

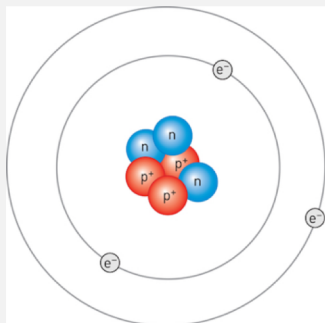
Biofizika I

13. Magsugárzások

Liliom Károly

2022. 12. 01.

*liliom.karoly@med.semmelweis-univ.hu
karoly.liliom.mta@gmail.com*



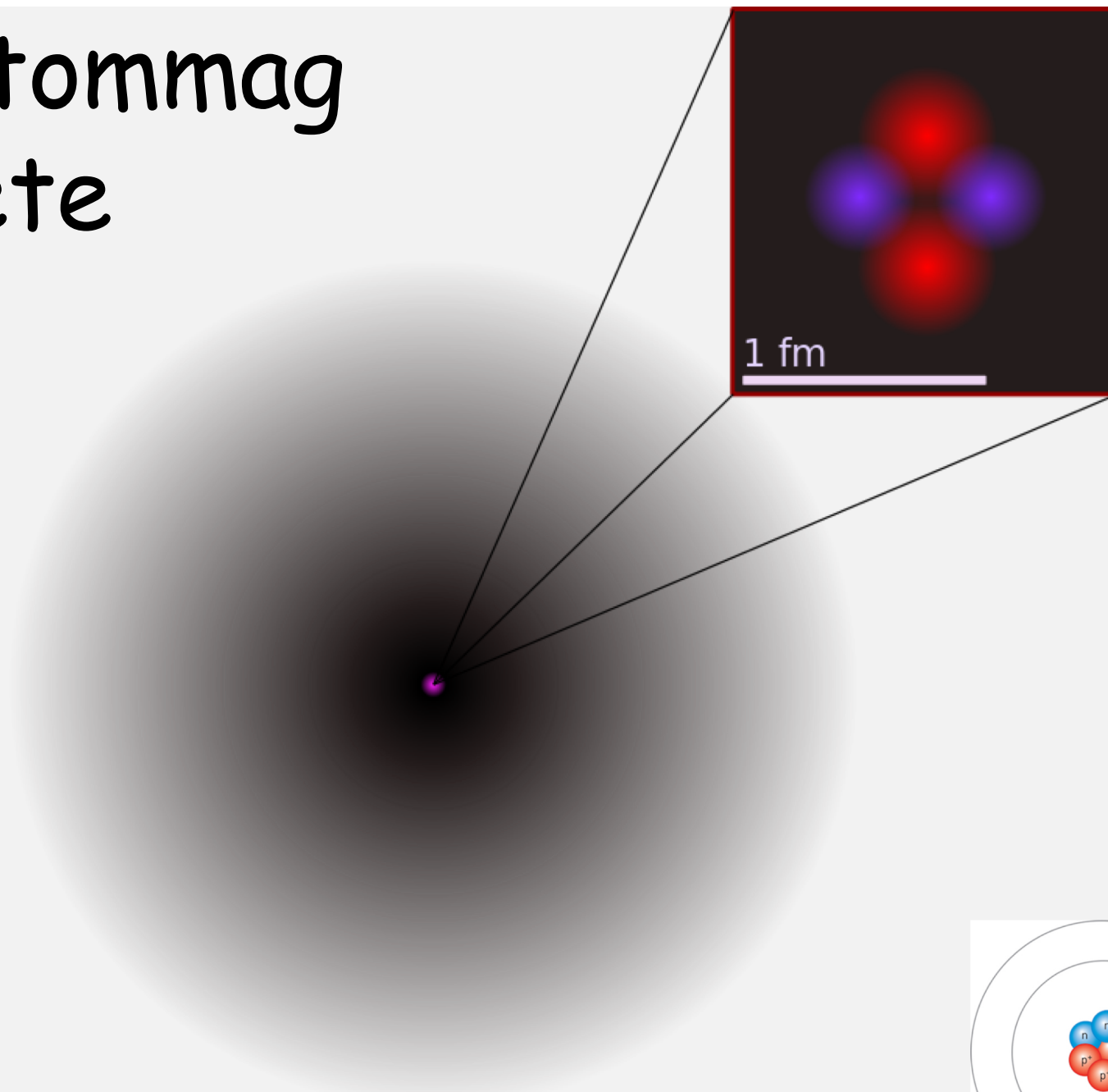
Az atomok alkotórészei

| Particle | Symbol | Resting Energy (MeV) | Relative Charge* | Mass (kg) | Relative Mass (AMU)** |
|----------|--------|----------------------|------------------|--------------------------|-------------------------|
| electron | e | 0.51100 | 1- | 9.11×10^{-31} | 5.4858×10^{-4} |
| proton | p | 938.272 | 1+ | 1.6726×10^{-27} | 1.0072765 |
| neutron | n | 939.566 | 0 | 1.6749×10^{-27} | 1.0086649 |

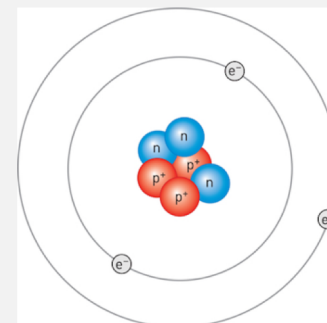
* elektronok töltése (elemi töltés): $-1.602 \times 10^{-19}\text{C}$

** Atomtömeg-egység: (^{12}C) atom 1/12-ed része

Az atommag mérete



$$1 \text{ \AA} = 100,000 \text{ fm}$$

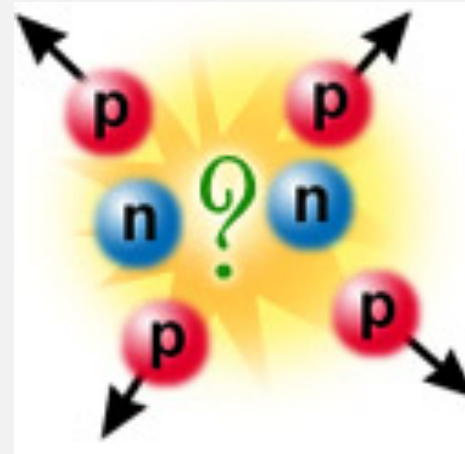


Atommag stabilitása

Protonok között erős az elektrosztatikus taszítás!

(mi tartja egyben a magot)

Kell, hogy legyen egy
vonzóerő a magon belül!



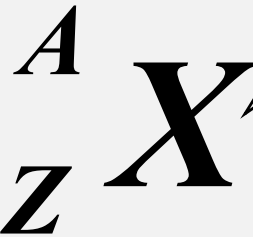
Rutherford, 1911 – magerő: rövid hatótávolságú vonzóerő, független a töltéstől és erősebb a Coulomb-erőknél.

A neutron hipotézise (Chadwick 1932, Nobel-díj 1935)

jelölések

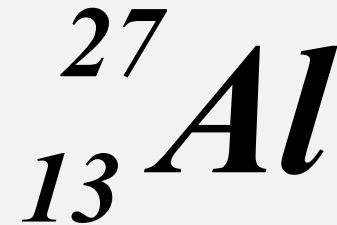
tömegszám

$$A = Z + N$$



*az elem kémiai
szimbóluma*

*rendsám =
protonok száma*



N = neutronok száma

nukleon = proton vagy neutron

A mag stabilitása

$$\Delta M = [Zm_p + (A-Z)m_n] - M(A,Z)$$

Tömegdefektus: az atommag tömege kisebb, mint az alkotó protonok és neutronok tömegeinek összege! A különbség Einstein tömeg-energia egyenértékűségi elvével magyarázható:

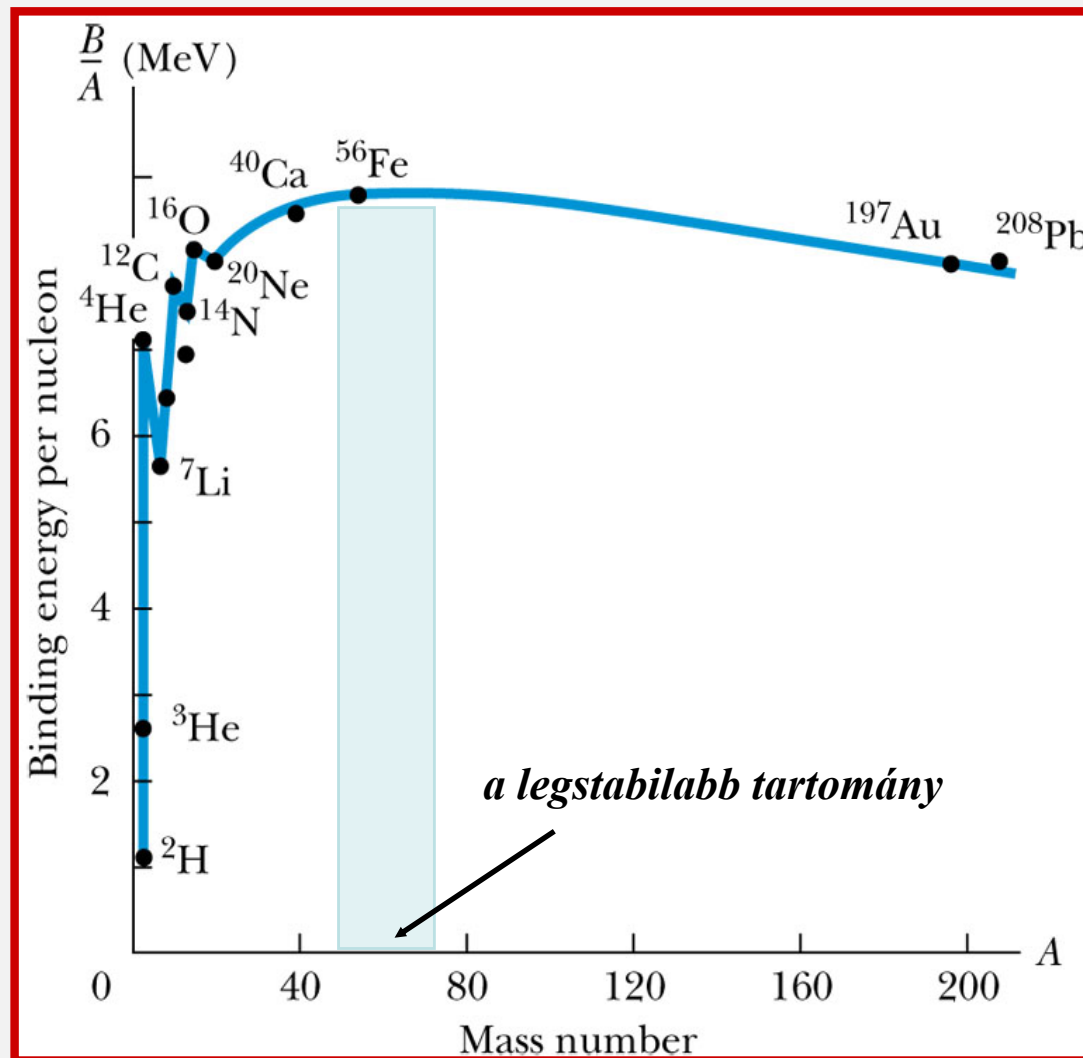
$$\Delta E = \Delta M c^2$$

A tömegdefektus = a kötési energia tömegegységben kifejezve.

