Gamma-ray Spectrometry

Training Workshop on
Applications of Gamma-ray Spectrometry
to Environmental Samples

Use of Decay Data

Tim Vidmar, PhD

SCK.CEN, Belgian Nuclear Research Centre, Boeretang 200, Mol, Belgium

Tim.Vidmar@sckcen.be

13-15 November, 2012

Vinča Institute of Nuclear Sciences,
Belgrade, Serbia

Copyright notice

Contents

- Evaluated data
- Decay modes and decay schemes
- Some pitfalls when using nuclear data
- Sources of recommended nuclear data
- How to manage your data

Nuclear and Atomic Data

Which ones ?

The data describing the radioactive disintegration: half-life, emission energy and intensity of the various radiations

For what specific needs ?

- **metrology : detector calibration, simulation calculations, …**
- **medical use :**
  - diagnostic (Tc-99m, Tl-201, F-18, …),
  - therapy (Ir-192, I-131, Y-90, …)
- **Nuclear fuel cycle : burn-up, waste management, …**
- **Radiation protection**
- **…**

Decay Data Evaluation Project

- **The evaluation of data is time consuming**
- **An international working group was formed in 1995 (DDEP-project):**

  LNHB (France)
  PTB (Germany)
  INEEL and LBNL (USA)
  KRI (Russia)

- **Its objective is to provide carefully evaluated, recommended data**

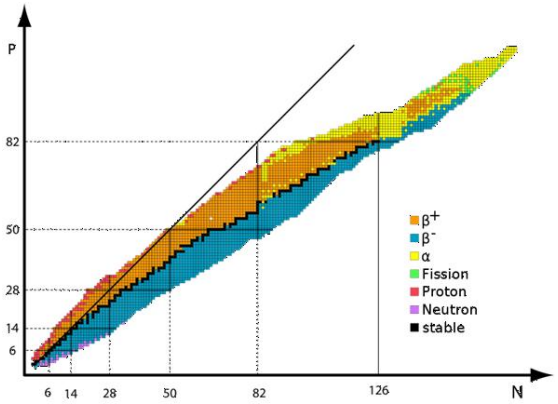
Decay Data Evaluation Project

The specific goals of this group are:

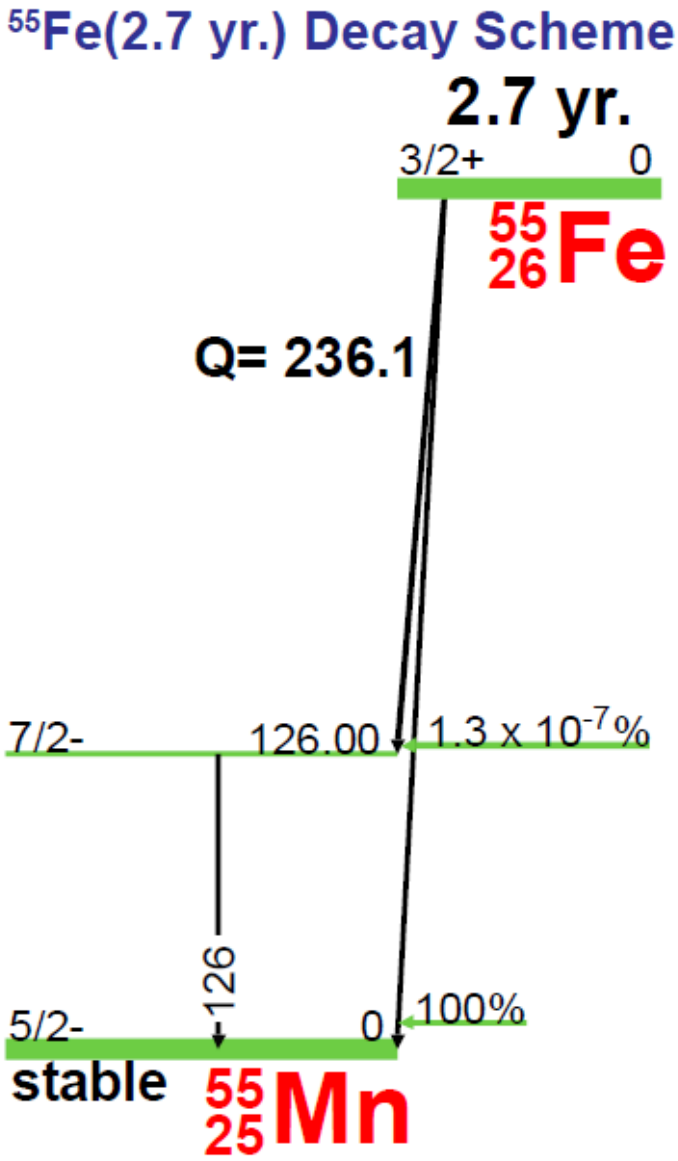
- to define a methodology to be used in the evaluations for specific data like Q-values or ICC and to choose a recommended set of values
- to provide written documentation of all the data used and all decisions taken and calculations performed
- To have a review of each new evaluation by several members of the group

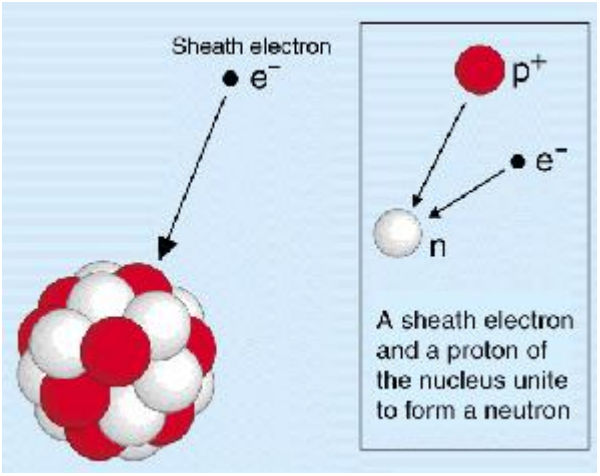
The results of these DDEP reports are compiled and edited by the LNHB and are available on their web site (see further on).

