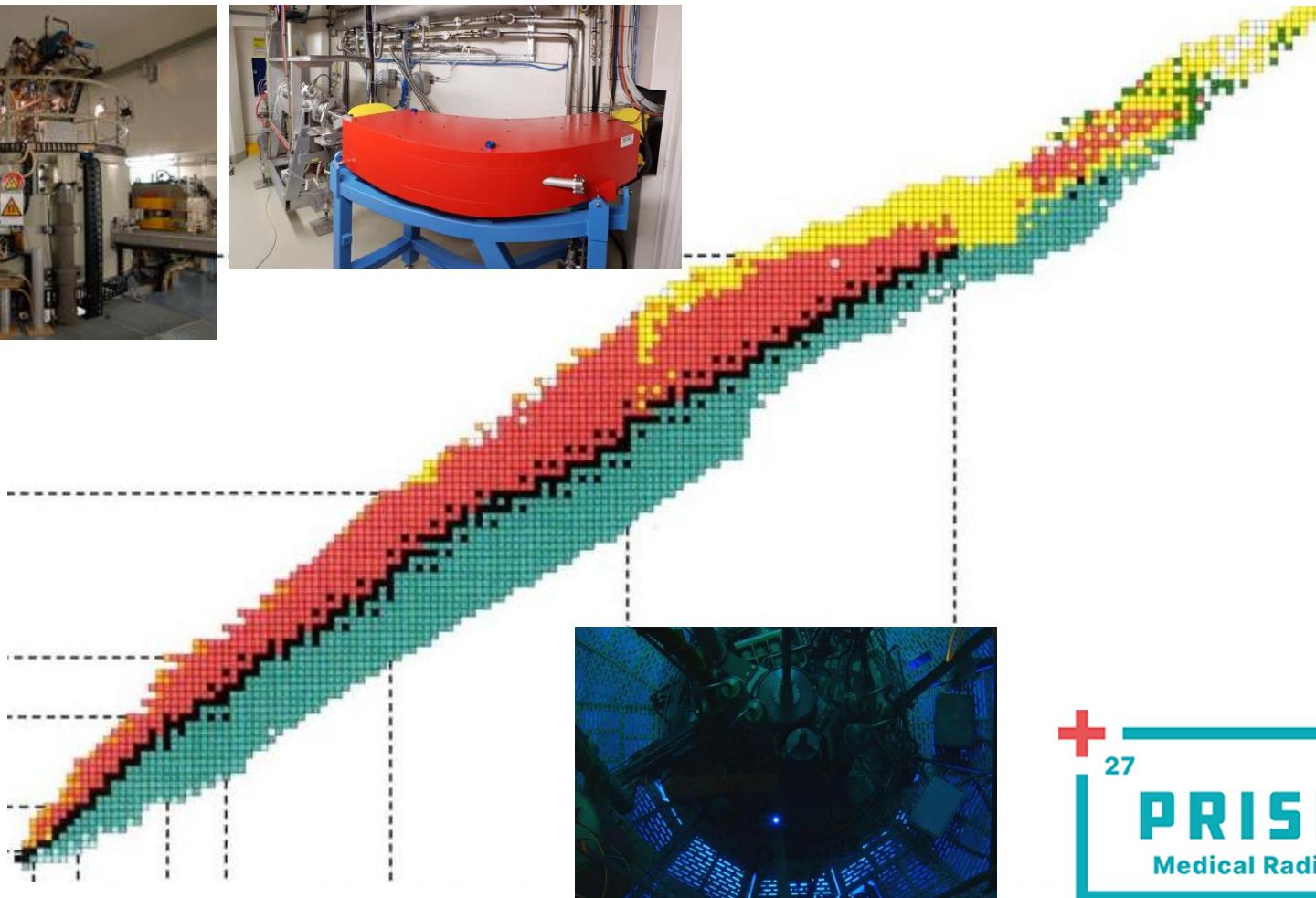


Radionuclides and their production



Ulli Köster

ILL & UGA, Grenoble, France



Finding the right theranostic partner

F 18
110 m
 β^+ 0.633
no γ



F 2X
few d
 $\beta^- < 0.3$
no γ

F 1X
few d
 α
no γ

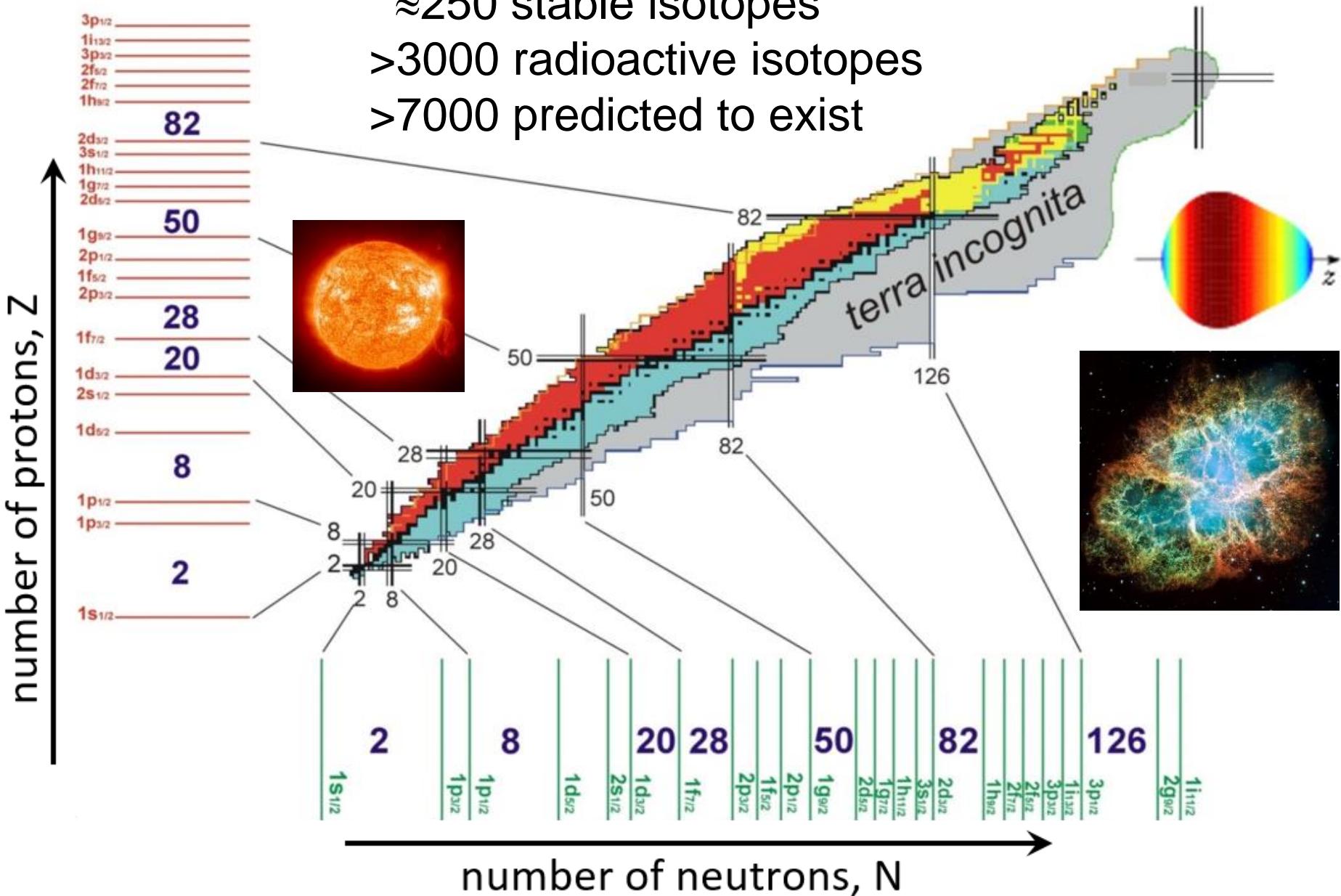


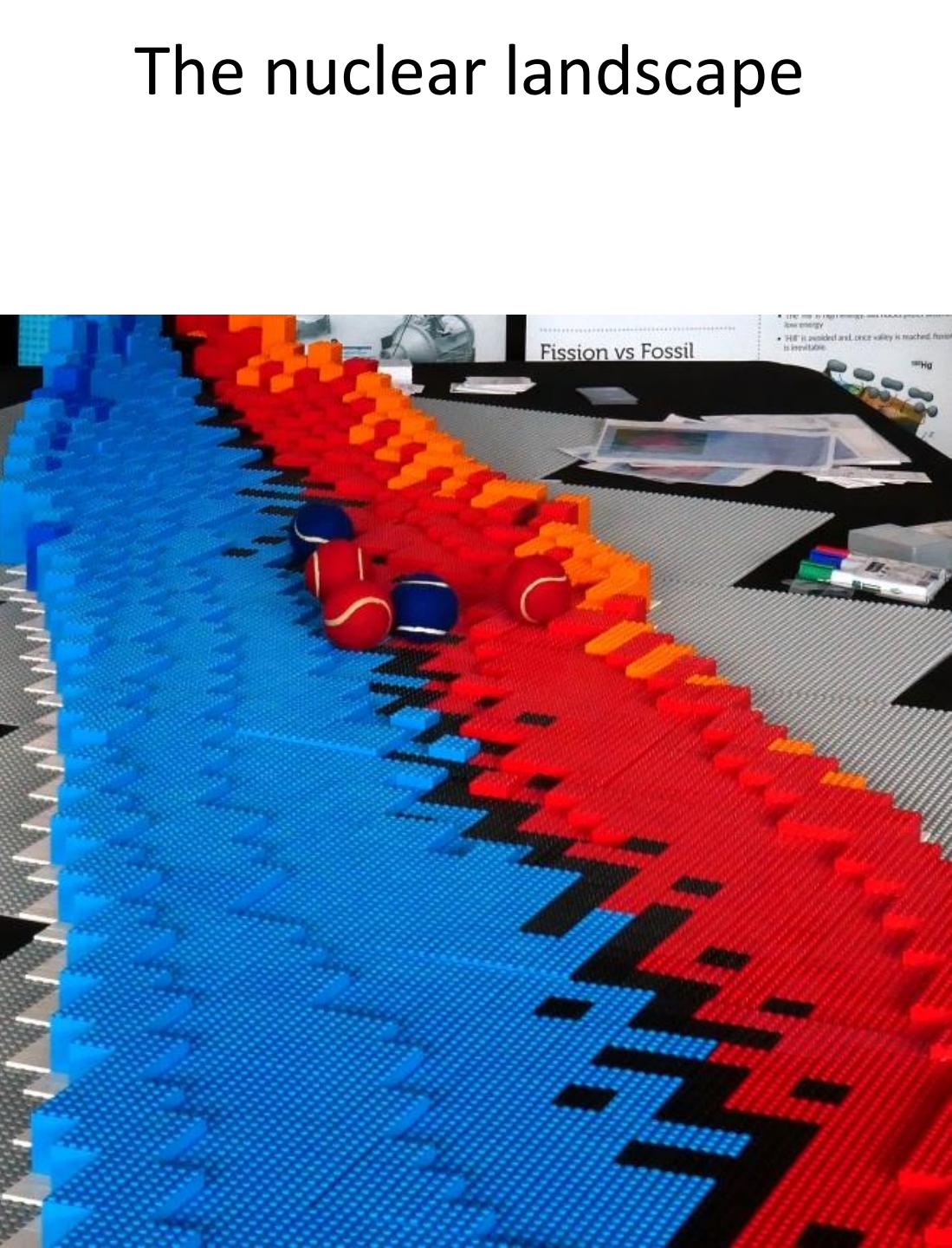
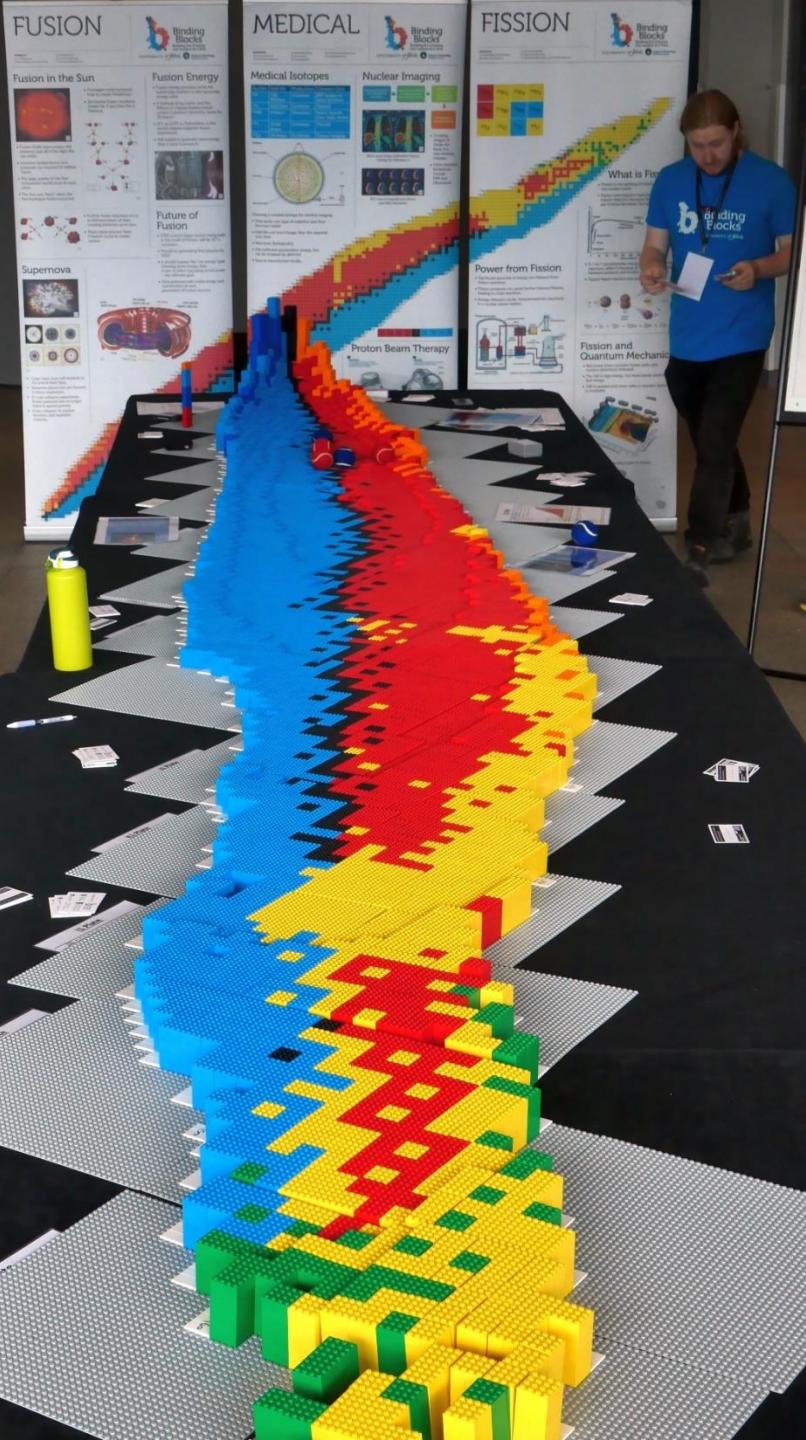
F 13
650 ys
 $3p \approx 7.1$
no γ

Charity 2021
DOI: [10.1103/PhysRevLett.126.132501](https://doi.org/10.1103/PhysRevLett.126.132501)

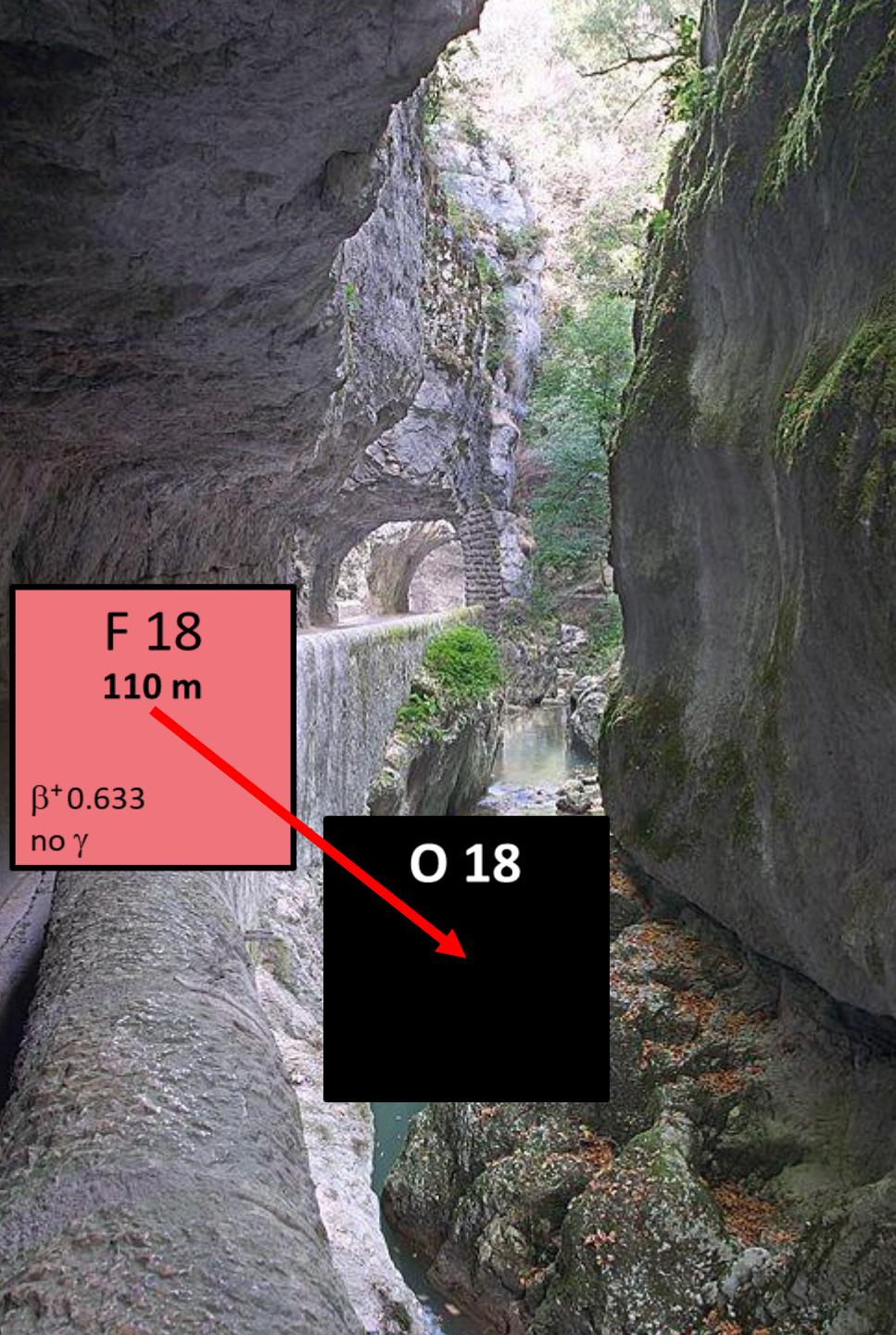
The chart of nuclides – nuclear physics perspective

≈250 stable isotopes
>3000 radioactive isotopes
>7000 predicted to exist

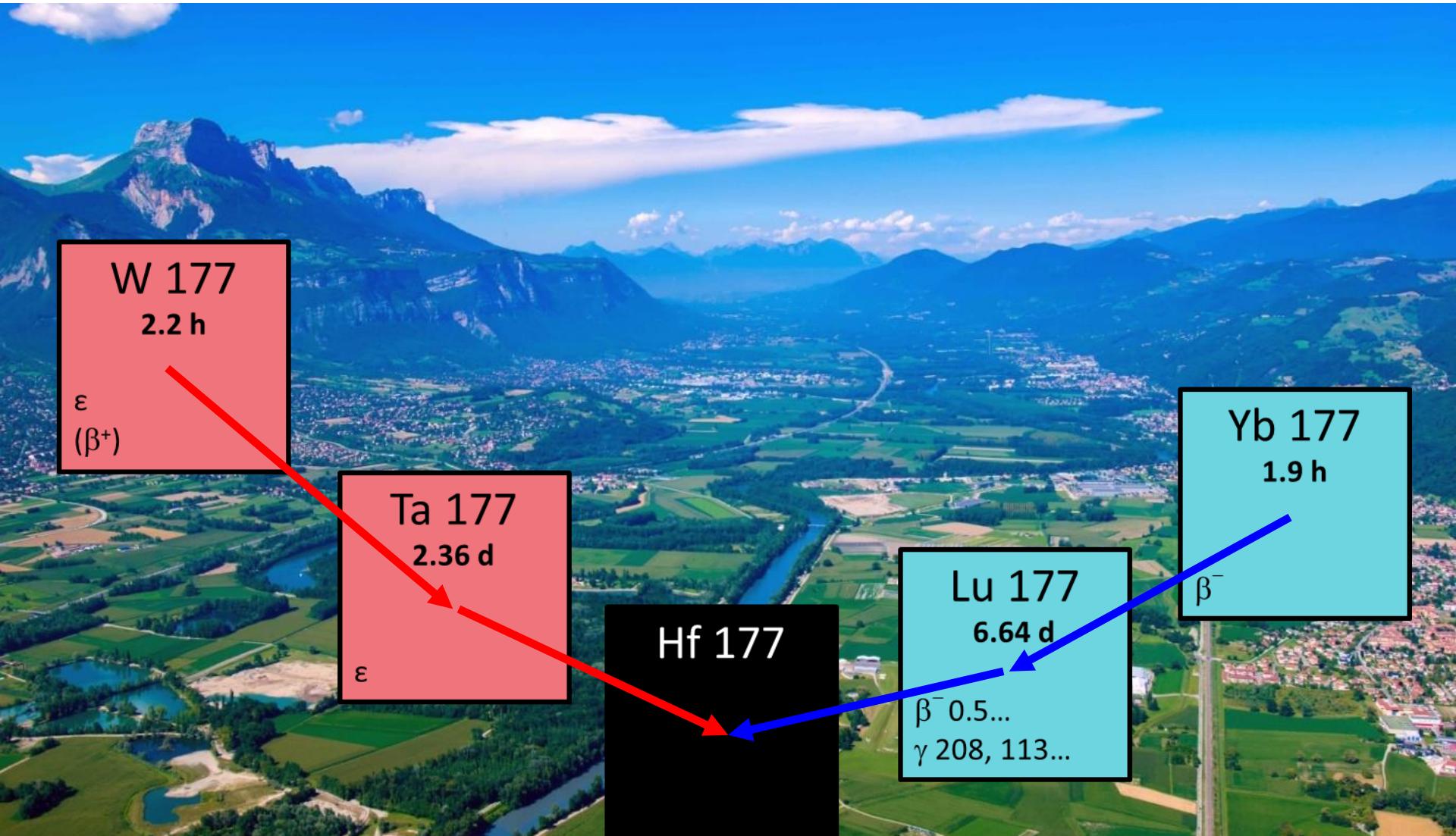




Light mass: narrow valley



Heavy masses: broad valley



^{131}I : radioprotection issues

I 131
8.0 d

β^- 1.0, 1.8,...
 γ 364, 637...