Nukleonokra eső kötési energia

- Kis tömegszámoknál gyors növekedés
- Éles csúcsok páros-páros magoknál:
 ${}^4_2\text{He}$, ${}^{12}_6\text{C}$, and ${}^{16}_8\text{O}$
- Maximum kb $A=56$

nukleon = proton vagy neutron



Izotópok

Görög *isos topos* = *azonos hely*

Egy elem izotópjai:

- azonos protonszámúak
- különböző neutronszámúak
- különböző tömegszámúak

izotóp = azonos rendszám

Mendeleev's Periodic Table of Elements

| Mendeleev's Periodic Table of Elements | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--|--|--|--|--|--|--|--|--|--|--|--|---|--|--|--|--|--|--|--|--|--|--|--|--|--|--|---|--|--|--|--|--|--|--|--|--|---------|
| 1 IA | | Table of Common Polyatomic Ions | | | | | | | | | | Element categories | | | | | State of matter at 25 °C | | | | | 18 VIIIA | | | | | | | | | | | | | | | |
| | | acetate chlorate hydroxide nitrate permanganate carbonate chromate dichromate | | | | | | | | | | C ₂ H ₃ O ₂ ⁻ ClO ₃ ⁻ OH ⁻ NO ₃ ⁻ MnO ₄ ⁻ CO ₃ ²⁻ CrO ₄ ²⁻ Cr ₂ O ₇ ²⁻ | | | | | silicate sulfate thiosulfate arsenate phosphate ammonium hydronium | | | | | SiO ₃ ²⁻ SO ₄ ²⁻ S ₂ O ₃ ²⁻ AsO ₄ ³⁻ PO ₄ ³⁻ NH ₄ ⁺ H ₃ O ⁺ | | | | | Alkali metals Alkaline-earth metals Transition metals Other metals Hydrogen Semiconductors Halogens Noble gases Other nonmetals | | | | | Gas Liquid Solid Artificially prepared Unknown | | | | | 2 He |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | 4.003 | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

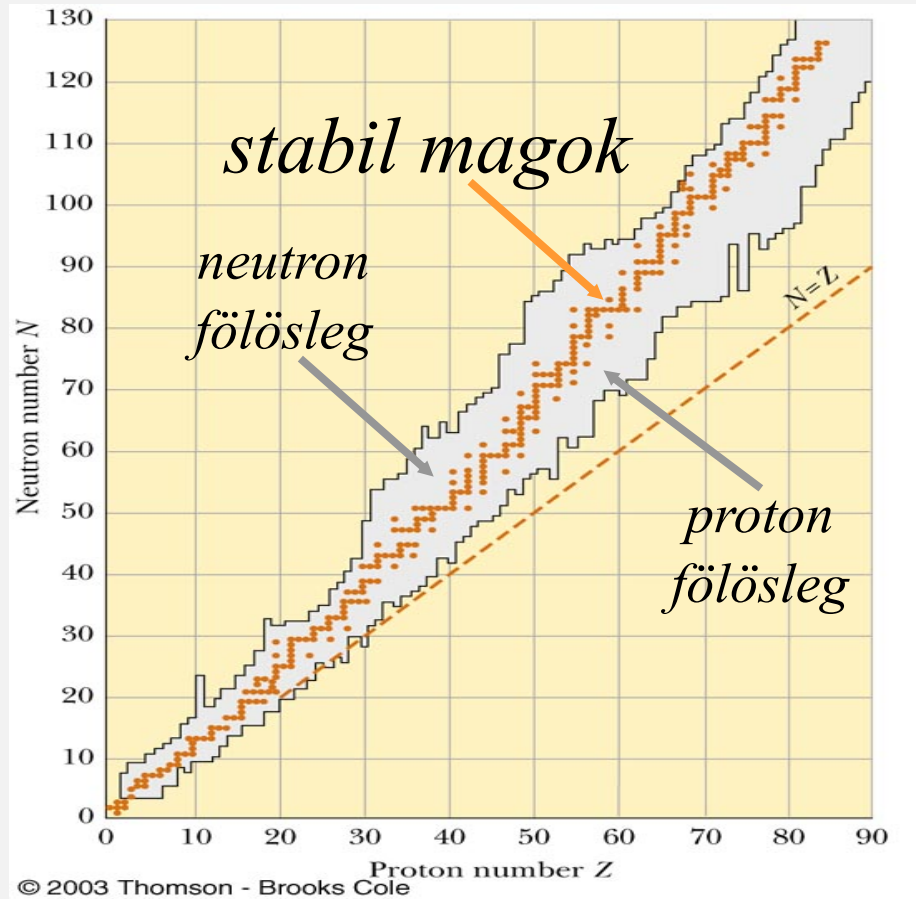
Atommag stabilitási diagramja

- könnyű magok stabilak, ha
 $N = Z$

- nehéz magok stabilak, ha
 $N > Z$

a protonszám növelésével növekszik
a Coulomb-féle taszítóerő, így
több neutron kell a mag egyben
tartására

- Nincs stabil mag, ha $Z > 83$



Mi történik, ha a mag nem stabil?

Radioaktív bomlás



Antoine Becquerel
1903 fizikai Nobel-díj a
radioaktivitás felfedezéséért



Becquerel fotólemeze, ami a fölé tett urániumsó sugárzása miatt exponálódott. A lemez és az urániumsó közé helyezett fém máltai kereszt jól kivehető (1896).

Radioaktív bomlás

- *Radioaktivitás*: az energia spontán kibocsátása részecskék vagy elektromágneses sugárzás útján
- a nem stabil atommagok bomlása hozza létre
- háromféle sugárzás keletkezhet

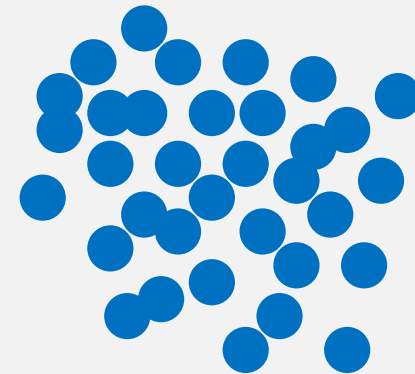
Alfa (α) részecske

Béta (β) részecske

Gamma (γ) sugarak

Radioaktív bomlás jellemzői

- statisztikai folyamat – az egyedi bomlások véletlenszerűen követik egymást
- a bomlásra képes magok száma csökken az idővel



A radioaktív bomlás jellemzői

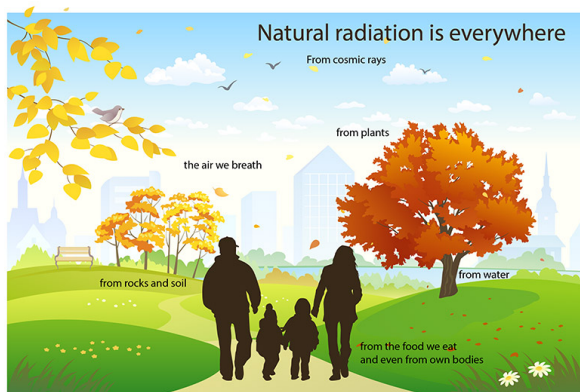
Aktivitás: $\Lambda = \left| \frac{\Delta N}{\Delta t} \right|$

*N: még el nem bomlott
magok száma
t: idő*

Aktivitás = egységnyi idő alatt elbomlott magok száma

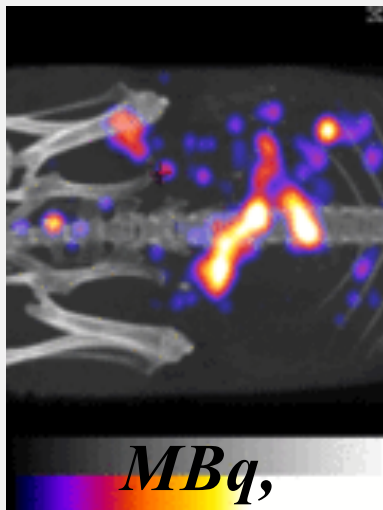
egysége: becquerel (Bq) 1Bq = 1 bomlás/s

háttersugárzás



kBq,

diagnosztika

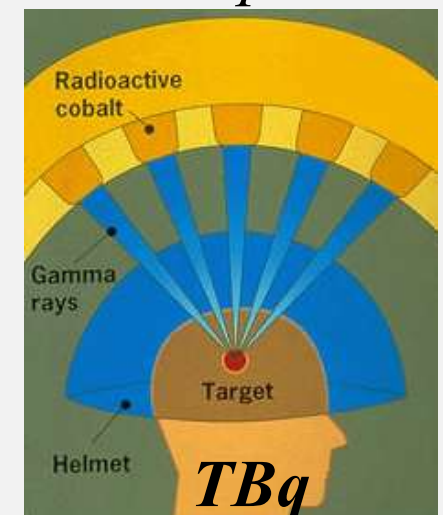


*laboratóriumi
gyakorlat*



GBq,

terápia



Bomlástörvények

Differenciális alak: $\frac{\Delta N}{\Delta t} = -\lambda N$

megoldás

λ : bomlási állandó (1/s)

