

Explanation of the Chart of the Nuclides

General

In this chart each experimentally observed nuclide is represented by a square containing the symbol of the element and the number of nucleons A. In the chart the nuclides are arranged such that the proton number Z is given on the ordinate and the neutron number $N = A - Z$ on the abscissa.

In the present nuclide chart update, the 1998 edition of the Karlsruhe Nuclide Chart was compared to the NUBASE 2003 evaluation [16] to establish a list of nuclides which were not present in the 1998 evaluation. From this list we have selected only nuclides which have been measured experimentally. In particular, nuclides were selected where the half-life or the mass has been determined or the nuclide has been clearly identified. Where a nuclide has been identified but the half-life has not been measured, a detection limit for half-life is given (greater or lower than a value).

Metastable states, which do not undergo α -, or β -decay, or spontaneous fission, i.e. decay only by gamma emission, are included only if their half-life is larger than 1 s. Where emission of a particle results from a resonance state in unstable nuclides, both the resonance width and corresponding half-life are given using the relations:

$$\Gamma_{c.m.} T_{1/2} \cong \hbar \ln 2, \quad T_{1/2}(s) \cong 4.562 \times 10^{-22} / \Gamma_{c.m.}(\text{MeV})$$

For mass numbers in the range $A = 266 - 294$ we have used the latest 2005 (till August 12, 2005) Nuclear Data Sheets revision [17]. For the period not covered by NUBASE, i.e. 2003 until summer 2006, nuclide information has been taken from Nuclear Data Sheets 100 - 107. In addition, original publications up to summer 2006 were taken into account. A full list of new and updated nuclides in the present chart is given later in this brochure.

Atomic weights of the elements and isotopic abundances have been taken from J. R. De Laeter [18]. For isomers which decay exclusively by spontaneous fission, no decay data is given in the chart. A table of half-lives (all less than 0.1 s), from B. Singh [19], are given in the brochure. Chain yields are from R. W. Mills [20] and neutron cross sections are from N. E. Holden [21].

Explicatii privind Harta nuclizilor

Generalitati

In aceasta harta fiecare nuclid observat experimental este reprezentat printr-un patrat continand simbolul elementului si numarul de nucleoni, A. Aranjarea in cadrul acestei harti este facuta astfel: pe ordonata este trecut numarul de protoni Z, iar pe abscisa numarul de neutroni $N = A - Z$.

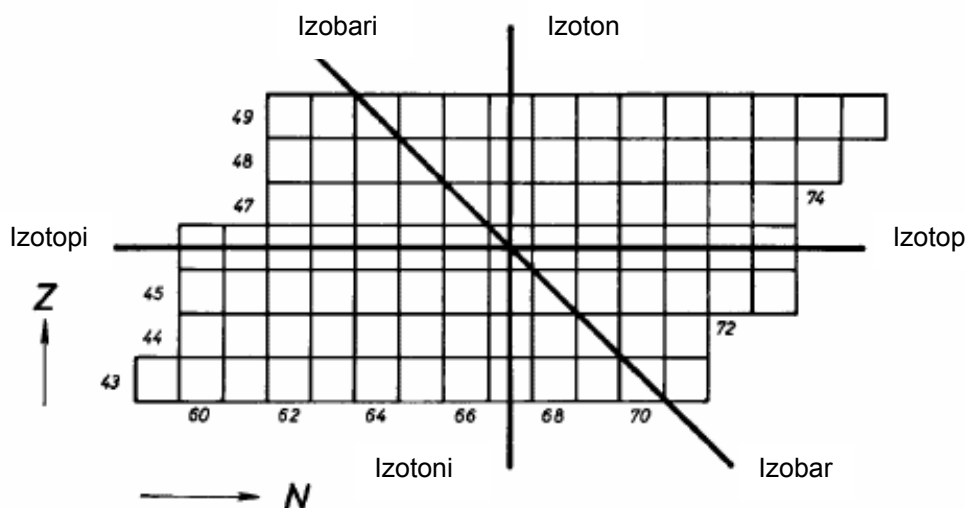
In cadrul acestei harti revizuite a nuclizilor, editia 1998 a Hartii Nuclizilor din Karlsruhe a fost comparata cu evaluarea NUBASE 2003 [16] in vederea crearii unei liste a nuclizilor care nu erau prezenti in evaluarea din 1998. Din aceasta lista, au fost selectati doar acei nuclizi care au putut fi determinati experimental. In particular, nuclizii au fost selectati daca au fost determinate timpul de injumatire sau masa sau daca au fost identificati in mod clar. Daca a fost identificat un nuclid al carui timp de injumatire nu a fost masurat, atunci este data o limita de detectie a timpului de injumatire (mai mare sau mai mica decat o anumita valoare).

