Radionuclides in Brachytherapy

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Radionuclides

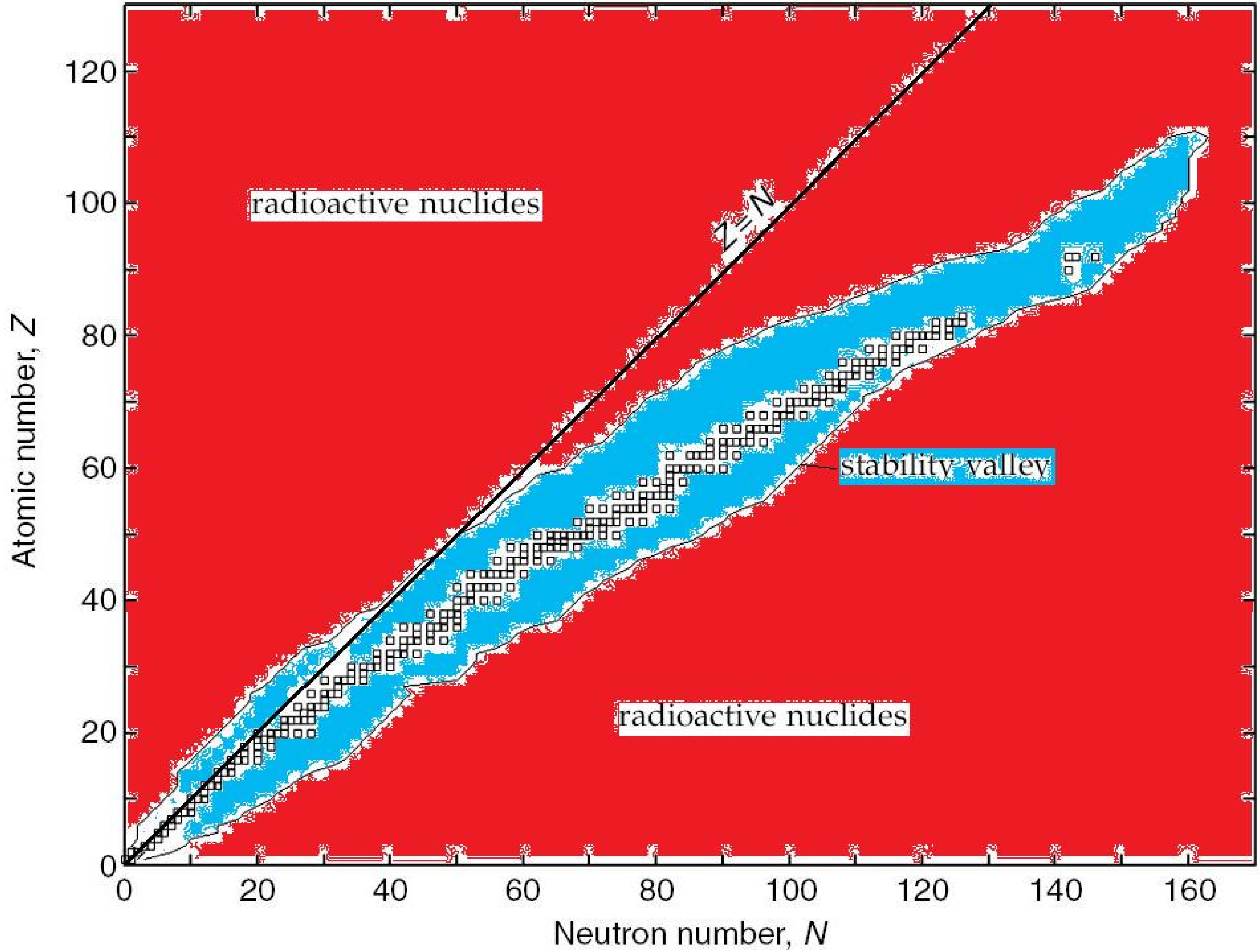
- *Radium 226*
- *Cobalt 60*
- *Cesium 137*
- *Iridium 192*
- *Gold 198*
- *Iodine 125*
- *Palladium 103*
- *Others – Radon 222, Thulium 170, Ytterbium 169*

Properties of Radionuclides

- *Radioactive decay scheme*
- *Half life*
- *Specific Activity*
- *Energy (HVL)*
- *Density & Atomic Number*

Radioactive Decay scheme

- *Radioactivity is determined by combinations of Neutrons and Protons in the nucleus.*
  - *Unstable combinations move towards stability via decay mechanisms*
  - *Stable combinations depend on*
    - *Atomic Number [Z] (For $Z < 20$, N/Z ratio = 1; For $Z > 20$, N/Z ratio > 1)*
    - *Even/ Odd combinations of Nucleons*
      - *Even(N) – Even(Z) Nuclei(50%)*
      - *Even(N) – Odd(Z) & Vice versa(20% each)*
      - *Odd(N) – Odd(Z) Nuclei (4 nuclei, H, Li, B, N)*



radioactive nuclides
Z=N
stability valley
radioactive nuclides
Atomic number, Z
Neutron number, N
0
20
40
60
80
100
120
140
160