Integrális alak: $N = N_0 e^{-\lambda t}$

N_0 : bomlásra képes (rádioaktív) magok száma $t=0$ -kor,

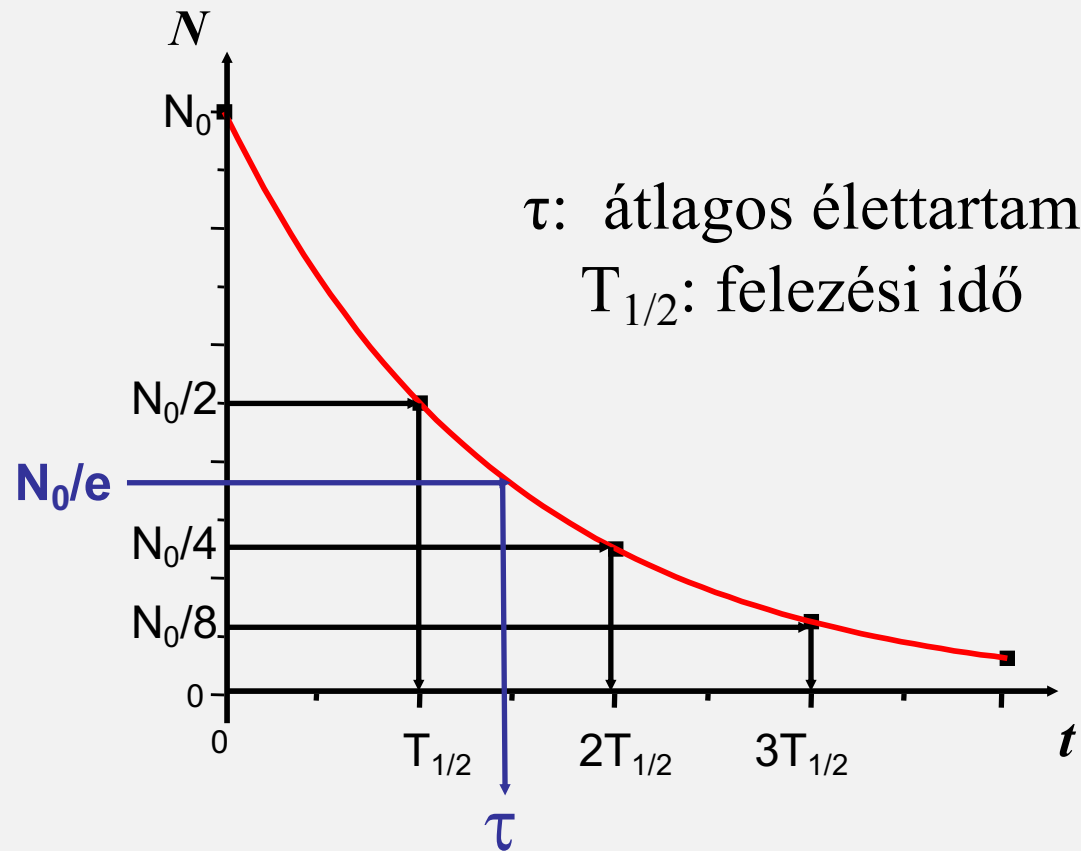
N : nem elbomlott magok száma egy későbbi t időpontban

Az aktivitás az izotóp típusától és a kezdetben jelen lévő bomlásra képes atommagok számától is függ.

Specifikus aktivitás: egységnyi tömegű izotóp aktivitása (Bq/kg)

Grafikus reprezentáció

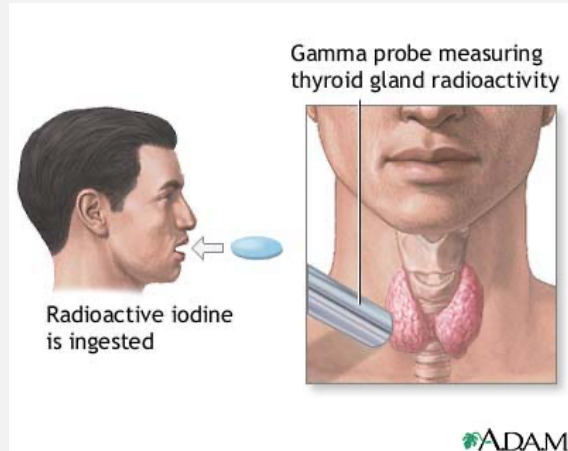
$$N = N_0 e^{-\lambda t}$$



$$\begin{aligned} t &= \tau \\ \downarrow \\ N_0 / e &= N_0 e^{-\lambda \tau} \\ \downarrow \\ \lambda &= \frac{1}{\tau} \end{aligned}$$

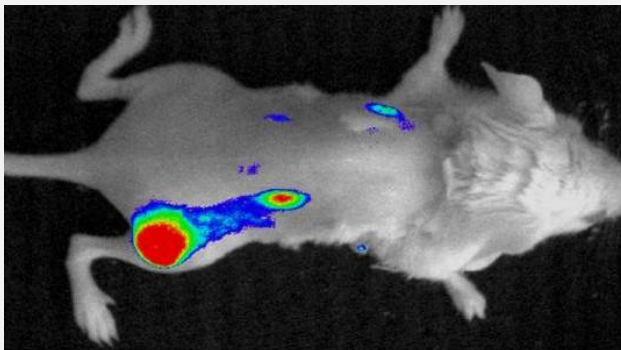
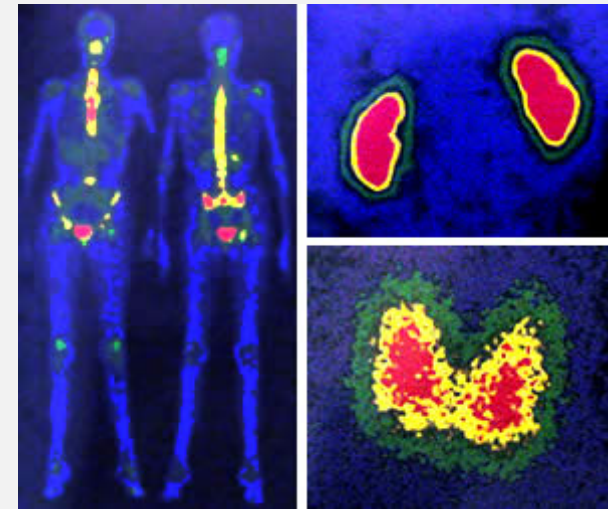
$$t = T_{1/2} \longrightarrow N_0 / 2 = N_0 e^{-\lambda T_{1/2}} \longrightarrow \lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{T_{1/2}}$$

Felezési idők a gyógyászatban



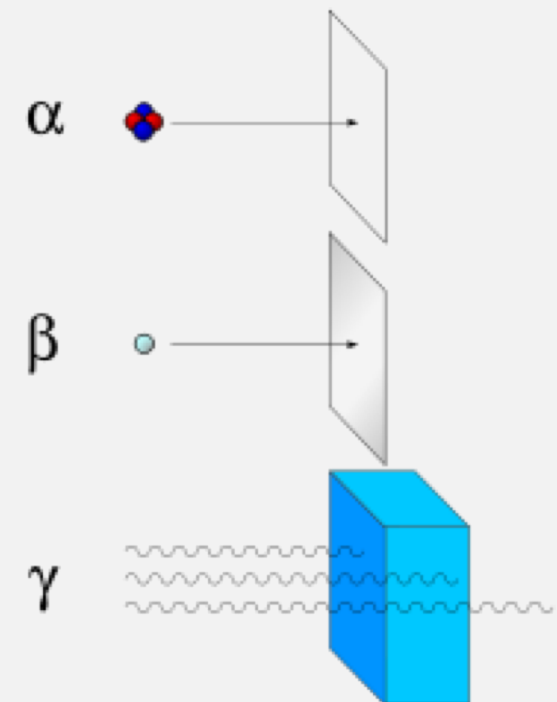
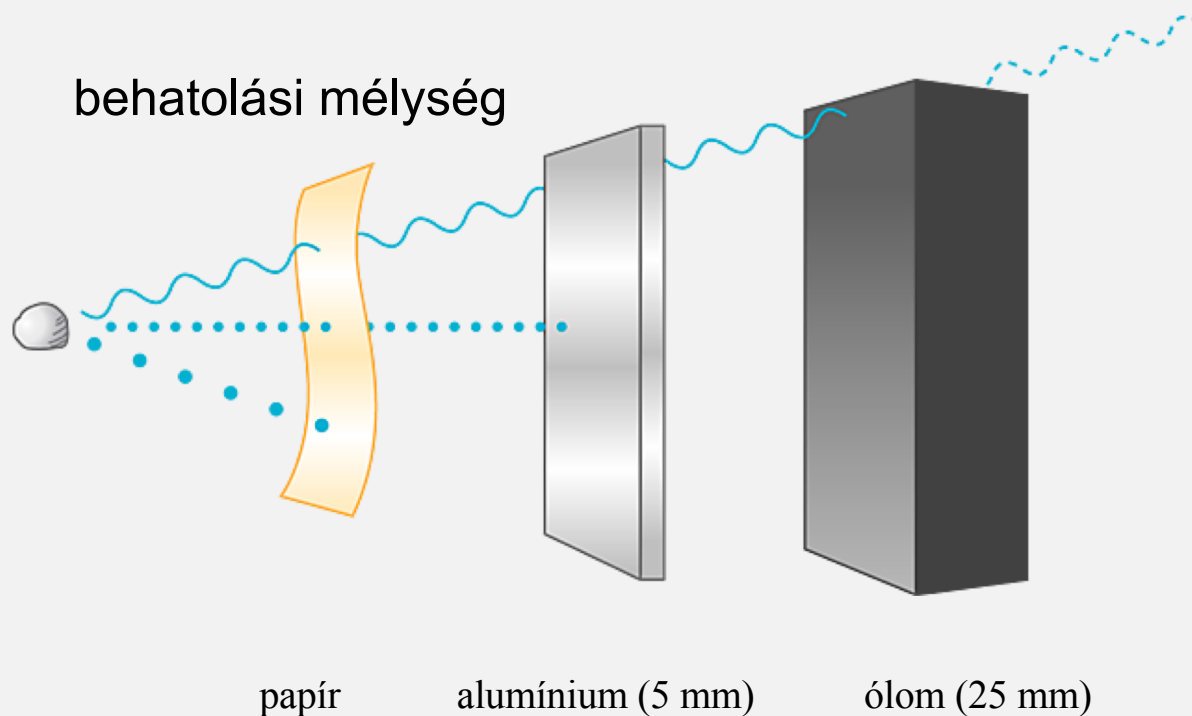
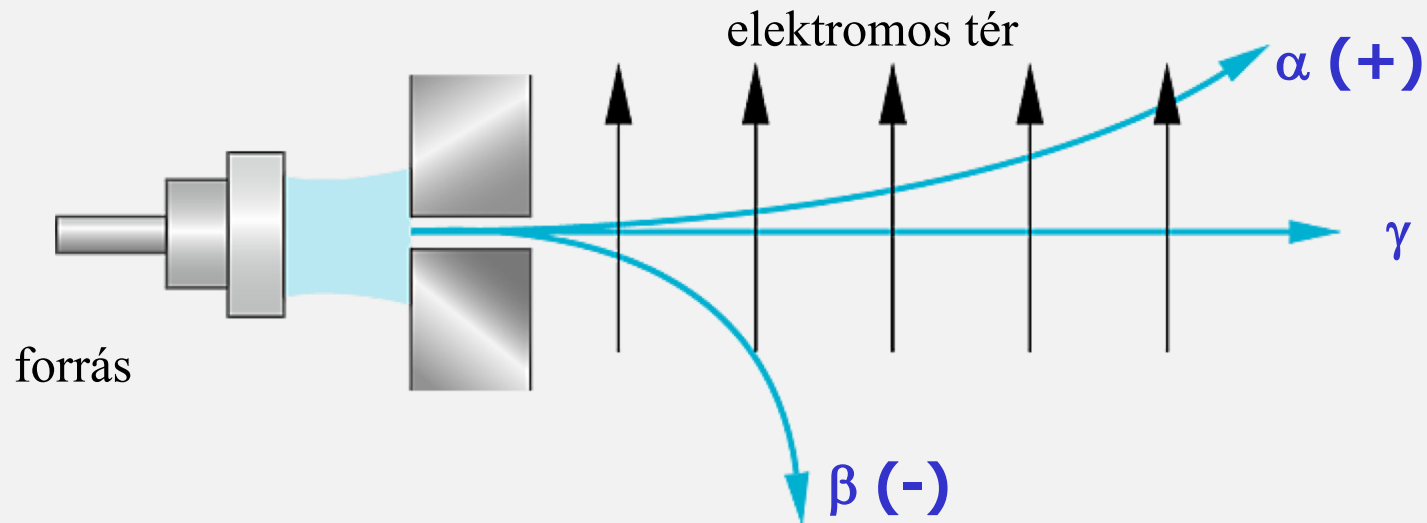
Jód - 131 (^{131}I) - $T_{1/2} = 8$ nap
pajzsmirigy kezelés