Stariile metastabile care nu sufera dezintegrare α , β sau fisiune spontana, ci doar emisie gamma, sunt incluse numai daca timpul lor de injumatire este mai mare de o secunda. Daca emisiunea unei particule rezulta dintr-o stare de rezonanta a unor nuclizi instabili, atat latimea de rezonanta cat si timpul de injumatire corespunzator sunt date folosind urmatoarele relatii:

$$\Gamma_{c.m.} T_{1/2} \cong \hbar \ln 2, \quad T_{1/2}(s) \cong 4.562 \times 10^{-22} / \Gamma_{c.m.}(\text{MeV})$$

Pentru numerele de masa cuprinse in intervalul $A = 266 - 294$ s-au folosit Fisele de Date Nucleare aflate la ultima revizie din 2005 (pana la 12 august 2005). Pentru perioada de timp neacoperita de NUBASE, din 2003 pana in vara anului 2006, informatiile despre nuclizi au fost luate din Fisele de Date Nucleare 100 - 107. In plus, au fost luate in considerare publicatiile originale pana in vara anului 2006. In aceasta brosură este prezentata o lista completa a nuclizilor noi si a celor actualizati in prezenta harta a nuclizilor.

Masele atomice ale elementelor si abundentele izotopice au fost luate de la J.R. De Laeter [18]. Pentru izomerii care se dezintegreaza exclusiv prin fisiune spontana nu sunt prezentate date despre dezintegrare. In brosură este dat si un tabel al timpilor de injumatire (toti sub 0.1 secunde), preluat de la B. Singh [19]. Randamentele de fisiune sunt preluate de la R.W.Mills [20], iar sectiunile eficace pentru neutroni de la N.E. Holden [21].



[16] G. Audi, O. Bersillon, J. Blachot and A.H. Wapstra, The NUBASE evaluation of nuclear and decay properties, Nuclear Physics A, 2003, 729, 3 (2003).

[17] M. Gupta and T. W. Burrows, Nuclear Data Sheets 106, 251 (2005).

[18] J. R. De Laeter, J. K. Bohlke, P. De Bièvre, H. Hidaka, H. S. Peiser, K. J. R. Rosman, and P. D. P. Taylor, Atomic Weights of the Elements: Review 2000, Pure & Appl. Chem., 75, 683 (2003).

[19] B. Singh, R. Zywina, and R. Firestone, Table of Superdeformed Nuclear Bands and Fission Isomers, 3rd Edition, Nuclear Data Sheets 97, 241 (2002).

[20] A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama "JEFF Report 2.1: The JEFF-3.1 Nuclear Data Library". OECD/NEA Report to be published. See also R. W. Mills "Fission Product Yield "Evaluation", Thesis, 1995, The University of Birmingham, UK.

[21] N. E. Holden, Neutron Scattering and Absorption Properties, Handbook of Chemistry and Physics on CD-ROM, version 2006, 11-185, Ed. D.R. Lide, CRC Press, Boca Raton, Florida.

Decay Modes: Colour and Symbols

Stable nuclide



Primordial radionuclides, i.e. those formed in the build-up of terrestrial matter and still present today.



Decay modes are represented by specific colours.

- p: Proton decay
- α : Alpha decay
- ϵ : Electron capture
- β^+ : Positron decay
- I_γ : Isomeric transition
- β^- : Negatron decay
- sf: Spontaneous fission
- ce: Cluster emission e. g. C 14, Ne 20
- n: Neutron emission



The data given in the left part apply to the metastable state, those in the right part to the ground state. I_γ denotes γ -quanta due to the decay to the ground state of the same nuclide (isomeric decay).



The assignment of decay properties to the metastable or ground state is uncertain.



One or more short-lived states, for which only decay via spontaneous fission has been observed (spontaneously fissioning isomers) are indicated by a vertical green bar.



Emission of γ -quanta; they are always listed together with the respective parent nuclide.

γ

Emission of the specified particles or spontaneous fission from an excited level of the daughter nuclide, populated via β -decay (" β -delayed particle emission or fission").