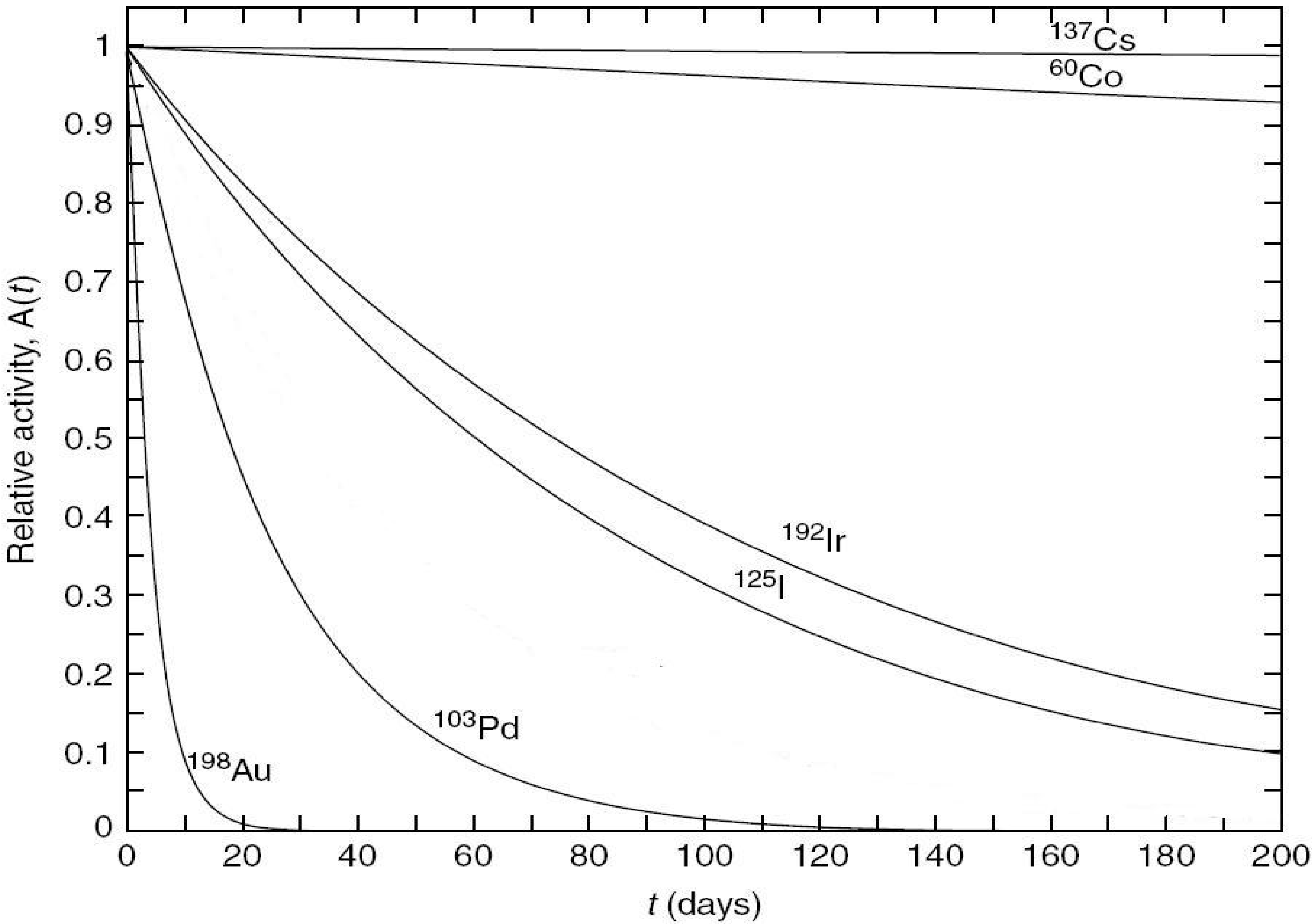
- *High N/ Z ratio nuclei(Excess Neutrons)*
  - *Negatron(Negative electron) / Beta Decay*
    - *Neutron decays into proton, Negatron, Antineutrino & energy*
    - *Energy shared between Daughter nucleus, particles and gamma radiation*
    - *Since energy between particles is shared, it forms a continuous spectrum*
  - *Alpha Decay – Leads to loss of Helium (Alpha) particle & Energy release*
    - *Energy released is shared as kinetic energy between daughter nuclei and alpha particle*
    - *Energy released is discrete*

