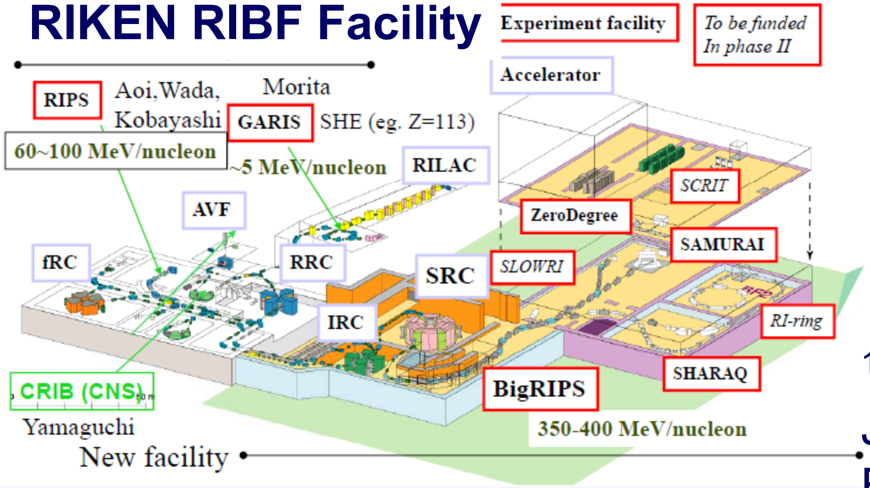
---

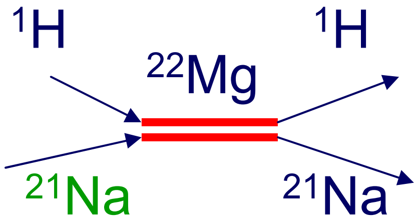
a(A,b)B

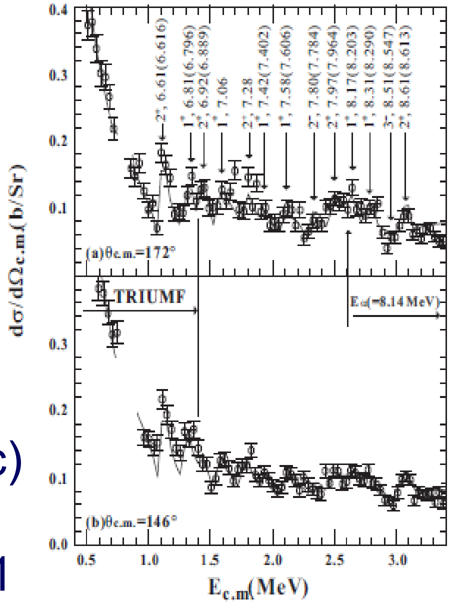


“*A*” can be a unstable nucleus.
(Flying particle has a longer life!)

RIKEN RIBF Facility







$^1H+^{21}Na$ ($T_{1/2}$=22.49 sec)
J.J.He *et al*.,
Euro.Phys.J.A36(2008)1

REACTION for Inverse Kinematics (cont)

An example of experimental data from inverse kinematics

R.Kanungo et al.,Phys.Lett.B660(2008)26

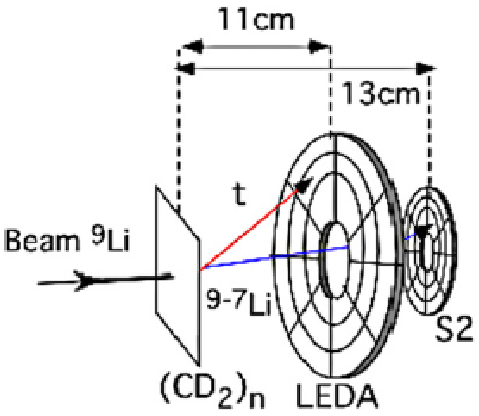
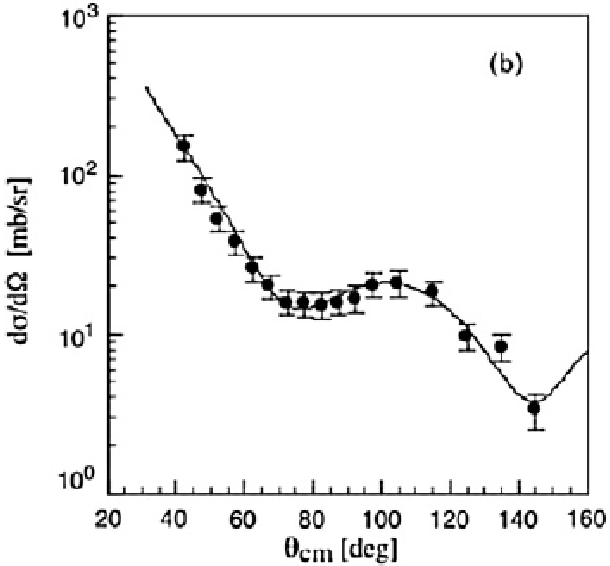


Fig. 1. Schematic view of experimental setup.



^{9}Li beam on ^{2}H (CD_2) target,

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 phenomenological optical potential.

Experiment was performed for ^{2}H(^{9}Li,^{9}Li)^{2}H reaction,
but refers data as ^{9}Li(d,d)^{9}Li reaction. How should we spell it in REACTION?

REACTION for Inverse Kinematics (cont)

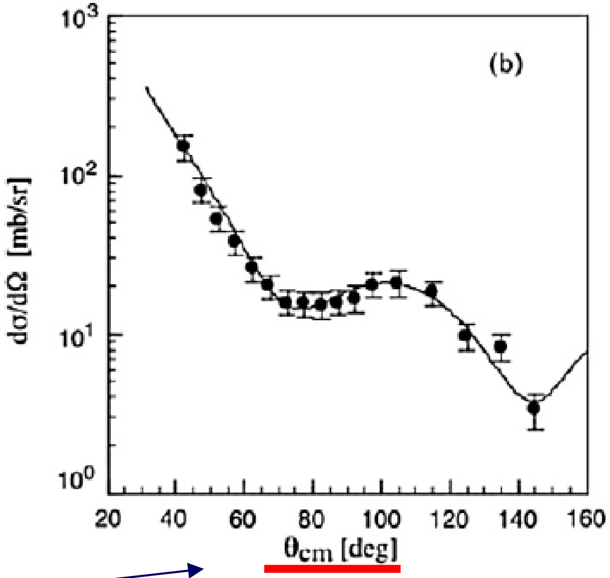
EXFOR rule:

1) Target and Projectile should follow the experimental set up.

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

2) If all variables are invariant under exchange of projectile and target, the tautology formalism must be used:

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



Invariant under a ↔ A

ANG-CM

DATA-CM

EN=…MEV/A

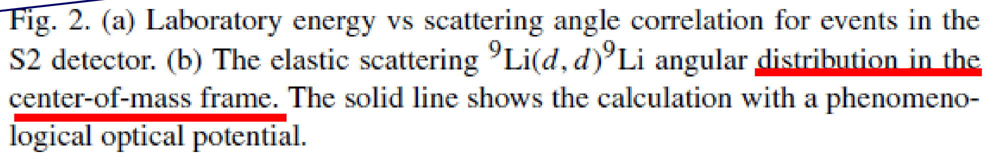
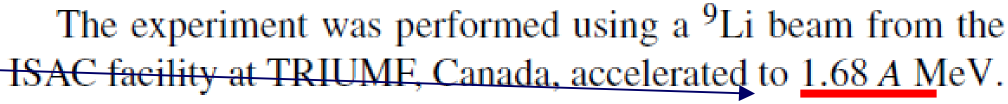


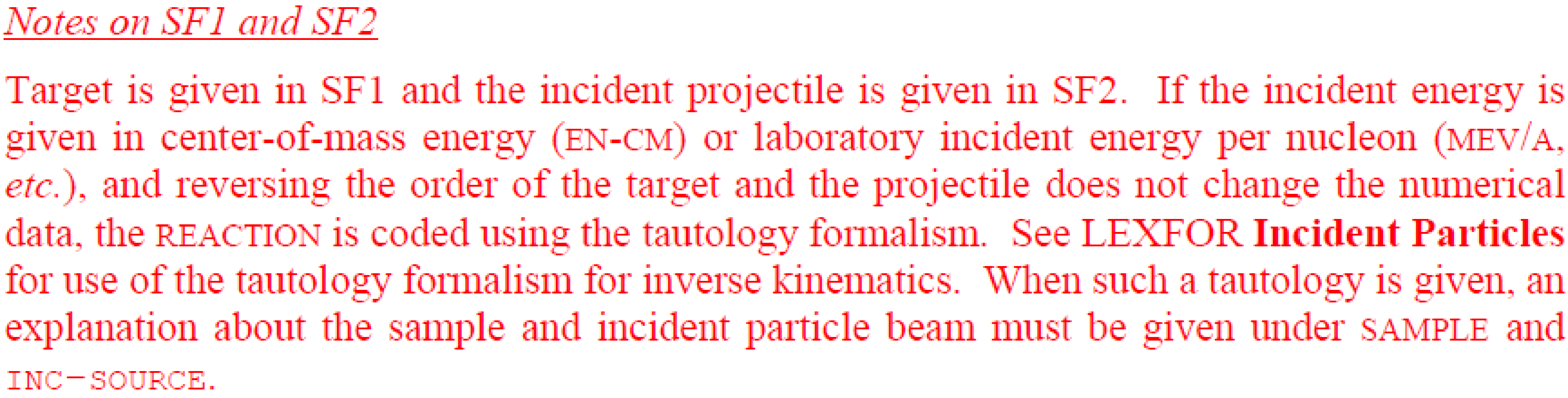
Fig. 2. (a) Laboratory energy vs scattering angle correlation for events in the S2 detector. (b) The elastic scattering ^{9}Li(d,d)^{9}Li angular distribution in the center-of-mass frame. The solid line shows the calculation with a phenomenological optical potential.