$\beta_x p$; $\beta_x n$;
 β_d ; β_t ;
 $\beta_x \alpha$; $\beta_x sf$

Simultaneous emission of two β -particles (" β -double decay", e.g. Te 130 \rightarrow Xe 130).

$2\beta^-$

Emission of the specified particles from a particle-unstable nuclide. Simultaneous emission of two particles is indicated only, if one-particle-emission is excluded for energetical reasons (e.g. Be 6 \rightarrow 2p).

p; n
2p; 2 α

Multiple Decay Modes and Branching Ratios

The branching ratios of the decay modes are indicated by 3 different sizes of the coloured sections and by the sequence of the symbols. Pure decay modes are indicated by a single colour (e.g. see previous section). Mixed decay modes are indicated by the use of coloured triangles. A small coloured triangle in the top left or bottom right indicates a branching ratio for this mode of $\leq 5\%$ (conversely, the major mode has a branching ratio of $\geq 95\%$) as shown in the figure. The small triangles representing proton or alpha emission are always on the top left corner (first two boxes). The triangles for β^-

Moduri de dezintegrare: culori si simboluri

Nuclid stabil

Nuclizi primordiali, acei nuclizi aparuti in timpul formarii materiei terestre si inca prezenti astazi

Modurile de dezintegrare sunt reprezentate prin culori specifice

- P: dezintegrare prin emisie de protoni
- α : dezintegrare alfa
- ϵ : captura electronica
- β^+ : dezintegrare prin emisie de pozitroni
- I_γ : tranzitie izomera
- β^- : dezintegrare prin emisie de electroni
- sf: fisiune spontana
- ce: emisie cluster, ex. C14, Ne20
- n: emisie de neutroni

Datele prezentate in partea stanga sunt referitoare la starea metastabila, cele prezentate in partea dreapta la starea fundamentala. I_γ indica emisia de cuante γ datorita trecerii in starea fundamentala a aceluasi nuclid (relaxare izomera).

Atribuirea proprietatilor de dezintegrare starii metastabile sau starii fundamentale este incerta.

Una sau mai multe stari cu viata scurta pentru care a fost observata doar dezintegrare prin fisiune spontana (izomeri fisionabili spontan) sunt indicate printr-o bara verticala de culoare verde.

Emisie de cuante γ ; ele sunt prezentate intotdeauna impreuna cu nuclidul parinte corespunzator

Emisia unor anumite particule sau fisiune spontana a unui nuclid aflat intr-o stare de excitatie, produs de filiatie prin dezintegrari β (" β -fisiune β^- intarziata sau emisie β^- intarziata de particule")

Emisie simultana de doua particule (" β -dezintegrare β dubla", ex. Te 130 \rightarrow Xe 130).

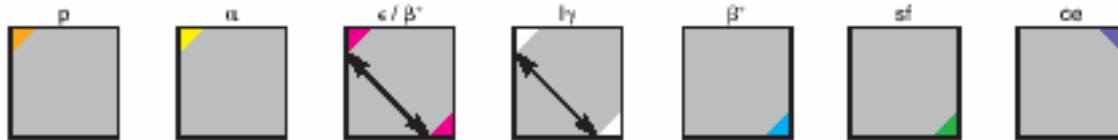
Emisia particulelor specificate de catre un nuclid instabil. Emisia simultana a doua particule este indicata doar daca emisia unei singure particule este exclusa din motive energetice (ex. Be 6 \rightarrow 2p).

Moduri de dezintegrare multipla si factori de ramificare

Factorii de ramificare ai modurilor de dezintegrare sunt indicati prin 3 marimi diferite ale sectiunilor colorate si prin succesiunea simbolurilor. Modurile unice de dezintegrare sunt indicate printr-o singura culoare (ex. vezi sectiunea precedenta). Modurile multiple de dezintegrare sunt indicate prin folosirea de triunghiuri colorate. Un mic triunghi colorat in partea stanga sus sau dreapta jos indica un factor de ramificare pentru acest mod $\leq 5\%$ (in consecinta modul principal are un factor de ramificare $\geq 95\%$) dupa cum este aratat in figura. Triunghiurile mici reprezentand emisie de protoni sau alfa sunt prezentate intotdeauna in partea stanga

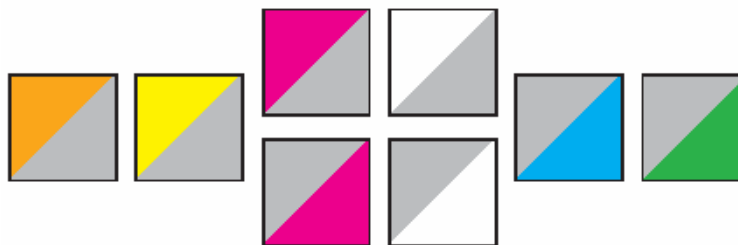
emission or spontaneous fission are always at the bottom right. Triangles representing ϵ/β^+ or I_γ may be at the top left or bottom right depending on the major mode. For ϵ/β^+ , the red triangle is at the bottom right if the main mode is alpha or proton emission.