- *Low N/ Z ratio nuclei(Excess protons)*
  - *Positron(Positive Electron)/ Beta Decay*
    - *Proton decays into Neutron, Positron, neutrino & Energy*
    - *Positron is unstable and immediately combines with electron to release two photons in opposite directions(Principle utilized in PET)*
  - *Electron Capture*
    - *Nucleus captures an orbital electron and converts a proton into a neutron with release of Gamma ray subsequently.*

- *Energy from excited nuclei can be dissipated*
  - *Instantaneously*
    - *Gamma radiation*
    - *Internal Conversion*
      - *Excess energy passed to orbital electron followed by ejection with energy(Energy from nucleus – Binding energy of electron)*
  - *Delayed*
    - *Isomeric Transition*
      - *Mo 99 -> Tc 99m -> Tc 99*

Half Life(and Specific Activity)

- *Determines Specific Activity(Activity per unit mass)*
  - *Activity = Decay constant x Number of atoms undergoing decay*
  - *Decay constant = 0.693/ Half life*
  - *Specific Activity inversely proportional to half life*
  - *Specific activity determines limits of miniaturization of source*
- *Practical importance of half life*
  - *Transport of sources*

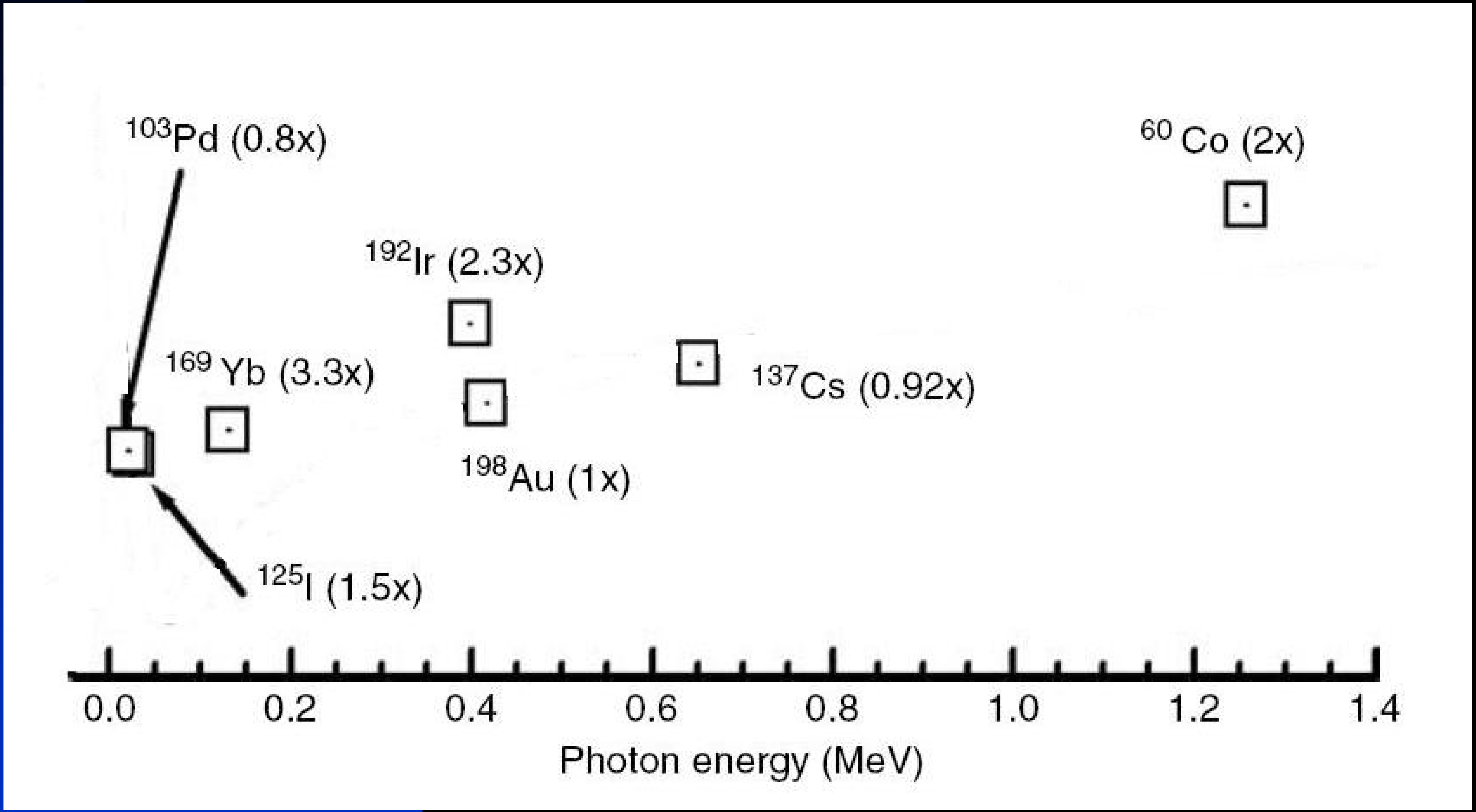


The exponential time decrease for a unit of initial activity of radionuclides used in brachytherapy: ^{137}Cs ($T_{1/2} = 30.20$y), ^{60}Co ($T_{1/2} = 5.27$y), ^{192}Ir ($T_{1/2} = 73.81$d), ^{125}I ($T_{1/2} = 59.49$d), ^{103}Pd ($T_{1/2} = 16.99$d), and ^{198}Au ($T_{1/2} = 2.70$d) .

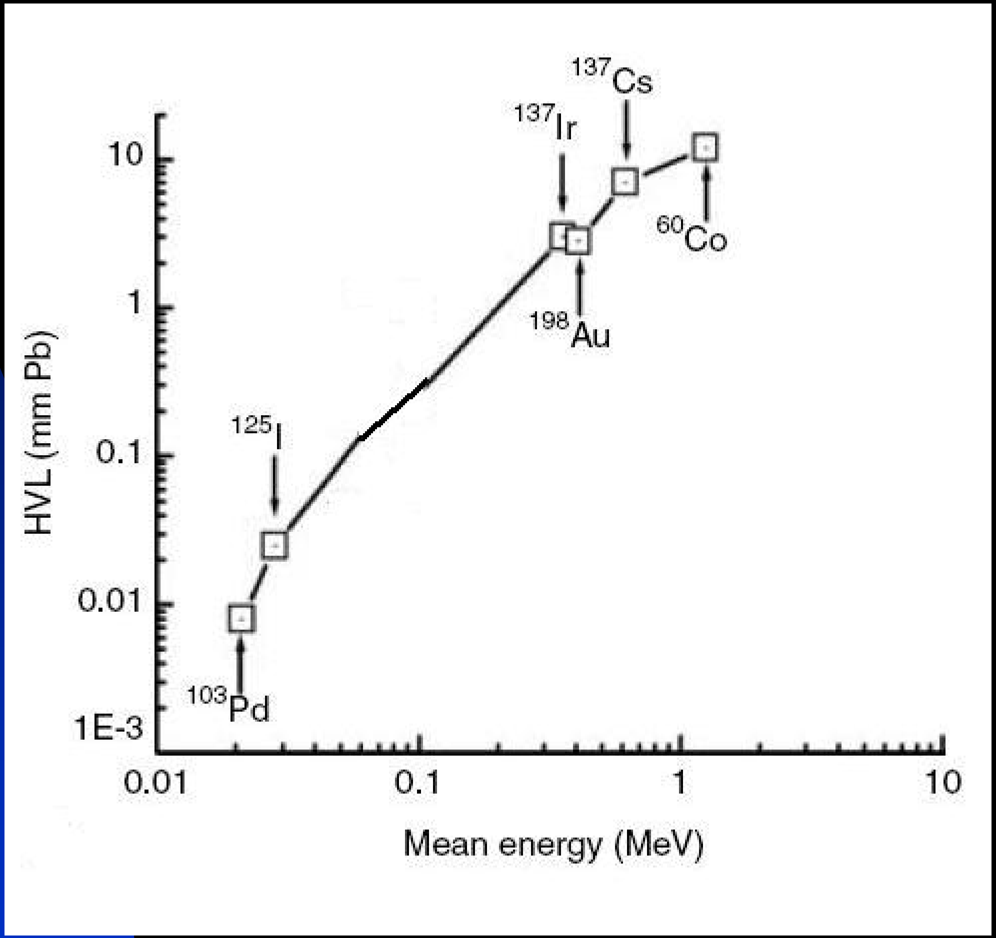
Energy

Described in terms of

- *Half value layer*
  - *Thickness of stated material which will reduce intensity of beam by half*
  - *Important for protection*
  - *For a heterogenous beam*
    - *HVL increases after every succesive attenuation of beam(Beam Hardening)*
  - *For a narrow monoenergetic beam*
    - *HVL = 0.693/ Linear attenuation coefficient*
    - *Linear attenuation coefficient is a constant of proportionality which relates the change in the number of photons/ Intensity after passing through a certain thickness of material.*



(Number of photons released)


137Cs
137Ir
10
60Co
1
198Au
HVL (mm Pb)
125I
0.1
0.01
103Pd
1E-3
0.01
0.1
1
10
Mean energy (MeV)