364 keV gamma ray
emitted with 82% B.R.

3.7 GBq patient dose
⇒ 0.2 mSv/h at 1 m
“hot zone” (IAEA/NRCP)

requires dedicated
shielded treatment
rooms



^{90}Y : collateral damage from long range betas ?

$Q_{\beta^-} = 2.28 \text{ MeV}$
up to 12 mm range



$\text{Y } 90$
 2.67 d

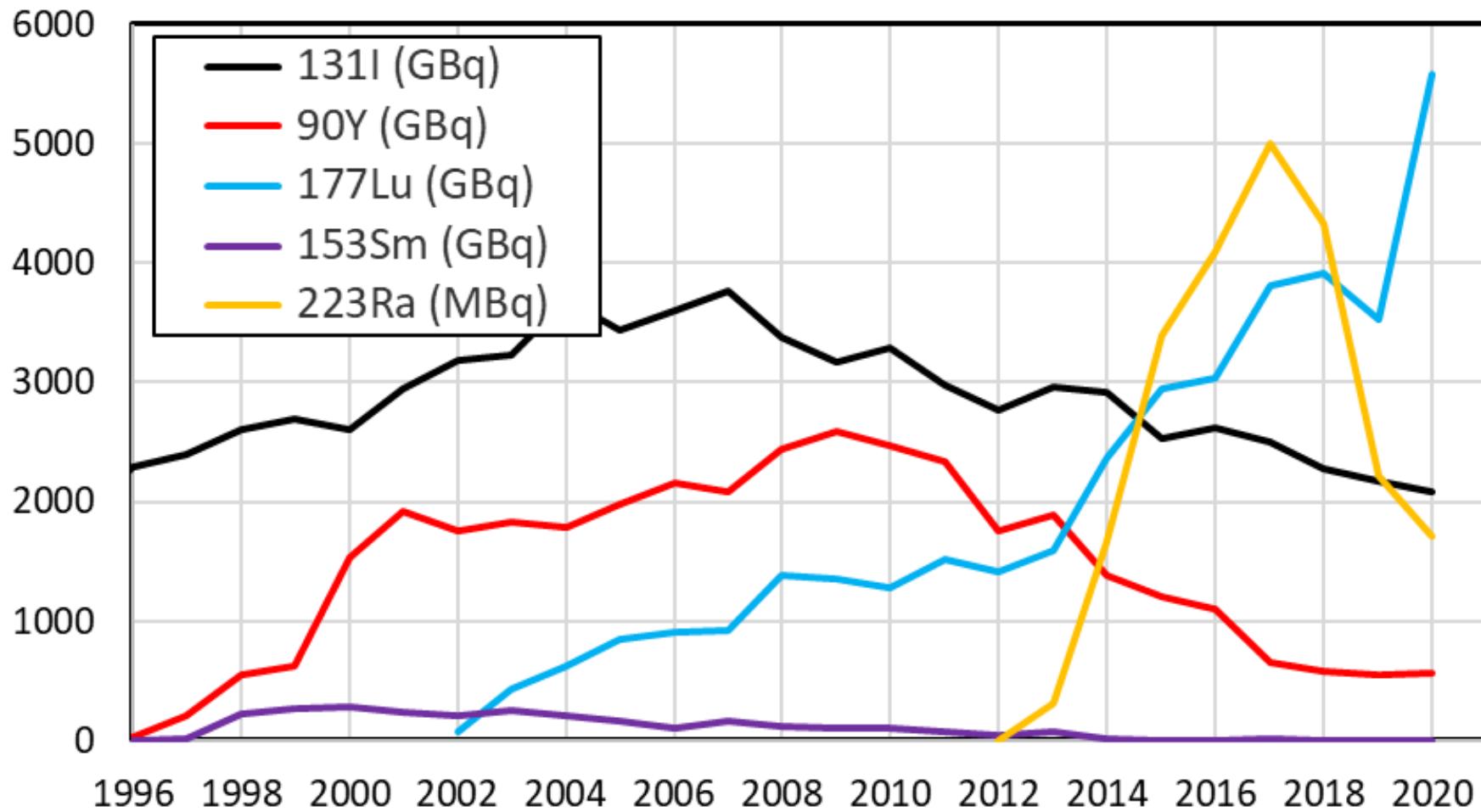
β^- 2.3...
 γ (2186...)

The “gold standard” for radioligand therapy

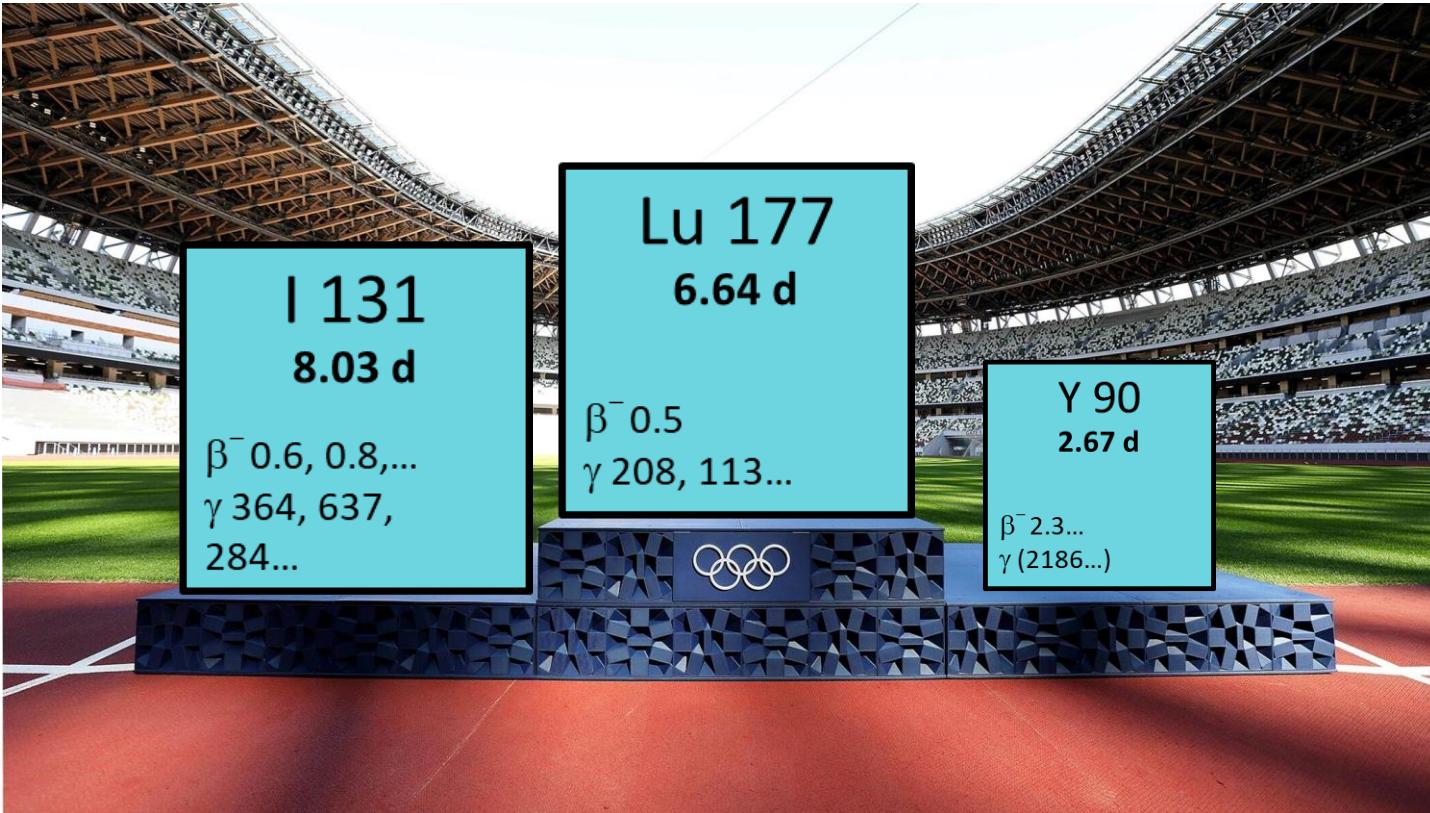


Established and emerging therapeutic radionuclides

Annual use of activity in CH hospitals



The beta emitter podium



The beta emitter race



Lu 177
6.64 d

β^- 0.5
 γ 208, 113...

The ideal beta emitter ?

Lu 177
6.64 d

β^- 0.5
 γ 208, 113...

Specific activity:
Theo. 4.1 TBq/mg
n.c.a. >3.0 TBq/mg

endolucin
beta

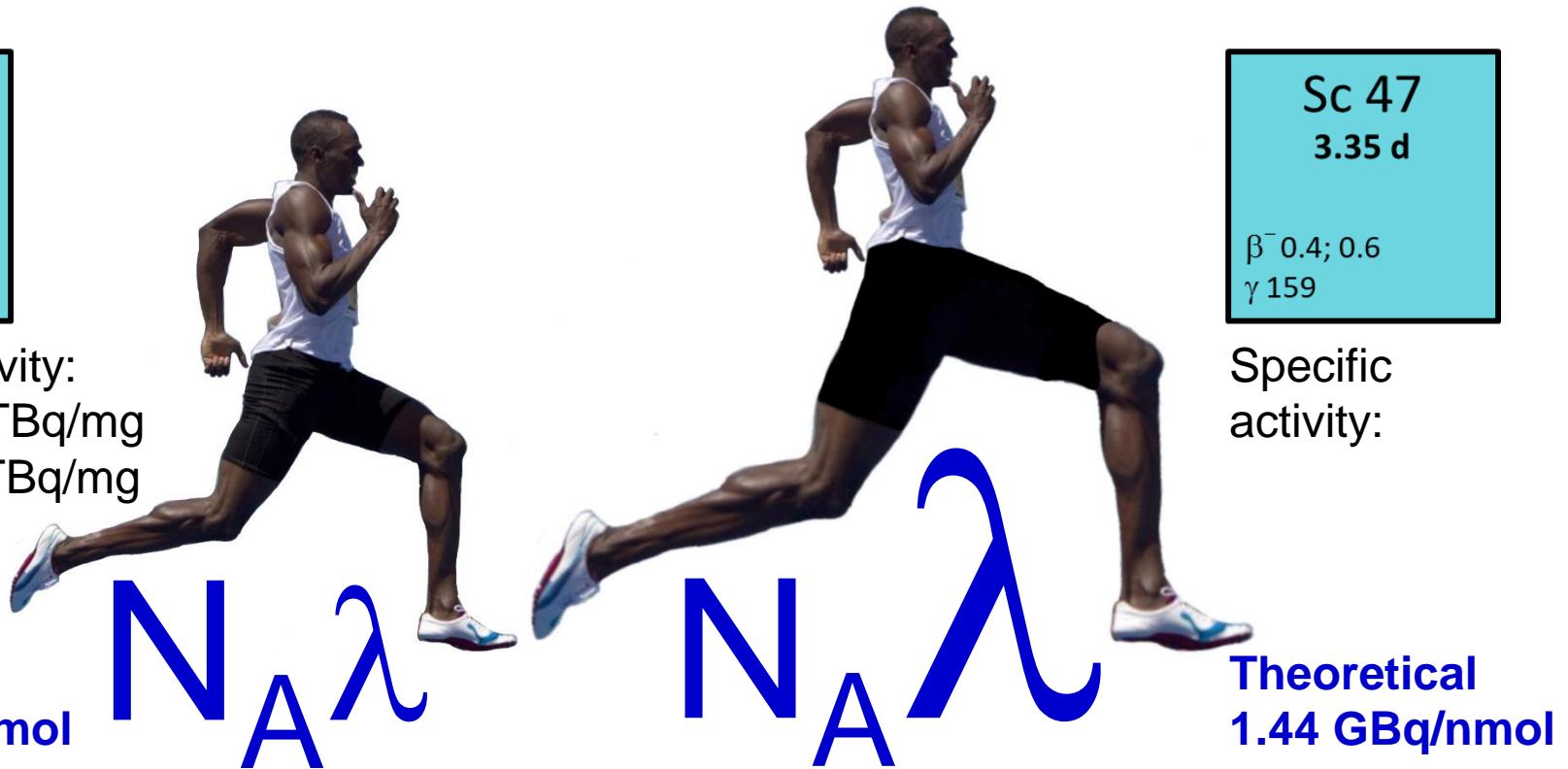
Theoretical
0.73 GBq/nmol

Sc 47
3.35 d

β^- 0.4; 0.6
 γ 159

Specific
activity:

Theoretical
1.44 GBq/nmol



Hernández Gómez 2013
DOI: [10.1088/0143-0807/34/5/1227](https://doi.org/10.1088/0143-0807/34/5/1227)

Domnanich 2017

DOI: [10.1186/s41181-017-0024-x](https://doi.org/10.1186/s41181-017-0024-x)

Siwowska 2019

DOI: [10.1088/0143-0807/34/5/1227](https://doi.org/10.1088/0143-0807/34/5/1227)

Mikolajczak 2021

DOI: [10.1186/s41181-021-00131-2](https://doi.org/10.1186/s41181-021-00131-2)

The ideal beta emitter ?

Lu 177

6.64 d

β^- 0.5

γ 208, 113...

Specific activity:

Theo. 4.1 TBq/mg

n.c.a. >3.0 TBq/mg

endolucin
beta



Theoretical
0.73 GBq/nmol

Tb 161

6.96 d

β^- 0.5; 0.6

γ 26; 49; 75...

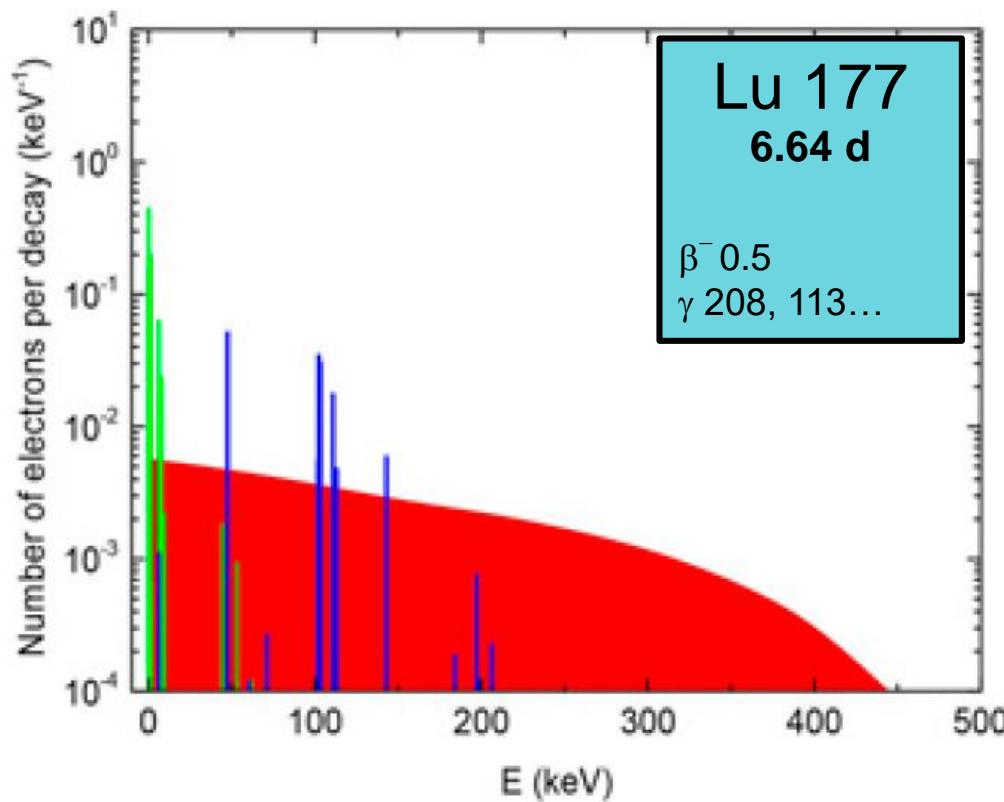
e^-

Specific activity:

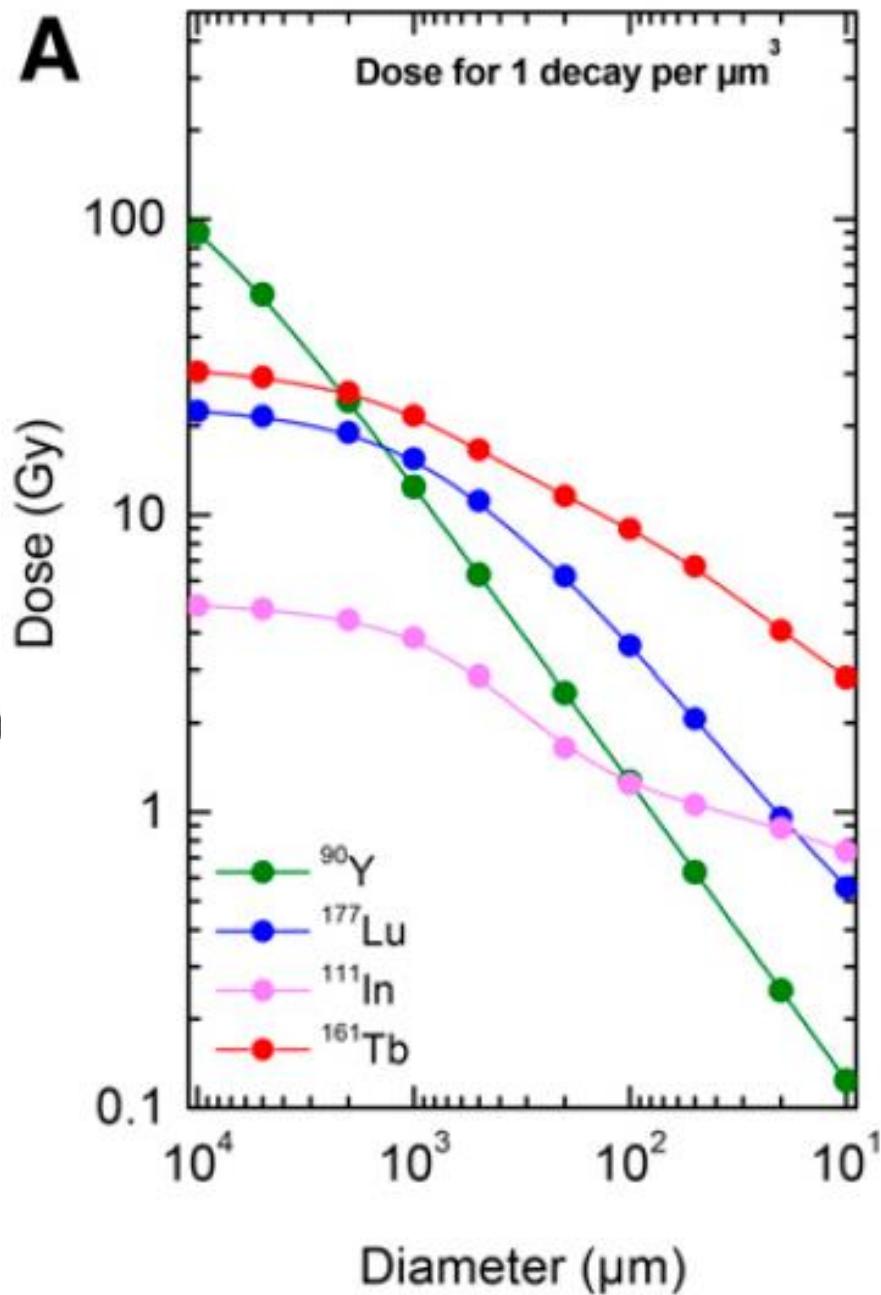
Theoretical

0.69 GBq/nmol

^{161}Tb versus ^{177}Lu



Hindié 2016 <https://doi.org/10.2967/jnumed.116.244101>



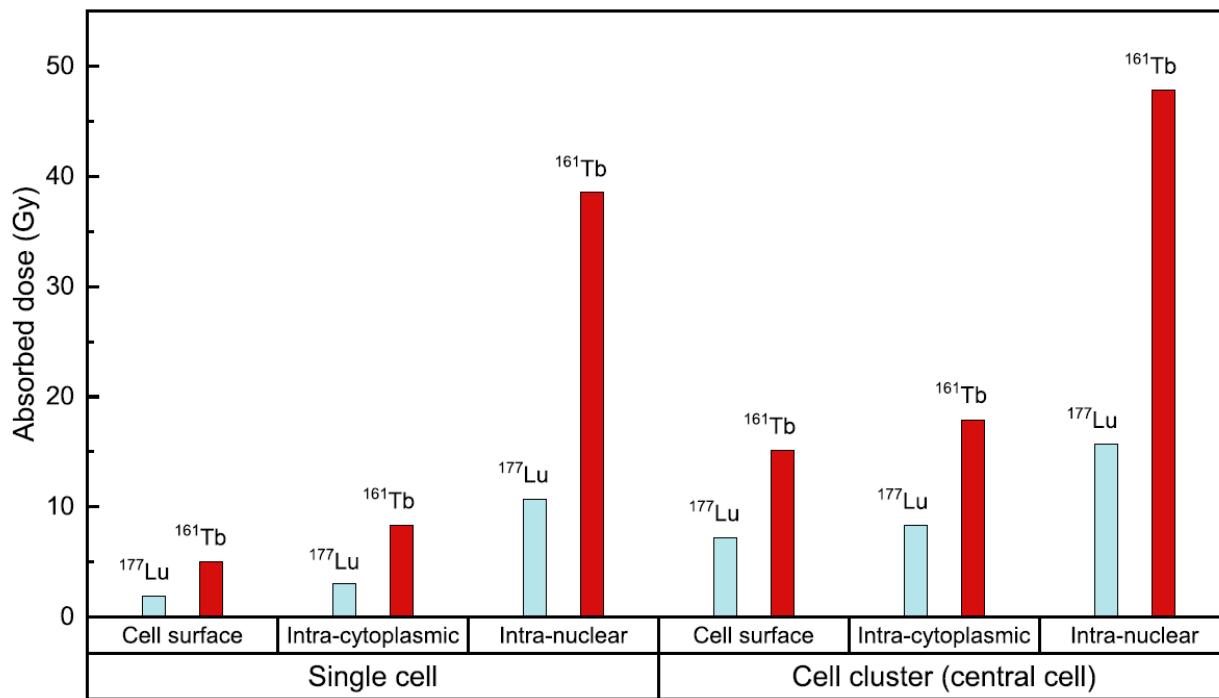
The ideal beta emitter ?