Otherwise, the red triangle is at the top left corner. For isomer transition I_γ , the white triangle is at the bottom right if the main mode is α - or p- emission or ϵ/β^+ , otherwise it is at the top left corner. Cluster emission is always indicated with a small triangle in the top right corner. Hence the location of the small triangles is as follows:



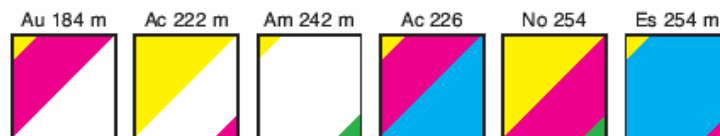
If the branching ratio of the minor mode is in the range 5 – 50% (implying a branching ratio for the major mode in the range 50 – 95%), the box is divided into two by a diagonal connection the lower left and top right corners. The location of the large triangles is similar to that described above.

Daca factorul de ramificare al modului secundar de dezintegrare este cuprins intre 5 si 50% (in consecinta factorul de ramificare a modului principal de dezintegrare este cuprins intre 50 si 95%), casuta este impartita in doua de diagonala ce leaga coltul din dreapta jos de cel din dreapta sus. Locatia triunghiurilor mari este similara cu cea descrisa anterior.



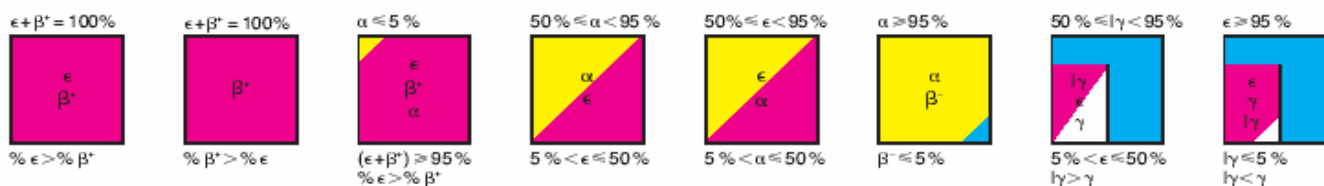
In some cases, three decay modes are possible. Some examples are shown below.

In unele cazuri sunt posibile trei moduri de dezintegrare. Mai jos sunt prezentate cateva exemple:



Examples:

Exemple:



The symbols for the particle emitting decay modes are arranged according to branching ratio with the highest branching ratio first, followed by γ -quanta and conversion electrons. The data for the isomeric decay have been arranged corresponding to the branching ratio of the decay mode. β -delayed particles or fission (β_n , β_p , β_{sf}) precede or follow the γ -quanta according to the relative intensities.

For a given type of radiation the sequence of the energies corresponds to the relative intensities (in decreasing order) of the respective radiation. In case of β -decay a slightly different rule is used (see below).

Points indicate further transitions of the same type with lower intensities.

Energies are given in keV for γ -quanta, in MeV for all kinds of particles. A radiation symbol without energy value indicates that the radiation occurs but the energy has not been measured.

Endpoint energy of the most abundant β -transition. In case further transitions with higher energies exist, the second number corresponds to the highest endpoint energy observed.

β -transitions with known energies, for which the sum of their abundances is less than 1%.

Electron capture is specified only, if it is more probable than β^+ -decay.

Particle energies listed according to decreasing probabilities of the respective transitions. At least one energy is given, even if the abundance of the most prominent group is less than 1%.

Energies of the strongest γ -quanta arranged in order of decreasing intensities. Intensities less than 1% are given in brackets.

γ -Energies followed by an asterisk denote transitions after β -delayed particle emission.

Several γ -quanta of unknown intensities within the energy interval 291-1319 keV.

Conversion electrons are specified only if they are more abundant than the γ -quanta. Energies are not quoted.

Cross Sections

All cross sections are given in barn (10^{-24} cm²) and refer to reactions with thermal neutrons (0.0253 eV).