Density and Atomic Number

- *Determine radiographic visibility(positioning)*

Physical Property	Relevance to Brachytherapy
Radiation emitted	Source geometry and structure
Half-life $T_{1/2}$	Determines if permanent or temporary implant or both are practical
Specific activity	Source size
Energy of emitted radiation	radiation protection requirements
Density and atomic number	Radiographic visibility/localization

Radium 226

- *Part of Uranium series(Ends in Pb 206)*

  (Three basic series: Uranium, Actinium & Thorium starting with U 238, U 235 & Th 232 respectively and ending in Pb 206, 207 & 208 respectively)

- *Ra 226 -> Rn 222 + Helium + Energy*
- *Disintegrates into daughter nuclei and achieves secular equilibrium with its products.*
- *Releases 49 gamma rays with energies varying between 0.184 – 2.45 MeV*
- *Average energy after achieving equilibrium with its products(1 month) & filtered through 0.5mm of platinum is 0.83MeV.*
- *Construction: RaSO4/ RaCl + Inert filler sealed in 0.1-0.2mm gold foil(1 cm long and 1 mm diameter cylinders), which is again sealed in platinum.*

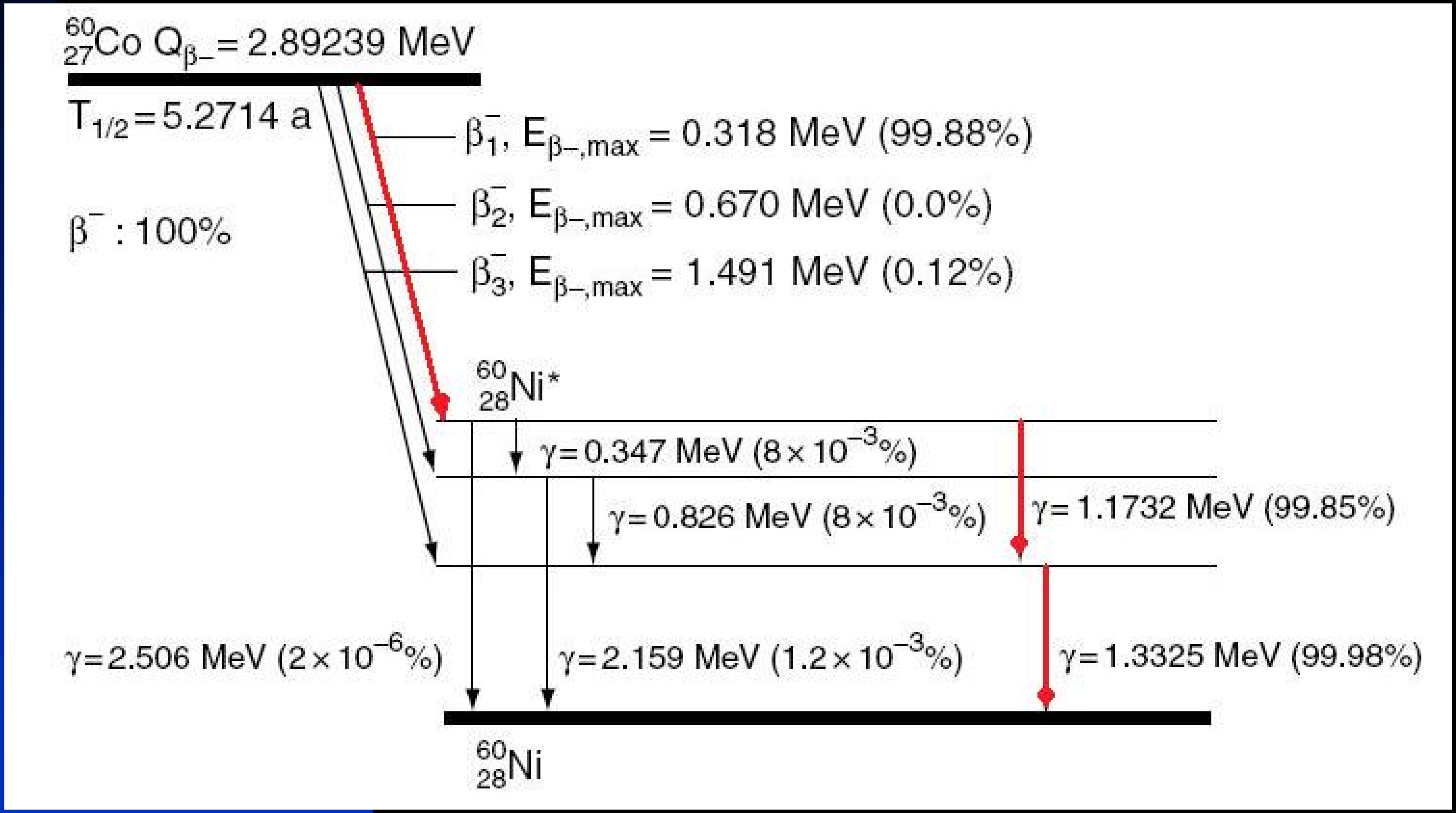
- *Radium 226 though discontinued is still used to specify strength of sources. (Mg-Ra-Eq: 1gm = 1 Ci, 1mg = 1 mCi)*
- *Artificially produced radio-isotopes: Exposure rate at 1 meter divided by the exposure rate constant of radium (point source filtered by 0.5 mm Pt) at 1 meter*