The experiment was performed using a ^{9}Li beam from the ISAC facility at TRIUMF, Canada, accelerated to 1.68 A MeV.

REACTION for Inverse Kinematics (cont)

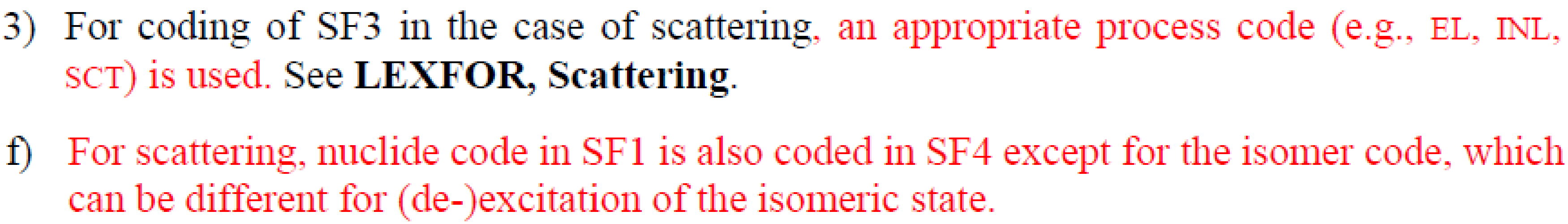
EXFOR Formats 6.3



Notes on SF1 and SF2

Target is given in SF1 and the incident projectile is given in SF2. If the incident energy is given in center-of-mass energy (EN-CM) or laboratory incident energy per nucleon (MEV/A, *etc.*), and reversing the order of the target and the projectile does not change the numerical data, the REACTION is coded using the tautology formalism. See LEXFOR **Incident Particles** for use of the tautology formalism for inverse kinematics. When such a tautology is given, an explanation about the sample and incident particle beam must be given under SAMPLE and INC−SOURCE.

EXFOR Formats 6.4



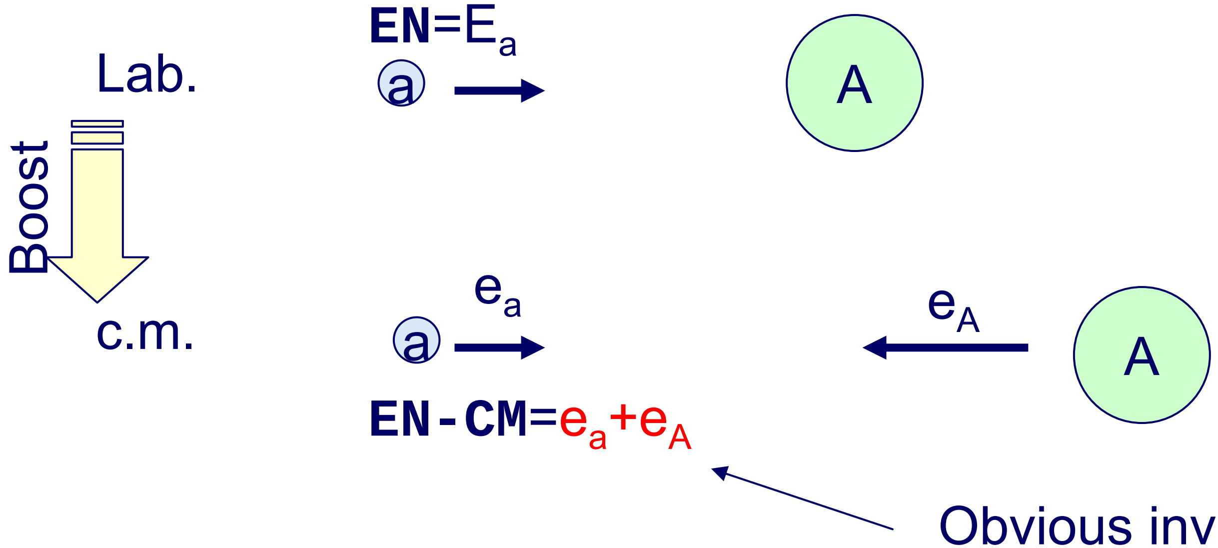
3) For coding of SF3 in the case of scattering, an appropriate process code (e.g., EL, INL, SCT) is used. See **LEXFOR, Scattering**.

f) For scattering, nuclide code in SF1 is also coded in SF4 except for the isomer code, which can be different for (de-)excitation of the isomeric state.

REACTION for Inverse Kinematics (cont)

Remarks on incident energy expression:

1) **`EN-CM`** (E_{cm}) is not “incident energy in the centre-of-mass system!
   It is “centre-of-mass energy”.



`EN`$=E_a$

`EN-CM`$=e_a+e_A$

Obvious invariance under a ↔ A.

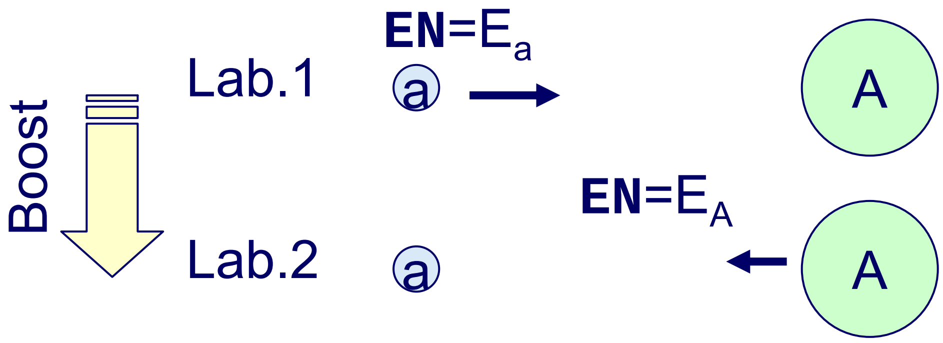
Problem:

Derive $e_a+e_A = E_aM_A/(m_a+M_A)$

REACTION for Inverse Kinematics (cont)

Remarks on incident energy expression:

2) EN is also invariant under “a ↔ A” if it is given as energy per projectile mass.



Boost

Lab.1 **EN**=E_a

Lab.2 **EN**=E_A

Centre-of-mass energy

$E_{cm}=E_aM_A/(m_a+M_A)$ (1)

$E_{cm}=E_AM_a/(M_A+m_a)$ (2)

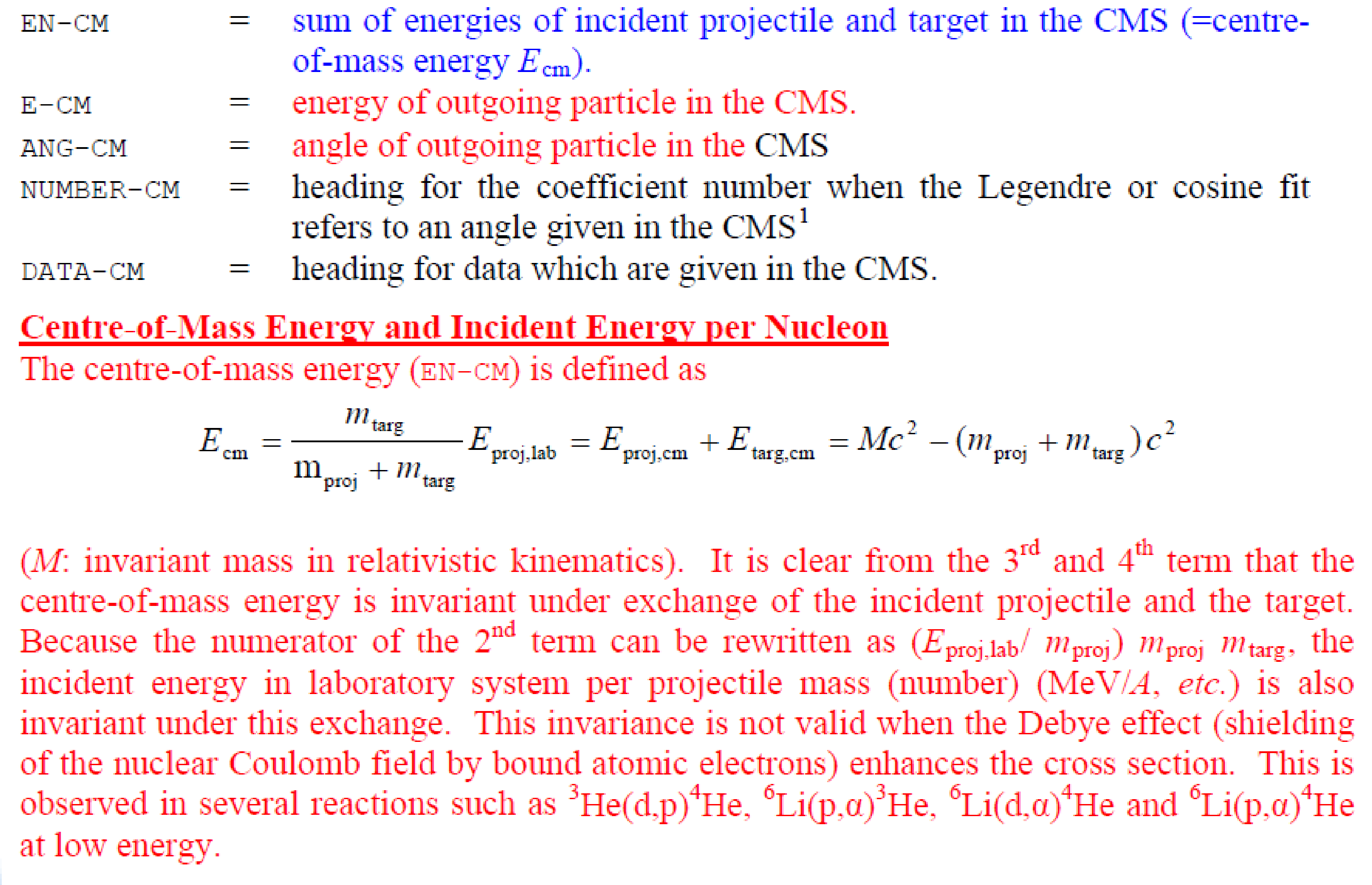
Because E_{cm} is invariant under a ↔ A, (1)=(2).