Lu 177
6.64 d

β^- 0.5
 γ 208, 113...

Tb 161
6.96 d

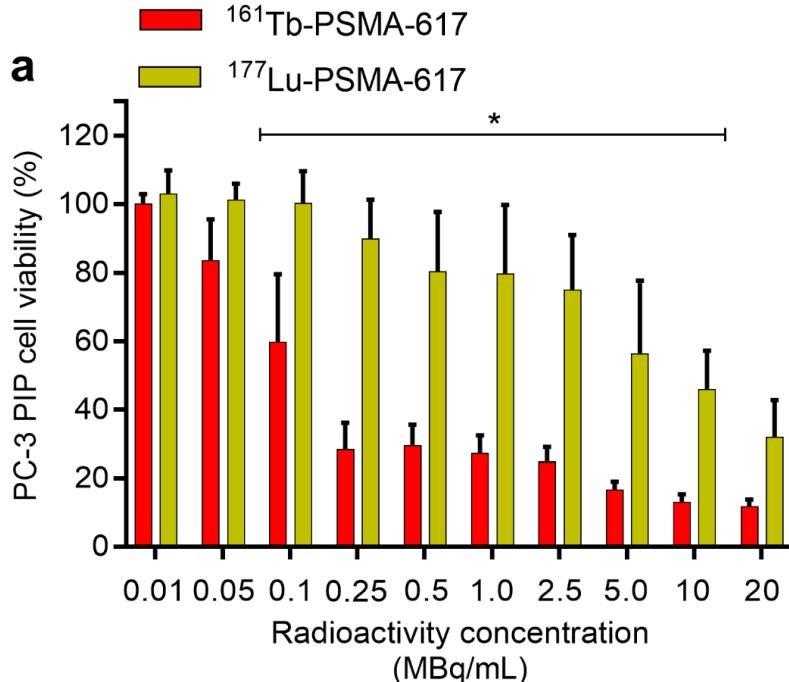
β^- 0.5; 0.6
 γ 26; 49; 75...
 e^-



Alcocer-Ávila 2020 DOI: [0.1186/s40658-020-00301-2](https://doi.org/10.1186/s40658-020-00301-2)

Bernhardt 2021 DOI: [10.3390/cancers13092011](https://doi.org/10.3390/cancers13092011)

The ideal beta emitter ?



Lu 177
6.64 d

β^- 0.5
 γ 208, 113...

Tb 161
6.96 d

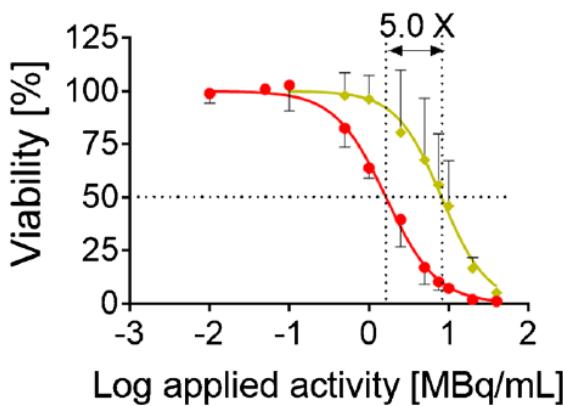
β^- 0.5; 0.6
 γ 26; 49; 75...
 e^-

Müller 2019

[doi: 10.1007/s00259-019-04345-0](https://doi.org/10.1007/s00259-019-04345-0)

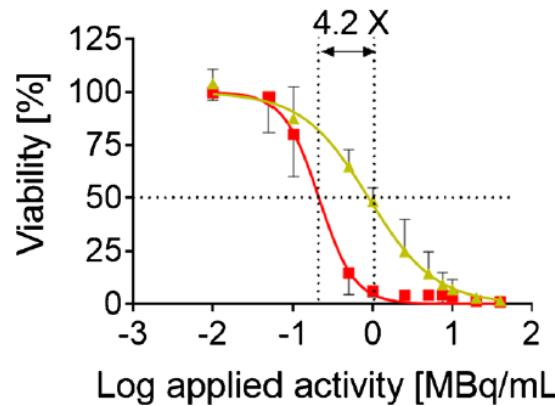
Borgna 2021

[doi: 10.1007/s00259-021-05564-0](https://doi.org/10.1007/s00259-021-05564-0)



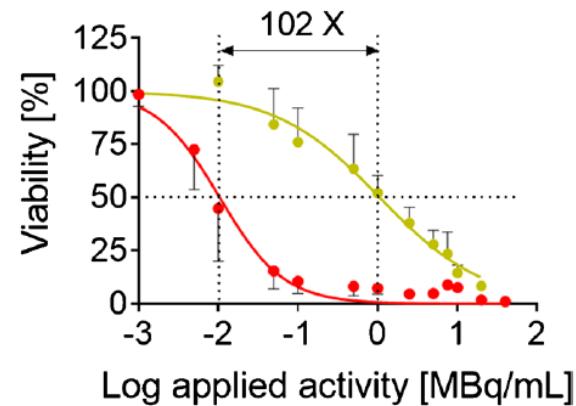
● [¹⁶¹Tb]Tb-DOTATOC

◆ [¹⁷⁷Lu]Lu-DOTATOC



● [¹⁶¹Tb]Tb-DOTATOC-NLS

◆ [¹⁷⁷Lu]Lu-DOTATOC-NLS

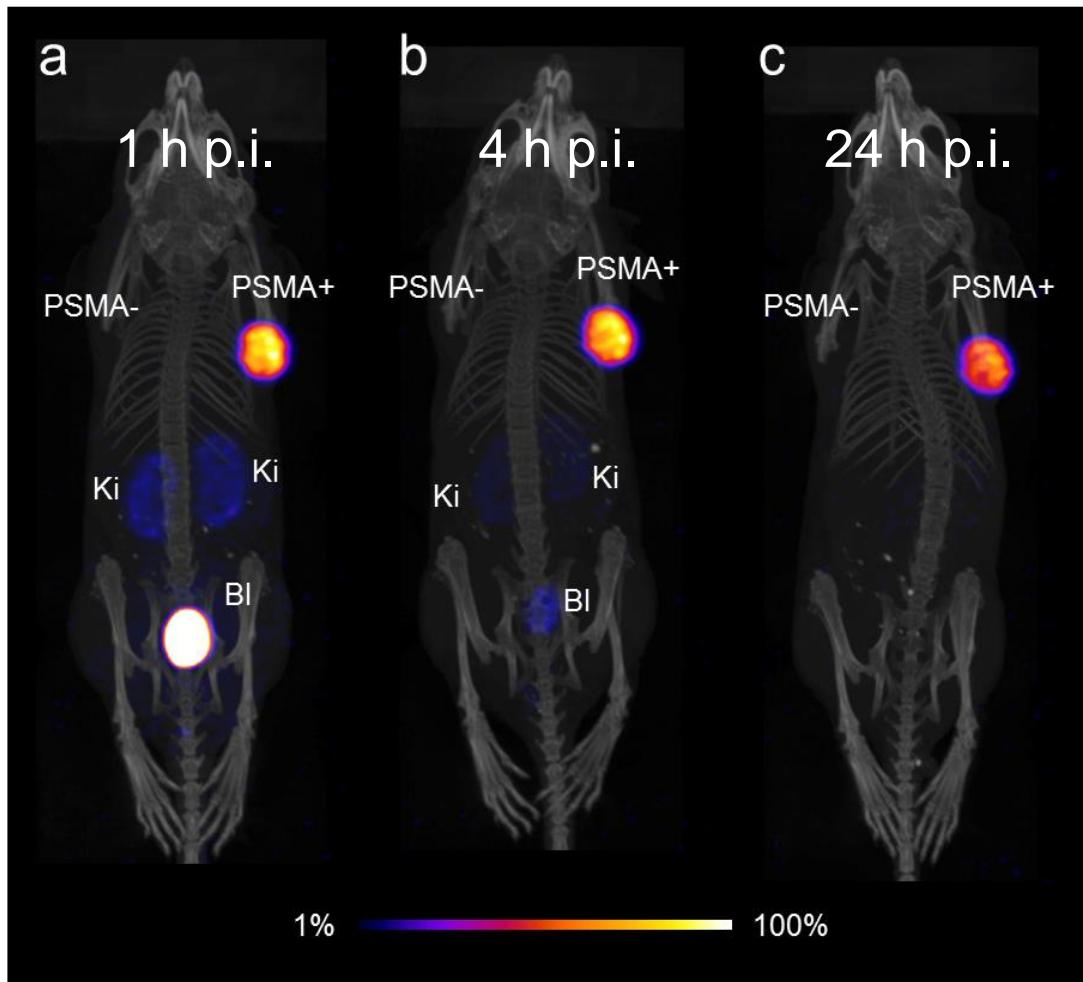
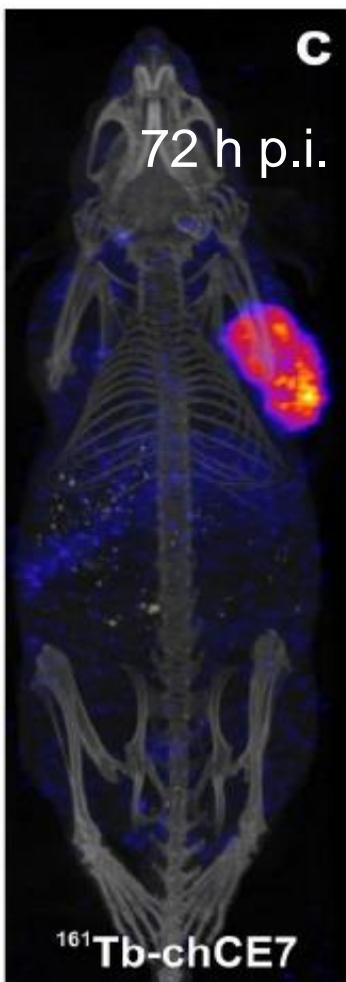


● [¹⁶¹Tb]Tb-DOTA-LM3

◆ [¹⁷⁷Lu]Lu-DOTA-LM3

SPECT imaging with ^{161}Tb

Tb 161
6.96 d
 β^- 0.5; 0.6
 γ 26; 49; 75...
 e^-



6 MBq $^{161}\text{Tb-chCE7}$

25 MBq $^{161}\text{Tb-PSMA-617}$

Grünberg 2014 doi: [10.1007/s00259-014-2798-3](https://doi.org/10.1007/s00259-014-2798-3)

Müller 2019 doi: [10.1007/s00259-019-04345-0](https://doi.org/10.1007/s00259-019-04345-0)

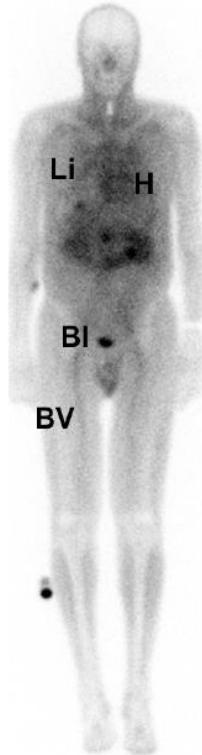
The ideal beta emitter ?

Tb 161
6.96 d

β^- 0.5; 0.6
 γ 26; 49; 75...
 e^-

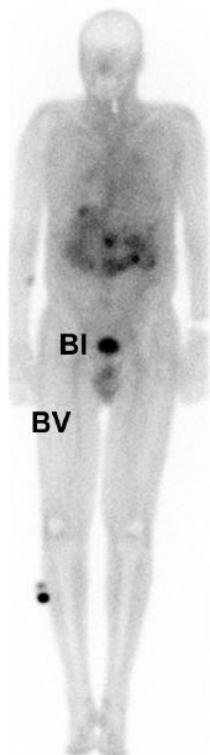
A

0.5 h p.i.



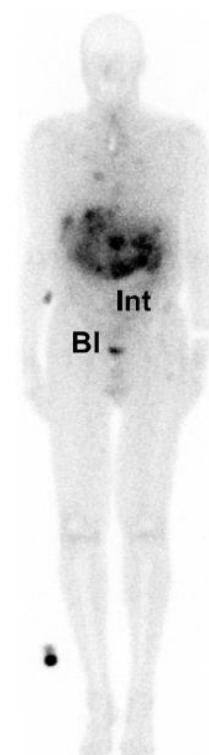
B

2.5 h p.i.



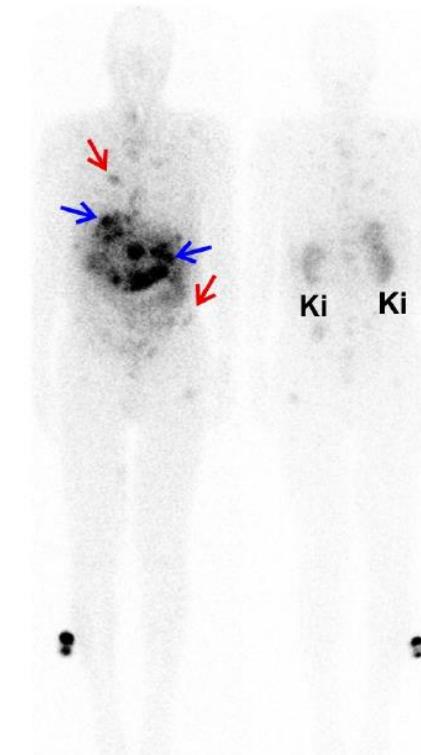
C

20 h p.i.



D

113 h p.i.