Technécium-99m ($^{99\text{m}}\text{Tc}$) - $T_{1/2} = 6$ óra
Izotóp diagnosztika

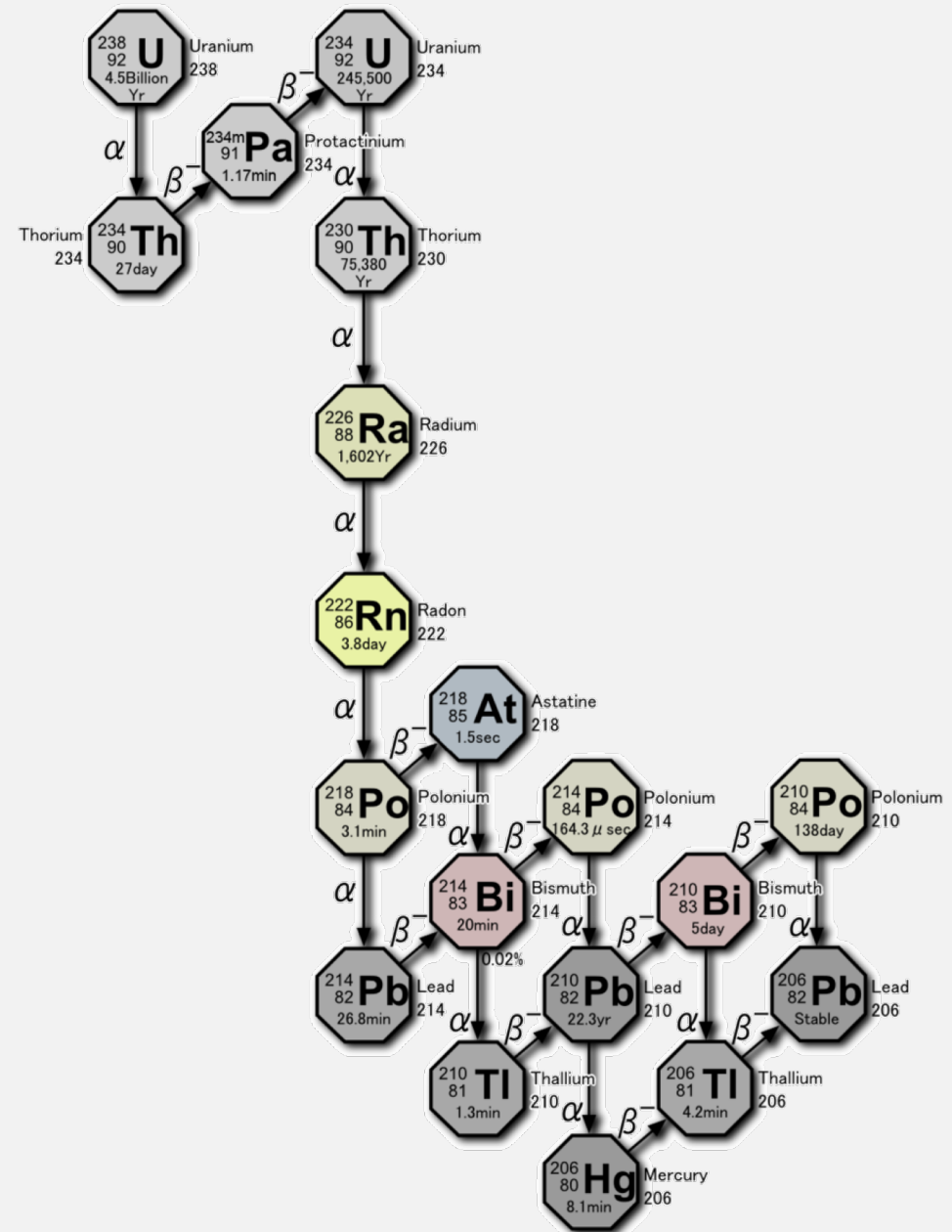
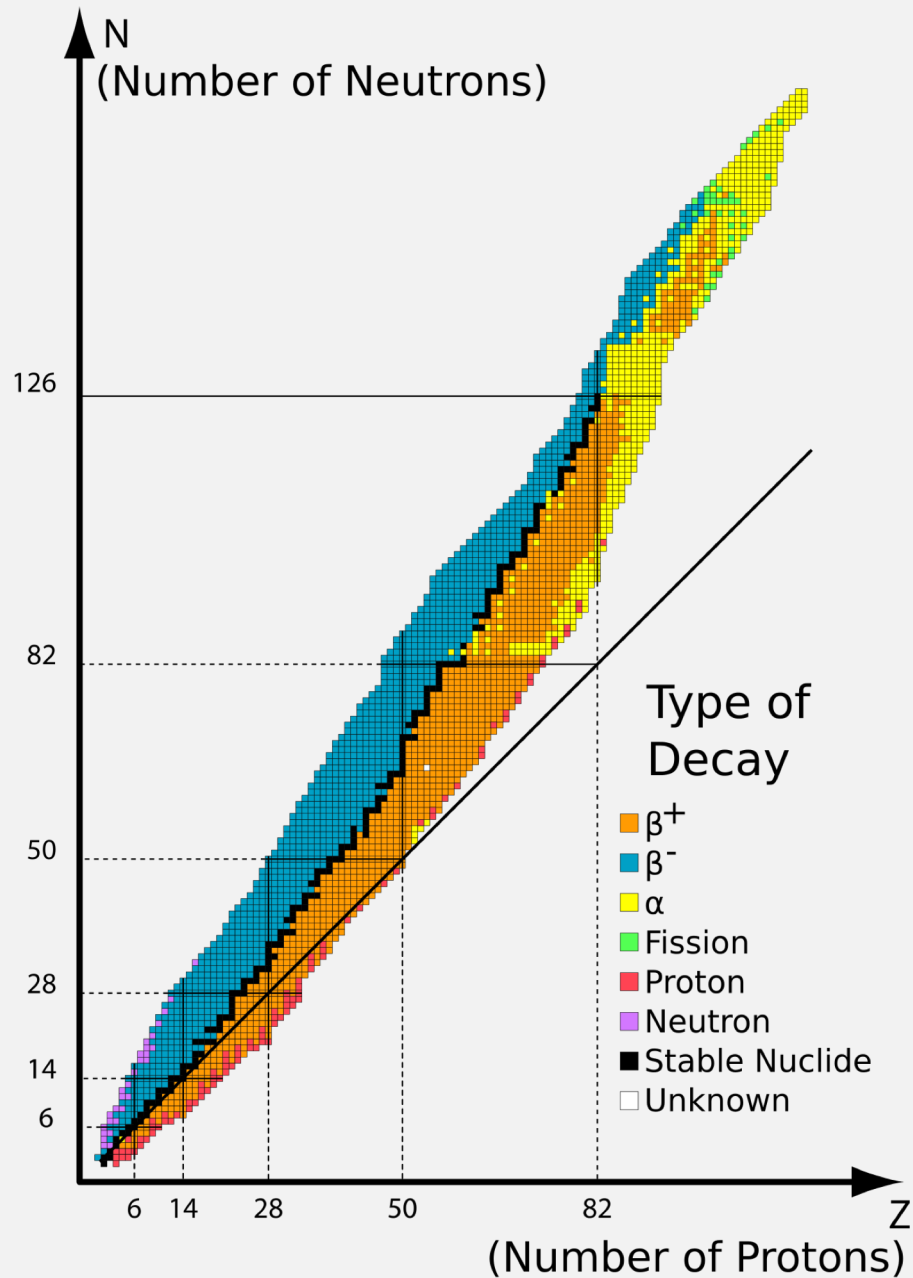


Arany-198 (^{198}Au) - $T_{1/2} = 2,7$ nap
Tumorterápia

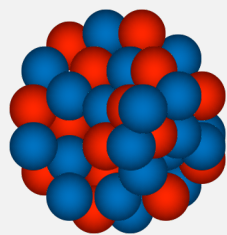
Radioaktív bomlás típusai



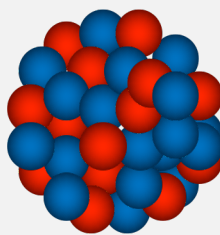
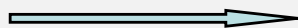
Radioaktív bomlás típusai



α bomlás



anyamag

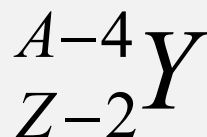
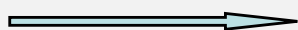
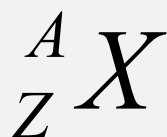


leánymag

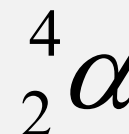
+



α részecske

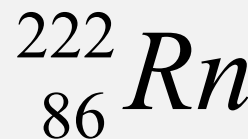
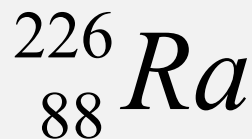