→ $E_aM_A= E_Am_a$.

→ $E_a/m_a = E_A/M_A$.

REACTION for Inverse Kinematics (cont)

LEXFOR C.1 (Centre-of-mass system)



`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.

Centre-of-Mass Energy and Incident Energy per Nucleon

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

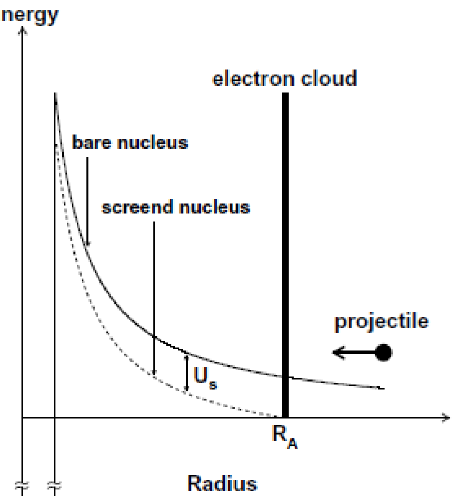
$$E_{\mathrm{cm}} = \frac{m_{\mathrm{targ}}}{m_{\mathrm{proj}} + m_{\mathrm{targ}}} E_{\mathrm{proj,lab}} = E_{\mathrm{proj,cm}} + E_{\mathrm{targ,cm}} = Mc^2 - (m_{\mathrm{proj}} + m_{\mathrm{targ}})c^2$$

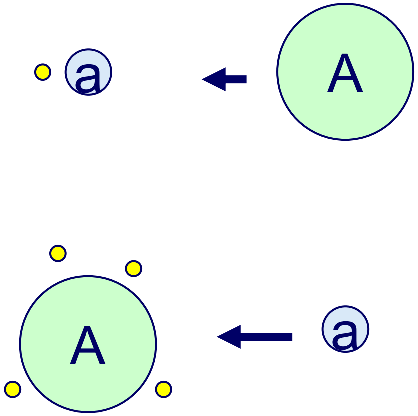
(M: invariant mass in relativistic kinematics). It is clear from the 3rd and 4th term that the centre-of-mass energy is invariant under exchange of the incident projectile and the target. Because the numerator of the 2nd term can be rewritten as ($E_{\mathrm{proj,lab}}/\ m_{\mathrm{proj}}$) $m_{\mathrm{proj}}\ m_{\mathrm{targ}}$, 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.

REACTION for Inverse Kinematics (cont)

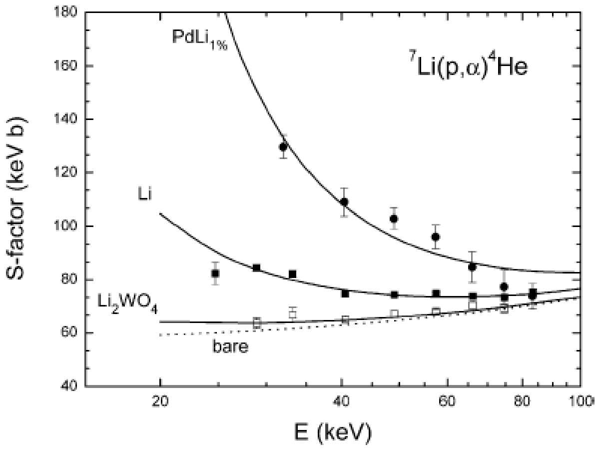
Invariance breaking under “a ↔ A” due to target state.

H. Yonemura, thesis (2008)





Screening potential depends on the sample. (Electron cloud reduce Coulomb potential.)



Cross section strongly depends on the sample state. (J. Cruz et al.,Phys.Lett.B624(2005)181)

Target information must be given under **`SAMPLE`**.

(The current rule does not these differentiate right 3 data sets by coded information… See EXFOR O1282)

Nuclides Unstable Against Prompt Particle Emission

Problem

Prepare REACTION codes for two data sets below.

Note: Be is monoisotopic (^{9}Be)

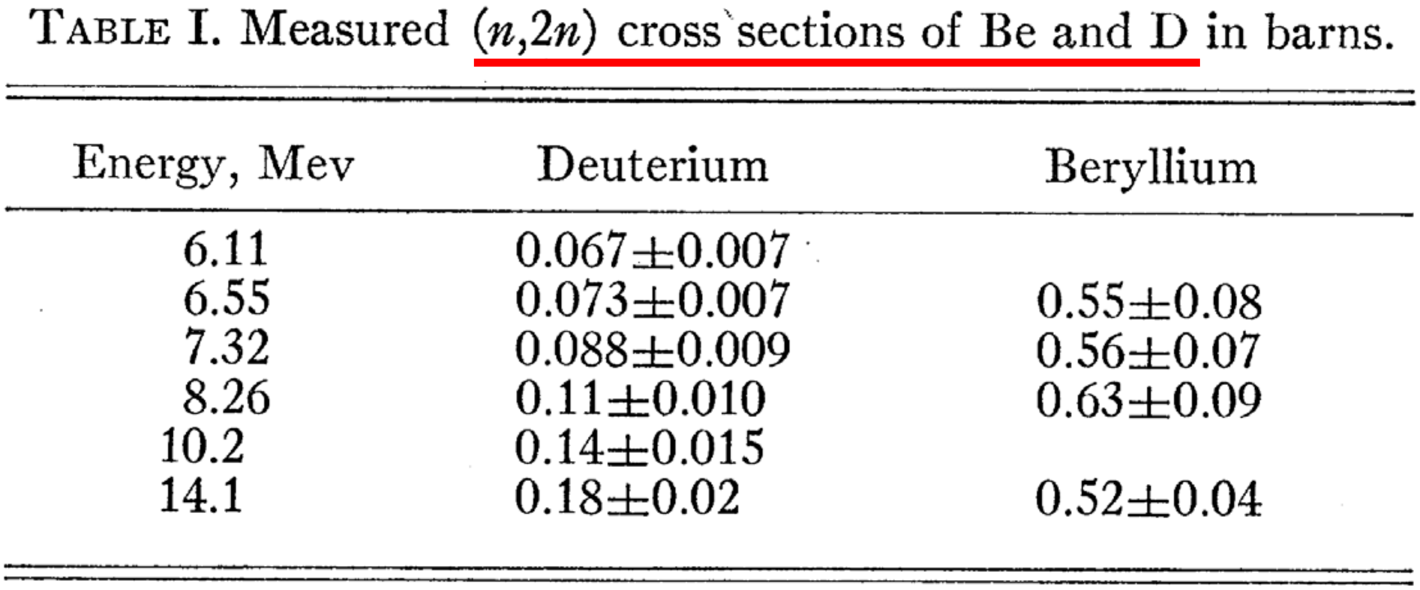


TABLE I. Measured (*n*,2*n*) cross sections of Be and D in barns.