Reminders: disintegration modes



Electron capture transition



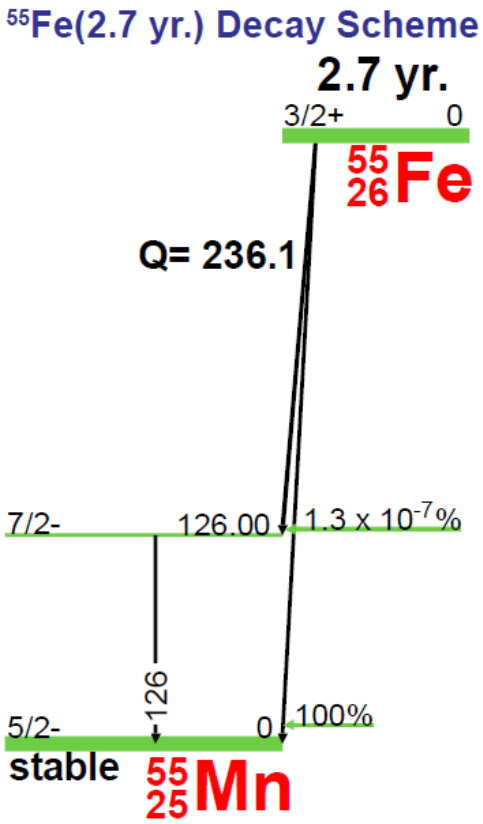


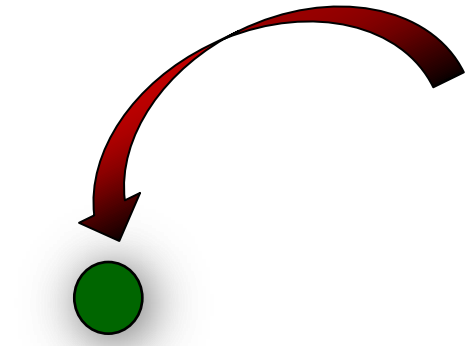
$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \nu $$

$$ p + e^{-} \rightarrow n + \nu $$

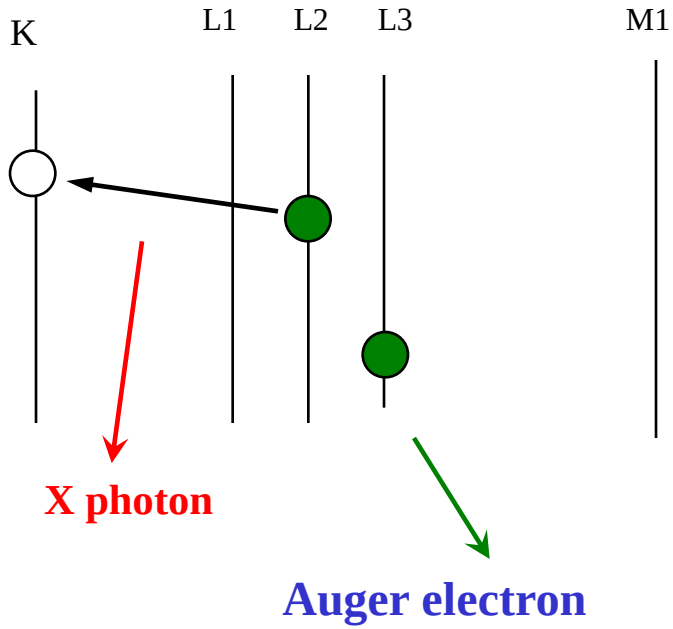
$$ P_K + P_L + P_M + \ldots = 1 $$

Electron capture transition





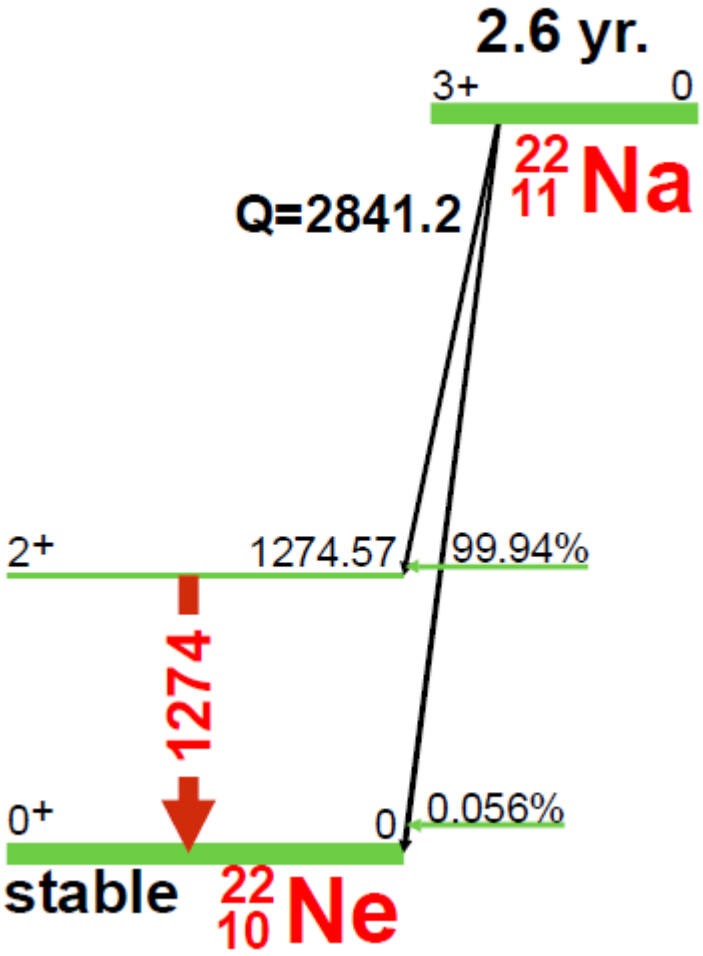
Captured electron

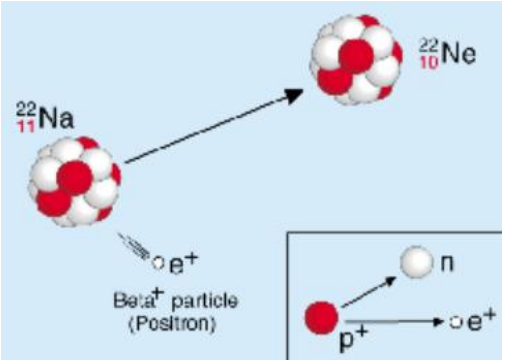


Emissions :