Anterior

Posterior

Anterior

Posterior

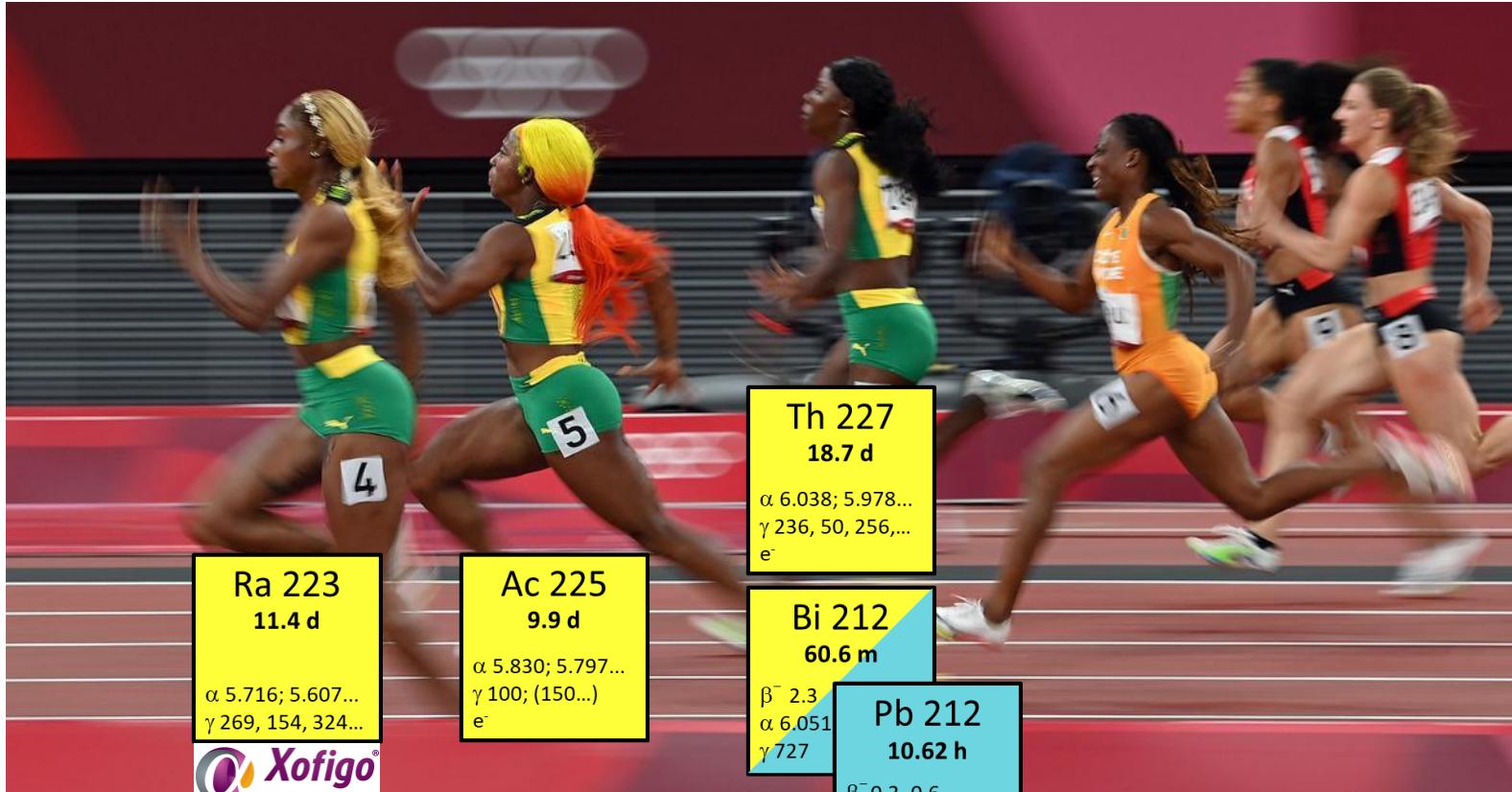
Anterior

Posterior

Anterior

Posterior

The alpha emitter race



Isotopes for targeted alpha therapy

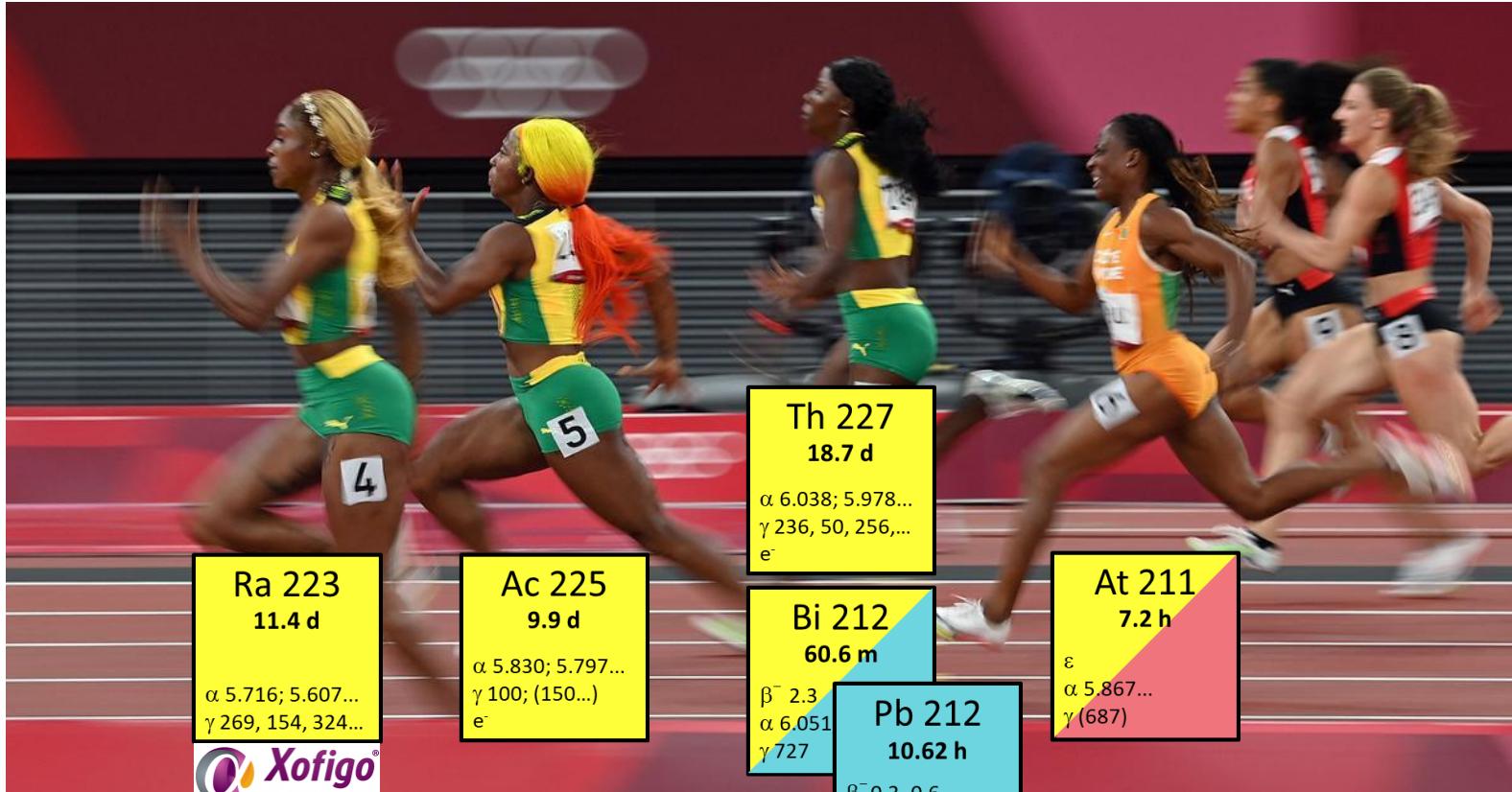
12	s	Ac 213 0.80 s	Ac 214 8.2 s	Ac 215 0.17 s	Ac 216 0.44 ms	Ac 217 0.74 μ s	Ac 218 1.1 μ s	Ac 219 11.8 μ s	Ac 220 26 ms	Ac 221 52 ms	Ac 222 63 s	Ac 223 2.10 m	Ac 224 2.9 h	Ac 225 10.0 d	Ac 226 29 h		
		α ; 7.36	α ; 7.215; 7.081... ϵ ; γ ; 139; 244...	α ; 7.600; 7.211... ϵ ; γ ; (396...)	α ; 9.029; 9.105... γ ; 83; 854; 771...	ν ; 600; 438; 382... α ; 10.54...	α ; 9.205 g	α ; 8.864	α ; 7.85; 7.81; 7.68... γ ; 134...	α ; 7.65; 7.44; 7.38...	α ; 6.847; 6.682; 6.68...; ϵ ; γ ; (99; 191; 84...) ν ; 7.1...	α ; 6.142; 6.000; 6.214... γ ; 216; 132...	ϵ ; 6.142; 6.000; 6.214... γ ; 100; (150; 198; 63...); ϵ ; γ	β^+ ; 0.8; 1.1 ϵ ; 5.34 γ ; 230; 156; 254; 166...			
11	s	Ra 212 13.0 s	Ra 213 2.1 ms	Ra 214 2.46 s	Ra 215 1.67 ms	Ra 216 2.0 ns	Ra 217 0.18 μ s	Ra 218 1.6 μ s	Ra 219 25.6 μ s	Ra 220 10 ms	Ra 221 23 ms	Ra 222 28 s	Ra 223 38 s	Ra 224 11.4 d	Ra 225 3.66 d	Ra 225 14.8 d	
		α ; 5.899... ϵ ; 7 γ ; (635)	α ; 5.56; 5.624; 5.73; 5.93... ϵ ; 7; 810; 161...; γ ; 849; 1110; 215...	α ; 7.137; 7.605... ϵ ; 9 γ ; (642)	α ; 8.700; 7.879... ϵ ; 9 γ ; 834; 540	α ; 9.349	α ; 8.99	α ; 8.39 g	α ; 7.679; 7.989... γ ; 316; 214; 592...	α ; 7.48... γ ; 465	α ; 6.613; 6.761; 6.668... γ ; 149; 93; 174; C 14...	α ; 6.559; 6.237... γ ; 324; (389; 473...) C 14	α ; 6.142; 6.067... γ ; 234; 154; 324... γ ; 241...; C 14	β^+ ; 0.3; 0.4 ϵ ; 1.40 γ			
10	m	Fr 211 3.10 m	Fr 212 20.0 m	Fr 213 34.6 s	Fr 214 3.35 ms	Fr 215 5.0 ms	Fr 216 0.09 μ s	Fr 217 0.70 μ s	Fr 218 16 μ s	Fr 219 22 ms	Fr 220 1.0 ms	Fr 221 21 ms	Fr 222 27.4 s	Fr 223 4.9 m	Fr 224 3.66 d	Fr 225 14.8 d	
		α ; 6.535 ϵ ; 6.262; 6.354; 6.406; 6.340... γ ; 540; 918; 281...	α ; 6.775	α ; 6.477; 6.426; 6.347... ϵ	α ; 9.36	α ; 9.01 g	α ; 8.315	α ; 8.315	α ; 7.600; 7.556... ν ; 7.576... γ	α ; 7.48... γ ; 45; 106; 162...	α ; 7.312... γ ; (352; 517...) C 14	α ; 6.68; 6.63; 6.58... γ ; 218; (101; 411...)	α ; 6.341; 6.126... γ ; 218; (101; 411...)	β^+ ; 0.8; 1.1 ϵ ; 5.34 γ			
9	m	Rn 210 2.4 h	Rn 211 14.8 h	Rn 212 24 m	Rn 213 19.5 ms	Rn 214 55 ns	Rn 215 0.7 ns	Rn 216 0.27 μ s	Rn 217 2.3 μ s	Rn 218 45 μ s	Rn 219 0.54 ms	Rn 220 35 ms	Rn 221 3.9 s	Rn 222 55.6 s	Rn 223 25 m	Rn 222 3.825 d	Rn 223 23.2 m
		α ; 6.040... ϵ ; 5.783; 5.851... γ ; 458; (571; 649; 73...)	α ; 6.264... ϵ ; 6.264... γ ; 540...	α ; 8.088; 7.252... ϵ ; 7.252...	α ; 8.67 g	α ; 8.67	α ; 8.05 g	α ; 7.740...	α ; 7.133... ν ; (809)	α ; 7.133... ν ; (809)	α ; 6.288... γ ; (550)	α ; 6.288... γ ; (550)	β^+ ; 0.8; 1.1 ϵ ; 6.037; 5.788; 5.778... γ ; 188; 180...	β^+ ; 0.8; 1.1 ϵ ; 6.037; 5.788; 5.778... γ ; 188; 180...			
8	h	At 209 5.4 h	At 210 8.3 h	At 211 7.22 h	At 212 119 ms	At 213 314 ms	At 214 0.11 μ s	At 215 0.78 μ s	At 216 0.1 ms	At 217 ?	At 218 0.3 ms	At 219 32.3 ms	At 220 ~2 s	At 221 0.9 m	At 222 3.71 m	At 221 2.3 m	At 222 54 s
		α ; 5.647... ϵ ; 5.524; 5.442; 5.361... γ ; 548; 782; 790...	α ; 5.867... ϵ ; 5.867... γ ; (687...)	α ; 7.84... ϵ ; 7.84... γ ; 83... β^-	α ; 8.78... ϵ ; 8.78... γ ; 83... β^-	α ; 9.08	α ; 8.782... ϵ ; 8.782... γ ; 83... β^-	α ; 8.026... ϵ ; (405)	α ; 7.089... ν ; (764)	α ; 7.089... ν ; (764)	α ; 6.694; 6.653... γ ; (259; 334; 585...)	α ; 6.27 β^-	β^+ ; 0.8; 1.1 ϵ ; 5.493; 5.493; 422...	β^+ ; 0.8; 1.1 ϵ ; 5.493; 5.493; 422...			
7	44 h	Po 208 2.898 a	Po 209 102 d	Po 210 138.38 d	Po 211 0.516 s	Po 212 45.1 s	Po 213 17.1 ms	Po 214 4.2 μ s	Po 215 164 μ s	Po 216 1.78 μ s	Po 217 0.15 s	Po 218 1.53 s	Po 219 3.05 m	Po 220 >300 ns	Po 220 >300 ns	Po 220 >300 ns	
		α ; 5.1152... ϵ ; 4.87... γ ; (292; 571...)	α ; 5.30438... ϵ ; 5.003... γ ; <0.0006	α ; 7.450... ϵ ; 7.450... γ ; 728...	α ; 8.65... ϵ ; 8.65... γ ; 728...	α ; 9.22... ϵ ; 9.22... γ ; 779...	α ; 8.376... ϵ ; 8.376... γ ; 779...	α ; 7.5869... ϵ ; 7.5869... γ ; (779)	α ; 7.602... ϵ ; 7.602... γ ; (779)	α ; 7.6783... ϵ ; (805)	α ; 6.543 β^-	α ; 6.0024... β^-	β^- ? α ? β^- ?	β^- ? α ? β^- ?			
6	d	Bi 207 31.55 a	Bi 208 3.68 $\cdot 10^5$ a	Bi 209 100	Bi 210 1.0 $\cdot 10^{-8}$	Bi 211 5.013 d	Bi 212 2.17	Bi 213 45.59 m	Bi 214 19.9 m	Bi 215 36.9 s	Bi 216 7.7 m	Bi 217 3.8 m	Bi 218 98.5 s	Bi 219 33 s	Bi 218 33 s	Bi 218 33 s	
		α ; 5.16... ϵ ; 5.16... γ ; 516...	α ; 5.261; 5.261; 5.261...	α ; 6.011... ϵ ; 6.011... γ ; 2615	α ; 6.948... ϵ ; 6.948... γ ; 295...	α ; 7.295... ϵ ; 7.295... γ ; 304...	α ; 7.450... ϵ ; 7.450... γ ; 304...	α ; 7.450... ϵ ; 7.450... γ ; 304...	α ; 7.450... ϵ ; 7.450... γ ; 304...	α ; 7.450... ϵ ; 7.450... γ ; 304...	α ; 7.450... ϵ ; 7.450... γ ; 304...	α ; 7.450... ϵ ; 7.450... γ ; 304...	β^+ ; 3.5; 3.7... γ ; 510; 386; 429; 263...	β^+ ; 3.5; 3.7... γ ; 510; 386; 429; 263...			
5	a	Pb 206 24.1	Pb 207 22.1	Pb 208 52.4	Pb 209 3.253 h	Pb 210 22.3 a	Pb 211 36.1 m	Pb 212 10.64 h	Pb 213 10.2 m	Pb 214 26.8 m	Pb 215 ?	Pb 216 ?	Pb 217 ?	Pb 218 ?	Pb 219 ?	Pb 219 ?	
		α ; 0.027	α ; 0.64	α ; 0.00023 ϵ ; α ; <BE-6	β^- ; 0.6 α ; γ	β^- ; 0.02; 0.06 ϵ ; 0.47; 0.49 γ ; 372 β^- ; 0.5	β^- ; 1.4... ϵ ; 372 γ ; 427	β^- ; 1.4... ϵ ; 372 γ ; 427	β^- ; 0.3; 0.6... ϵ ; 239; 300... γ	β^- ; 0.7; 1.0... ϵ ; 352; 295; 242...	β^- ; 0.7; 1.0... ϵ ; 352; 295; 242...	β^- ; 0.7; 1.0... ϵ ; 352; 295; 242...	β^- ; 0.7; 1.0... ϵ ; 352; 295; 242...	β^- ; 0.7; 1.0... ϵ ; 352; 295; 242...	β^- ; 0.7; 1.0... ϵ ; 352; 295; 242...	β^- ; 0.7; 1.0... ϵ ; 352; 295; 242...	
4	a	Tl 205 70.48	Tl 206 1.7 m	Tl 207 4.20 m	Tl 208 1.33 s	Tl 209 4.77 m	Tl 208 3.053 m	Tl 209 2.16 m	Tl 210 1.30 m	Tl 211 >300 ns	Tl 212 >300 ns	Tl 213 ?	Tl 214 ?	Tl 215 ?	Tl 216 ?	Tl 217 ?	
		α ; 0.11	β^- ; 1.4... ϵ ; (803)... γ ; 351	β^- ; 1.8; 2.4... ϵ ; 2615; 583; 511; 860; 277	β^- ; 1.8... ϵ ; 1567; 465; 117...	β^- ; 1.9; 2.3... ϵ ; 800; 298...	β^- ; 1.9; 2.3... ϵ ; 800; 298...	β^- ; 1.9; 2.3... ϵ ; 800; 298...	β^- ; 1.9; 2.3... ϵ ; 800; 298...	β^- ; 1.9; 2.3... ϵ ; 800; 298...	β^- ; 1.9; 2.3... ϵ ; 800; 298...	β^- ; 1.9; 2.3... ϵ ; 800; 298...	β^- ; 1.9; 2.3... ϵ ; 800; 298...	β^- ; 1.9; 2.3... ϵ ; 800; 298...	β^- ; 1.9; 2.3... ϵ ; 800; 298...		

Alkali metals may migrate

134

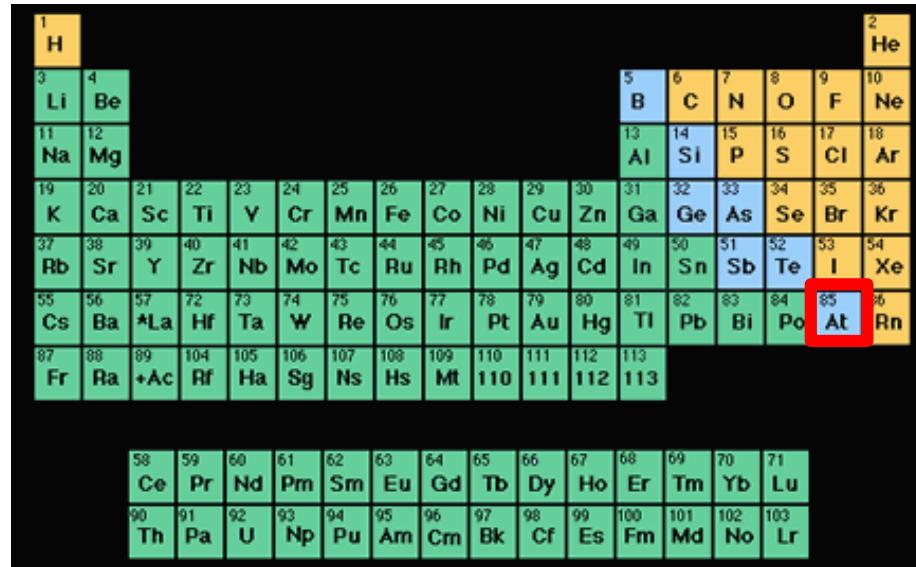
132

The alpha emitter race

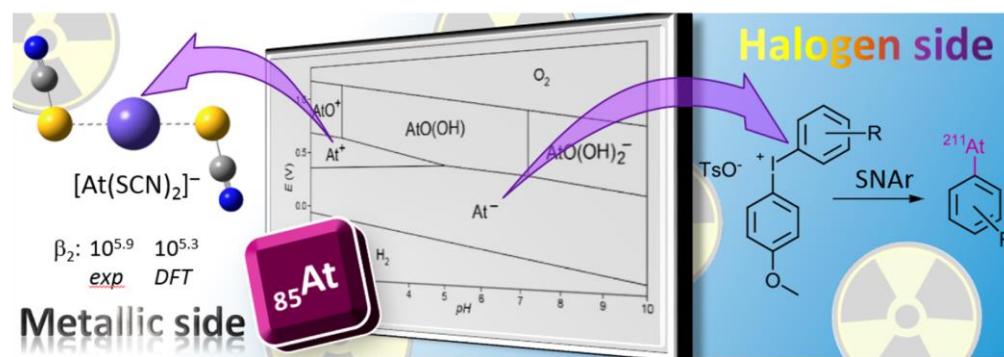


Astatine: a chemical hybrid – halogen/metalloid

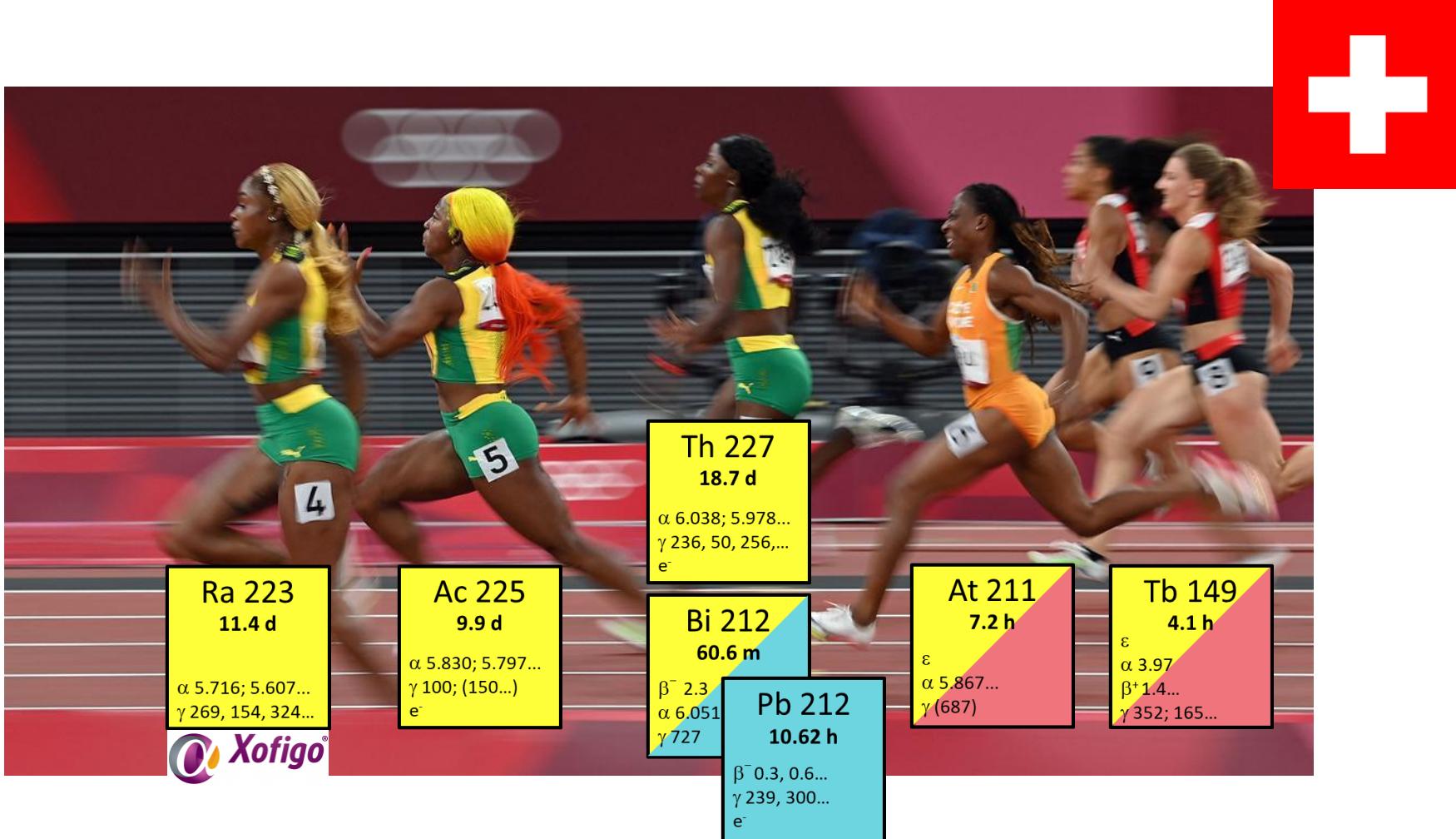
At 211
7.2 h
ε
α 5.867...
γ (687)



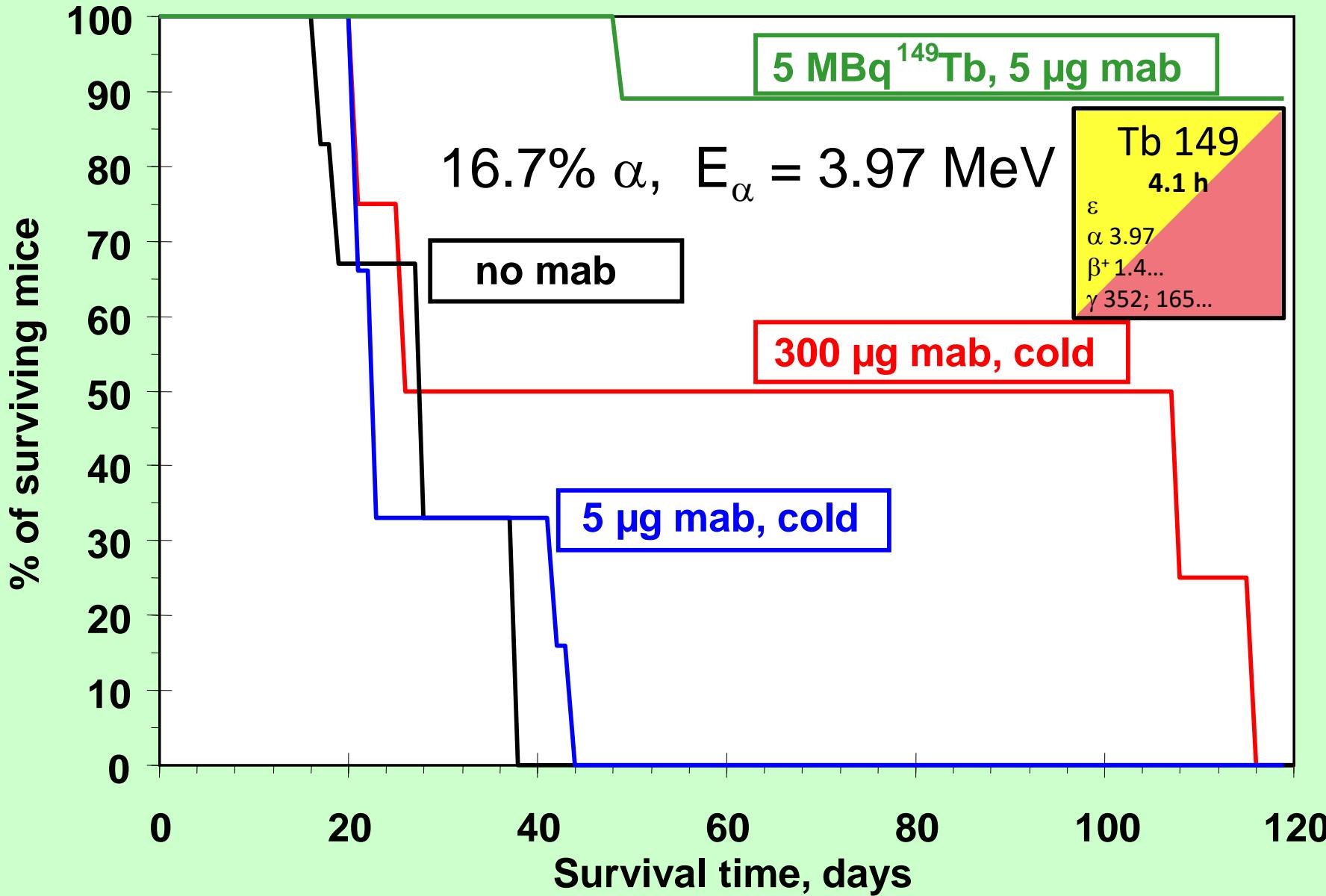
Property	Definition	Value
Electron affinity	EA	2.41578(7) eV
Ionization energy	IE	9.31751(8) eV ¹²
Electronegativity	$\chi_M = \frac{IE+EA}{2}$	5.86665(7) eV
Hardness	$\eta = \frac{IE-EA}{2}$	3.45087(7) eV
Softness	$S = \frac{1}{2\eta}$	0.14489(2) eV ⁻¹
Electrophilicity	$\omega = \frac{\chi_M^2}{2\eta}$	4.98680(16) eV