Energy, Mev	Deuterium	Beryllium
6.11	0.067±0.007	
6.55	0.073±0.007	0.55±0.08
7.32	0.088±0.009	0.56±0.07
8.26	0.11±0.010	0.63±0.09
10.2	0.14±0.015	
14.1	0.18±0.02	0.52±0.04

H.C. Catron, Phys.Rev.123(1961)218 (EXFOR 11111)

Nuclides Unstable Against Prompt Particle Emission (cont)

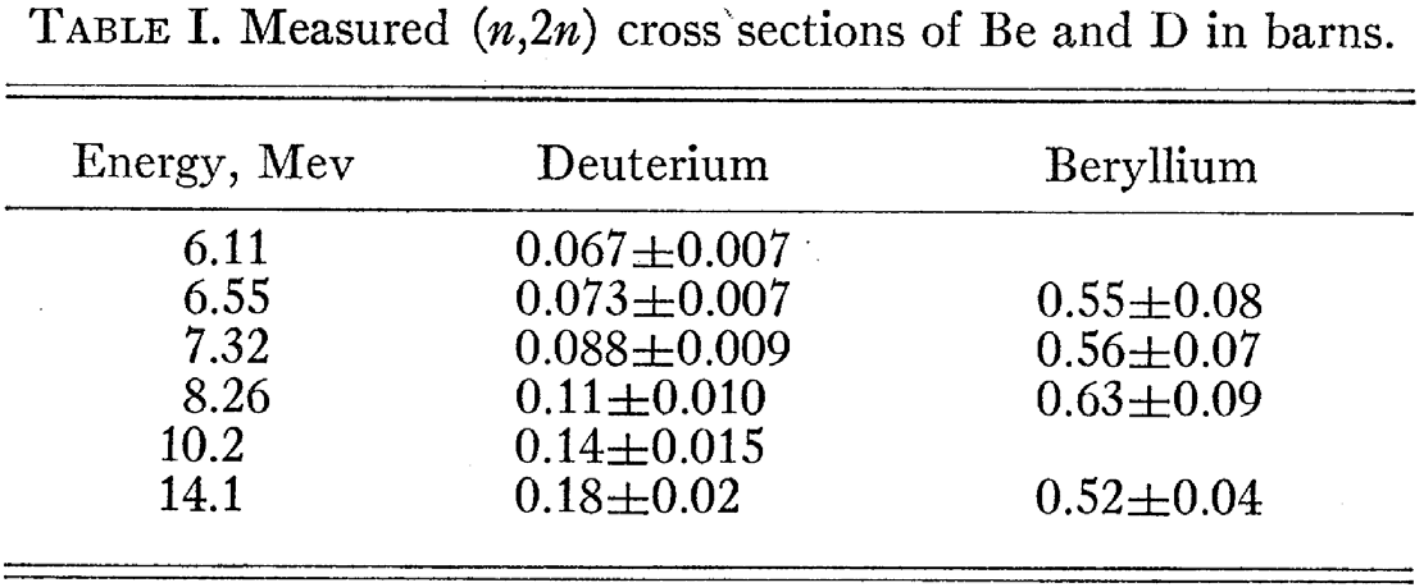


TABLE I. Measured (n,2n) cross sections of Be and D in barns.

Energy, Mev	Deuterium	Beryllium
6.11	0.067±0.007	
6.55	0.073±0.007	0.55±0.08
7.32	0.088±0.009	0.56±0.07
8.26	0.11±0.010	0.63±0.09
10.2	0.14±0.015	
14.1	0.18±0.02	0.52±0.04

For D target: ^{2}H(n,2n)□ → □=^{2}H+n-2n=^{1}H

`1-H-2(N,2N)1-H-1,,SIG` **(correct)**

For Be target: ^{9}Be(n,2n)□ → □=^{9}Be+n-2n=^{8}Be

`4-BE-9(N,2N)4-BE-8,,SIG` **(incorrect)**

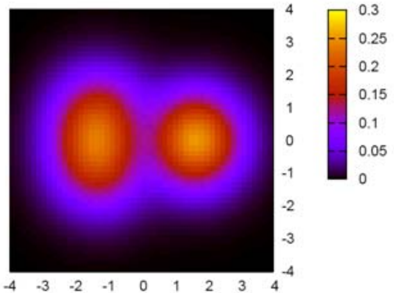
Nuclides Unstable Against Prompt Particle Emission (cont)

^{9}Be(n,2n)☐ → `4-BE-9(N,2N)4-BE-8,,SIG` **(incorrect)**

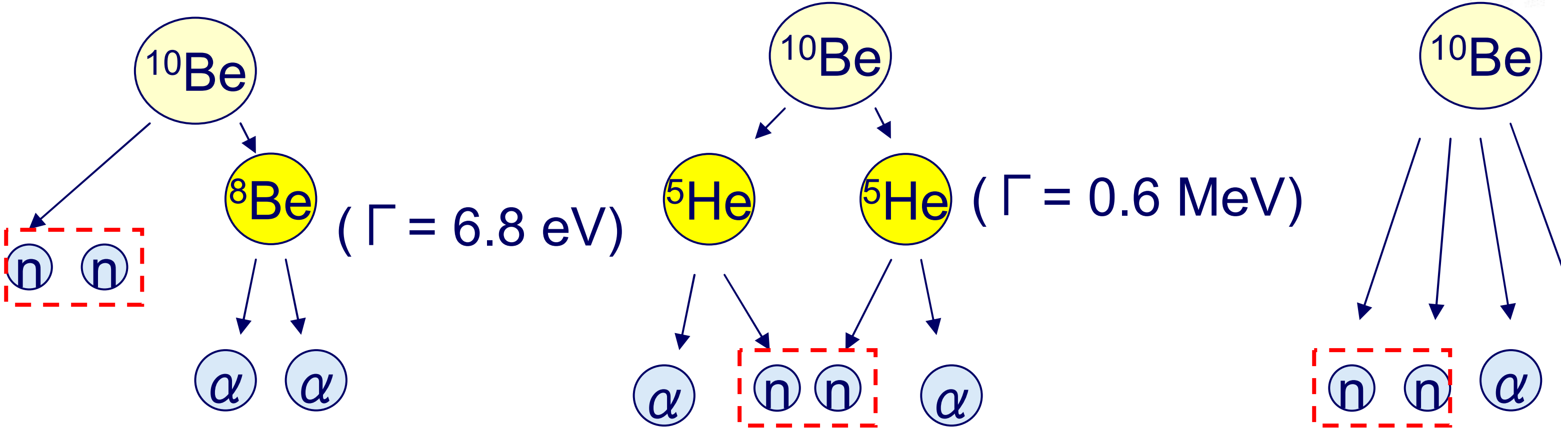
☐ can be ^{8}Be or 2α.

Some compound processes for 9Be(n,2n)☐:

^{9}Be (π=-1) by AMD



K. Kato et al. (2007)



^{9}Be+n→2n+^{8}Be

^{9}Be+n→^{5}He+^{5}He

^{9}Be+n→2n+2α

After decay or break-up, the final products are 2n+2α for all cases.

Nuclides Unstable Against Prompt Particle Emission (cont)

List of all ^{9}Be(n,2n)□ channels considered in JENDL evaluation (En<20 MeV)

$n + {}^{9}Be \rightarrow 2n + {}^{8}Be$

$\rightarrow {}^{5}He + {}^{5}He$

$\rightarrow \alpha + {}^{6}He$ (1.8 MeV)

$\rightarrow n + {}^{9}Be$ (2.4 MeV)

$\rightarrow n + {}^{9}Be$ (4.7 MeV)

$\rightarrow n + {}^{9}Be$ (6.8 MeV)

$\rightarrow n + {}^{9}Be$ (7.9 MeV)

$\rightarrow n + {}^{9}Be$ (11.28 MeV)

$\rightarrow n + {}^{9}Be$ (11.81 MeV)

$\rightarrow n + {}^{9}Be$ (13.79 MeV)

+) $\rightarrow n + {}^{9}Be$ (continuum)

$\rightarrow 2n + 2\alpha$

^{9}Be(n,2n)

$={}^{9}$Be(n,2n2α)

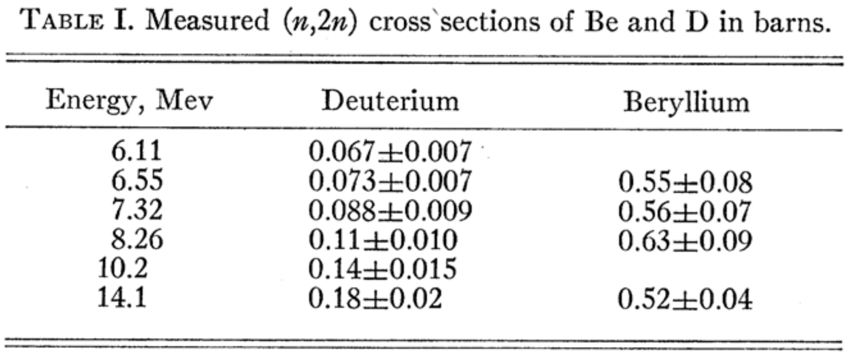


TABLE I. Measured (*n*,2*n*) cross sections of Be and D in barns.

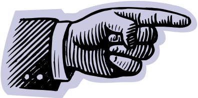
Energy, Mev	Deuterium	Beryllium
6.11	0.067±0.007	
6.55	0.073±0.007	0.55±0.08
7.32	0.088±0.009	0.56±0.07
8.26	0.11±0.010	0.63±0.09
10.2	0.14±0.015	
14.1	0.18±0.02	0.52±0.04