+

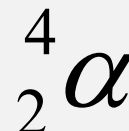


α részecske: a hélium atommagja, 2 proton és 2 neutron alkotja

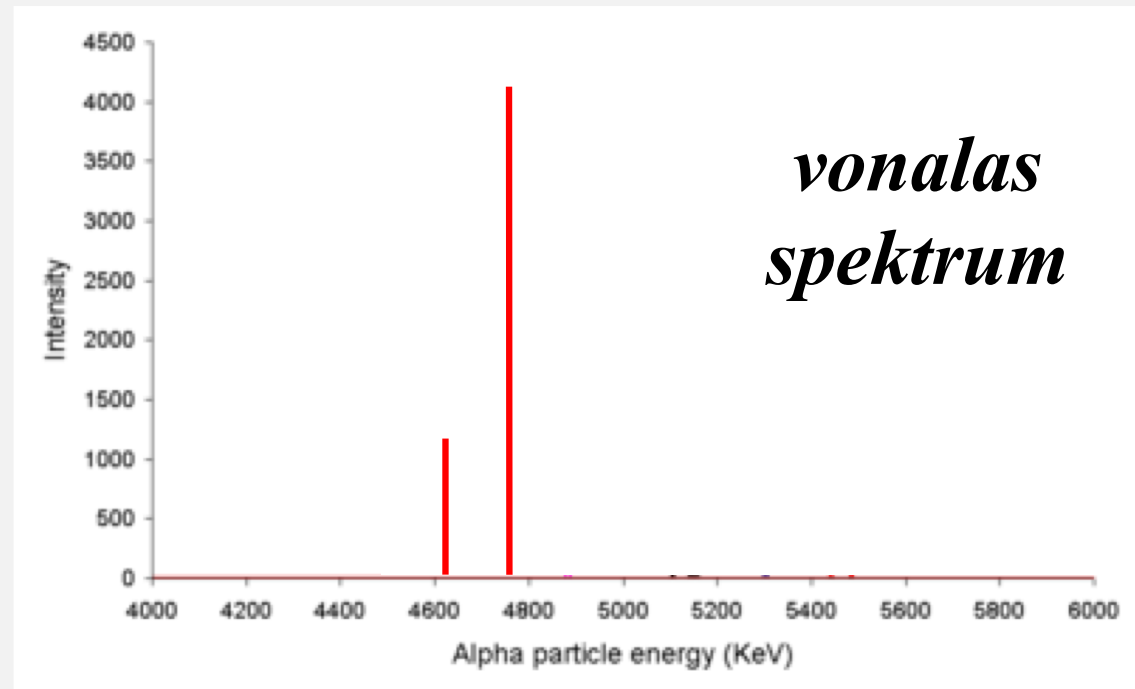
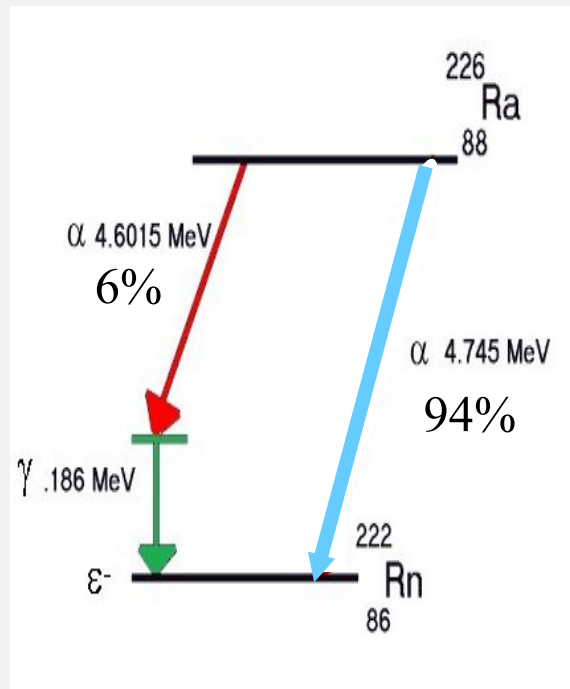
Nehéz magok ($A > 150$) tipikusan α részecske kibocsájtásával bomlanak



+

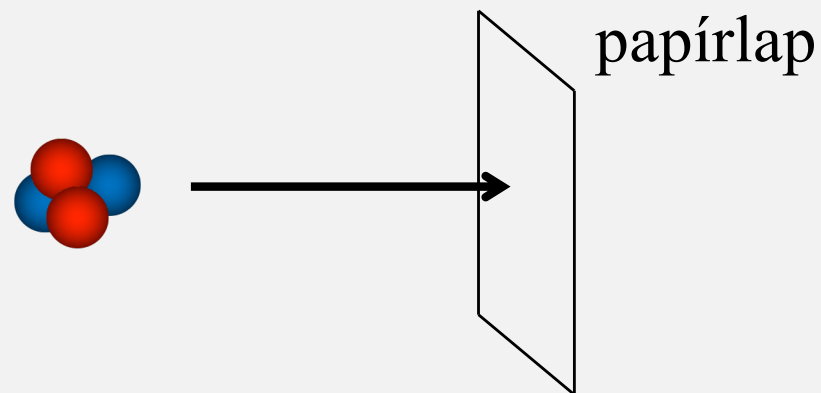


α sugárzás energia-spektruma



Az energiaszintek jellemzőek a magra

α részecskék behatolási mélysége

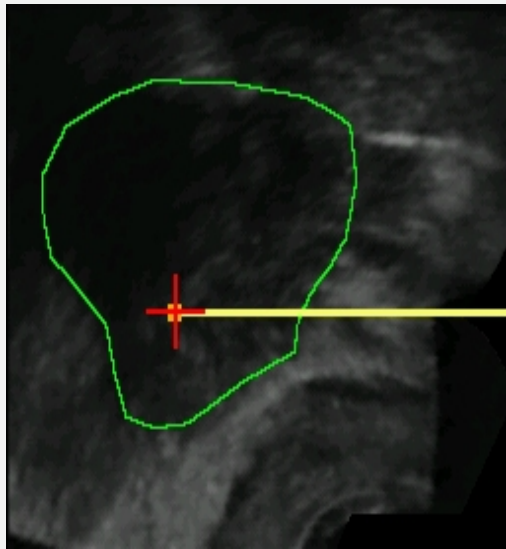


| absorber | density | alpha range |
|---------------------|------------------------|-------------|
| air (STP) | 1.2 mg/cm ³ | 3.7 cm |
| paper (20lb) | 0.89 g/cm ³ | 53 μ m |
| water (soft tissue) | 1.0 g/cm ³ | 45 μ m |