Cross section for the (n, γ) reaction. If two values are given, the first refers to the formation of the product nucleus in the metastable, the second to the formation in the ground state.

Fission cross section

(n, p) cross section

(n, α) cross section

Absorption cross section

Additional Symbols and Abbreviations

Chain yield (%) for the thermal neutron fission of U235 (above) and Pu239 (below) the arrowed line.

Nuclides with a closed neutron or proton shell are characterized by heavy horizontal or vertical lines.

The symbols "m" and/or "g" indicate that the metastable and/or ground state of the daughter nuclide is populated, respectively. The symbols are presented in order of decreasing probability. Branches with probabilities less than 5% are not shown. Subscripts on "m", e.g. m_1 , m_2 , are used to denote different metastable states (with m_2 being a higher energy state than m_1).

Data or assignment uncertain.

Nanosecond, microsecond, millisecond, second, minute, hour, day, year.

Simbolurile pentru modurile de dezintegrare prin emisie de particule sunt aranjate conform factorilor de ramificare, factorul cel mai mare fiind primul, urmat de cuantele γ si electronii de conversie. Datele pentru dezintegrarea izomera au fost aranjate conform factorului de ramificare al modului de dezintegrare. Fisiunea intarziata sau emisia intarziata de particule (β_n , β_p , β_{sf}) precede sau urmeaza cuantelor γ conform intensitatilor relative.

Pentru un anumit tip de radiatie secventa energiilor corespunde intensitatilor relative (in ordine descrescatoare) ale radiatiei respective. In cazul dezintegrarii β este folosita o regula putin diferita.

Punctele indica tranzitii ulterioare de acelasi tip, dar cu intensitati mai scazute.

Energiile sunt date in keV pentru cuantele γ si in MeV pentru toate tipurile de particule. Un simbol de radiatie fara valoare a energiei indica faptul ca acea radiatie apare, dar energia nu a fost masurata.

Energia finala a celei mai abundente tranzitii β . In cazul in care exista tranzitii ulterioare cu energii mai ridicate, al doilea numar corespunde energiei finale observate avand energia cea mai ridicata.

Tranzitii β cu energii cunoscute, pentru care suma abundentelor lor este mai mica de 1%.

Captura electronica este specificata doar daca este mai probabila decat dezintegrarea β^+ .

Energiile particulelor listate conform probabilitatilor tranzitiilor respective in ordine descrescatoare. Este data cel putin o valoare a energiei, chiar daca abundenta celui mai proeminent grup este mai mica de 1%.

Energiile celei mai puternice cuante γ aranjate in ordinea descrescatoare a intensitatilor. Intensitatile mai mici de 1% sunt date intre paranteze.

Energiile γ urmate de un asterisc denota tranzitii dupa emisia unei particule intarziate de emisie β .

Cateva cuante γ de intensitati necunoscute in intervalul de energie 291-1391 keV.

Electronii de conversie sunt specificati doar daca au o abundenta mai mare decat cuantele γ . Energiile nu sunt citate.

Sectiuni Eficace

Toate sectiunile eficace sunt date in barni (10^{-24} cm²) si se refera la reactii cu neutroni termici (0.0253 eV).

Sectiunile eficace pentru reactia (n, γ). Daca sunt date doua valori, prima se refera la formarea nucleului in starea metastabila, iar a doua la formarea in starea fundamentala..

Sectiune eficace de fisiune

Sectiune eficace pentru reactia (n, p)

Sectiune eficace pentru reactia (n, α)

Sectiune eficace de absorbtie

Simboluri Aditionale si Abrevieri

Randamentul de fisiune (%) pentru fisiunea cu neutroni termici a U 235 deasupra si Pu 239 dedesubtul liniei cu sageata.

Nuclizii cu nivele complete de neutroni sau protoni sunt caracterizati prin linii groase orizontale si verticale.

Simbolurile "m" si/sau "g" indica faptul ca este populata starea metastabila si/sau starea fundamentala a nuclidului de filiatie. Simbolurile sunt prezentate in ordinea descrescatoare a probabilitatii. Factorii de ramificare cu probabilitati mai mici de 5% nu sunt prezentati. Indicii dupa "m", ex. m_1 , m_2 , sunt folositi pentru indicarea unor stari metastabile diferite (cu m_2 fiind o stare energetica mai ridicata decat m_1).

Date sau atribuire incerta.