The right REACTION is

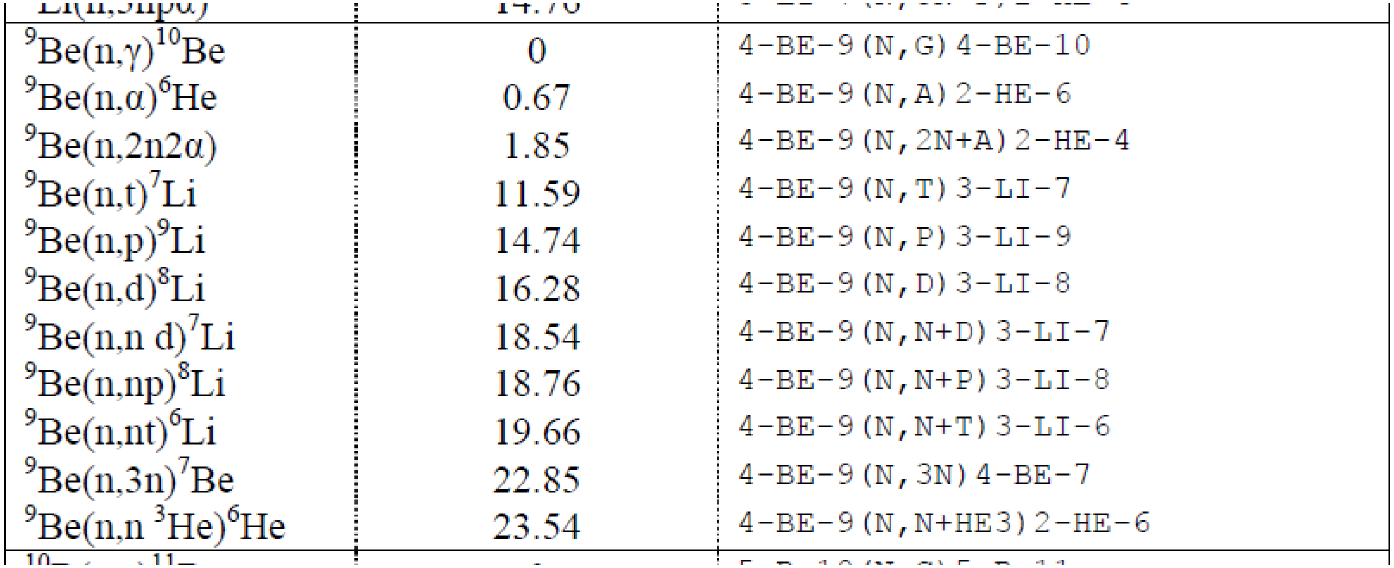
`4-BE-9(N,2N+A)2-HE-4,,SIG`

Nuclides Unstable Against Prompt Particle Emission (cont)

All stable final states for neutron induced reaction on light nuclei are listed in LEXFOR.



LEXFOR L.2-L.4 (Light Nuclei Reactions (Z≤6))
(Below ^{9}Be target part is extracted.)

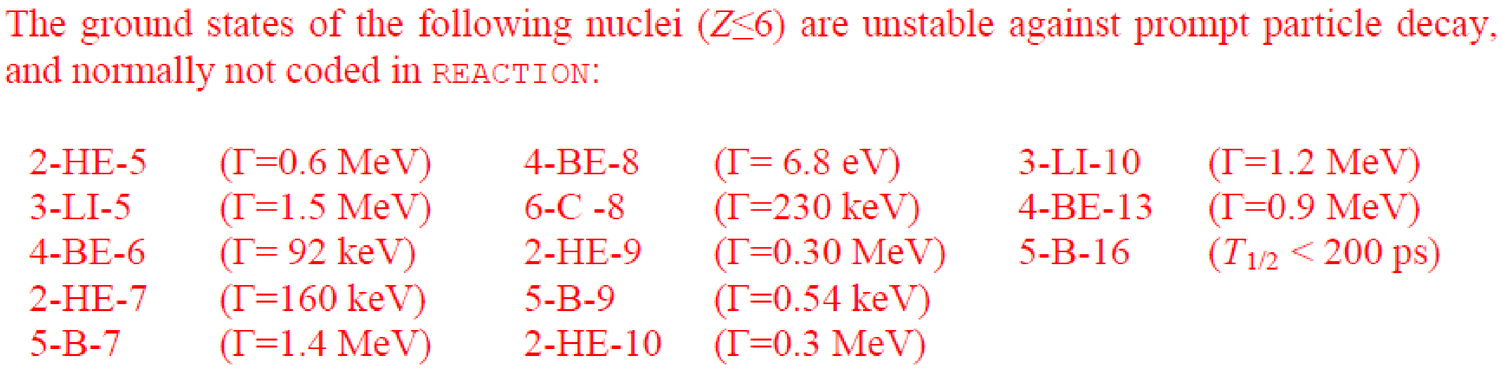


$^{9}\mathrm{Be}(n,\gamma)^{10}\mathrm{Be}$	0	4-BE-9(N,G)4-BE-10
$^{9}\mathrm{Be}(n,\alpha)^{6}\mathrm{He}$	0.67	4-BE-9(N,A)2-HE-6
$^{9}\mathrm{Be}(n,2n2\alpha)$	1.85	4-BE-9(N,2N+A)2-HE-4
$^{9}\mathrm{Be}(n,t)^{7}\mathrm{Li}$	11.59	4-BE-9(N,T)3-LI-7
$^{9}\mathrm{Be}(n,p)^{9}\mathrm{Li}$	14.74	4-BE-9(N,P)3-LI-9
$^{9}\mathrm{Be}(n,d)^{8}\mathrm{Li}$	16.28	4-BE-9(N,D)3-LI-8
$^{9}\mathrm{Be}(n,n\ d)^{7}\mathrm{Li}$	18.54	4-BE-9(N,N+D)3-LI-7
$^{9}\mathrm{Be}(n,np)^{8}\mathrm{Li}$	18.76	4-BE-9(N,N+P)3-LI-8
$^{9}\mathrm{Be}(n,nt)^{6}\mathrm{Li}$	19.66	4-BE-9(N,N+T)3-LI-6
$^{9}\mathrm{Be}(n,3n)^{7}\mathrm{Be}$	22.85	4-BE-9(N,3N)4-BE-7
$^{9}\mathrm{Be}(n,n\ ^{3}\mathrm{He})^{6}\mathrm{He}$	23.54	4-BE-9(N,N+HE3)2-HE-6

Nuclides Unstable Against Prompt Particle Emission (cont)

Below is the list of all nuclides unstable against prompt particle emission. Usually they should not be in REACTION.

LEXFOR L.1 (Light Nuclei Reactions (Z≤6)



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

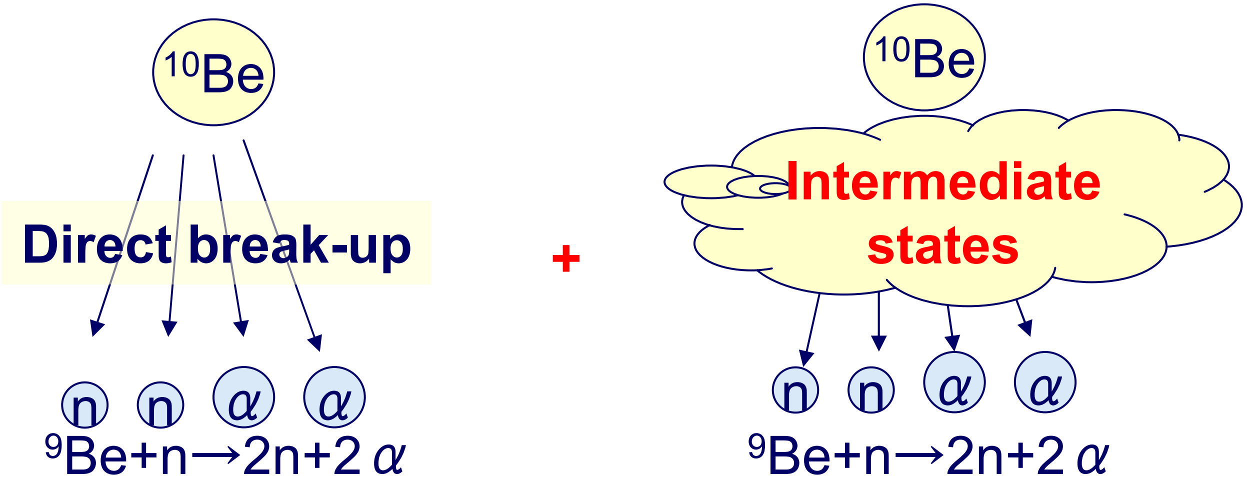
2-HE-5	(Γ=0.6 MeV)	4-BE-8	(Γ= 6.8 eV)	3-LI-10	(Γ=1.2 MeV)
3-LI-5	(Γ=1.5 MeV)	6-C -8	(Γ=230 keV)	4-BE-13	(Γ=0.9 MeV)
4-BE-6	(Γ= 92 keV)	2-HE-9	(Γ=0.30 MeV)	5-B-16	($T_{1/2} < 200$ ps)
2-HE-7	(Γ=160 keV)	5-B-9	(Γ=0.54 keV)		
5-B-7	(Γ=1.4 MeV)	2-HE-10	(Γ=0.3 MeV)		

Nuclides Unstable Against Prompt Particle Emission (cont)

Remark 1:
Cross section

`(4-BE-9(N,2N+A)2-HE-4,,SIG)  - (1)`

gives contribution of not only direct break-up, but also contributions of all intermediate states unstable against prompt particle emission.

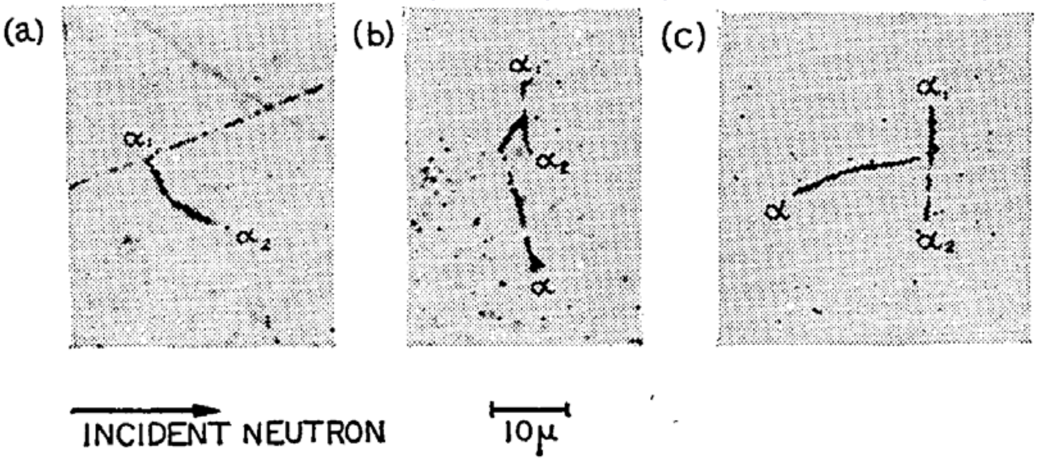


Direct break-up is a **part** of cross section coded by (1).
(We do not have such a branch code now.)