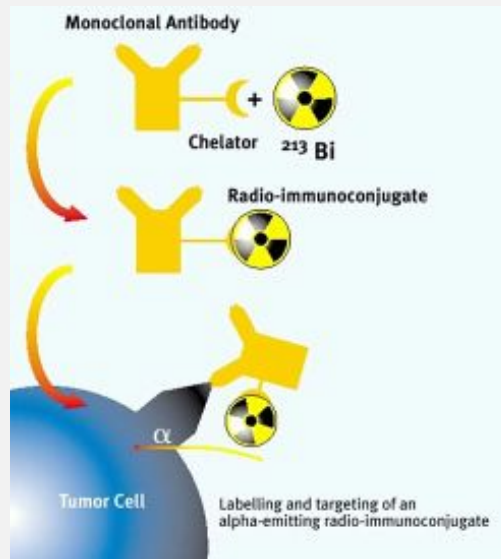
α sugárzás a gyógyásban

Diagnózis: –

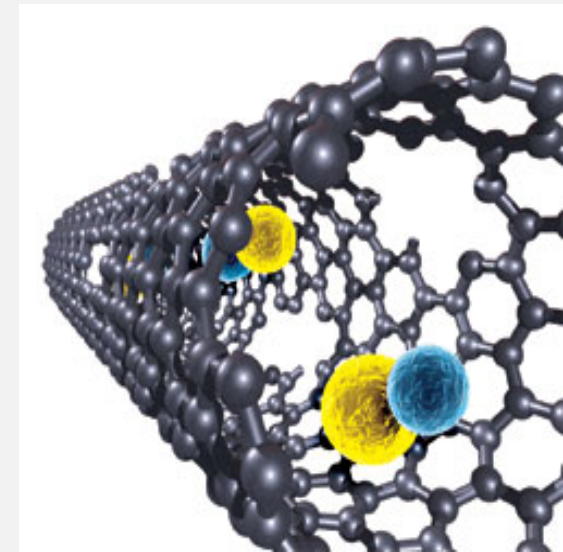
Célzott rákterápia α sugárzással



beültetés tűvel



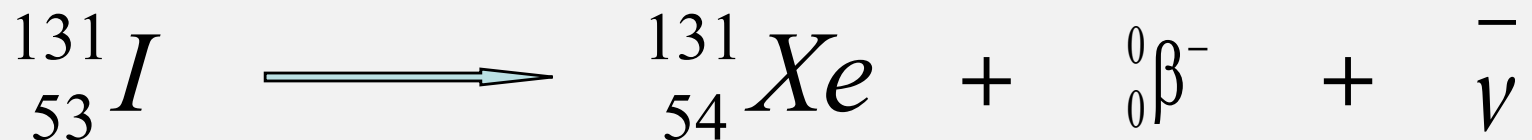
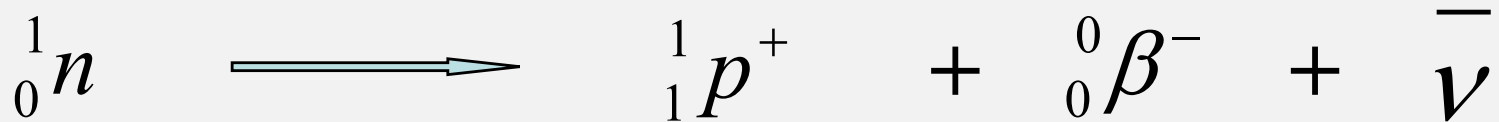
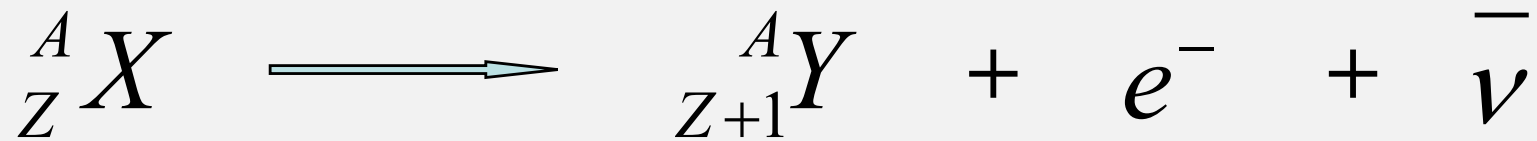
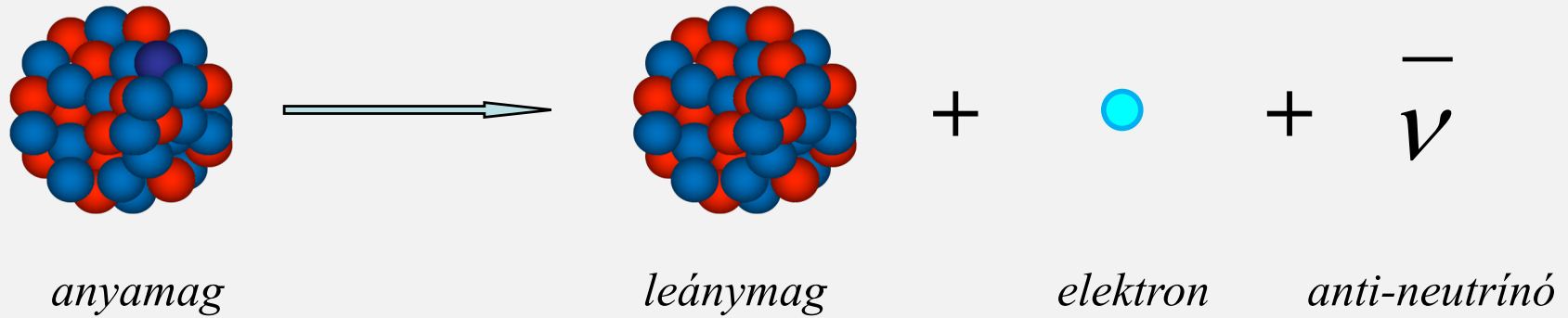
monoklonális antitest



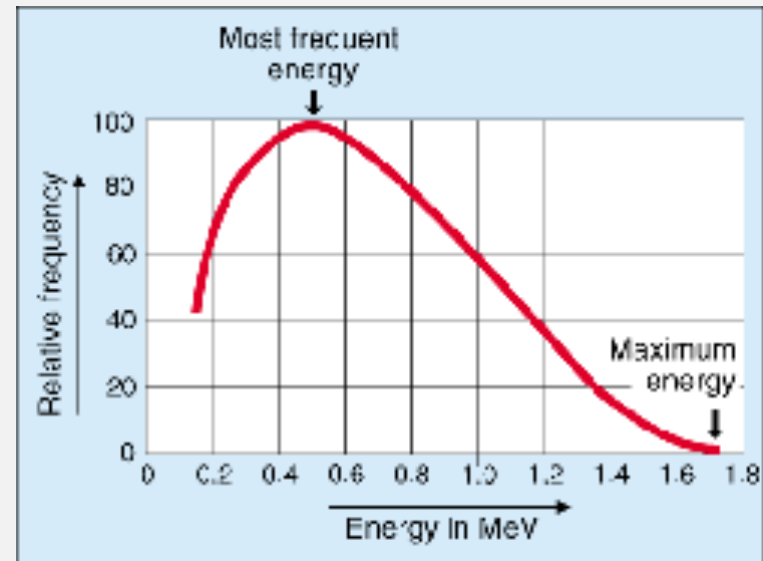
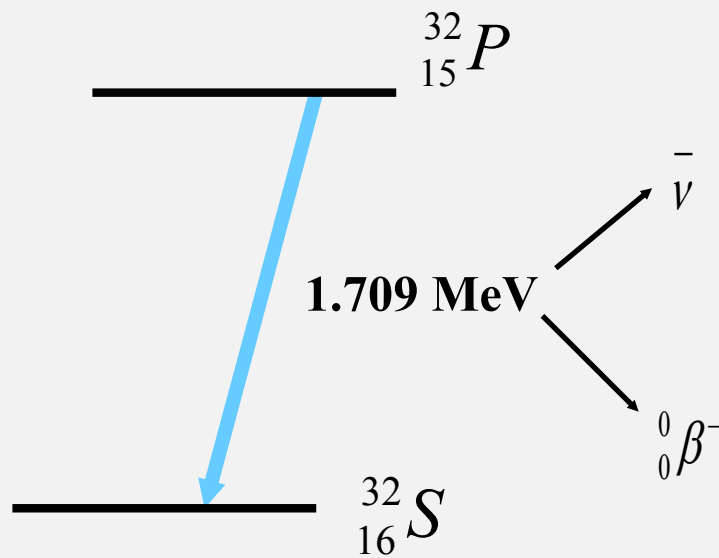
karbon nano-cső

β bomlás

1. Neutron-felesleg: β^- bomlás



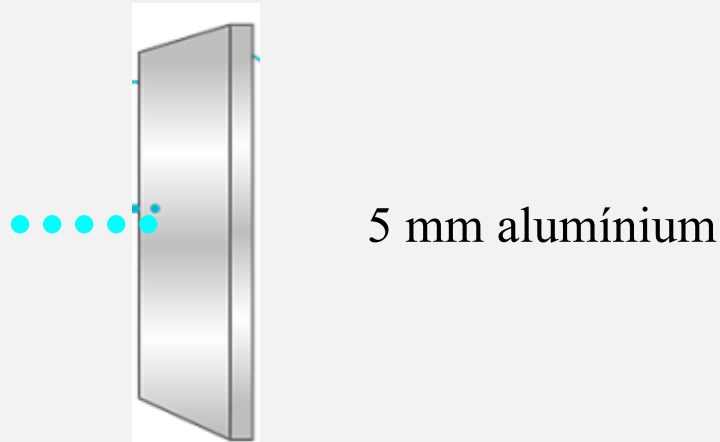
β sugárzás energia-spektruma



folytonos spektrum

DE, a β részecske energiájának van maximuma!

β^- részecskék behatolási mélysége

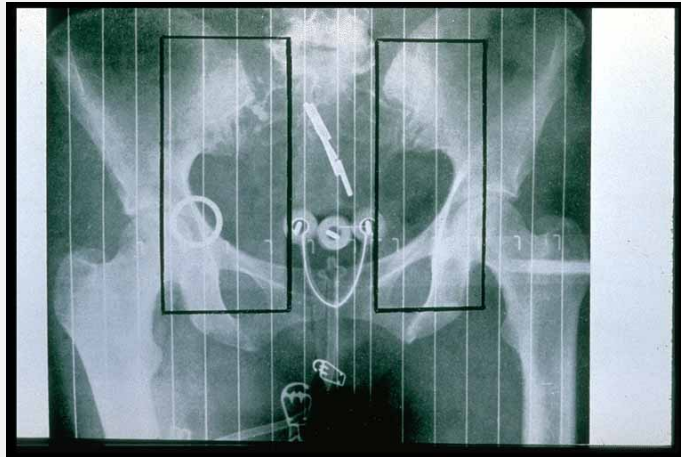


| <i>absorber</i> | <i>density</i> | <i>maximum beta range</i> | |
|------------------------|------------------------|----------------------------------|-------------------------|
| | | <i>(2.3 MeV)</i> | <i>(1.1 MeV)</i> |
| air | 1.2 mg/cm ³ | 8.8 m | 3.8 m |
| water (soft tissue) | 1.0 g/cm ³ | 11 mm | 4.6 mm |
| aluminum | 2.7 g/cm ³ | 4.2 mm | 2.0 mm |
| lead | 11.3 g/cm ³ | 1.0 mm | 0.4 mm |