Nanosecunde, microsecunde, milisecunde, secunde, minute, ore, zile, ani.

...

β^+ 2.7 ...
 β^- 1.2; 1.9...

β^- ...
 β^+ ...

ϵ

α 3.75,
4.43...
p 1.56
 β_p 4.5

γ 815; 1711...
 γ (1340)

γ 815*

γ 291-1319

e^-

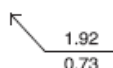
σ

σ_f

$\sigma_{n,p}$

$\sigma_{n,\alpha}$

σ_{abs}



m, g

?

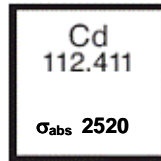
ns, μ s, ms, s,
m, h, d, a

Arrangement of Symbols and Data

Elements

symbol of the element
standard atomic weight based on C 12 = 12

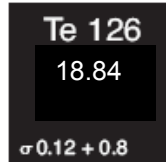
absorption cross section for thermal neutrons (barn)



Stable Nuclides

symbol of the element, number of nucleons
abundance in naturally occurring element (atom %)

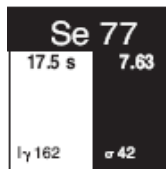
(n, γ)-cross sections for the formation of the metastable
and the ground state of Te 127 by thermal neutrons (barn)



symbol of the element, number of nucleons

left hand side: half-life of metastable state;
 γ -energy (keV) of the isomeric transition

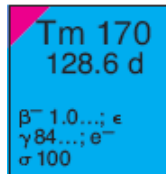
right hand side: abundance in the natural element (atom %)
(n, γ)-cross sections for the thermal neutrons (barn)



Unstable Nuclides

symbol of the element, number of nucleons
half-life

modes of decay, endpoint energy of β^- -radiation (MeV)
 γ -energy (keV), conversion electrons,
(n, γ)-cross section (barn)



symbol of the element, number of nucleons
half-lives

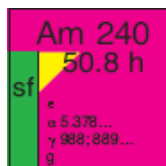
both states decay by electron capture; the metastable
state decays to the ground state
with a branching ratio for I_γ in the range of 50% – 95%



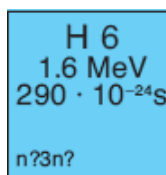
symbol of the element, number of nucleons

left hand side: spontaneous fission isomer, $T < 0.1$ s

right hand side: decay data of the ground state
"g" indicates that the daughter Pu 240g is formed to at least
95 %; a population of Pu 240m up to 5% cannot be
excluded



where emission of a particle results from a resonance
state in an unstable nucleus, both the resonance
width Γ (MeV) and the half-life $T_{1/2}$ are given



Aranjarea Simbolurilor si a Datelor

Elemente

simbolul elementului
masa atomica standard bazata pe C 12 = 12

sectiunea eficace de absorbtie pentru neutronii termici (barni)

Nuclizi Stabili

simbolul elementului, numarul de nucleoni
abundenta in elementul care se gaseste in natura (% atomice)

sectiuni eficace (n, γ) pentru formarea starii metastabile si a
starii fundamentale a Te 127 cu neutroni termici (barni)

simbolul elementului, numarul de nucleoni

in partea stanga: timpul de injumatatire al starii metastabile;
energia γ (keV) a transitionii isomere

in partea dreapta: abundenta in elementul natural (% atomice)
sectiuni eficace (n, γ) pentru neutronii termici (barni)

Nuclizi Instabili

simbolul elementului, numarul de nucleoni
timpul de injumatatire

moduri de dezintegrare, energia finala a radiatiei β^- (MeV)
energia γ (keV), electroni de conversie;
sectiunea eficace (n, γ) (barni)

simbolul elementului, numarul de nucleoni
timpul de injumatatire

ambele stari se dezintegreaza prin captura electronica; starea
metastabila trece in starea fundamentala cu un factor de
ramificare de 50-95% pentru I_γ

simbolul elementului, numarul de nucleoni

in partea stanga: izomer fisionabil spontan, $T < 0.1$ s

in partea dreapta: datele de dezintegrare ale starii
fundamentale "g" indica faptul ca nuclidul de filiatie Pu 240g
este format intr-o proportie de minim 95%; o populare cu Pu
240m pana la 5% nu este exclusa

daca emisia unei particule rezulta dintr-o stare de rezonanta a
unui nucleu instabil, sunt date atat latimea de rezonanta Γ
(MeV) cat si timpul de injumatatire $T_{1/2}$