Nuclides Unstable Against Prompt Particle Emission (cont)

Remark 2:
Nuclides unstable against prompt particle emission can be coded when it is exclusively identified.

Example: Track detector
M. Sakisaka, J.Phys.Soc.Jpn.14(1959)554 (EXFOR 20285)



(a) $^{9}Be(n,2n)^{8}Be$ (Γ=6.8eV)→ $\alpha_1 + \alpha_2$ **4-BE-9(N,2N)4-BE-8**

(b,c) $^{9}Be(n,\alpha)^{8}Li$ (838 ms)→$^{8}Be \rightarrow \alpha_1 + \alpha_2$ **4-BE-9(N,A)3-LI-8**

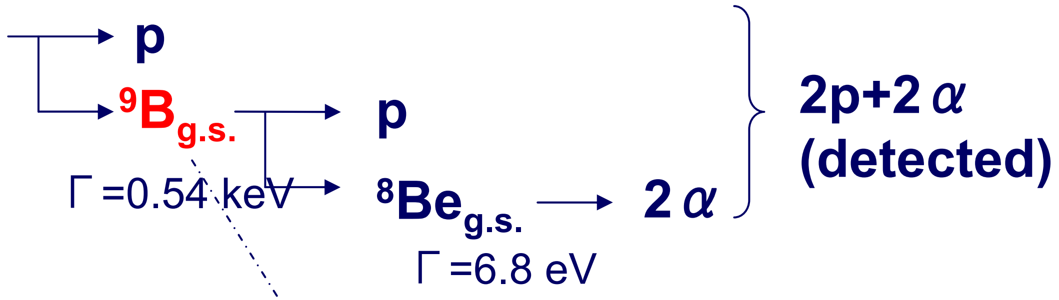
Nuclides Unstable Against Prompt Particle Emission (cont)

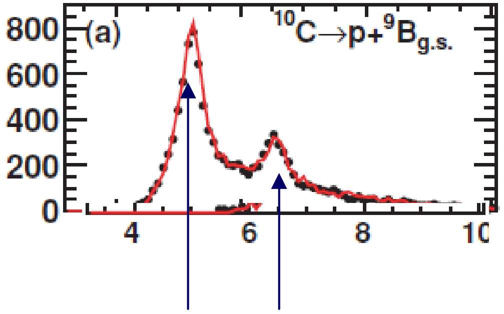
Example: Identification by 2p2α detection in coincidence

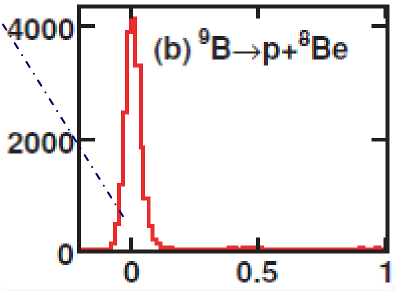
R.J. Charity, Phys.Rev.C80(2009)024306 (EXFOR C1732)

Nucleus	$\langle E^* \rangle$[a] (MeV)	Γ (keV)	Initial decay	Exit channel	σ_{Be} (μb)
^{10}C	5.222 ± 0.004	294 ± 16	$p + {}^{9}B_{g.s.}$	$2p + 2\alpha$	1000 ± 90
^{10}C	6.553 ± 0.007[b]	214 ± 31	$p + {}^{9}B_{g.s.}$	$2p + 2\alpha$	370 ± 33

^{9}Be(^{10}C,X) ^{10}C(5.222 MeV)





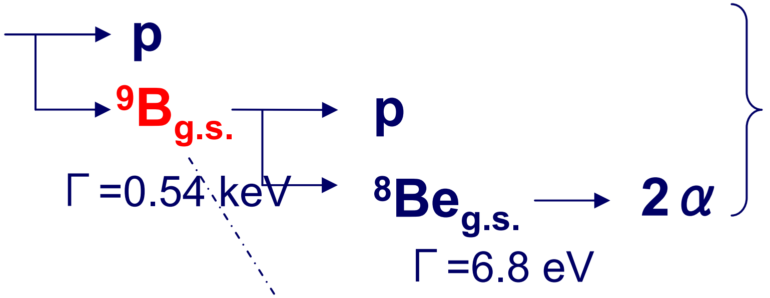


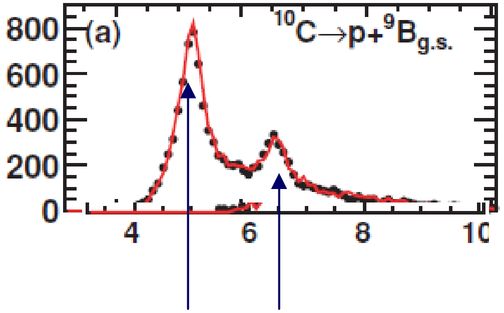
Nuclides Unstable Against Prompt Particle Emission (cont)

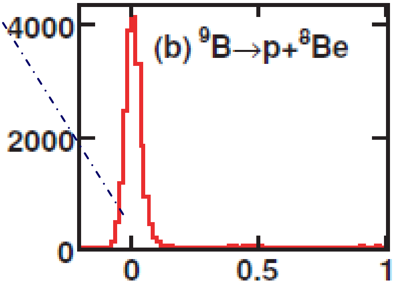
Example: Identification by 2p2α detection in coincidence

R.J. Charity, Phys.Rev.C80(2009)024306 (EXFOR C1732)

^{9}Be(^{10}C,X) **^{10}C(5.222 MeV)**







`4-BE-9(6-C-10,INL)4-BE-9,PAR,SIG ?`

`4-BE-9(6-C-10,X)6-C-10,PAR,SIG ?` ← Correct $^{10}C \to p + {}^{9}B_{g.s.}$ is 100%

`4-BE-9(6-C-10,P+X)5-B-9,PAR,SIG ?` ← Author's preference

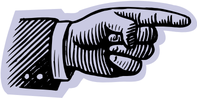
Nuclides Unstable Against Prompt Particle Emission (cont)

Example: Identification by 2p2α detection in coincidence

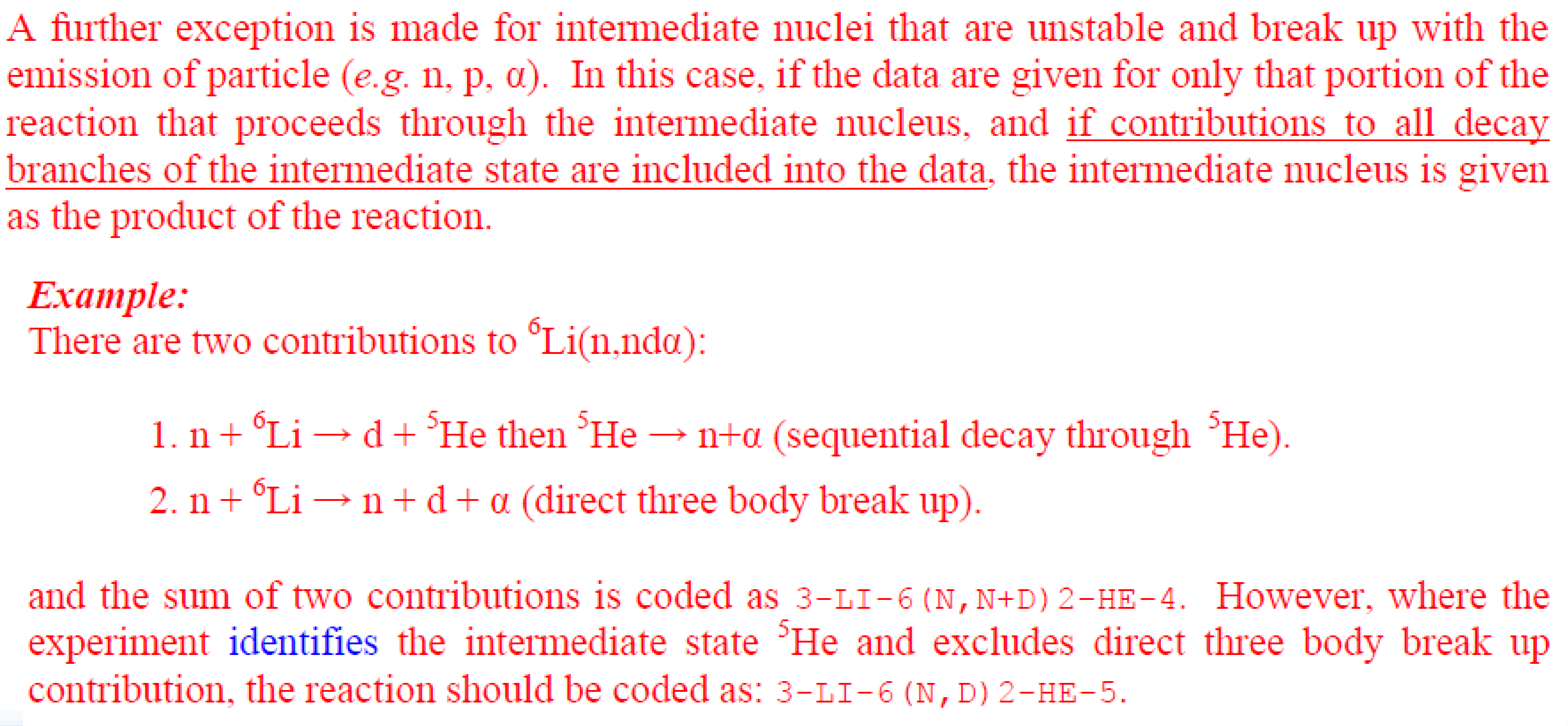
R.J. Charity, Phys.Rev.C80(2009)024306 (EXFOR C1732)

```
REACTION   (4-BE-9(6-C-10,X)5-B-9,PAR,SIG)
METHOD     (COINC) 2 alpha and 2 proton
PART-DET   (A,P)
EN-SEC     (E-LVL1,6-C-10)
           (E-LVL2,5-B-9)
...
E-LVL1     E-LVL2     DATA
MEV        MEV        MB
5.222      0.0        ...
```