β^- sugárzás a gyógyászatban

Diagnózis: –

Célzott terápiák: hipertiroidizmus,
pajzsmirigy, prosztata és egyéb tumorok



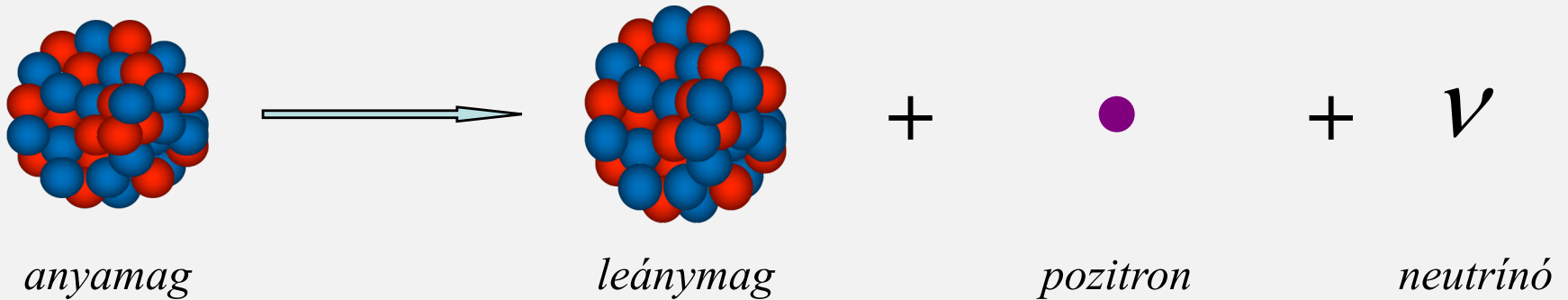
Brachytherapy:
implants into the
tumor



Endovascular
irradiation

β bomlás

2. Proton-felesleg: β^+ bomlás



Annihiláció - részecske-antirészecske párok megsemmisítik egymást

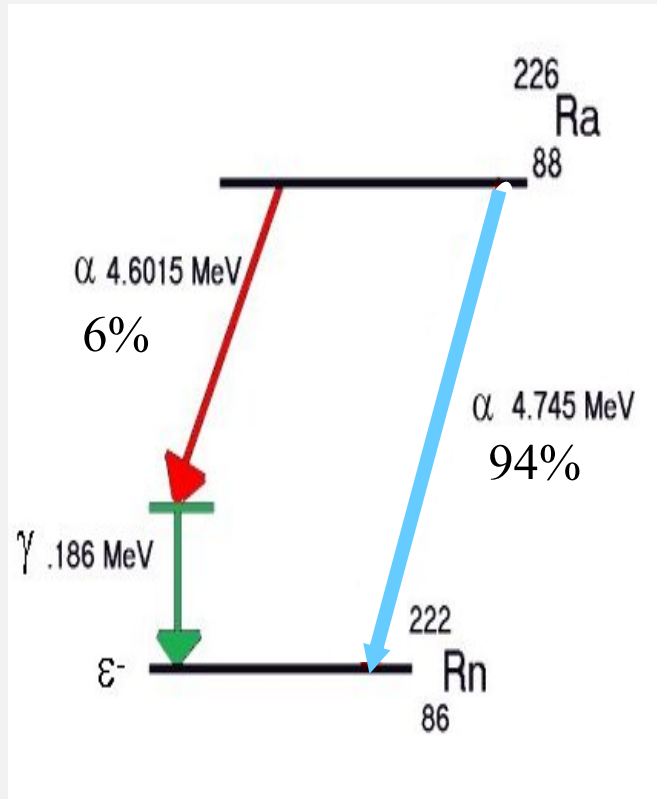


1. Lendület megmaradás törvénye: két egymással átellenesen kirepülő foton születik

2. Energiamegmaradás törvénye:

$$m_e c^2 + m_p c^2 = 2 h f$$

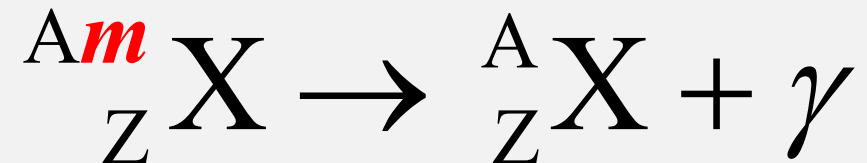
γ bomlás – nukleonok izomerizációja



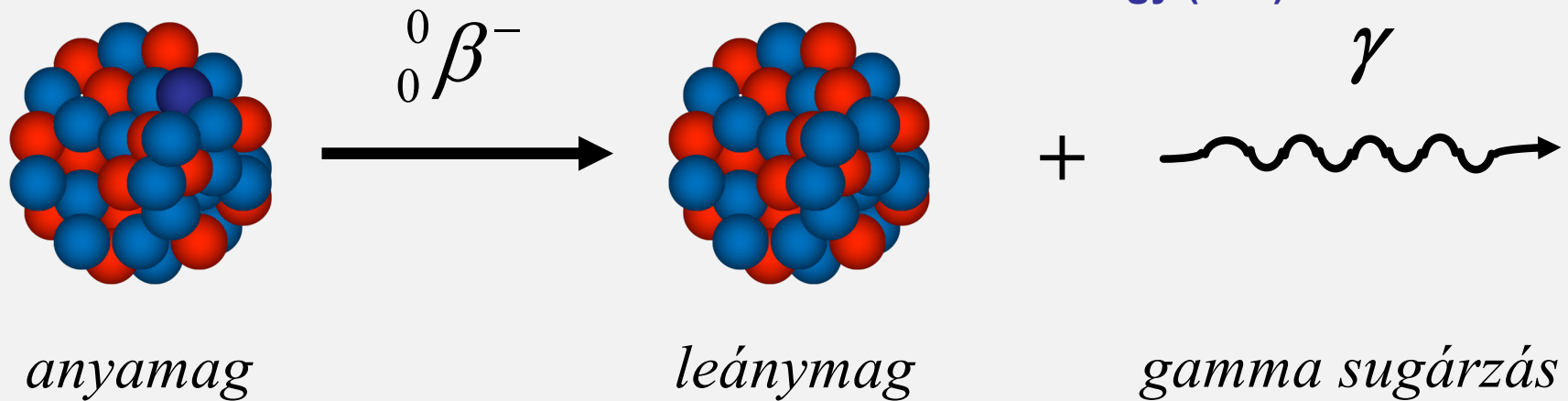
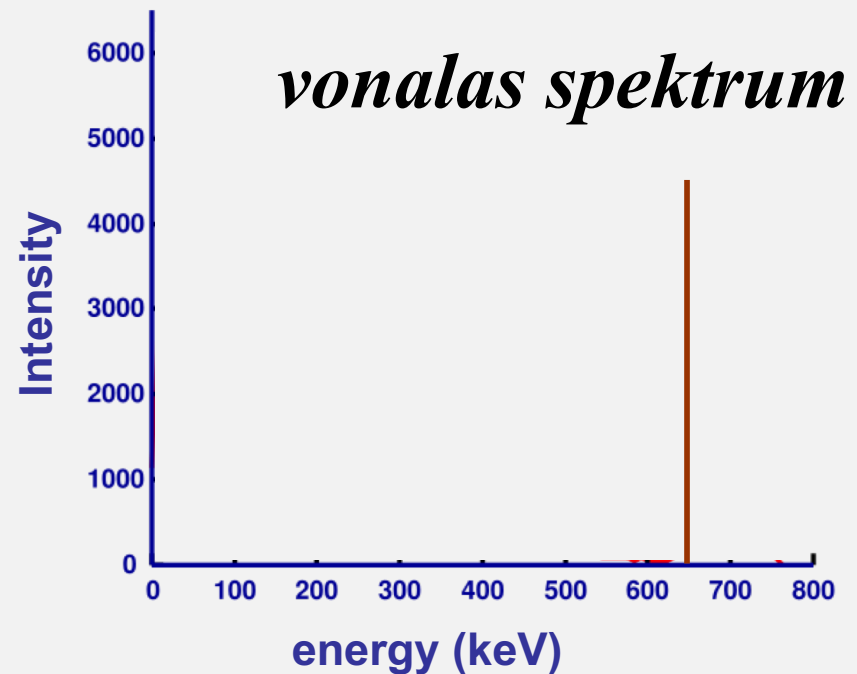
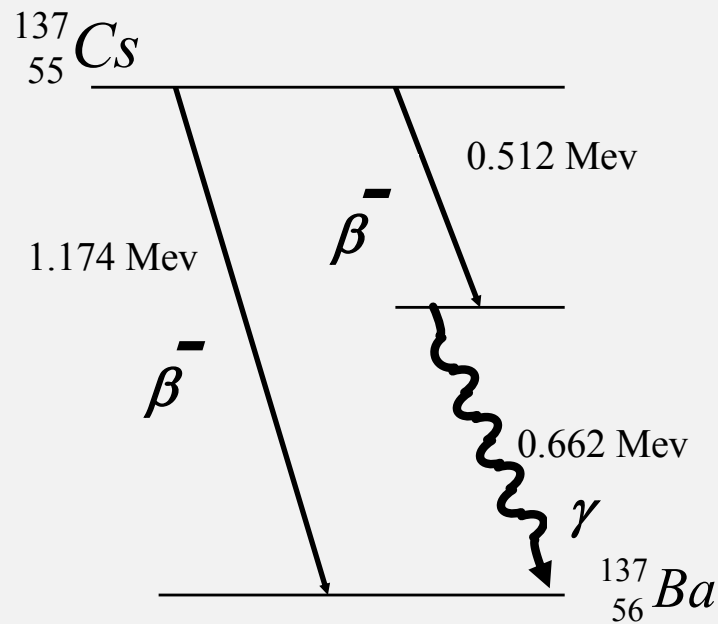
A leánymag néha gerjesztett állapotban van α vagy β bomlást követően.

A gerjesztett mag gamma-sugárzással szabadul meg fölös energiájától.

A fél-életidő néhány órától néhány száz évig változhat.

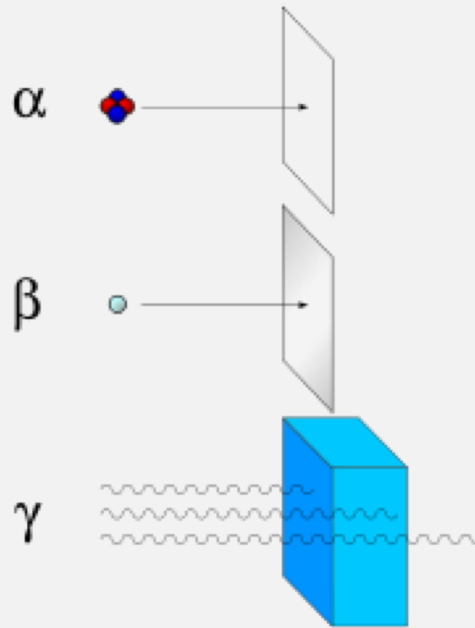


γ sugárzás energia-spektruma



A gamma-energia jellemző a magra.

γ sugárzás behatolási mélysége

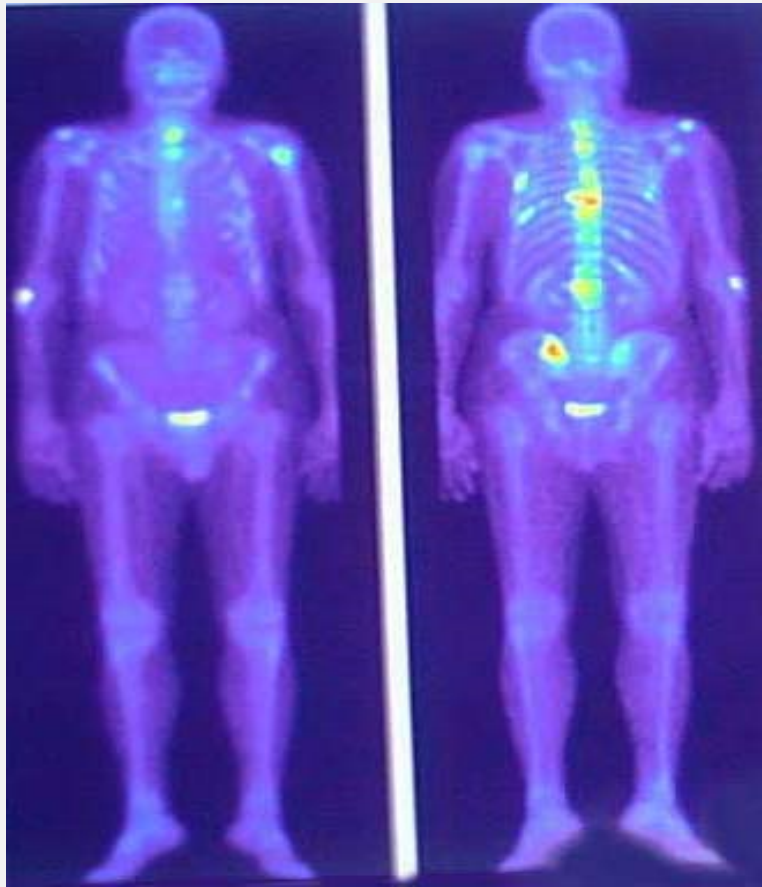


A gamma sugárzás behatolási mélysége sokkal nagyobb, mint az α vagy β részecskéké, és nagymértékben függ a gamma foton energiájától.