- Manganese K X- Rays (at 5,9 keV)
- Manganese Auger electrons

Electron capture and beta plus transition





$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + e^{+} + \nu$

$p \rightarrow n + e^{+} + \nu$

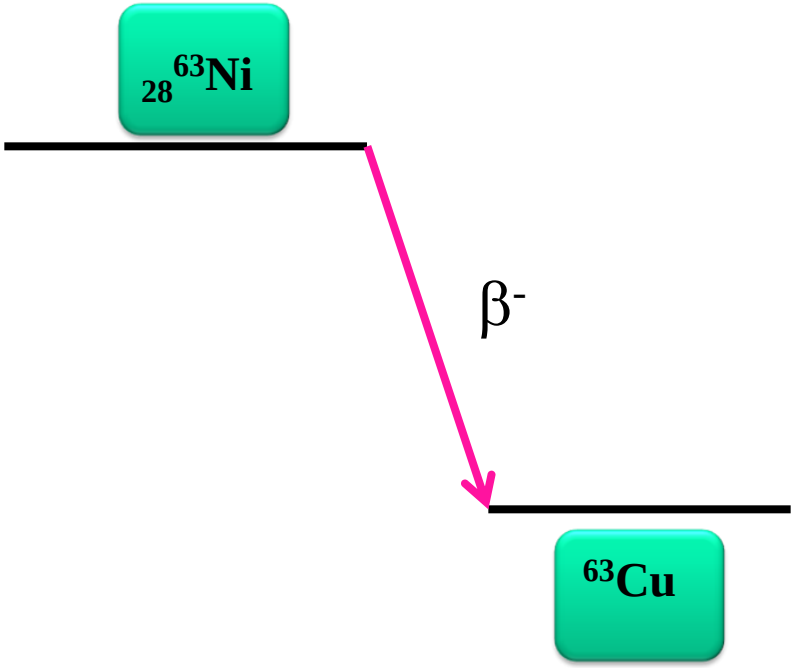
β^{+} is possible if :

$Q^{+} - E_i \geq 2m_0c^2$ (= 1022 keV)

Emissions :

- β+ → gamma 511 keV
- ec → photons X and Auger electrons
- γ transition → γ photons and conversion electrons

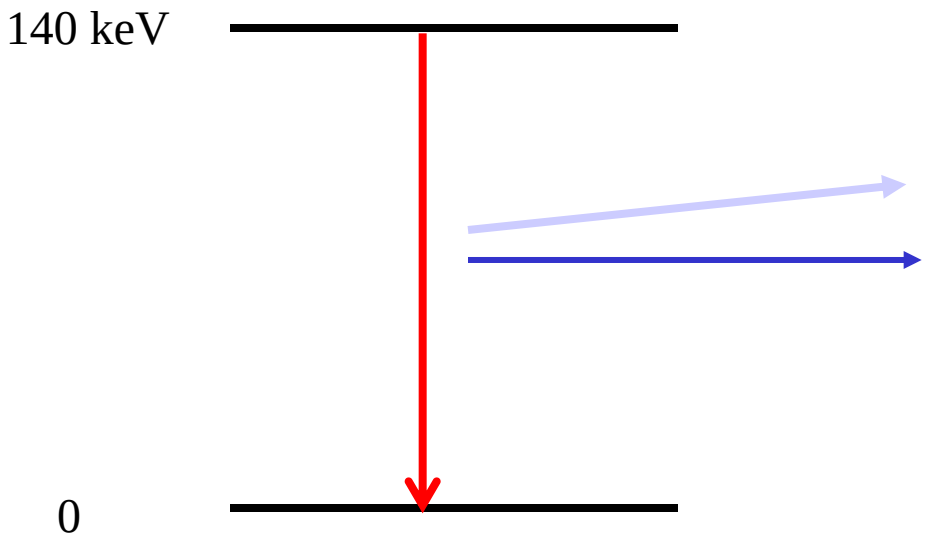
Beta minus transition



$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^{-} + \bar{\nu}$$

$$n \rightarrow p + e^{-} + \bar{\nu}$$

Gamma Transition



Gamma Transition T(ce+γ)

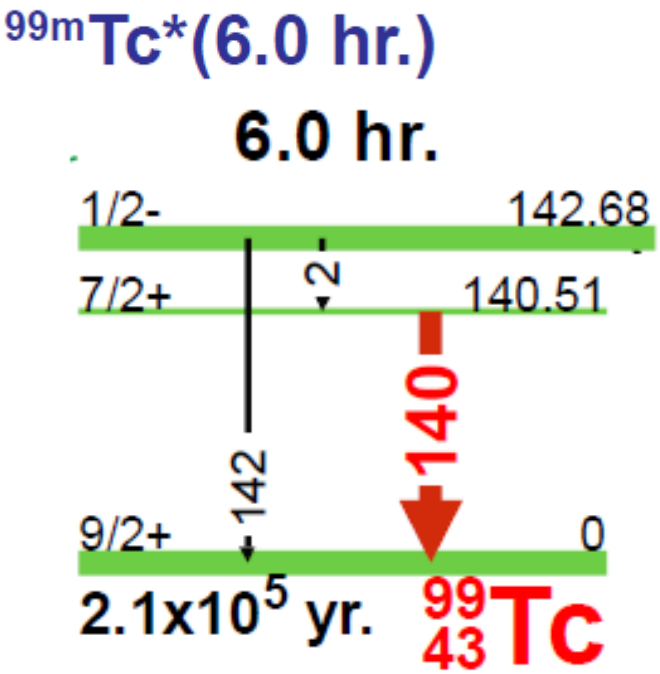
Emissions :

- **gamma photons** Iγ
- **conversion electrons I_{ce}**
- internal conversion coefficient (ICC)

$\alpha = I_{ce} / I\gamma$

$T(ce+\gamma) = (1 + \alpha_T)\, I\gamma$

Gamma Transition



Gamma Transition 140 keV = 99%

Emissions :

- **gamma photons = 88,5%**
- **conversion electrons = 10,5%**
- internal conversion coefficient