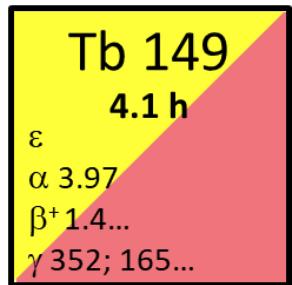
The alpha emitter race



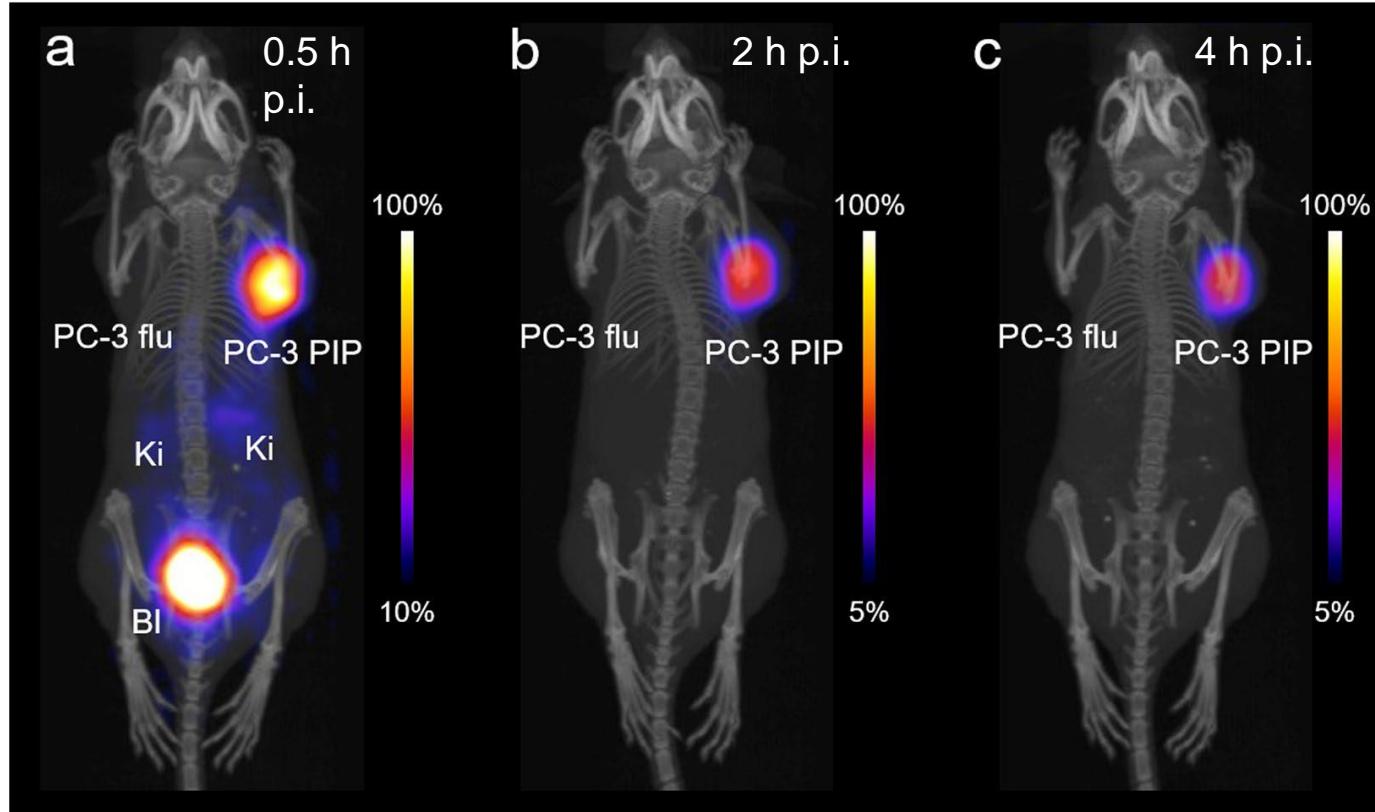
^{149}Tb -rituximab in leukemia mouse model



Alpha-PET = see where it treats



$$I_{\beta^+} = 7.2(3)\% \\ E_{\beta^+}(\text{av.}) = 730 \text{ keV}$$



Umbrecht 2019, doi: [10.1038/s41598-019-54150-w](https://doi.org/10.1038/s41598-019-54150-w)

Terbium: the Swiss knife for nuclear medicine

Tb 155

5.3 d

ε

γ 87; 105; 180...

e^-

Tb 152

17.5 h

ε

β^+ 3.0; 2.6; 2.0...

γ 344; 271; 586...

Tb 161

6.96 d

β^- 0.5; 0.6

γ 26; 49; 75...

e^-

Tb 149

4.1 h

ε

α 3.97

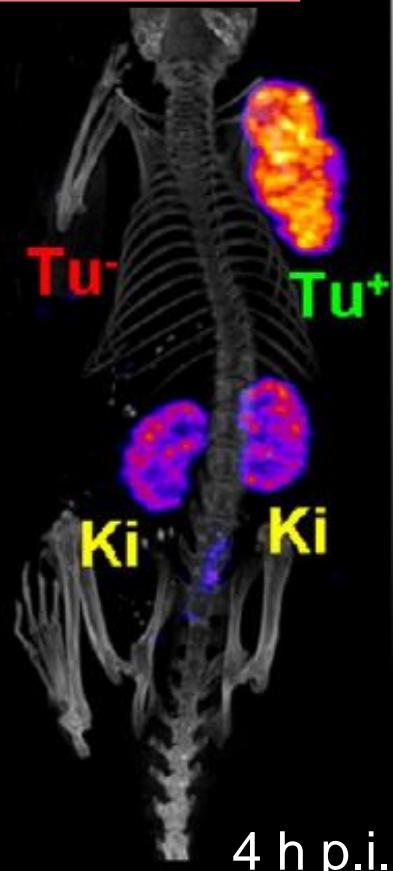
β^+ 1.4...

γ 352; 165...



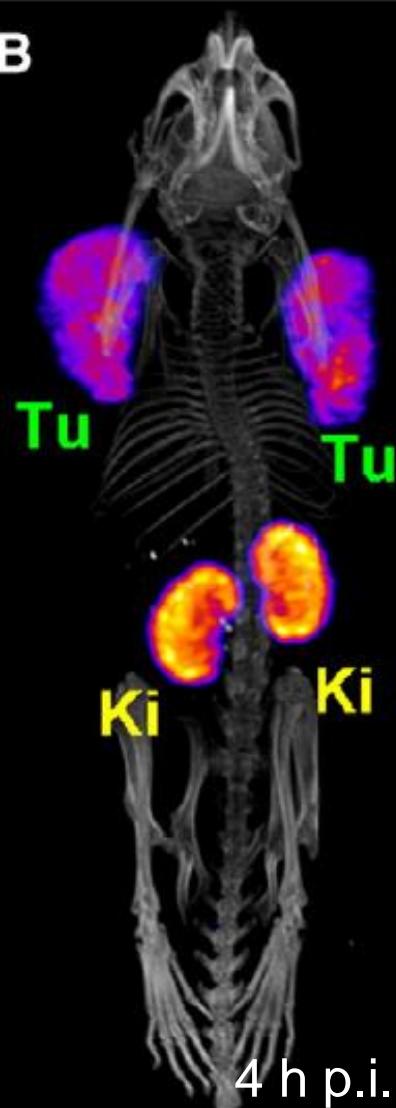
Tb 155
5.3 d

ε
 γ 87; 105; 180...

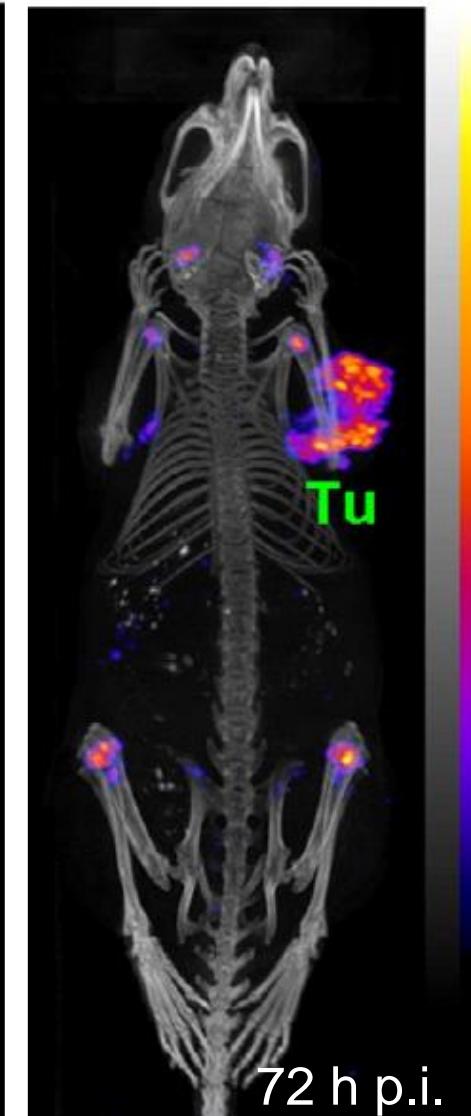
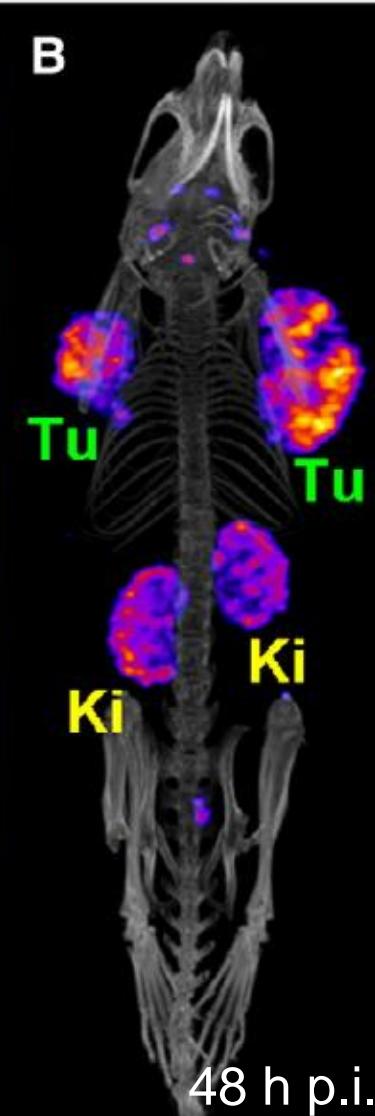


155Tb for SPECT

B

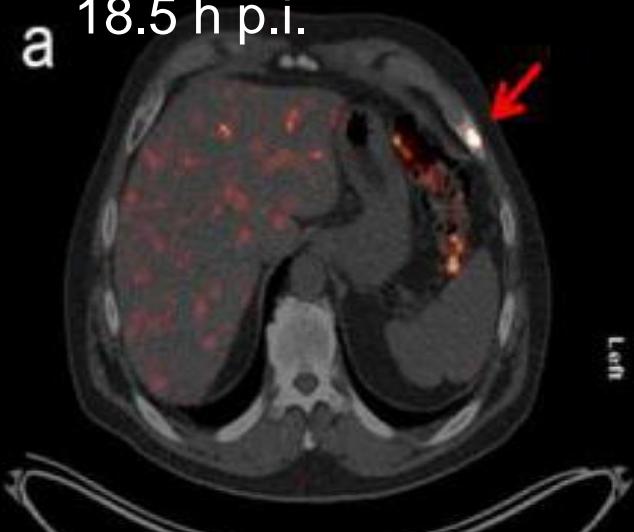


B

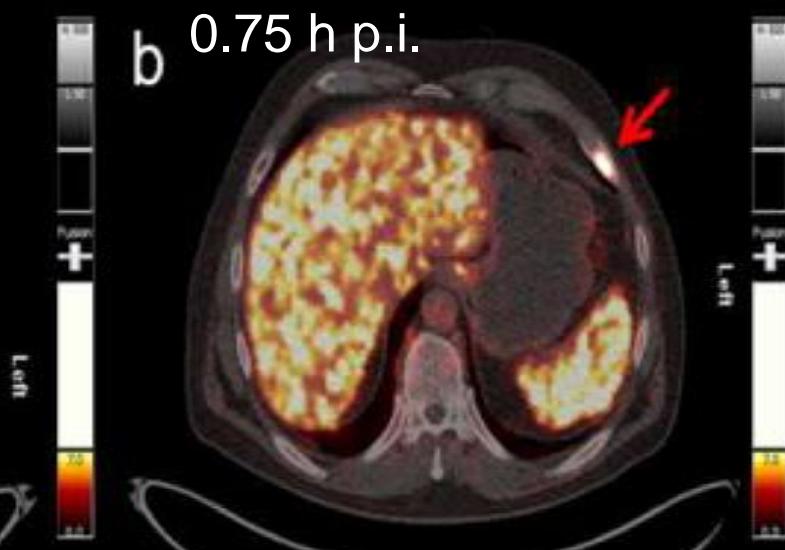


First-in-human study with ^{152}Tb -PSMA-617

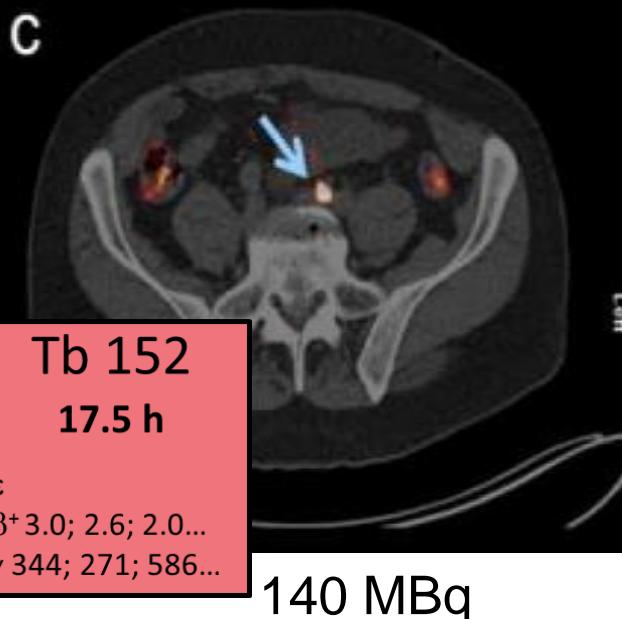
a 18.5 h p.i.



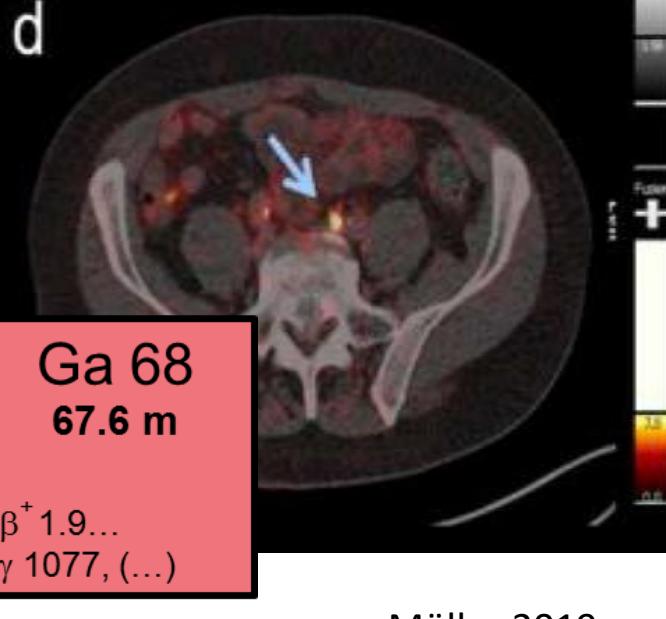
b 0.75 h p.i.



c



d



Zentralklinik Bad Berka

PAUL SCHERRER INSTITUT



ETH zürich



ENSAR²

Comparison

of the

bio-distribution

of different

tumor seeking tracers

labeled with

**radio-Lanthanides,
 ^{225}Ac and ^{111}In**

free chelates:

Citrate

EDTMP

specific tracers:

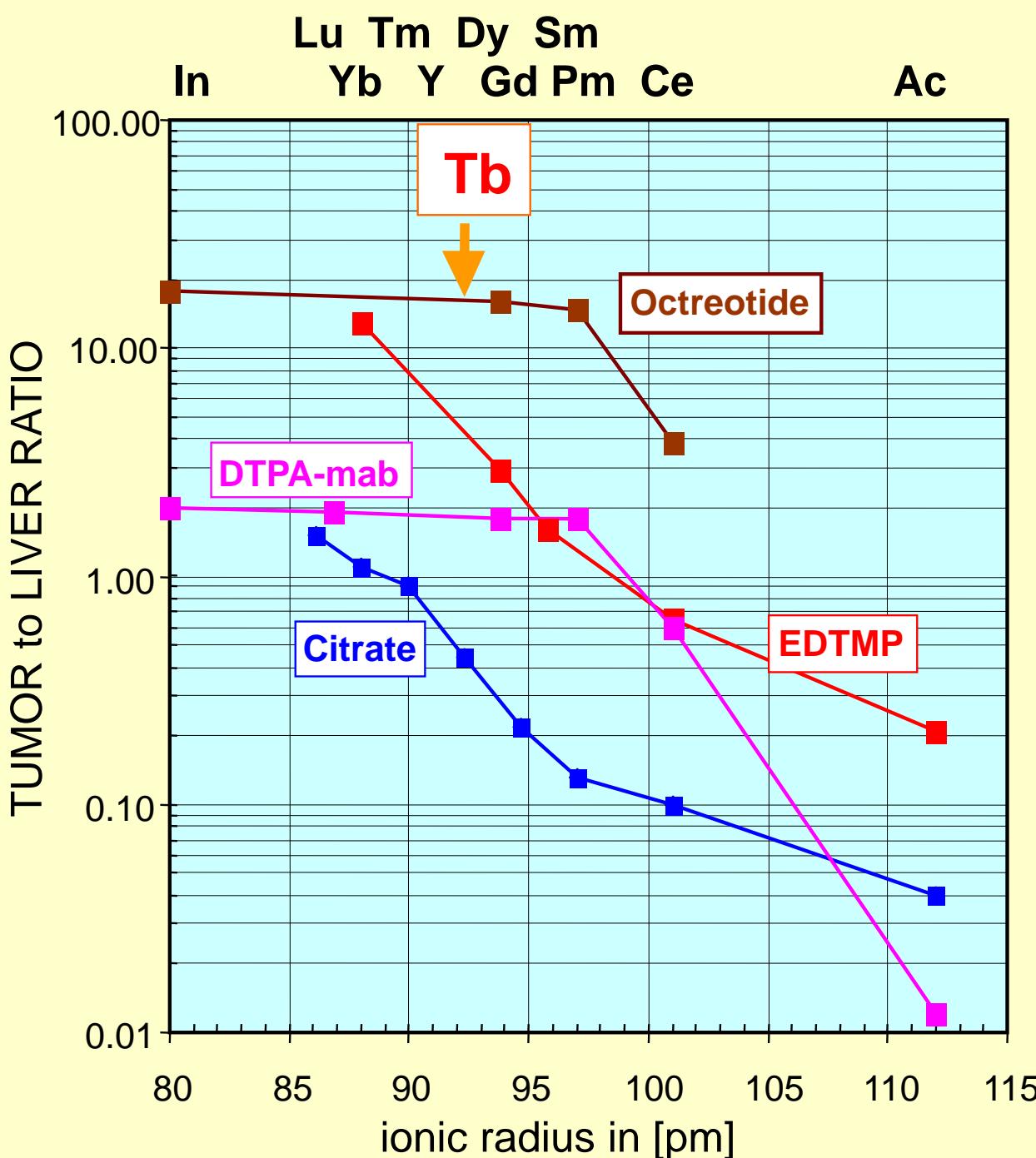
Octreotide

and

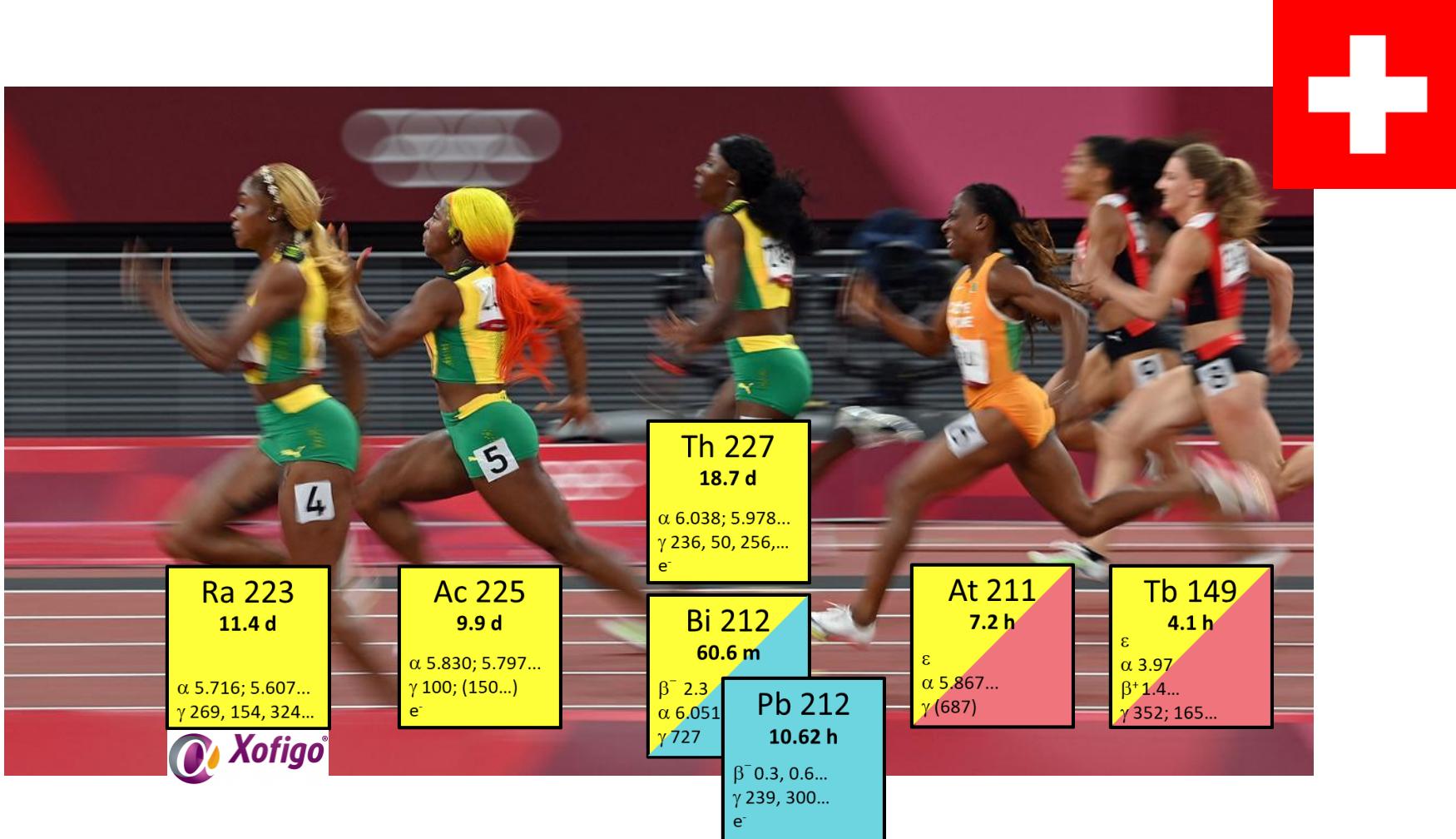
Mab

Linker:

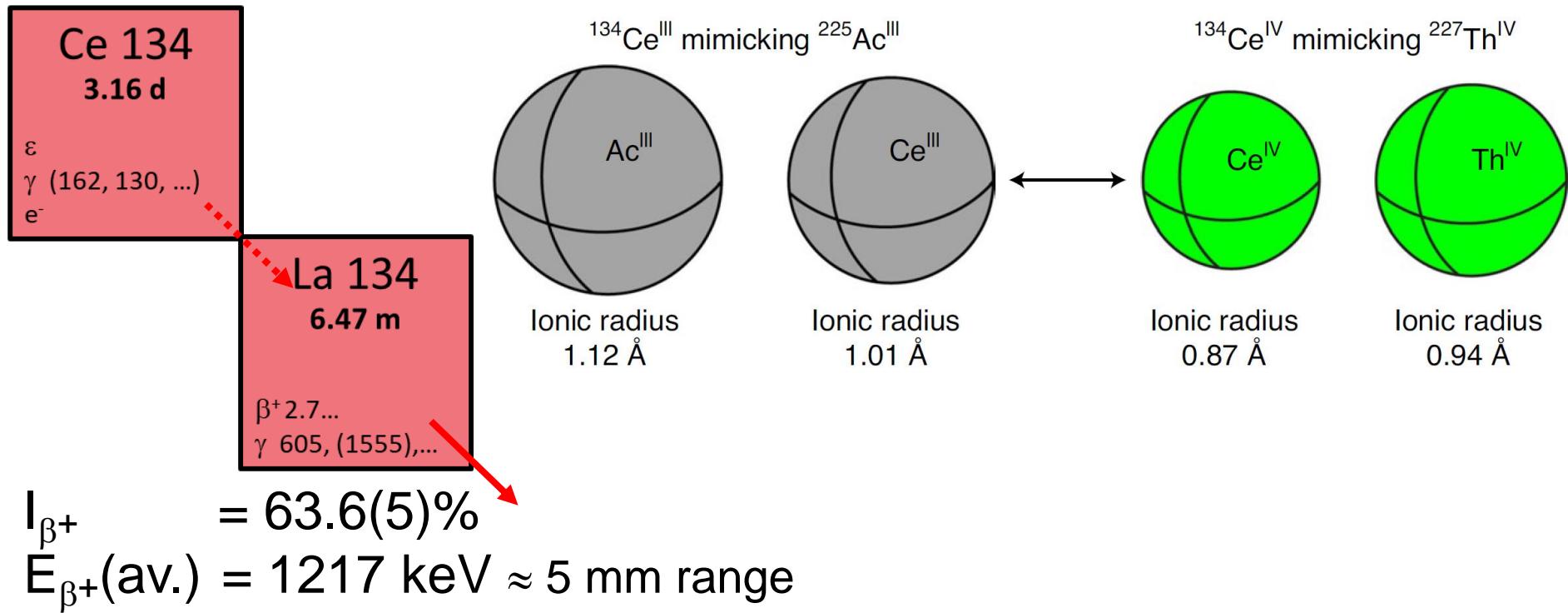
Aminobenzyl-DTPA



The alpha emitter race

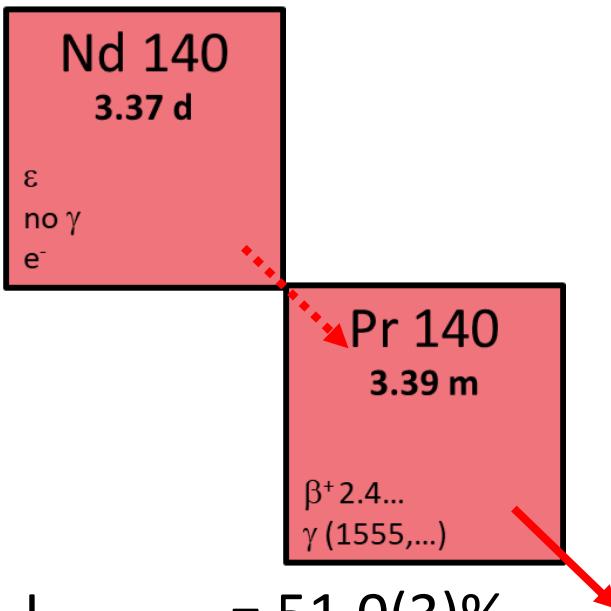


^{134}Ce : in-vivo PET generator as Th^{IV} or Ac^{III} surrogate

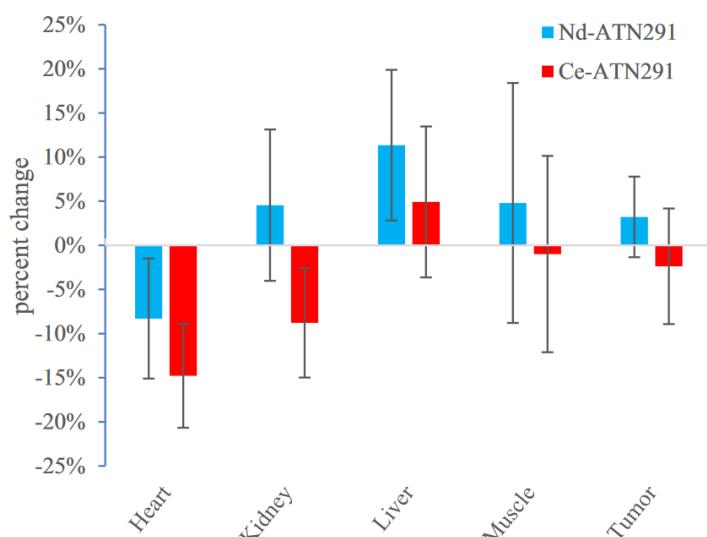
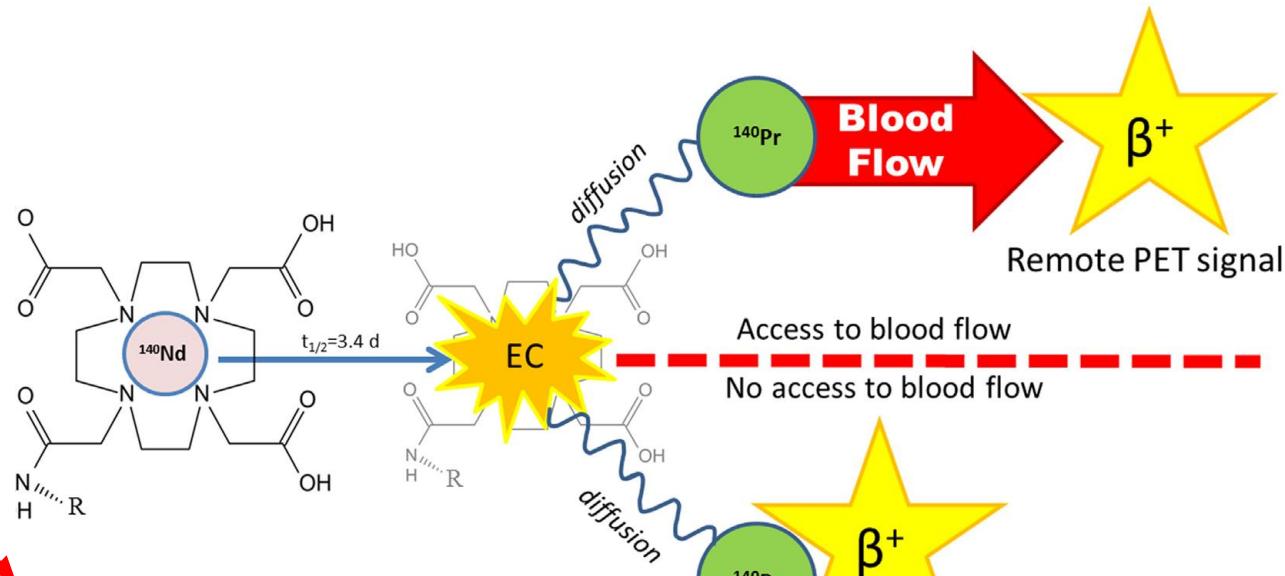


Bailey 2021, [doi 10.1038/s41557-020-00598-7](https://doi.org/10.1038/s41557-020-00598-7)

^{140}Nd : in-vivo PET generator as X^{III} surrogate



$$I_{\beta^+} = 51.0(3)\% \\ E_{\beta^+}(\text{av.}) = 1067 \text{ keV}$$



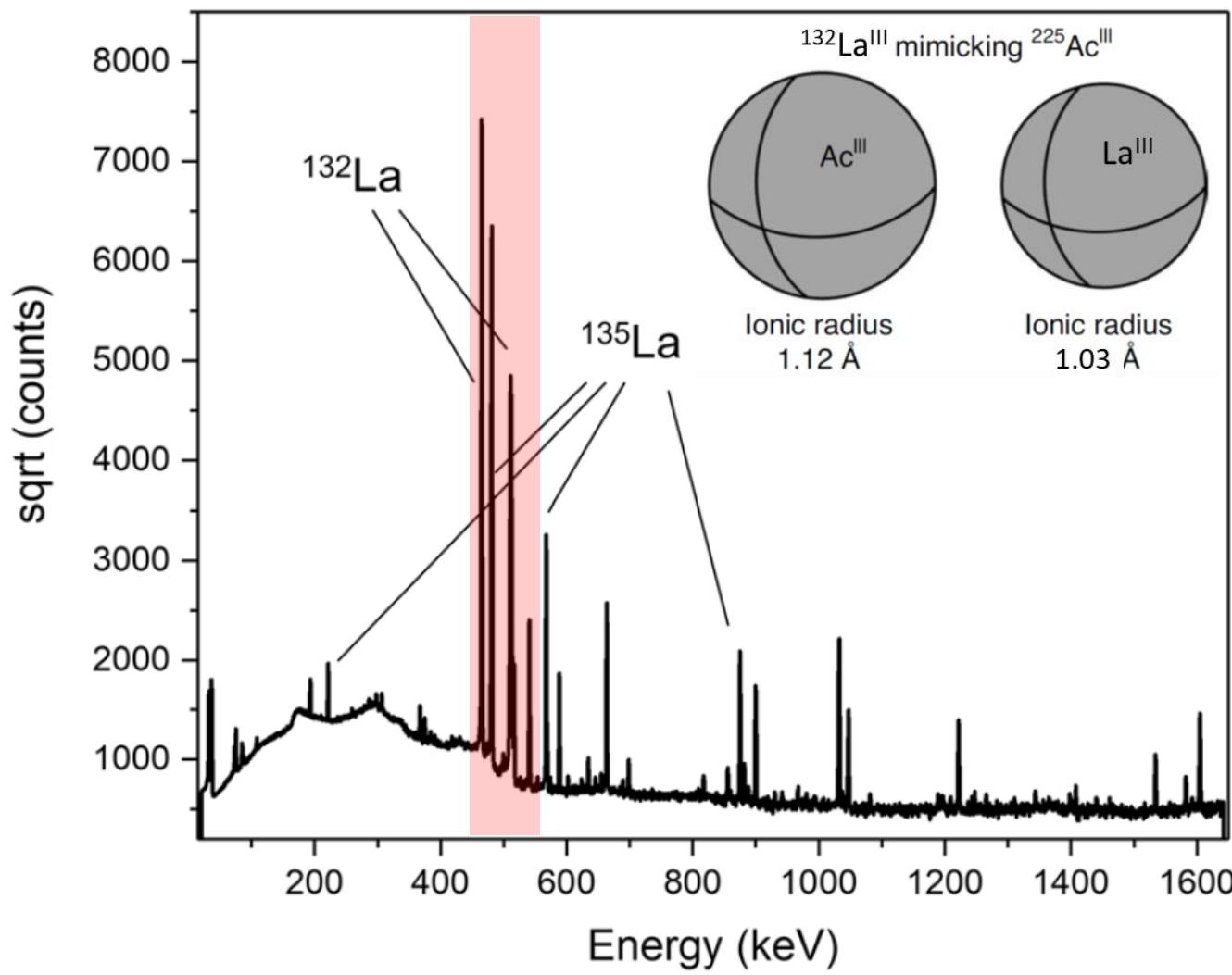
Severin 2017, doi: 10.3389/fmed.2017.00098
Severin 2022, doi 10.1038/s41598-022-07147-x

^{132}La

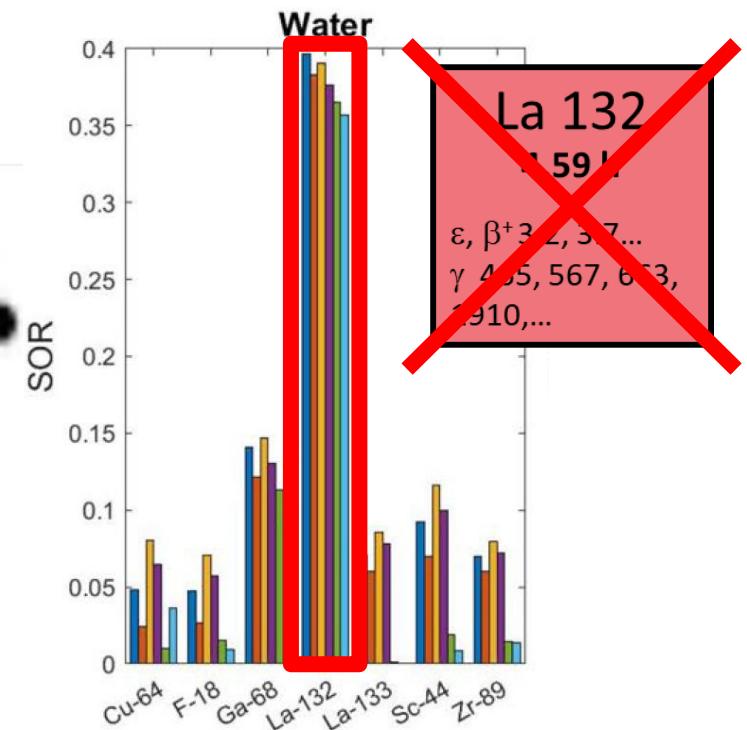
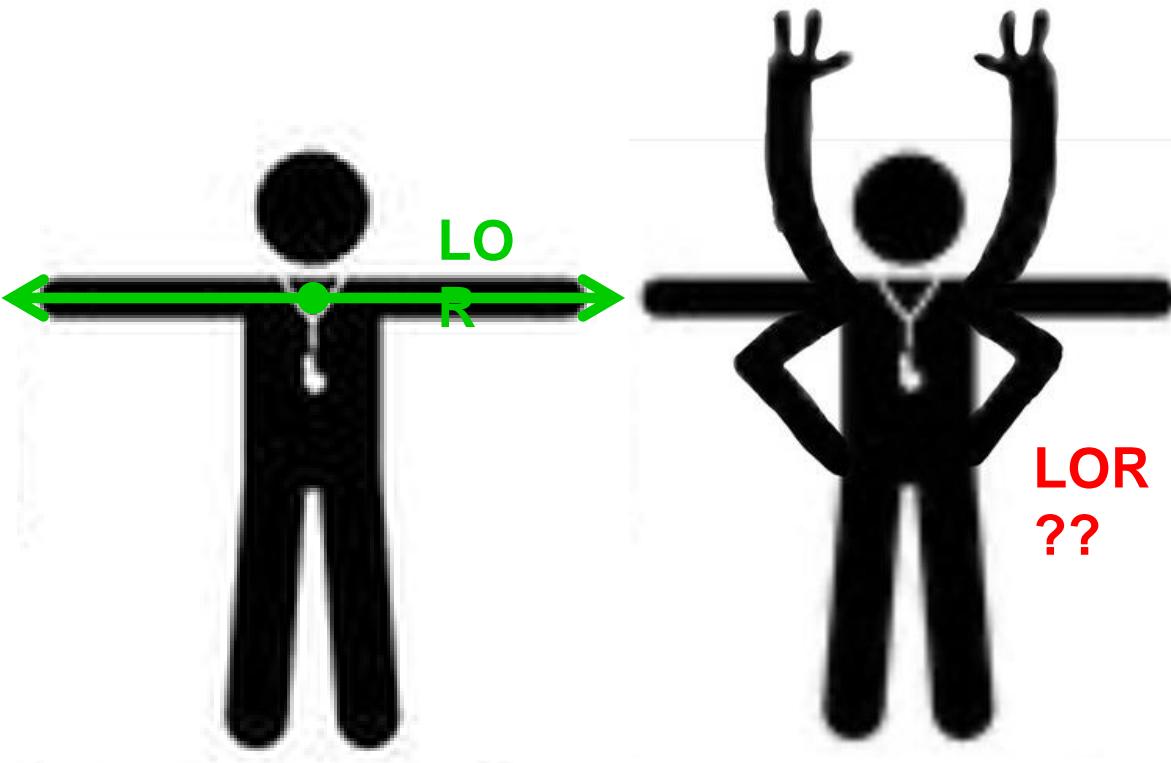
La 132
4.59 h

ε, β^+ 3.2, 3.7...
 γ 465, 567, 663,
1910,...