Unstable Nuclide
Against Prompt Particle Emission (cont)



LEXFOR L.1 (Light Nuclei Reactions (Z≤6))



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 if contributions to all decay branches of the intermediate state are included into the data, 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`.

International Atomic Energy Agency

Summary of Manual Updates
9. Miscellaneous

IAEA Nuclear Data Section
N. Otsuka

145

Unit of Multiplicity/Yield: PRT and PRD

“Multiplicity” and “Product yield”

Multiplicity: Yield of an outgoing particle (SF3) - MLT
Product yield: Yield of reaction product (SF4) - PY

Example: capture gamma and continuous exclusive gamma

`(82-PB-207(N,G)82-PB-208,,MLT)`

Yield of outgoing particle (= γ)
Unit: PRT/REAC (particle per reaction) etc.

`(82-PB-207(P,X)0-G-0,,PY)`

Yield of reaction product (= γ)
Unit: PRD/INC (product per incident particle) etc.

Unit of Multiplicity/Yield: PRT and PRD (cont)

SF1(SF2,**SF3**)**SF4**,SF5,**SF6,SF7**

Particle considered	**Quantity name**	**SF6**	**Unit**
SF3 or SF7	Multiplicity	MLT	PRT
SF4	Product yield	PY	PRD

Usually "product yield" is defined for inclusive measurement (i.e. SF3=**X**).

Note: The same rule is also applied to unit of fission yield:

Example:

`(92-U-235(N,F)2-HE-4,,FY)`

"Inclusive" α fission yield (PRD/FIS)

`(92-U-235(N,F)53-I-133,,FY,A)`

"Exclusive" fission yield measured with ^{133}I (PRT/FIS)

Unit of Multiplicity/Yield: PRT and PRD (cont)

LEXFOR T.8 (Thin- and thick target yields)

b) Thick Target Product Yields: thick target yield of a reaction product coded in SF4 under keyword `REACTION`, where the value is given in units of number of nuclei per incident projectile.

REACTION Coding: `PY` in SF 6; `TT` in SF8.

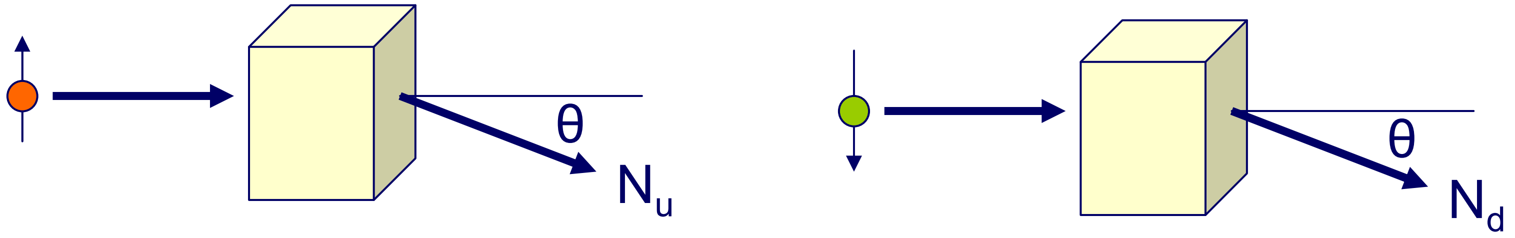
Units: a code from Dictionary 25 with dimension `YLD`, *e.g.*, `PRD/INC`

c) Thick Target Yield Multiplicities: yield of an outgoing particle (or radiation) coded in SF3 or SF7 under keyword `REACTION`, where the value is given as the number of particles per incident projectile.

REACTION Coding: `MLT` in SF 6; `TT` in SF8.

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

Various Notation of Spin Observable



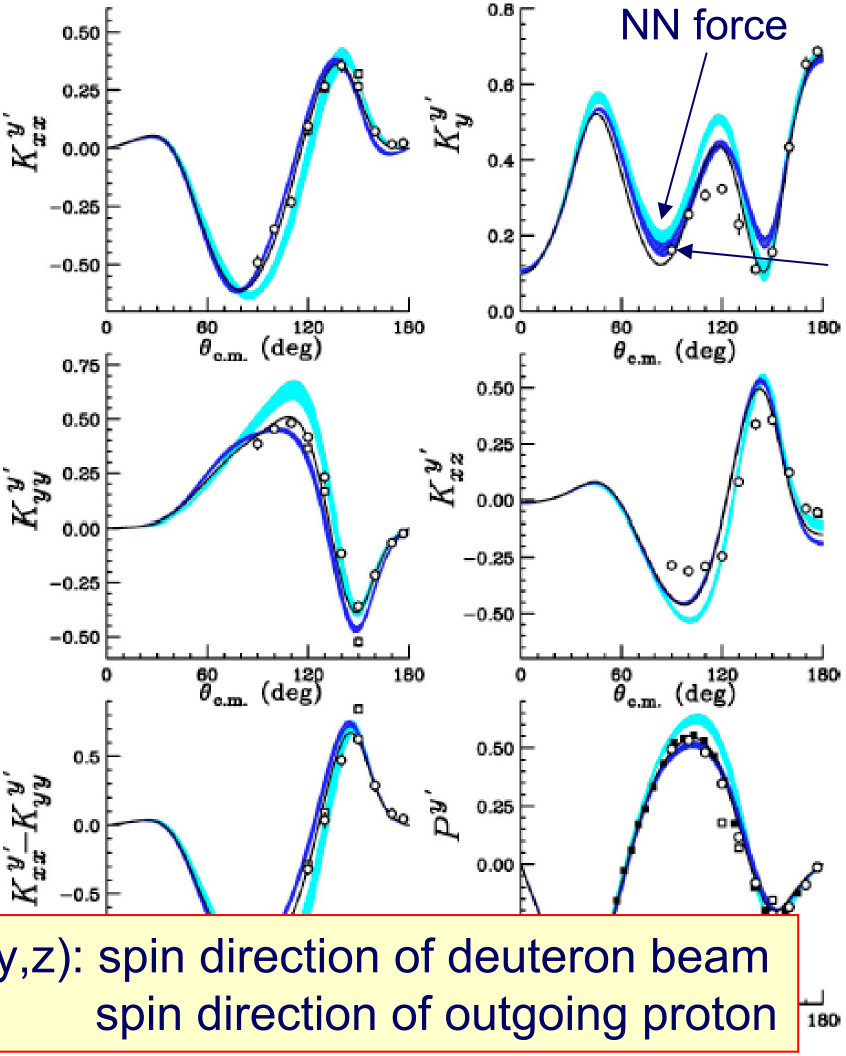
Analyzing power: A_y=(N_u –N_d) / (N_u +N_d)

Analyzing power is a basic spin observable in EXFOR.
In addition, more complicated spin observables are defined.

- Spin-spin correlation between projectile and outgoing particle (polarization transfer), projectile and target (initial spin correlation)
- Analyzing power for particle with spin ≥1 (Tensor polarization)
- Spin-spin correlation for particle with spin ≥1 (not in EXFOR)

etc…

Various Notation of Spin Observable (cont)



Spin transfer in
$p+\vec{d}\rightarrow\vec{p}+d$ scattering
(3-body force problem)

FIG. 6. (Color online) polarization-transfer coefficients $K_{xx}^{y'}$, $K_{yy}^{y'}$, $K_{xx}^{y'}-K_{yy}^{y'}$, $K_y^{y'}$, $K_{xz}^{y'}$, and the induced polarization $P^{y'}$ in elastic *d*-*p* scattering at the incident deuteron energy of 135 MeV/nucleon. Open circles are the data in the present measurement and open squares are the data in the test measurement (Ref. [18]). Solid squares on the $P^{y'}$ figure are the proton analyzing power data for the time-reversed reaction $^2H(\vec{p},p)^2H$ (Ref. [27]). The light shaded bands contain the *NN* force predictions (AV18, CD-Bonn, Nijmegen I, II and 93), and the dark shaded bands contain the combinations of the *NN*+TM′(99) 3NF predictions as described in the text. The solid curve is the AV18+Urbana IX 3NF prediction.