  α = Ice / Iγ

  T(ce+γ) = (1 + α_T) Iγ
- X photons
- Auger electrons

Data Organisation

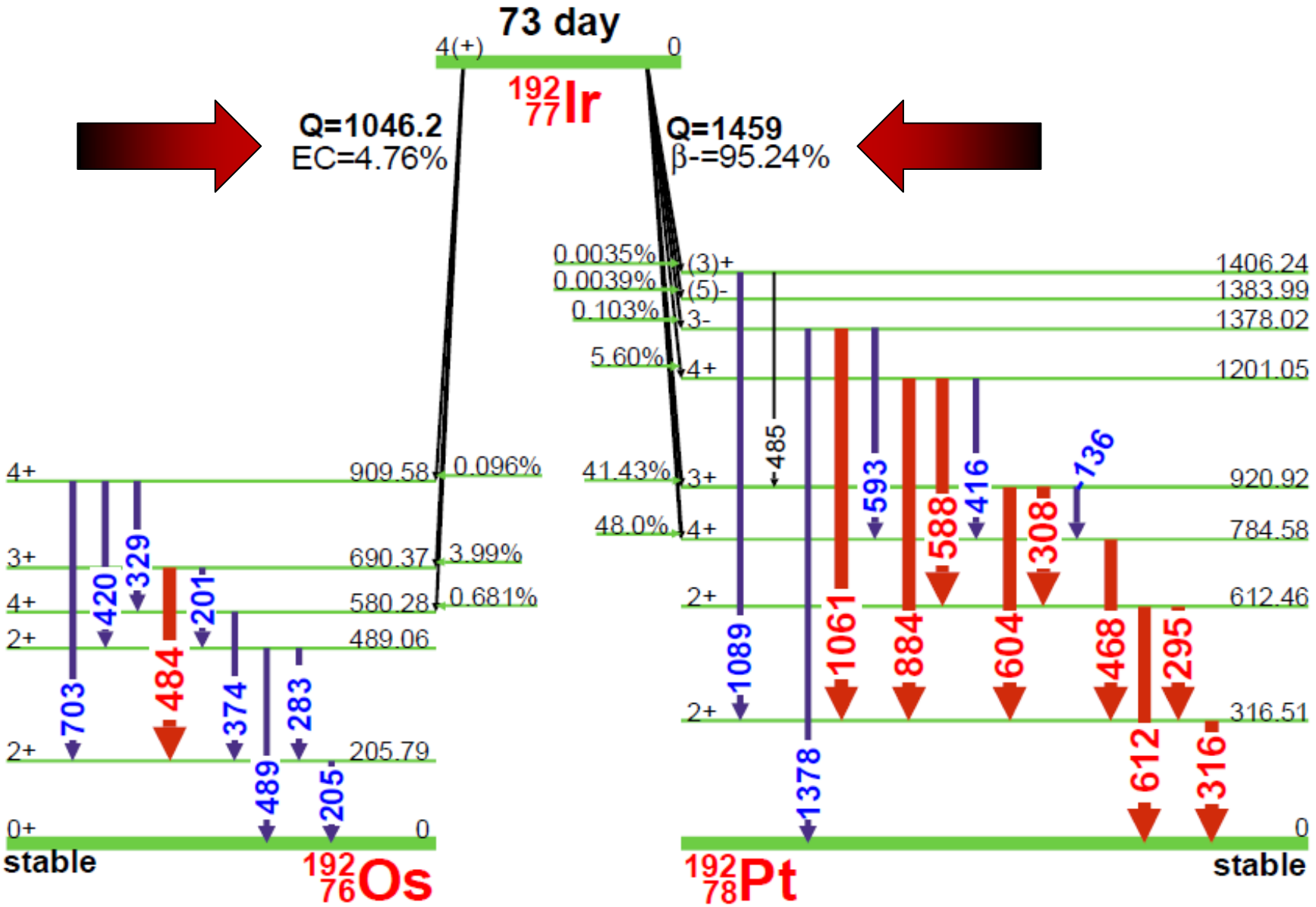
How are the data organised?

- **Parent** (+ daughter) → by branch (Nucléide, NuDat, IAEA Tecdoc)

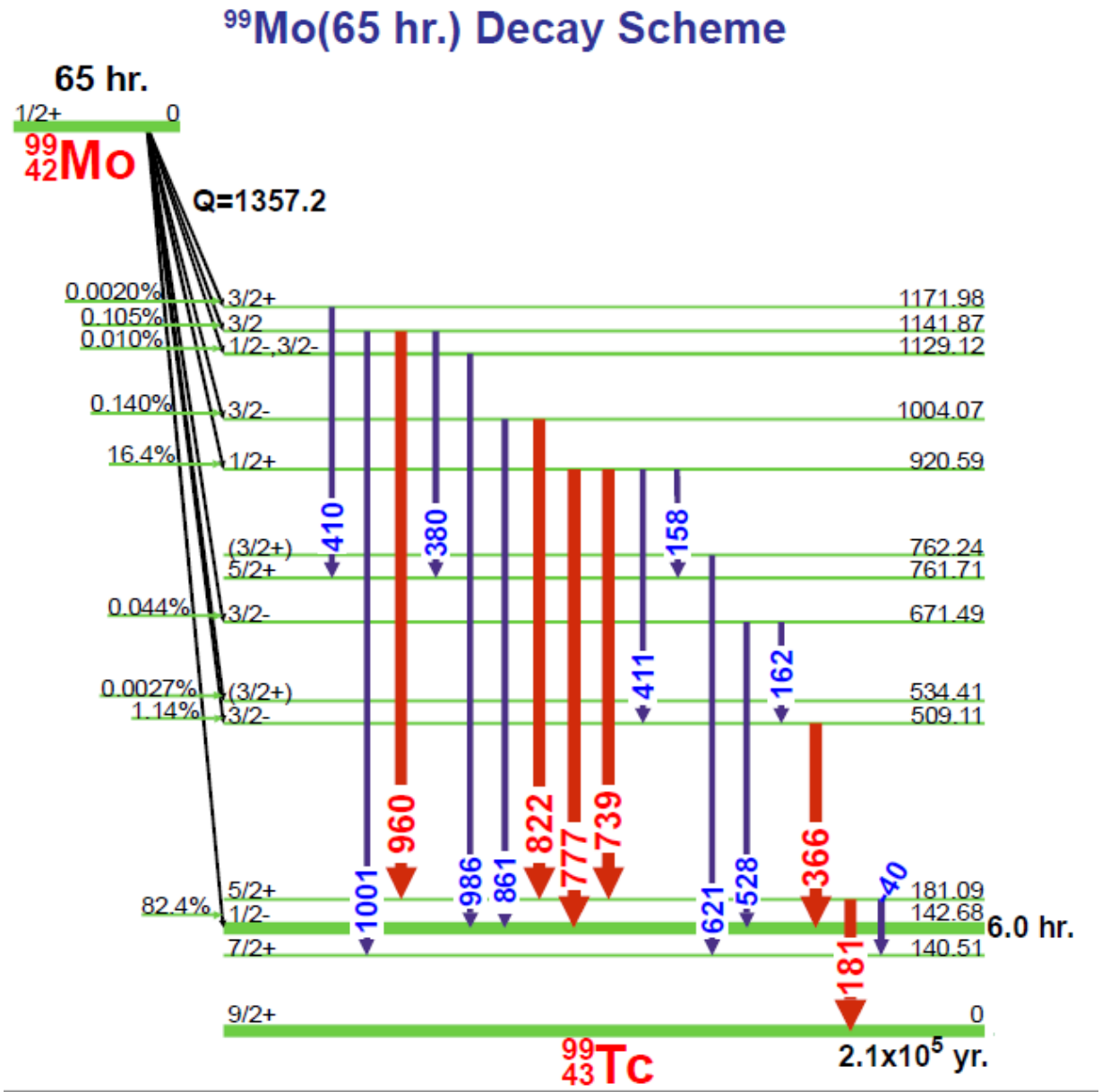
- By nucleus → gamma transitions belong to the daughter nucleus