Source	Exp.Rate const., Γx ($R.cm^2.h^{-1}.mCi^{-1}$)
Ra-226	8.25
Co-60	13.07
Cs-137	3.26
Ir-192	4.69
Au-198	2.38
I-125	1.46
Pd-103	1.48

- *Provided as needles with:*
    - *Uniform linear activity(Full or half intensity, 0.66mg/cm and 0.33mg/cm respectively)*
    - *More activity at one end(Indian Club)*
    - *More activity at both ends(Dumbbell)*

Cobalt 60

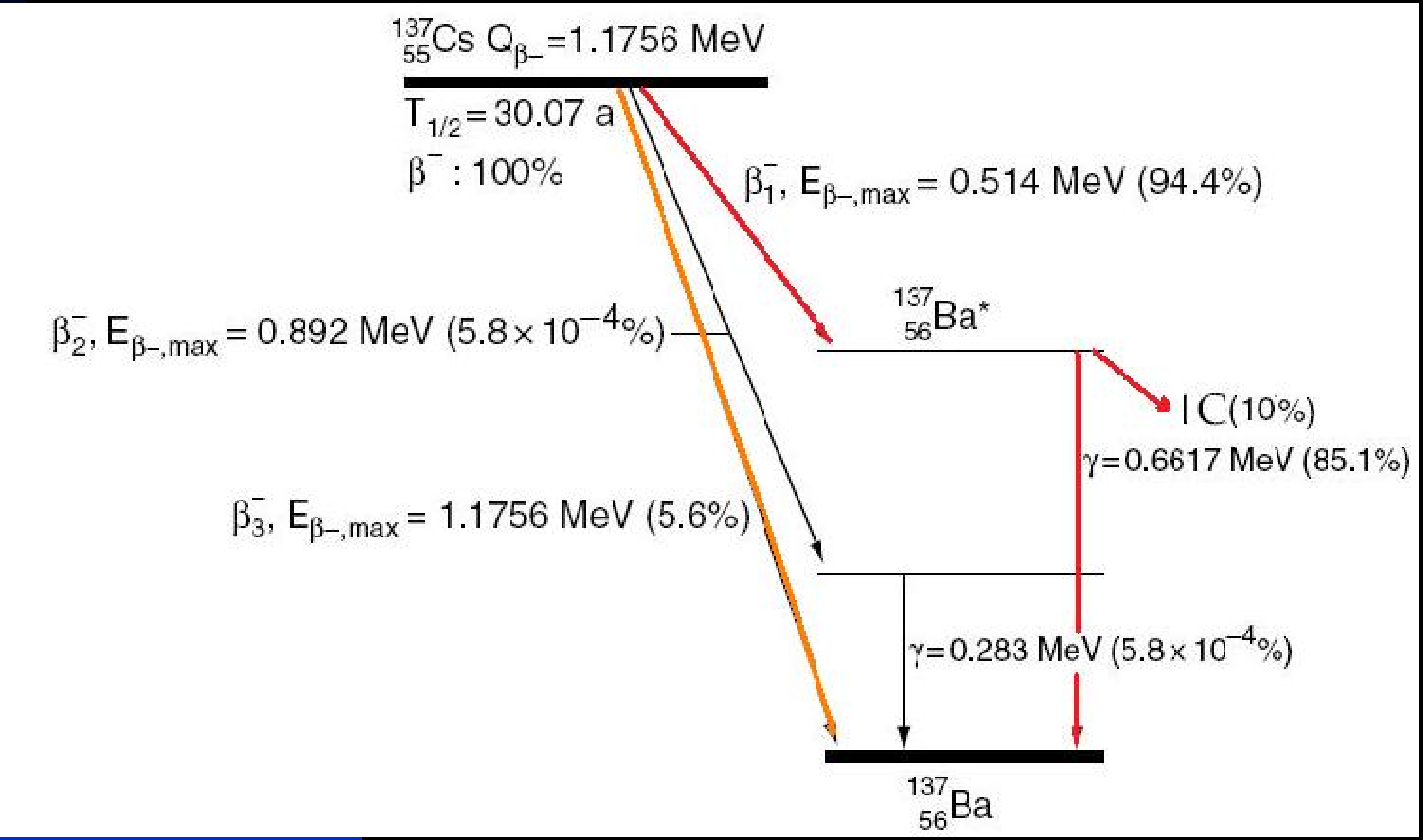
- *Co 60 -> Ni 60 + Negatron + 2 x Gamma rays*
- *Dominant energy of gamma rays is 1.1 & 1.3 MeV*
- *Maximum energy of Dominant Negatron is 0.3 MeV. (Therefore Cobalt itself is sufficient to absorb them and if required a thin sheath of filtering material may be used)*
- *Rarely used now & was introduced to replace Radium for gynecological cancers(could be moulded, no loss from leaks or breakage)*
- *More expensive than Cs 137. More cost effective than Ir 192 due to longer half life.*
- *Construction: Cobanic(45% Co + 55% Ni) wire with Diameter of 1mm in sheath of Platinum-Iridium or stainless steel*