$$I_{\beta^+} = 42.1(13)\%$$
$$E_{\beta^+}(\text{av.}) = 1290 \text{ keV}$$



pure positron emitter



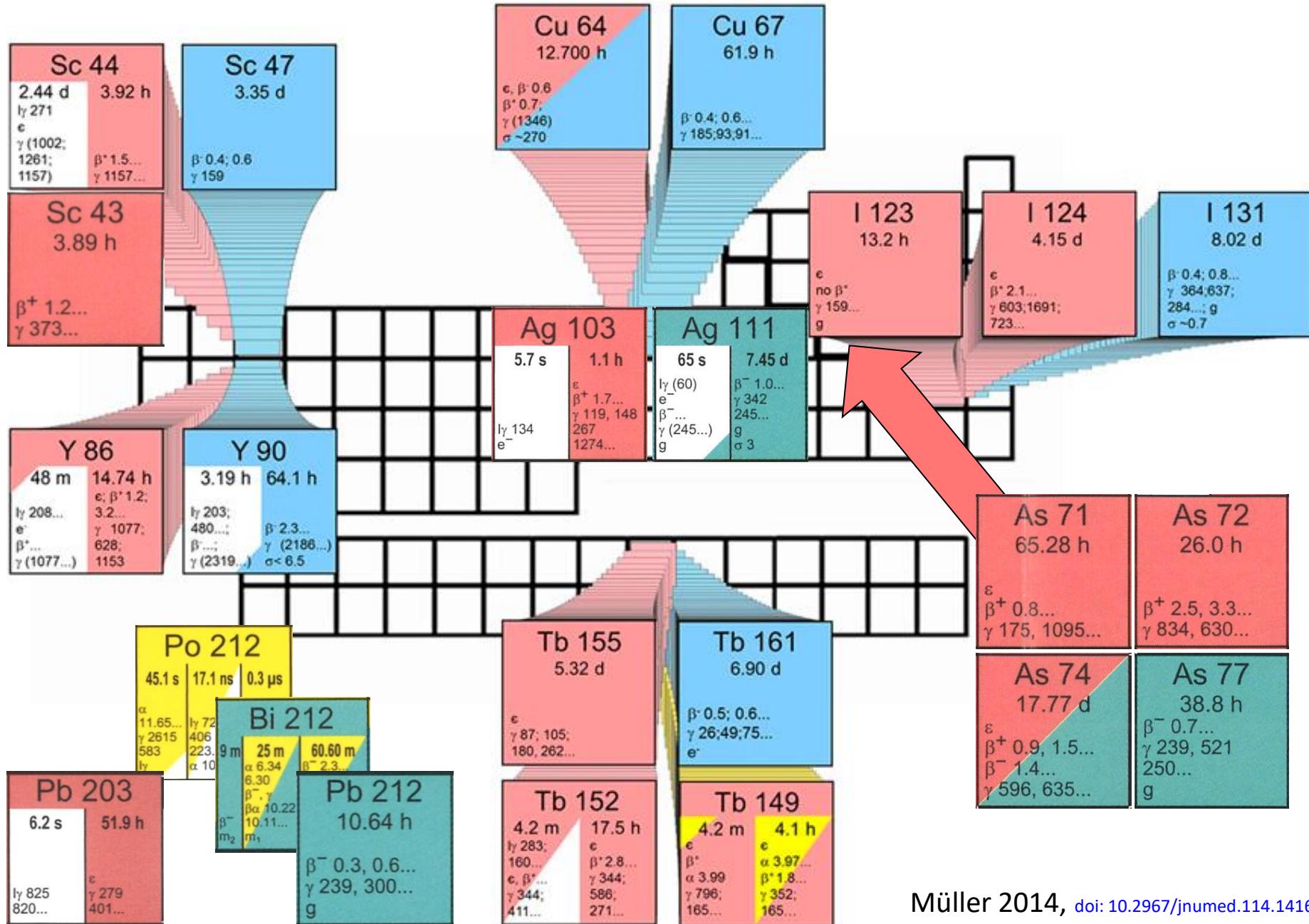
Nelson 2021,
doi: [10.2967/jnumed.121.262459](https://doi.org/10.2967/jnumed.121.262459)

DOTA-compatible positron emitters

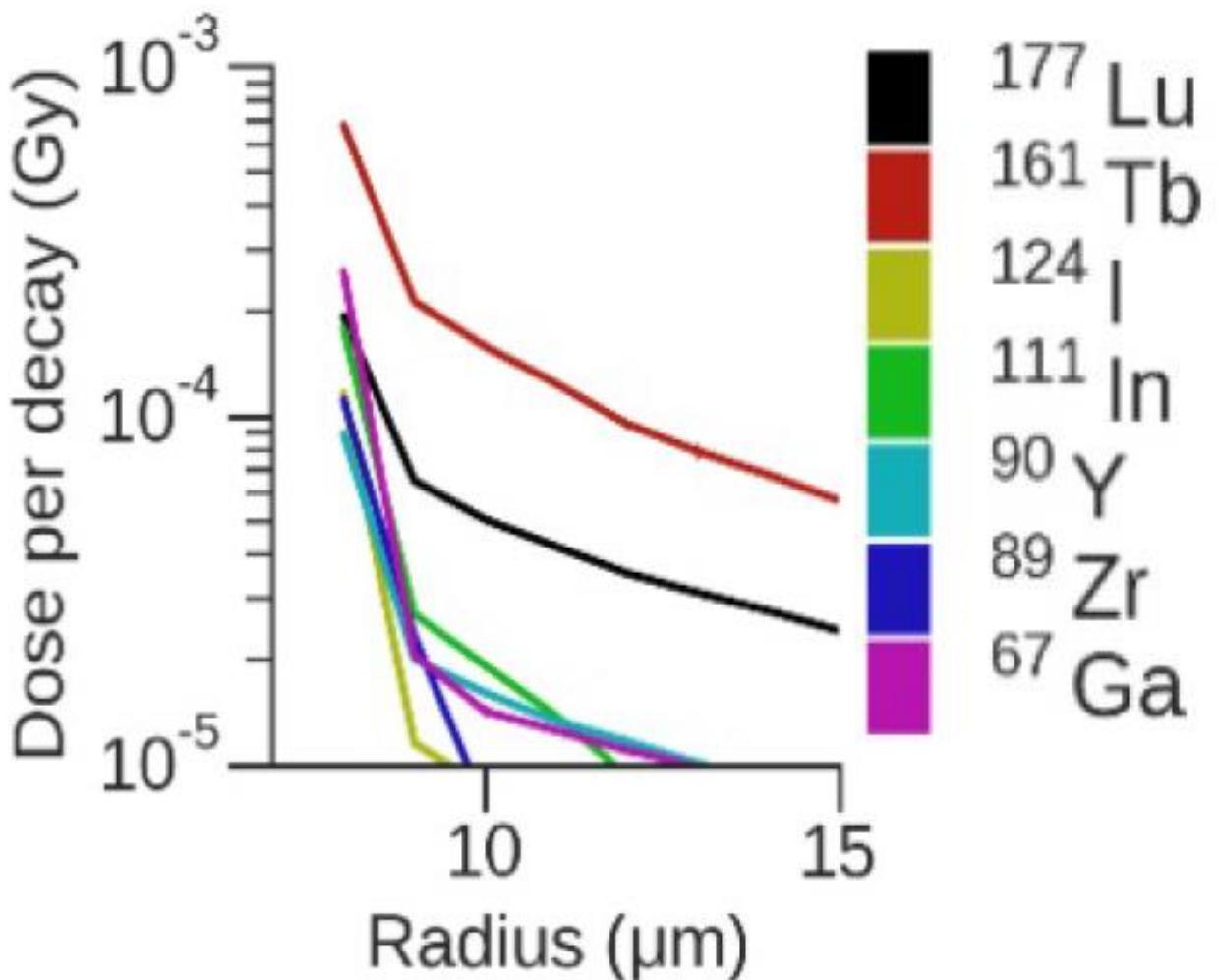
and other elements

Cu 61 3.4 h	Cu 64 12.7 h	Sc 44 2.44 d 4.0 h	As 71 2.72 d
β^+ 1.2... γ 283; 656; 67; 1186...	ε β^- 0.6, β^+ 0.7 γ (1346)	β^- 271... ε γ (...)	β^+ 1.5... γ 1157...
Ga 68 1.1 h	Sc 43 3.9 h	Co 55 17.5 h	Ce 134 3.2 d
ε β^+ 1.9... γ 1077; (1833...)	β^+ 1.2... γ 373...	β^+ 1.5... γ 931, 477, 1409, ...	ε γ (162, 130, ...) e^-
Sc 44 4.0 h	Tb 152 17.5 h	Nd 140 3.4 d	Zr 89 3.3 d
β^+ 1.5... γ 1157...	ε β^+ 3.0; 2.6; 2.0... γ 344; 271; 586...	ε no γ e^-	ε β^+ 0.9 γ (1713) m

Matched pairs for theranostics



^{161}Tb versus ^{177}Lu



Falzone 2018 doi:10.7150/thno.22217

Hindié 2016 <https://doi.org/10.2967/jnumed.115.170423>

Uusijärvi 2006 <https://jnm.snmjournals.org/content/47/5/807>

NuDat 2.7 database

PET/SPECT imaging for non-radioactive therapeutics

1. Organometallic anti-cancer drugs:

Pt, Ru, Au, Os, Ir, Ag, V, Nb, Re, Zr, Ti...

2. Metal-bases nanoparticles:

Ni, Au, Ag, Fe_2O_3 , Gd, TiO_2 , Si

3. Microparticles

HfO_2 , Gd, Fe_2O_3

PET/SPECT imaging for non-radioactive therapeutics

1. Organometallic anti-cancer drugs:

Pt, Ru, Au, Os, Ir, Ag, V, Nb, Re, Zr, Ti...

^{191}Pt , $^{195\text{m}}\text{Pt}$, ^{97}Ru , ^{103}Ru , ^{198}Au , ^{199}Au , ^{191}Os , ^{194}Ir , ^{111}Ag , ^{48}V , ^{90}Nb ,
 ^{186}Re , ^{188}Re , ^{89}Zr , ^{45}Ti ...

2. Metal-bases nanoparticles:

Ni, Au, Ag, Fe_2O_3 , Gd, TiO_2 , Si

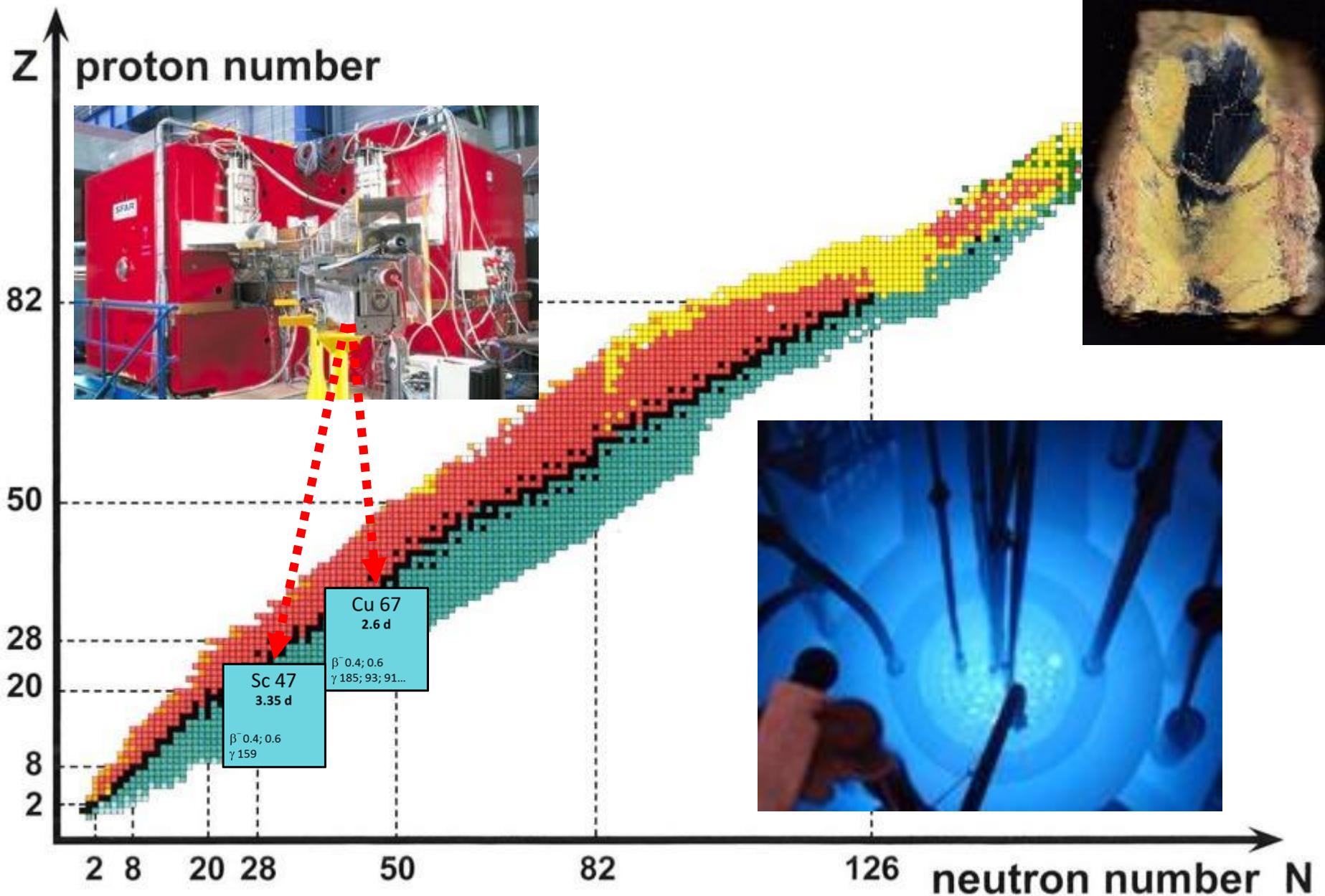
^{57}Ni , ^{198}Au , ^{199}Au , ^{111}Ag , (^{59}Fe), $^{159}\text{Gd}/^{161}\text{Tb}$, ^{45}Ti , no Si

3. Microparticles

HfO_2 , Gd, Fe_2O_3

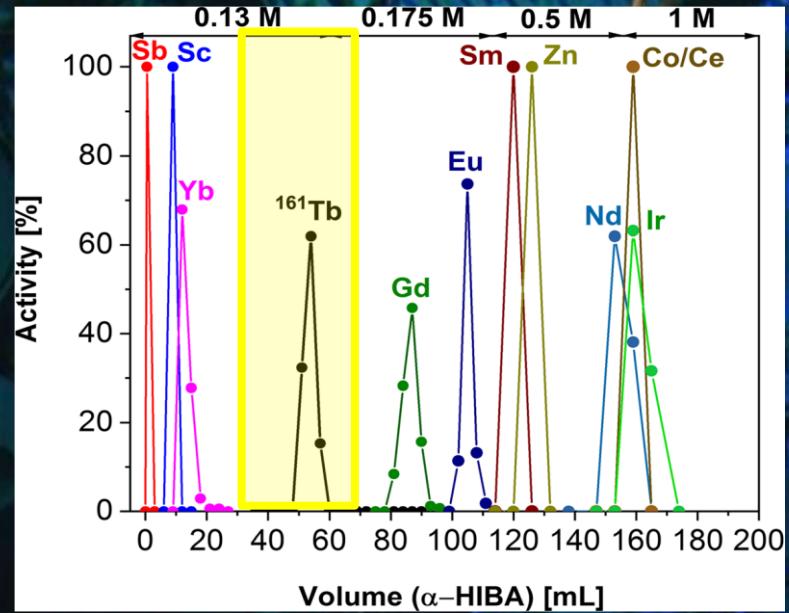
^{181}Hf , $^{159}\text{Gd}/^{161}\text{Tb}$, (^{59}Fe)

The “Alpine divide” of radioisotope production

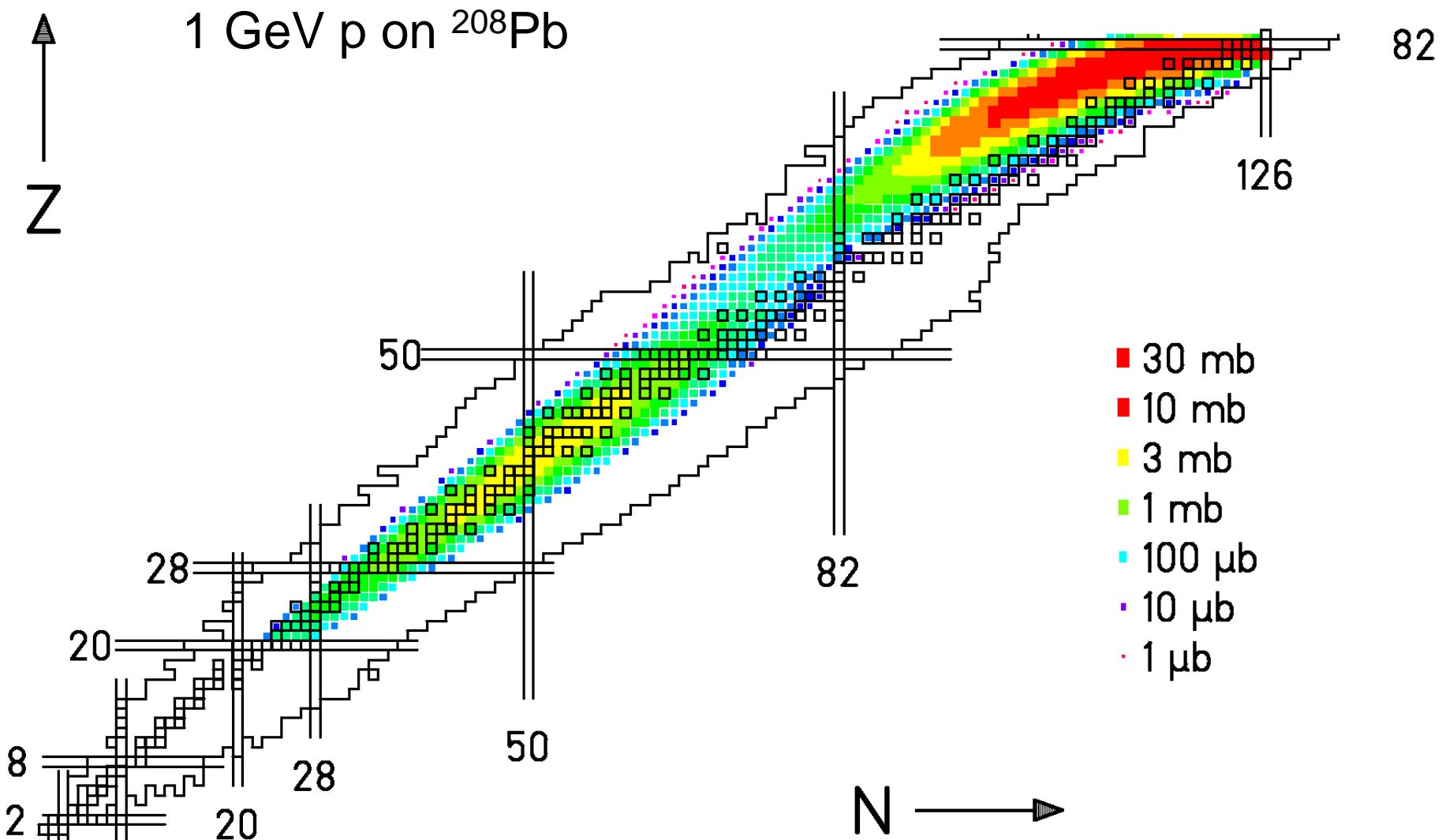


Production of non-carrier-added ^{161}Tb

Dy 160 2.329	Dy 161 18.889	Dy 162 25.475	Dy 163 24.896	Dy 164 28.260
σ_{60} $\sigma_{n,\alpha} < 0.0003$	σ_{600} $\sigma_{n,\alpha} < 1\text{E-}6$	σ_{170}	σ_{120} $\sigma_{n,\alpha} < 2\text{E-}5$	$\sigma_{1610 + 1040}$
Tb 159 100	Tb 160 72.3 d $\beta^- 0.6; 1.7\dots$ $\gamma 879; 299;$ $966\dots$ $\sigma 570$	Tb 161 6.90 d $\beta^- 0.5; 0\dots$ $\gamma 26; 49; 5\dots$ e^-	Tb 162 7.76 m $\beta^- 1.4; 2.4\dots$ $\gamma 260; 808;$ $888\dots$	Tb 163 19.5 m $\beta^- 0.8; 1.3\dots$ $\gamma 351; 390;$ $494\dots$
$\sigma 23.2$	Gd 158 24.84	Gd 159 18.48 h $\beta^- 1.0\dots$ $\gamma 364; 58\dots$	Gd 160 21.86 $\beta^- 1.6; 1.7\dots$ $\gamma 361; 315;$ $102\dots$ $\sigma 20000$	Gd 161 3.66 m $\beta^- 1.0\dots$ $\gamma 442; 403\dots$