  ⇒ selection of the **daughter** (ToI, NDS)

Data Organisation

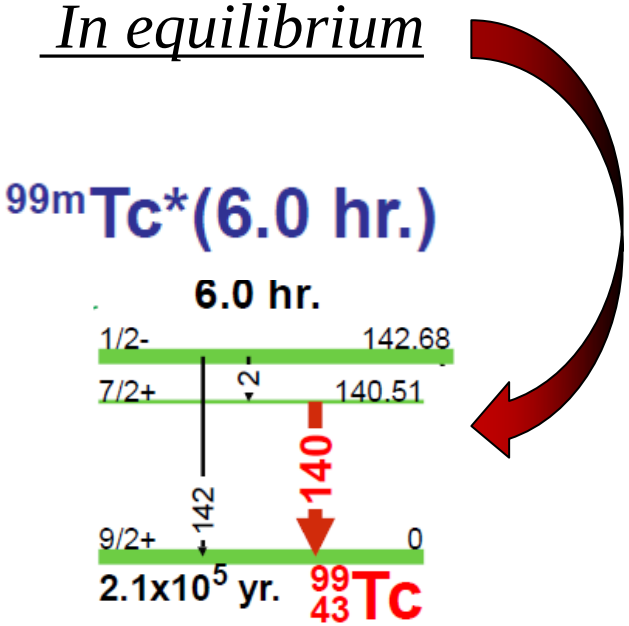


Nuclides in equilibrium

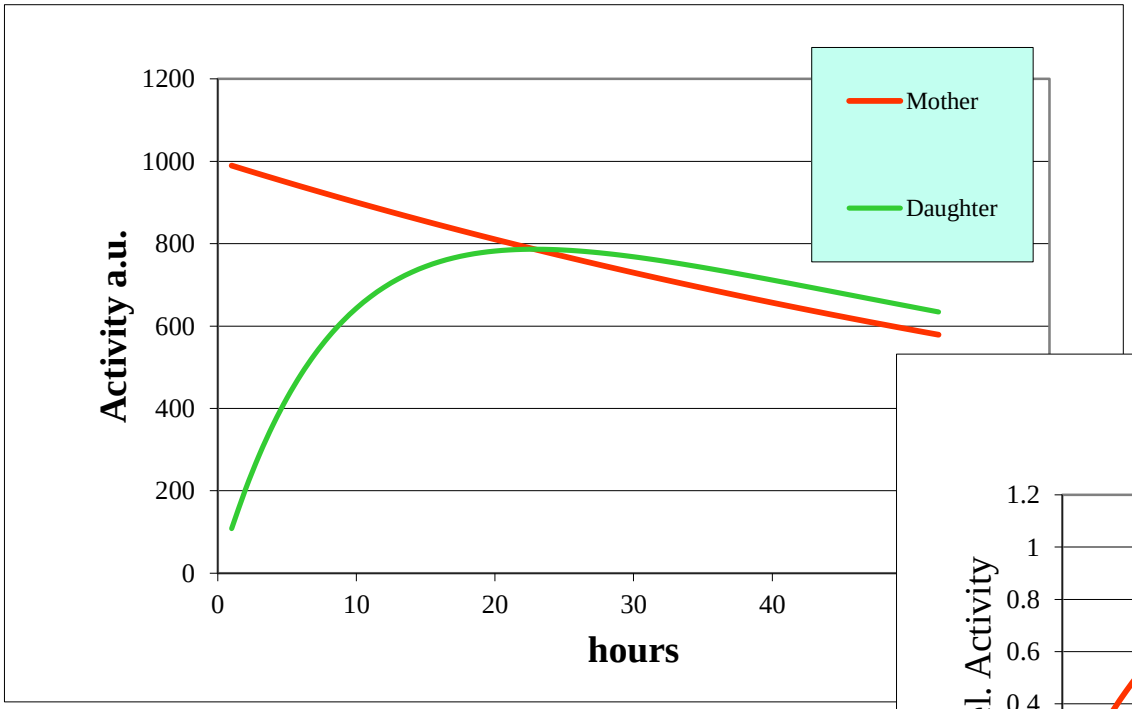


Iγ (140 keV) = **89,6%**

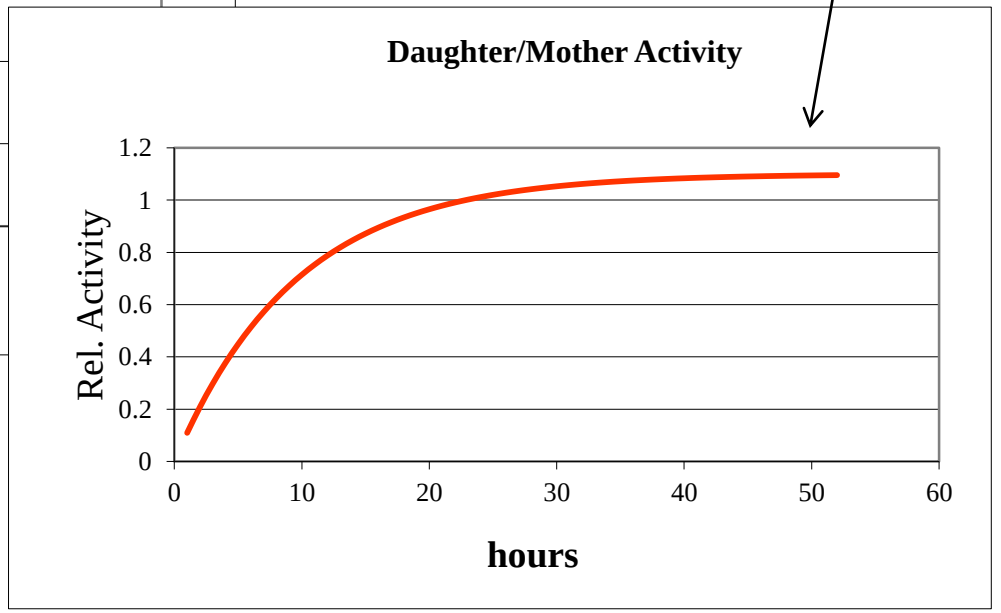
In equilibrium



Mo-99 and Tc-99m

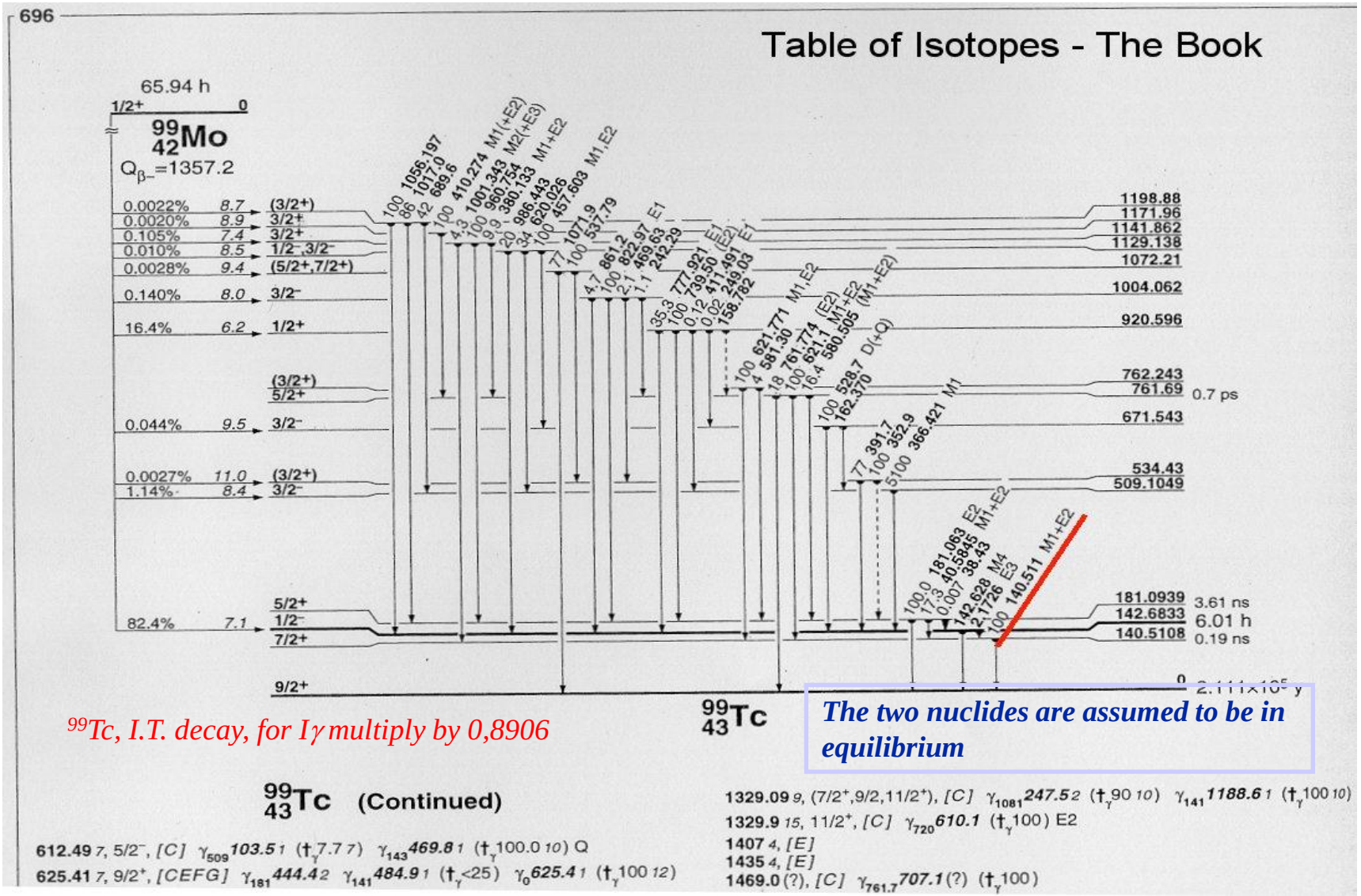


Ratio A(Tc)/A(Mo) = 1.1,
but due to branching
0.876(19) → 0.963,
for T > 60 h



Equilibrium or not ?

- What is the meaning of the values printed in a given table ?
- Must be carefully checked for each Table.


696
Table of Isotopes - The Book
65.94 h
1/2+ 0
99 42Mo
Qβ−=1357.2
99 43Tc
99 43Tc (Continued)
612.49 7, 5/2−, [C] γ509 103.5 1 (tγ 7.7 7) γ143 469.8 1 (tγ 100.0 10) Q
625.41 7, 9/2+, [CEFG] γ181 444.4 2 γ141 484.9 1 (tγ <25) γ0 625.4 1 (tγ 100 12)
1329.09 9, (7/2+,9/2,11/2+), [C] γ1081 247.5 2 (tγ 90 10) γ141 1188.6 1 (tγ 100 10)
1329.9 15, 11/2+, [C] γ720 610.1 (tγ 100) E2
1407 4, [E]
1435 4, [E]
1469.0 (?), [C] γ761.7 707.1 (?) (tγ 100)
99Tc, I.T. decay, for Iγ multiply by 0,8906
The two nuclides are assumed to be in equilibrium

Nulcear Data Sheets

^{99}Mo β$^-$ Decay 1992Go22 (continued)

γ(^{99}Tc) (continued)