(x,y,z): spin direction of deuteron beam
y’: spin direction of outgoing proton

K.Sekiguchi et al.,
Phys.Rev.C70(2004)014001
(EXFOR E1907)

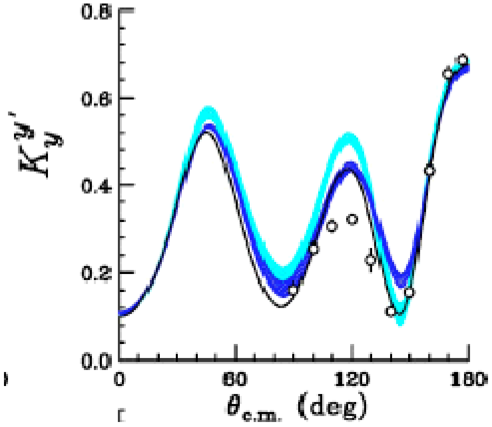
Various Notation of Spin Observable (cont)

- There are various notation for a given spin observable

  Example

  Spin-transfer from y component to y’ component $K_y^{y'}$ is denoted by D_{nn} , D_{n0n0} or D in other notations. In d+n scattering, REACTION is

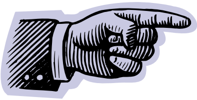
  `(1-H-1(D,EL)1-H-1,NN,POL/DA,P,D)`



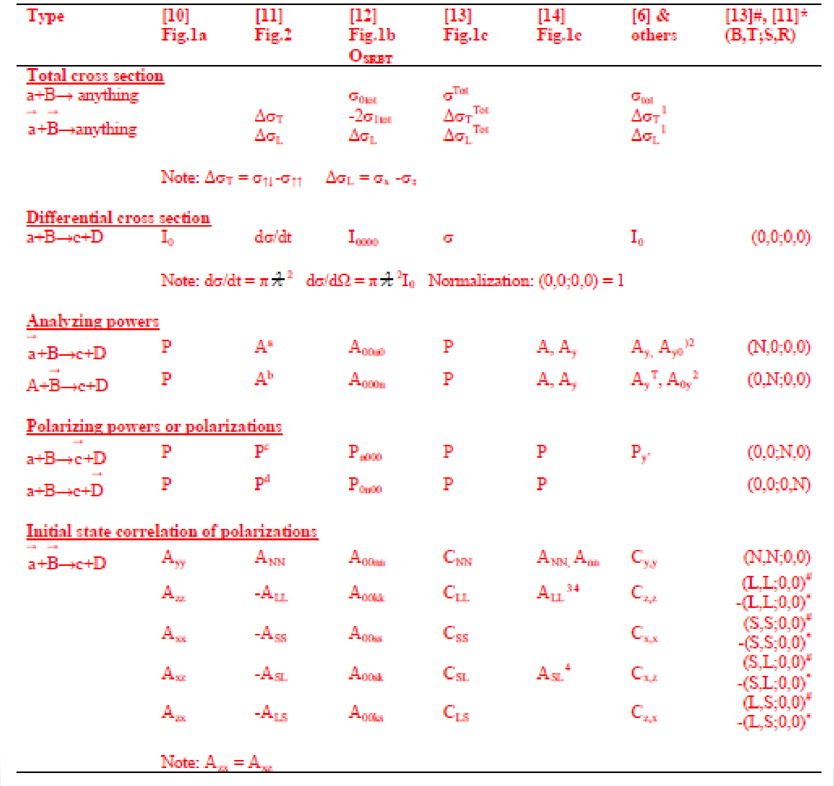
- Comparison of various notations are collected in LEXFOR. Compilers should determine the quantity code not by the symbol but by the definition.

- Compilation of complicated spin observables is not obligatory. You may simply skip them.

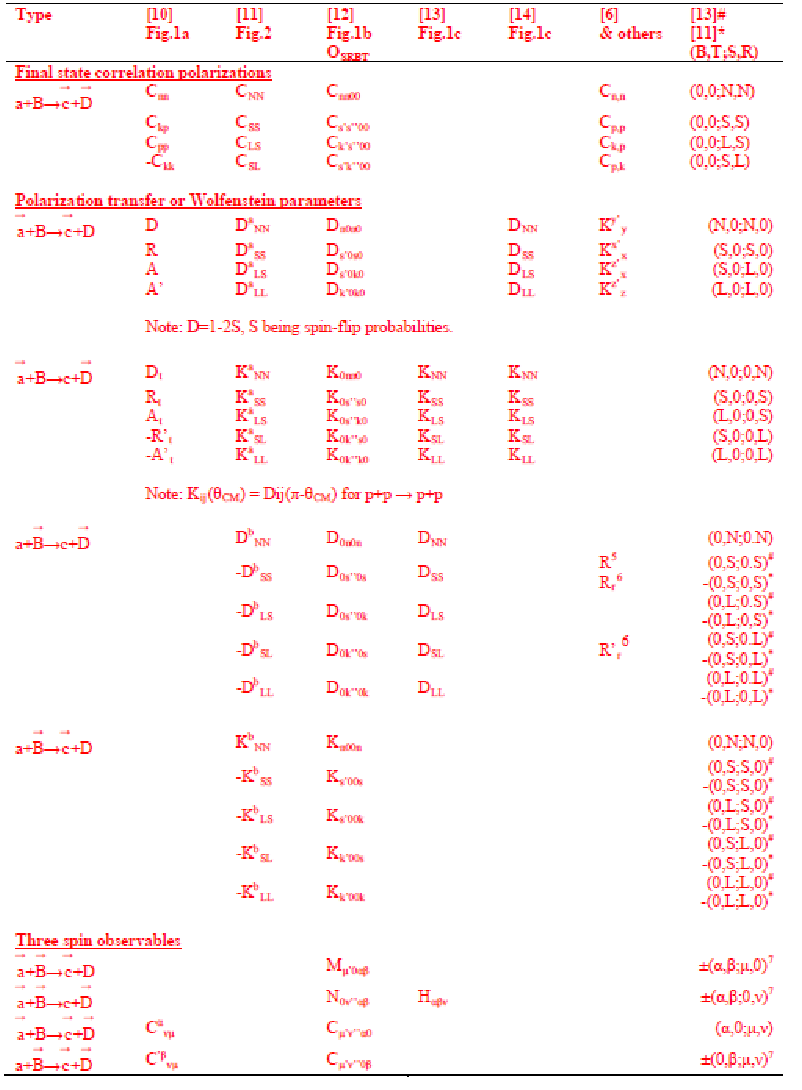
Various Notation of Spin Observables (cont)



LEXFOR P.12-P.14
(Polarization)
N. Hoshizaki et al.,
J.Phys.Soc.Jpn.55.S549(1986)



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							
$a+B\rightarrow$ anything			σ_{0tot}	σ^{Tot}		σ_{tot}	
$\vec{a}+\vec{B}\rightarrow$anything		$\Delta\sigma_T$ $\Delta\sigma_L$	$-2\sigma_{1tot}$ $\Delta\sigma_L$	$\Delta\sigma_T{}^{Tot}$ $\Delta\sigma_L{}^{Tot}$		$\Delta\sigma_T{}^1$ $\Delta\sigma_L{}^1$	
	Note: $\Delta\sigma_T = \sigma_{\uparrow\downarrow}-\sigma_{\uparrow\uparrow}$ $\Delta\sigma_L = \sigma_{\leftrightarrows}-\sigma_{\rightrightarrows}$						
Differential cross section							
$a+B\rightarrow c+D$	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)
$A+\vec{B}\rightarrow c+D$	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: $A_{zx} = A_{xz}$						



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							
$a+B\rightarrow\vec{c}+\vec{D}$	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							
$\vec{a}+B\rightarrow\vec{c}+D$	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.						
$\vec{a}+B\rightarrow c+\vec{D}$	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 → p+p						
$a+\vec{B}\rightarrow c+\vec{D}$		$D^b{}_{NN}$	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}			$(0,L;0.L)^{\#}$ $-(0,L;0,L)^{*}$
$a+\vec{B}\rightarrow\vec{c}+D$		$K^b{}_{NN}$	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							
$\vec{a}+\vec{B}\rightarrow\vec{c}+D$			$M_{\mu'0\alpha\beta}$				$\pm(\alpha,\beta;\mu,0)^7$
$\vec{a}+\vec{B}\rightarrow c+\vec{D}$			$N_{0\nu''\alpha\beta}$	$H_{\alpha\beta\nu}$			$\pm(\alpha,\beta;0,\nu)^7$
$\vec{a}+B\rightarrow\vec{c}+\vec{D}$	$C^{\alpha}{}_{\nu\mu}$		$C_{\mu'\nu''\alpha0}$				$(\alpha,0;\mu,\nu)$
$a+\vec{B}\rightarrow\vec{c}+\vec{D}$	$C'^{\beta}{}_{\nu\mu}$		$C_{\mu'\nu''0\beta}$				$\pm(0,\beta;\mu,\nu)^7$

International Atomic Energy Agency

Summary of Manual Updates

10. Conclusions

IAEA Nuclear Data Section
N. Otsuka

153

Conclusions

Too much complicate rule? Simplify coding rules?

> "The data we are compiling are getting ever more complicated. Compilation cannot be made a routine, secretarial-type job."
>
> (Otto Schwerer, presentation in the NRDC 2006 meeting)