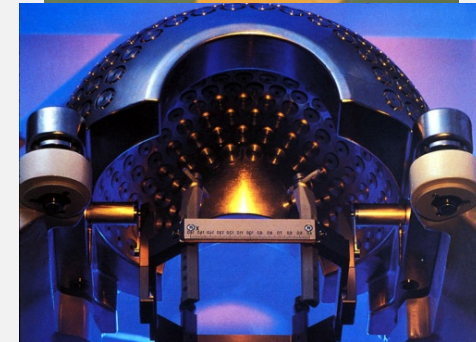
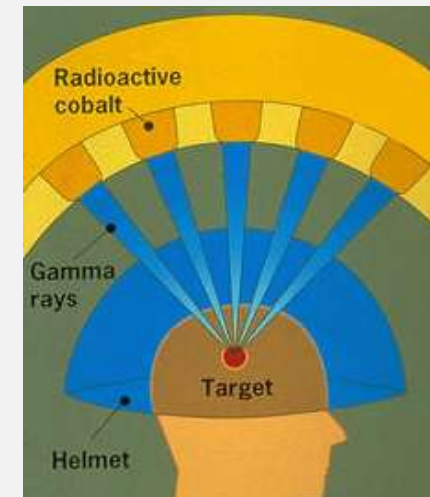
Gamma fotonok akár néhány száz métert is megtehetnek levegőben és könnyedén átszelik az emberi testet.

γ sugárzás a gyógyászatban

Diagnosztika: gamma kamera, SPECT (PET)

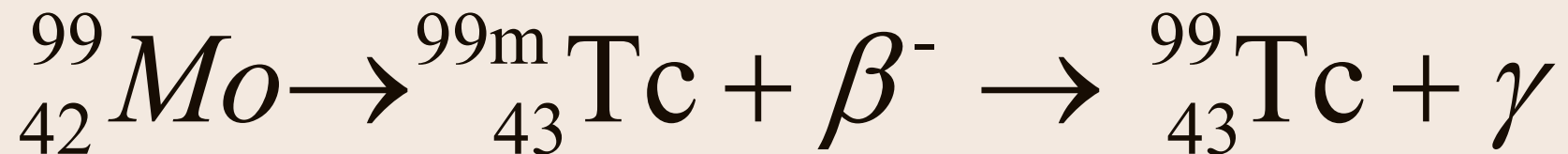
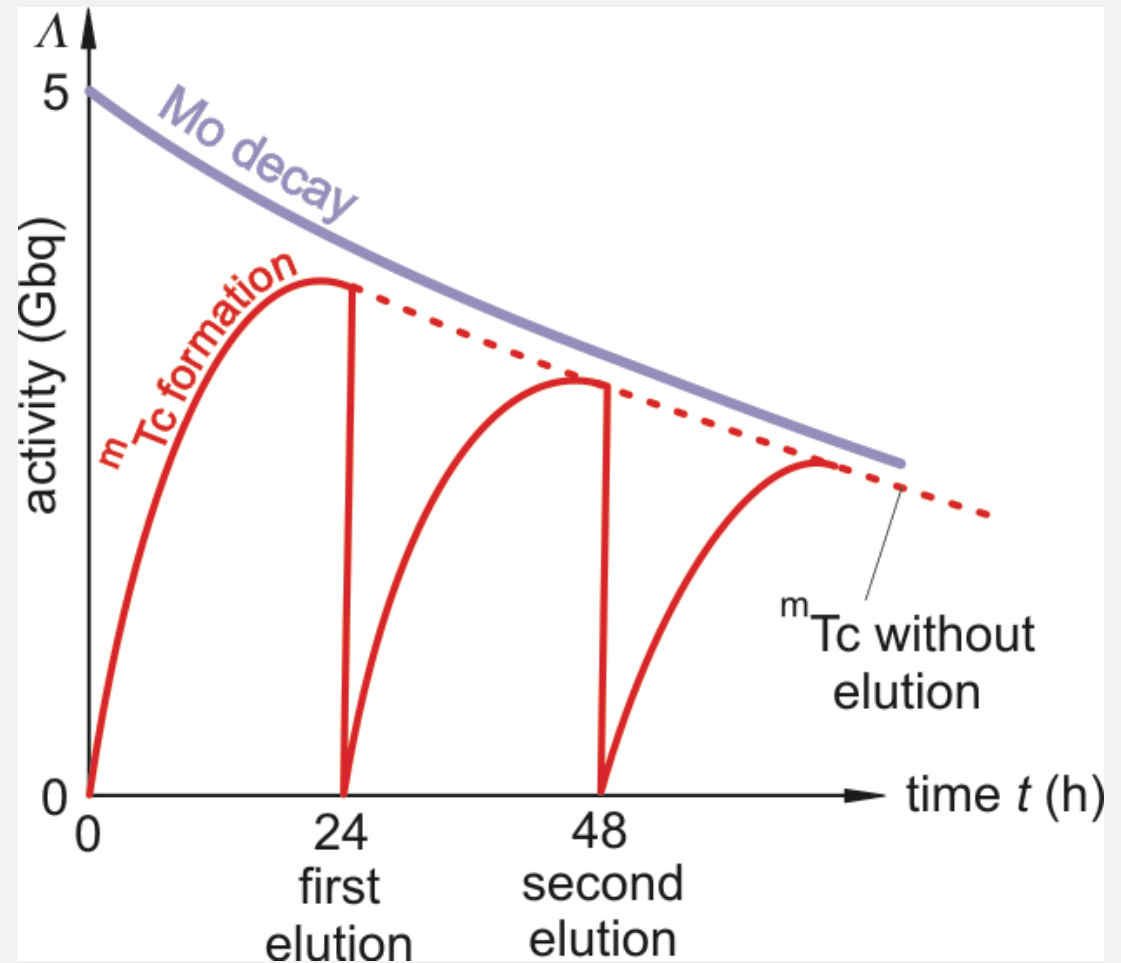
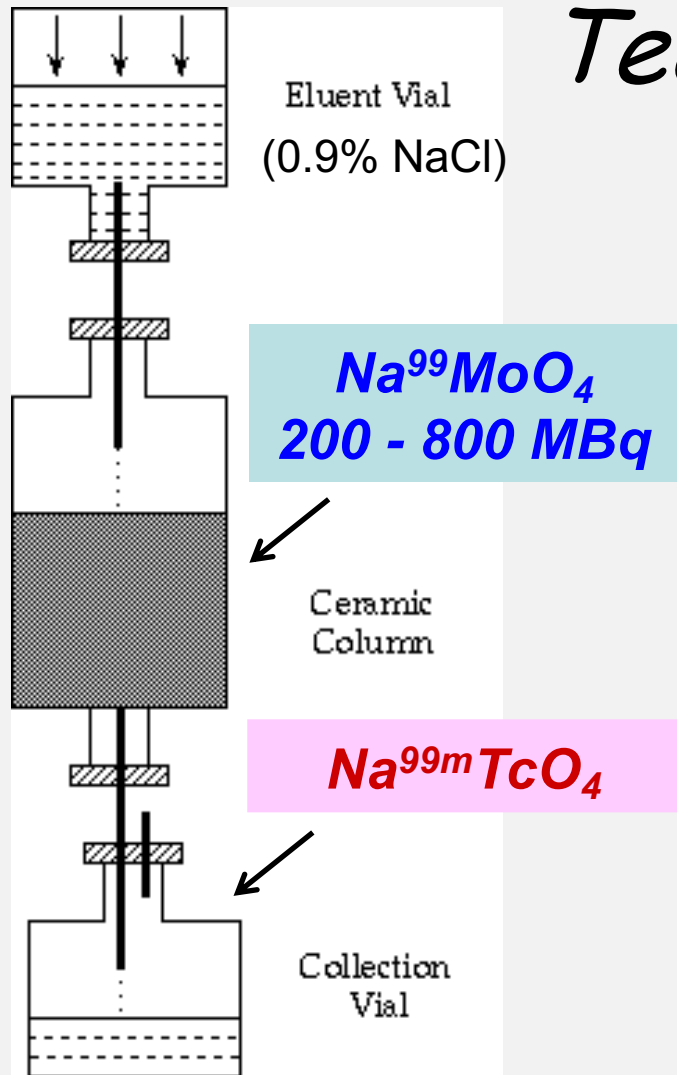


Csontfelvétel ^{99m}Tc -jelölt foszfátvegyülettel



terápia: gamma-kés

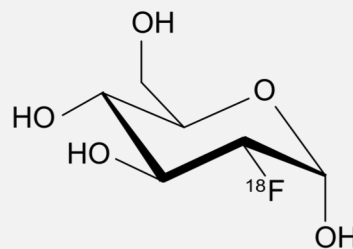
Technécium-99m generátor



$T_{1/2} = 67$ óra

$T_{1/2} = 6$ óra

| <i><u>Izotóp</u></i> | <i><u>radiofarmakon</u></i> | <i><u>szerv</u></i> | <i><u>funkció</u></i> |
|----------------------|-----------------------------|---------------------|------------------------|
| $^{99}\text{Tc}^m$ | <i>nátrium pertechnetát</i> | <i>agy</i> | <i>vérkeringés</i> |
| $^{99}\text{Tc}^m$ | <i>albuminhoz kötve</i> | <i>tüdő</i> | <i>vérkeringés</i> |
| $^{99}\text{Tc}^m$ | <i>kolloid szuszpenzió</i> | <i>máj</i> | <i>májfunkció</i> |
| $^{99}\text{Tc}^m$ | <i>pirofoszfát komplex</i> | <i>csont</i> | <i>csontanyagcsere</i> |
| ^{123}I | <i>jodid</i> | <i>pajzsmirigy</i> | <i>metabolizmus</i> |
| ^{123}I | <i>hippurán</i> | <i>vese</i> | <i>vesefunkció</i> |
| ^{133}X | <i>X gáz</i> | <i>tüdő</i> | <i>légzés</i> |
| ^{18}F | <i>fluorodeoxiglükóz</i> | | <i>metabolizmus</i> |



Ellenőrző kérdések

Atommag felépítése

Az atommag stabilitása – magerő – tömegdefektus

A bomlástörvény differenciális és integrális alakja

Bomlási állandó, felezési idő, átlagos élettartam

Magsugárzások típusai, spektrumuk, áthatolókéességük

$^{99\text{m}}$ Technécium generátor

Damjanovich, Fidy, Szöllősi: Orvosi biofizika

I. 1.5

1.5.1

1.5.2

1.5.4

II.3.2

3.2.1

3.2.2

3.2.3

3.2.4