Eγ†	E(level)	Iγ‡@	Mult.#	δ	α	Comments
140.511 *1*	140.5106	37.3 *19*	M1+E2	+0.129 *35*	0.114 *3*	α(K)=0.0993 *21*; α(L)=0.0120 *4*; α(M)=0.00218 *8*; α(N+..)=0.00042. α(K)exp=0.097 *3*; α(exp)=0.119 *3*. K/L=7.8 *3* (weighted average of 8.1 *5* (1969Ba03) and 7.70 *3* (1968Va14)); L1/L2=12 *4*; L1/L3=18 *7*; L2/L3=1.7 *7* (1969Ag04). Eγ: from curved-crystal measurement (1981He15). Others: E=140.512 *4* (1972Ga37), 140.511 *6* (1969Co18), 140.466 *15* (1990Me15). Iγ: 739 *8* (relative to Iγ(739γ)=100) (1992Go22); 747 *12* (1980Di16); in equilibrium including the prompt component. Others: Iγ=704 *45* (1969Co18), 649 *25* (1968Va14), 759 *20* (1980Ya10), 686 *49* (1982Si16), 755 *15* (1990Me15,1978MeZK); Iγ=660 *42* if %Iγ(prompt)=5.1 *4* as deduced from (n,γ) yield (1981Si15). δ: unweighted average of +0.118 *6* from γγ(θ) (1974Ga01), 0.194 *33* from α(exp), and 0.07 *7* from α(K)exp; 0.31 *2* (1982Si16). Mult.: α(K)exp: weighted average of 0.093 *6*, 0.096 *6* (both 1971Vo06), 0.094 *8* (1969Vu03), and 0.104 *7* (1968Va14); α(exp): weighted average of 0.118 *3* (1973Le29), and 0.122 *5* (1969Vu03).
142.675 *25*	142.6832	M4	39.9			α(K)=29.5; α(L)=9.2; α(M)=1.794; α(N+..)=0.352.

37 x 0,1213 = 4,52
The Mo-99 taken alone

@for absolute intensity multiply by 0,1213 (18)

Evaluation of data (main lines)

- **All published values are examined and analysed.**
- **Some values can be rejected or some unrealistic uncertainties increased.**
- **Then averaging procedure can begin.**

Building the decay scheme (2)

- **From gamma emission intensities, gamma transition probabilities can be calculated through the ICC : $T\gamma = (1 + \alpha_T)\, I\gamma$**
  (Where ICC are deduced from theoretical tables)

- **Then, from the transition probability balance at each nuclear level, the alpha transition probabilities are deduced.**

- **In particular : the sum of all the transitions feeding the ground state is equal to 100**

  $$\Sigma\,(T\gamma_i) + T\alpha_{gs} = 100$$

  [For Ra-226 → Rn-222 :
  $T\gamma(1,0) + T\gamma(3,0) = 5{,}97 + 0{,}00051$ → $T\alpha(0,0) = 94{,}03\ (8)\ \%$]

- **Deduced alpha intensities are compared with measured values.**

Data obtained by theoretical calculations

Sub shells capture probabilities : P_K, P_{L1}, P_{L2}, P_{L3}, P_M,….

- Schönfeld, report PTB-6.33-95-2 (for allowed and non-unique transitions)

- “logft program” (ENSDF)

Internal conversion coefficients (ICC) : α_K, α_{L1}, α_{L2}, α_{L3}, α_M, …

- Rösel *et al.*, Atomic Data Nuclear Data Tables 21 (1978) 91

- Band *et al.*, Atomic Data Nuclear Data Tables 81 (2002) 1

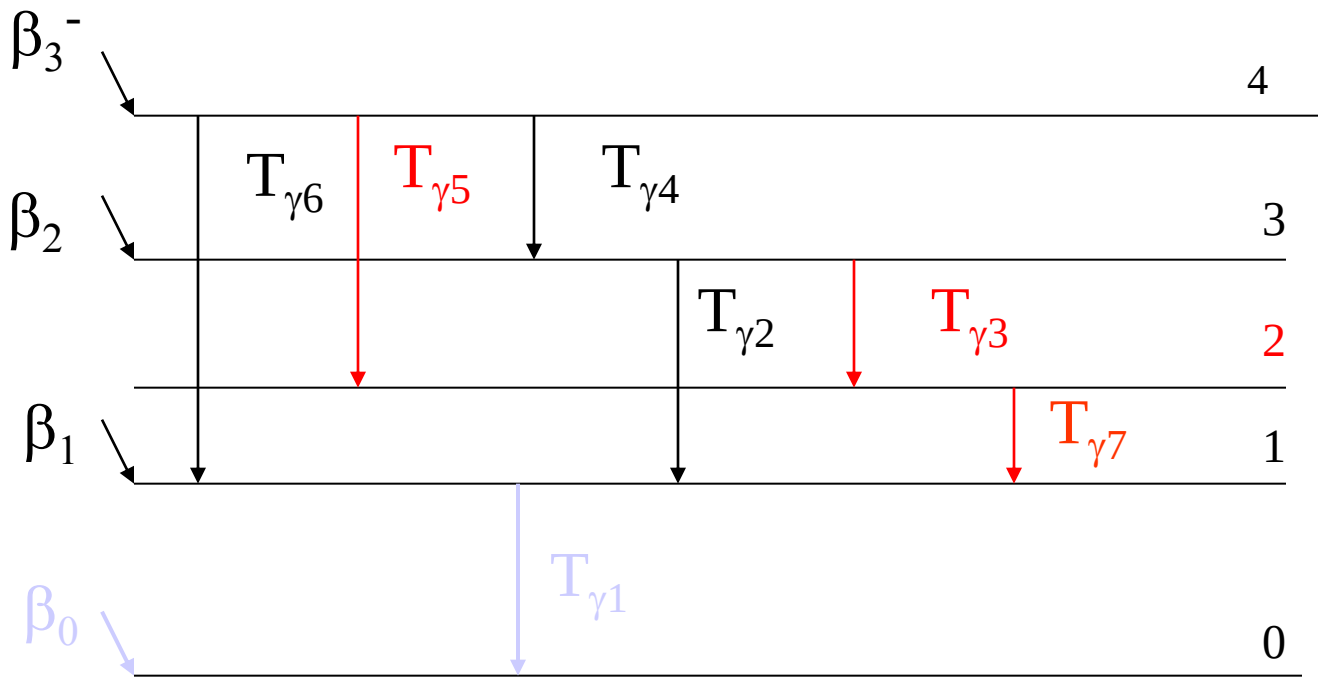
Consistency of the decay scheme

Level balance

Energy conservation

X-ray emission intensities are calculated from the data set (EC probabilities, gamma transition probabilities, …) and they should be equal to the measured values. Unfortunately, they are often missing.