$^{60}_{27}Co$ $Q_{\beta-} = 2.89239$ MeV
$T_{1/2} = 5.2714$ a
β^- : 100%
β_1^-, $E_{\beta-,max} = 0.318$ MeV (99.88%)
β_2^-, $E_{\beta-,max} = 0.670$ MeV (0.0%)
β_3^-, $E_{\beta-,max} = 1.491$ MeV (0.12%)
$^{60}_{28}Ni^*$
$\gamma = 0.347$ MeV (8×10^{-3}%)
$\gamma = 0.826$ MeV (8×10^{-3}%)
$\gamma = 1.1732$ MeV (99.85%)
$\gamma = 2.506$ MeV (2×10^{-6}%)
$\gamma = 2.159$ MeV (1.2×10^{-3}%)
$\gamma = 1.3325$ MeV (99.98%)
$^{60}_{28}Ni$

Cesium 137

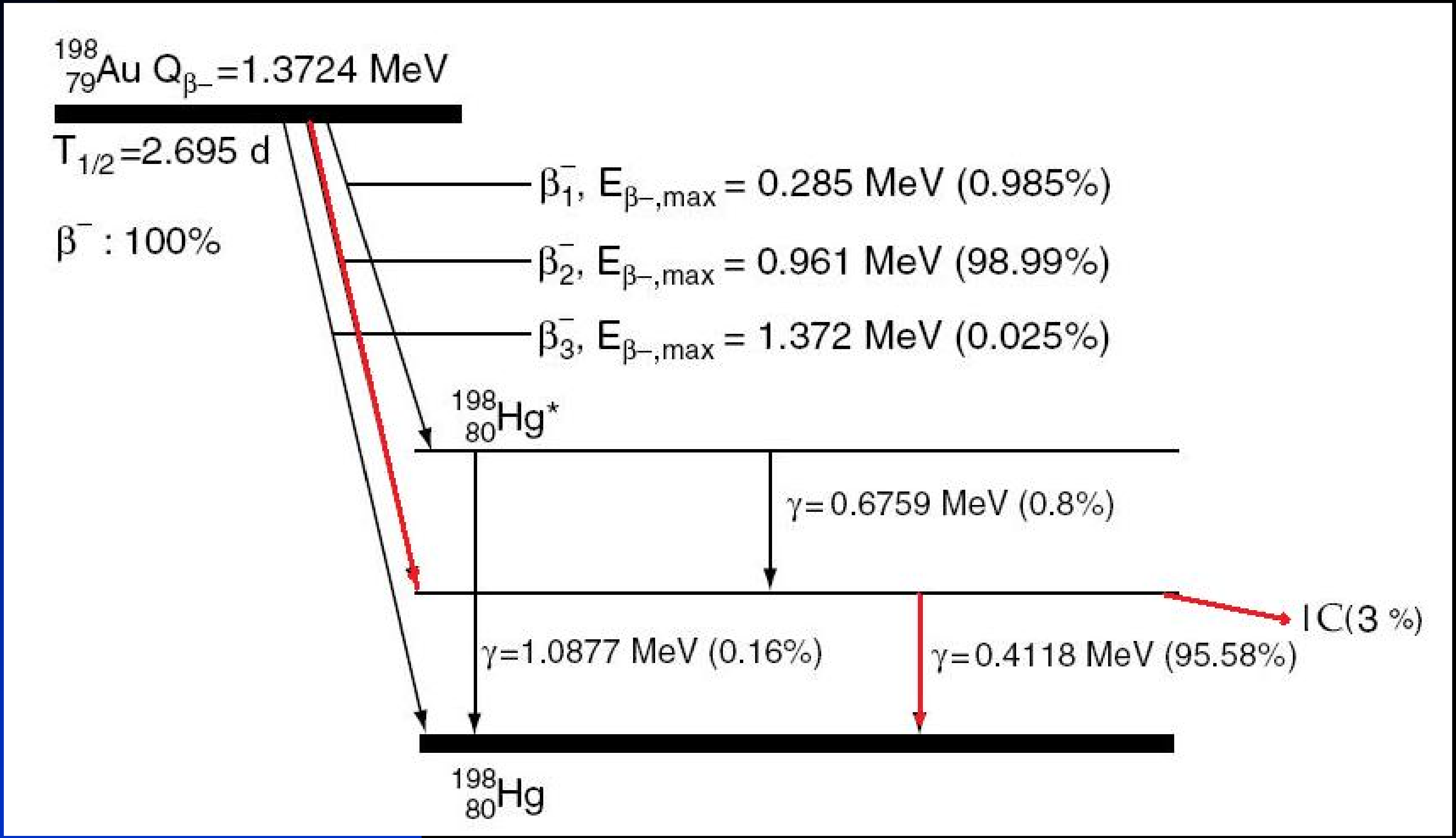
- *Cs 137 -> Ba 137 + Negatron + 0.9 gamma ray + 0.1 Internal conversion*
- *Dominant energy of gamma ray is 0.66 MeV*
- *Maximum energy of Negatron varies between 0.5(94%) to 1.1(6%) MeV(requires greater encapsulation than Co 60)*
- *Advantage over Ra is less shielding and over Co is a longer half life.*
- *Lowest Specific activity amongst all Ra replacements.*
- *Construction: Insoluble powders or spheres encapsulated in steel needles and tubes*