Transition probabilities balance



$T(\gamma_7) = T(\gamma_5) + T(\gamma_3)$

Where $T\gamma_7 = I(\gamma_7) \times [1 + \alpha(\gamma_7)]$

$T(\gamma_1) = T(\gamma_6) + T(\gamma_2) + T(\gamma_7) + T(\beta_1)$

$T(\gamma_1) + T(\beta_0) = 100$

$\Sigma\, T(\beta_i) = 100$

Remarks

The quality of the evaluated data and of the decay scheme depends on the measured values :

The higher the amount of data points
And the more the measurements have been carried out carefully

→ The more the decay scheme will be consistent

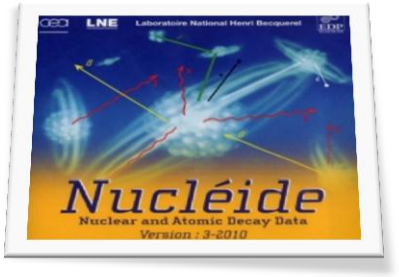
Before using the data, ask yourself :

- What is the exact meaning of this value ?
- How has this value been obtained ?

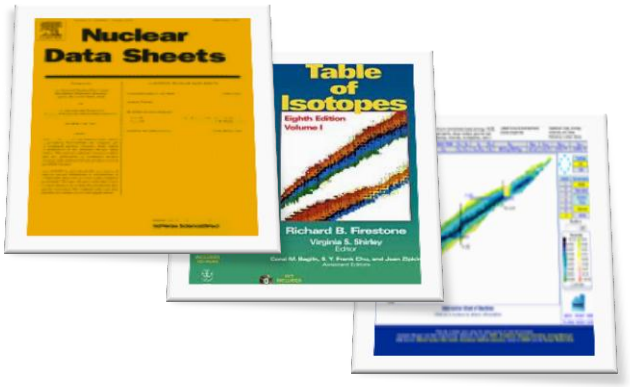
Databases

There are a few independent databases only :

Nucléide (DDEP) → **CD-Rom**
Monographie BIPM - 5
New IAEA Tecdoc



ENSDF → **Nuclear Data Sheets**
Table of Isotopes
Nubase
NuDat



Web pages

www.bnm.fr/bnm-lnhb/NucData.htm **= DDEP pages**

www.nndc.bnl.gov **= Nuclear Data Sheets (ENSDF)**

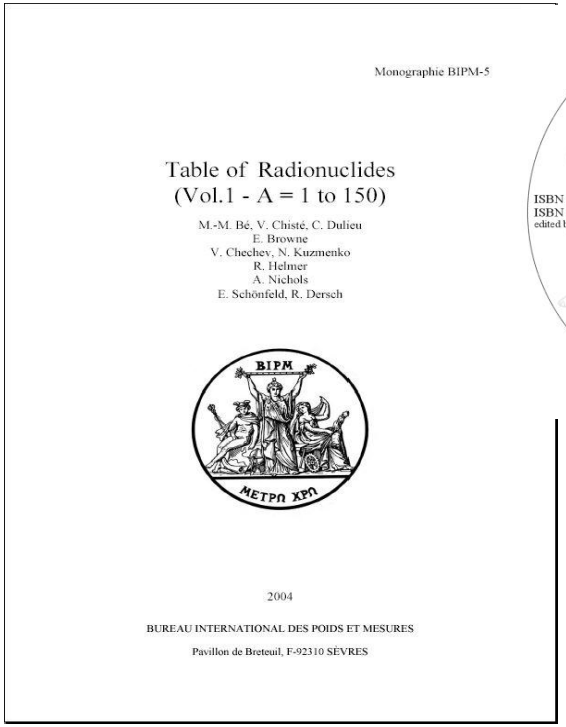
ie.lbl.gov/toi **= Table of Isotopes**

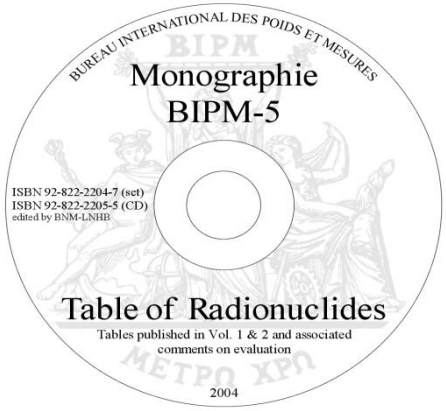
www.iaea.or.at/programmes/ripc/nd/ **= ENSDF copy**

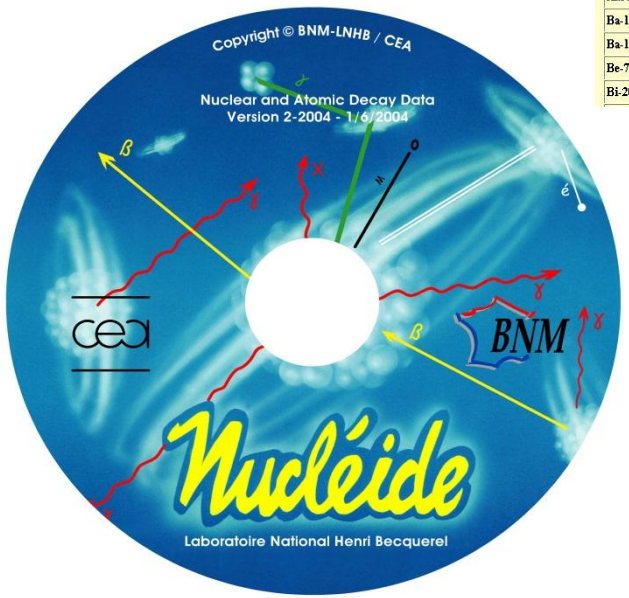
id.inel.gov/gamma/data1.html **= γ spectra catalogue**

www-csnsm.in2p3.fr/amdc/ **= atomic masses**

Publications







Web site :
www.nucleide.org

How to manage your nuclear data

- **Secure data to avoid unwanted alterations**
- **Use one mother dataset as source to create smaller data sets (always start from the mother data)**
- **Store data centrally (use file synchronisation of if multiple users need independent access)**
- **Document history of data evolution (traceability should be guarantied)**

How to manage your nuclear data

- **Nuclear data has to be selected according to the specifics of their use (e.g. low-resolution versus high-resolution gamma-ray spectrometry**
- **Consider carefully those cases where activity of the mother is reported based on the detection of the daughter (e.g., Ra-226)**