$^{137}_{55}Cs$ $Q_{\beta-}$=1.1756 MeV
$T_{1/2}$= 30.07 a
β^- : 100%
β_1^-, $E_{\beta-,max}$ = 0.514 MeV (94.4%)
$^{137}_{56}Ba^*$
β_2^-, $E_{\beta-,max}$ = 0.892 MeV (5.8×10^{-4}%)
IC(10%)
γ=0.6617 MeV (85.1%)
β_3^-, $E_{\beta-,max}$ = 1.1756 MeV (5.6%)
γ=0.283 MeV (5.8×10^{-4}%)
$^{137}_{56}Ba$

Gold 198

- *Au 198 -> Hg 198 + Negatron + 1 Gamma ray (+ 3% Internal Conversion)*
- *Dominant energy of gamma ray is 0.41 MeV*
- *Maximum energy of Negatron is 0.96 MeV(Filtered by Gold itself and 0.1mm thick Platinum foil)*
- *Was designed to replace Radon seeds, but has now been superseded by Iodine 125.*
- *Construction: 2.5 mm long with an outer diameter of 0.8 mm loaded in a special gun with 14 seeds.*


$^{198}_{79}Au$ $Q_{\beta-}$=1.3724 MeV
$T_{1/2}$=2.695 d
β^- : 100%
β_1^-, $E_{\beta-,max}$ = 0.285 MeV (0.985%)
β_2^-, $E_{\beta-,max}$ = 0.961 MeV (98.99%)
β_3^-, $E_{\beta-,max}$ = 1.372 MeV (0.025%)
$^{198}_{80}Hg^*$
γ=0.6759 MeV (0.8%)
IC(3 %)
γ=1.0877 MeV (0.16%)
γ=0.4118 MeV (95.58%)
$^{198}_{80}Hg$

Iridium 192

- *95% via Negatron Decay*
  - *Ir 192 -> Pt 192 + Negatron + 2.2 Gamma rays (+ 6% by Internal Conversion)*
  - *Several gamma rays emitted with average of 2.2/ decay and energy of 0.38 MeV*
  - *Several Negatrons with mean energy of 0.18 MeV*
- *5% via Electron Capture*
  - *Ir 192 -> Os 192 + Gamma ray*
  - *Several Gamma rays between 0.1 – 0.7 MeV*
- *Established standard for temporary brachytherapy at all tumor sites*
- *Construction: Thin flexible wires and Nylon ribbons containing Iridium seeds*

Iodine 125

- *Electron Capture*
  - *I 125 -> Te 125 + Characteristic X Rays (+ 7% Gamma rays)*
- *Complex dose distribution. Mean energy 0.028MeV via Internal conversion.*
- *More suitable for storage as longer half life.*
- *High specific activity is useful for both temporary and permanent implants.*
- *Main application in prostate cancer. Useful for permanent implants in Tumors of Brain, Lung, Pancreas, Breast & Pediatric Tx*

Palladium 103

- *Electron Capture*
  - *Pa 103 -> Rh 103 + Characteristic X Rays (+ Some gamma rays)*
- *Mean energy of 0.021 MeV*
- *High specific activity within a shorter time may be useful for rapidly proliferating tumors.*

Thank you