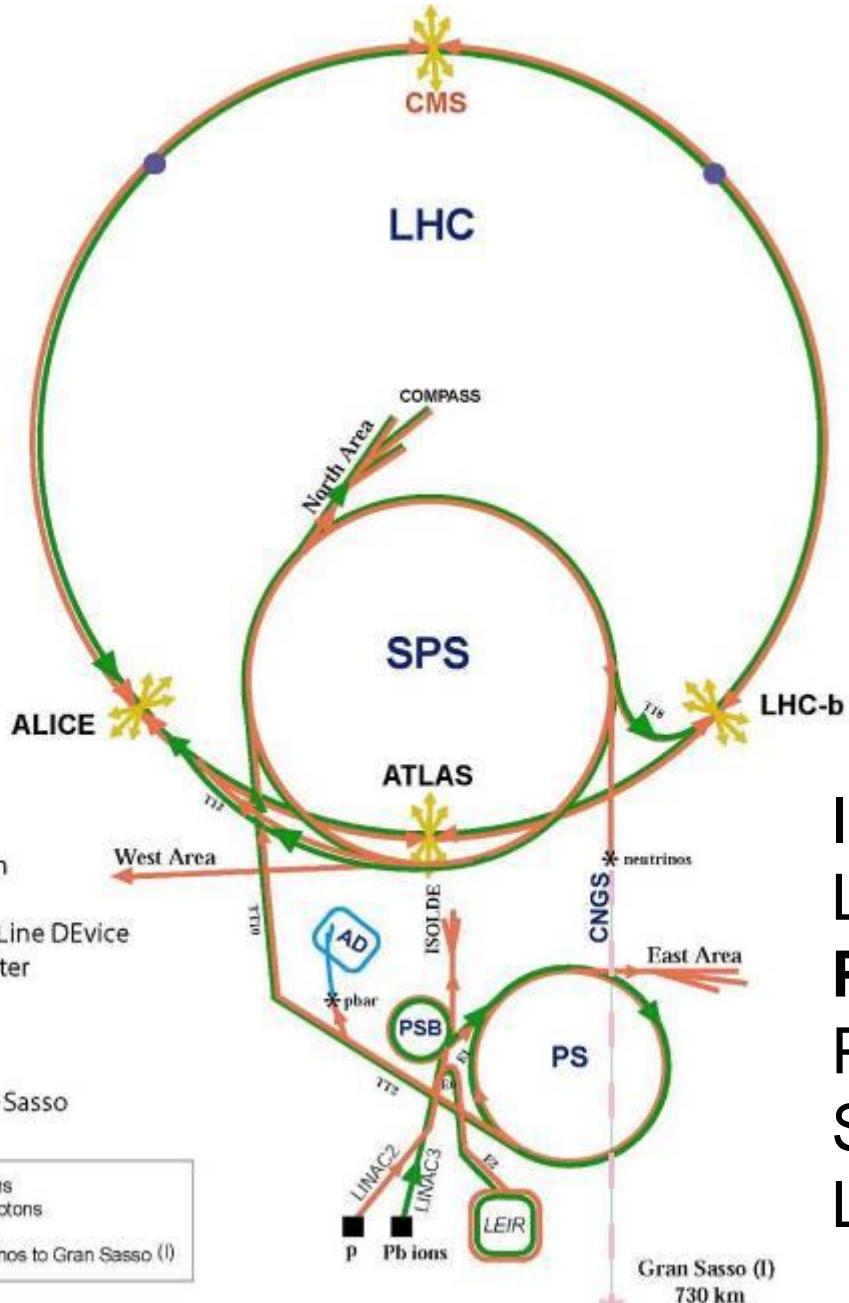
Spallation + Fragmentation + Fission



W. Włazło et al., Phys Rev Lett 2000;84:5736.

T. Enqvist et al., Nucl Phys A 2001;686:481.

The accelerator complex of CERN

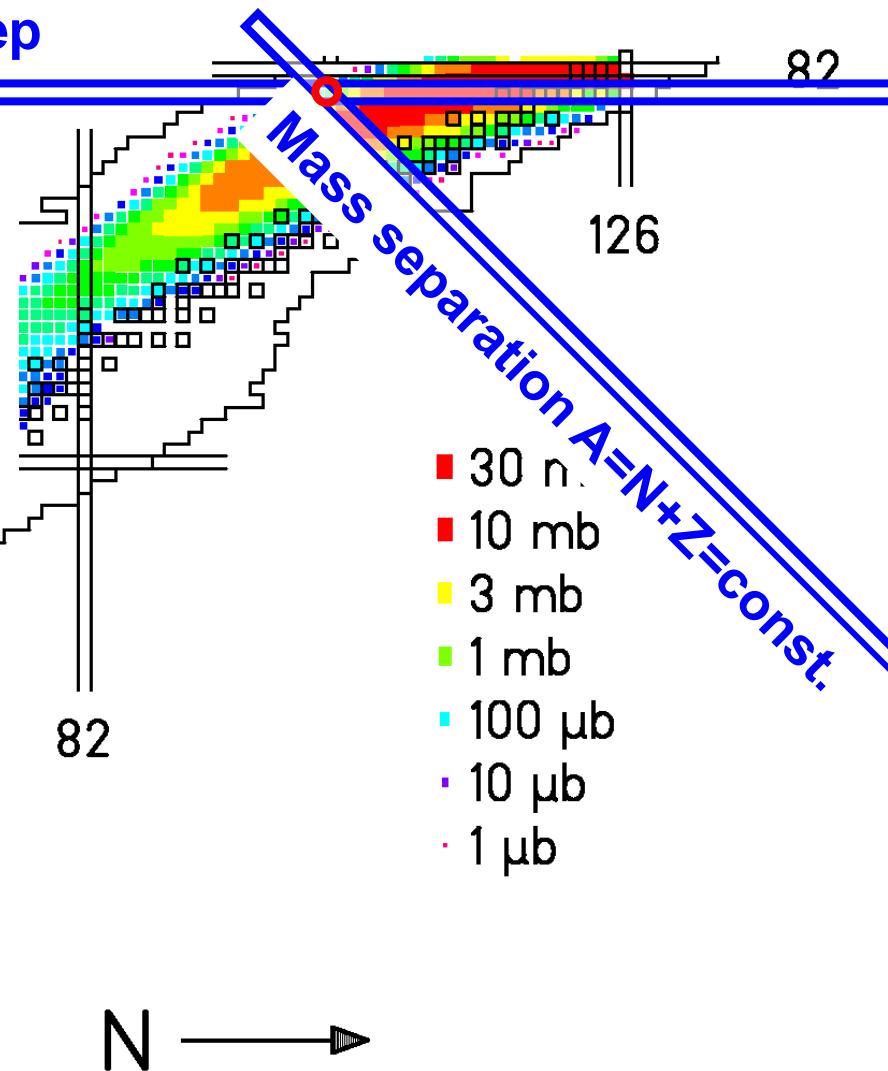
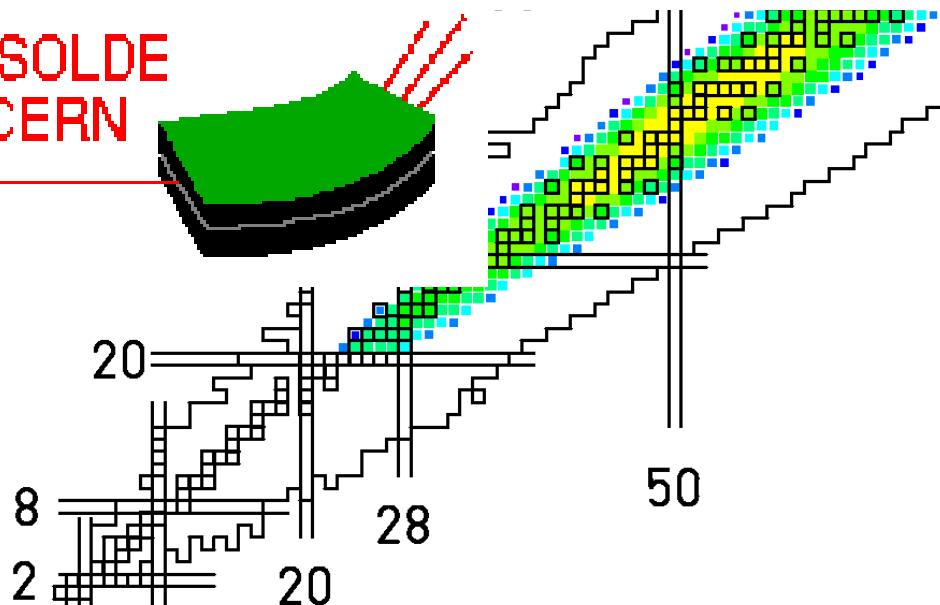


Isotope selection with the ISOL method

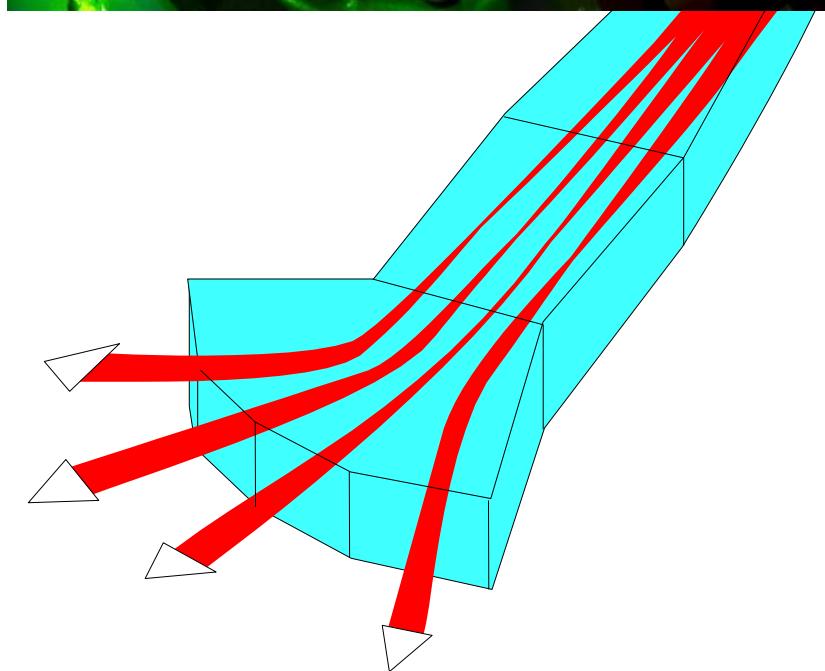
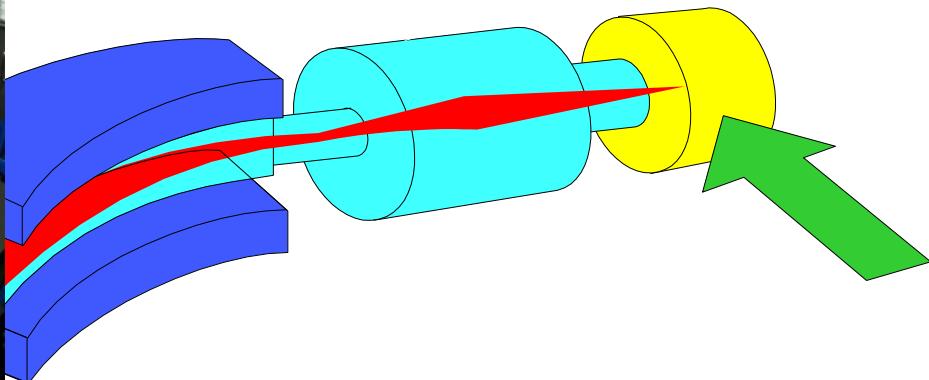
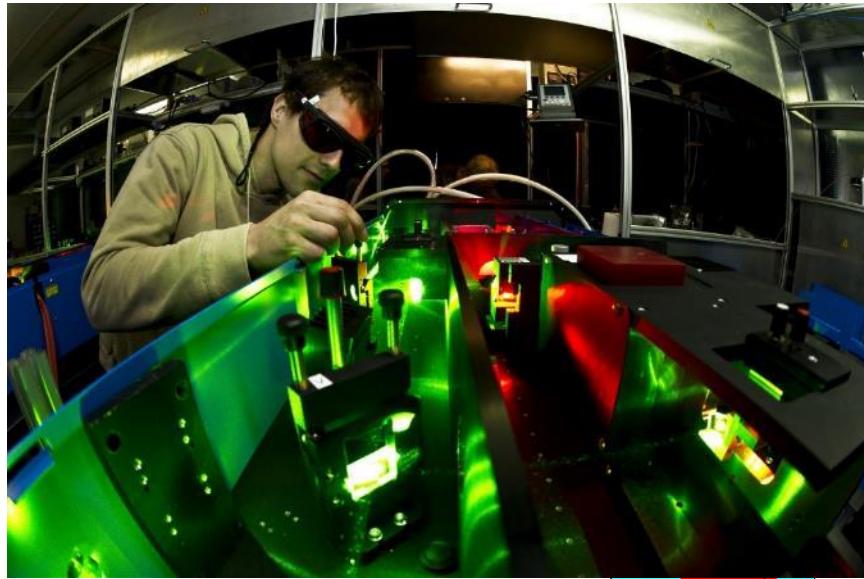
Z selection by chemically selective step

- Ionization to $q = 1+$
- Acceleration to 60 keV
- Mass selection by magnetic deflection
- $B\varphi = p/q \propto \sqrt{A}$

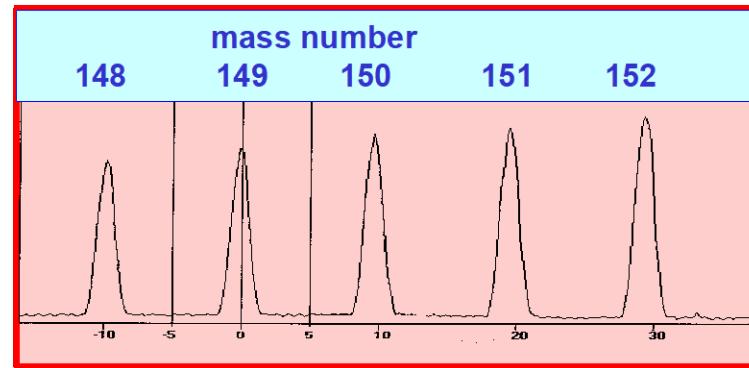
ISOLDE
CERN



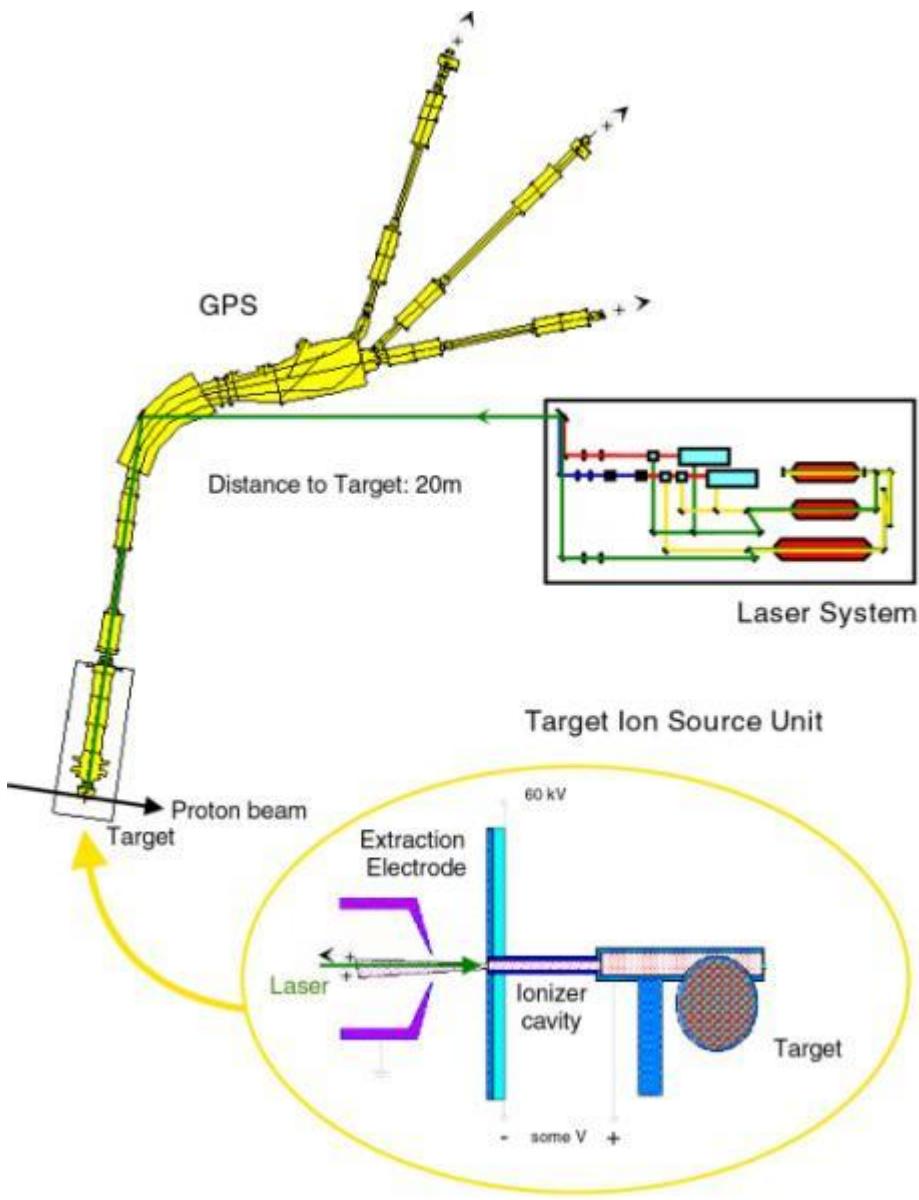
Production of ^{149}Tb , ^{152}Tb and ^{155}Tb at ISOLDE



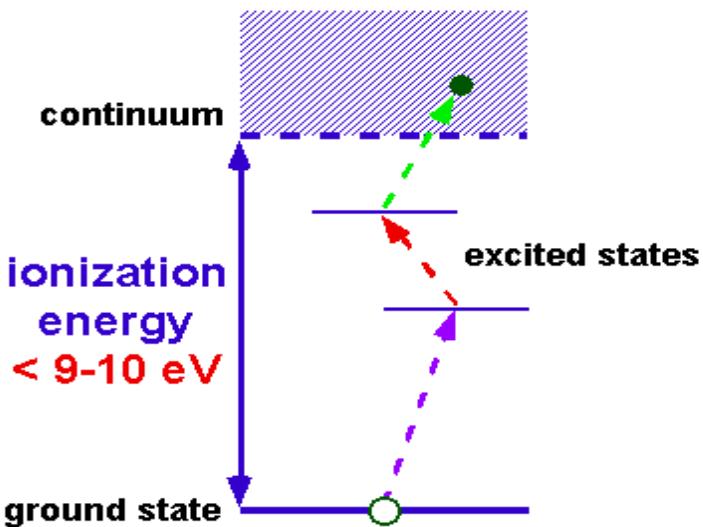
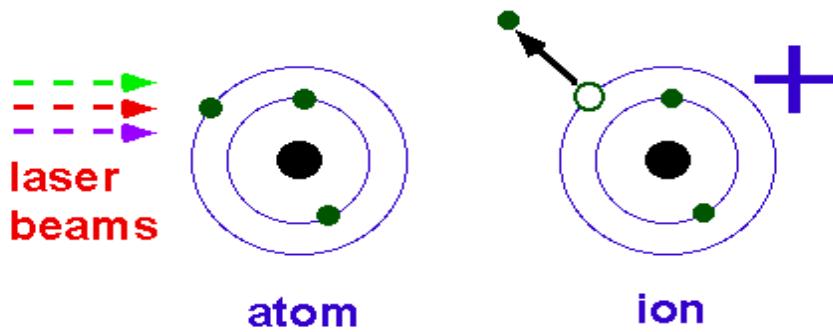
radioactive ion beams



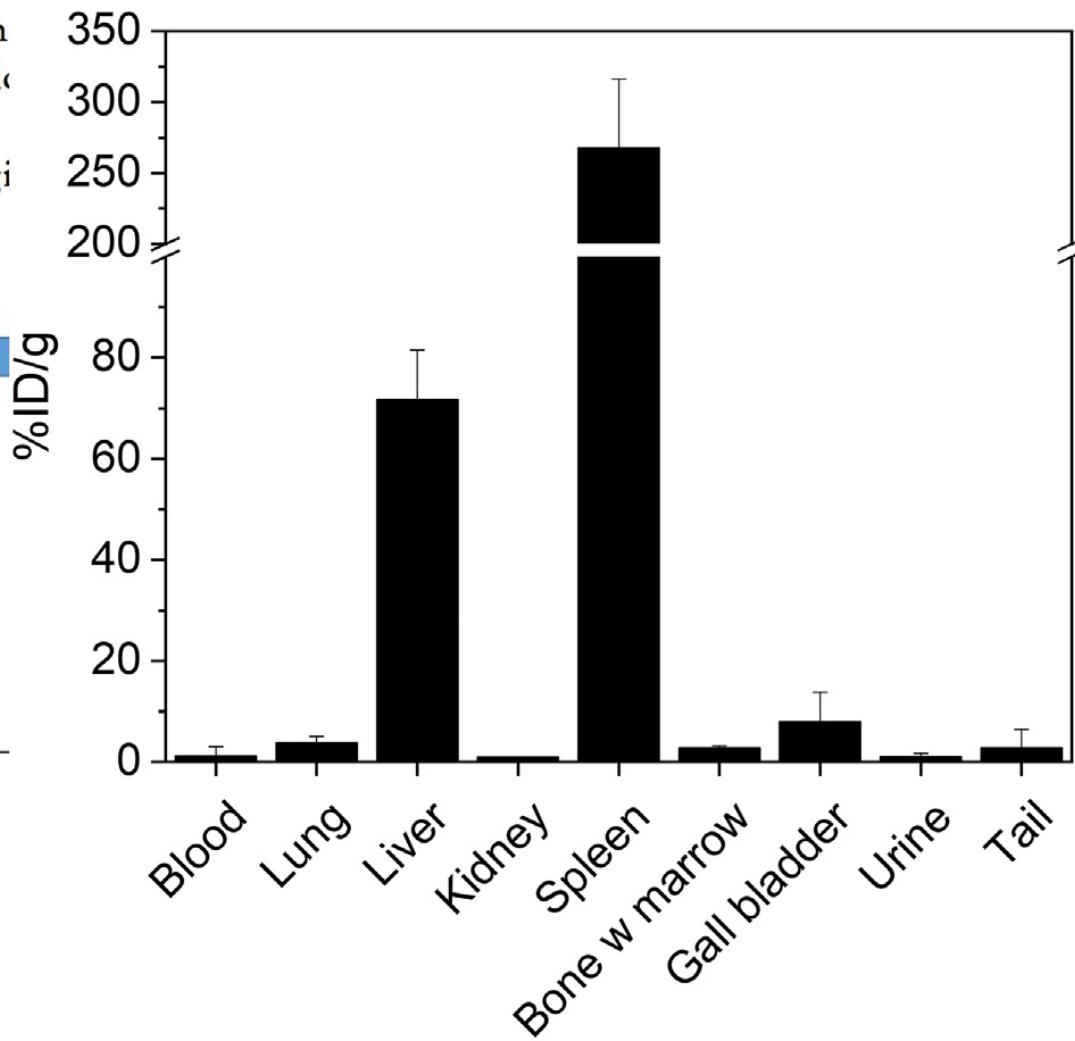
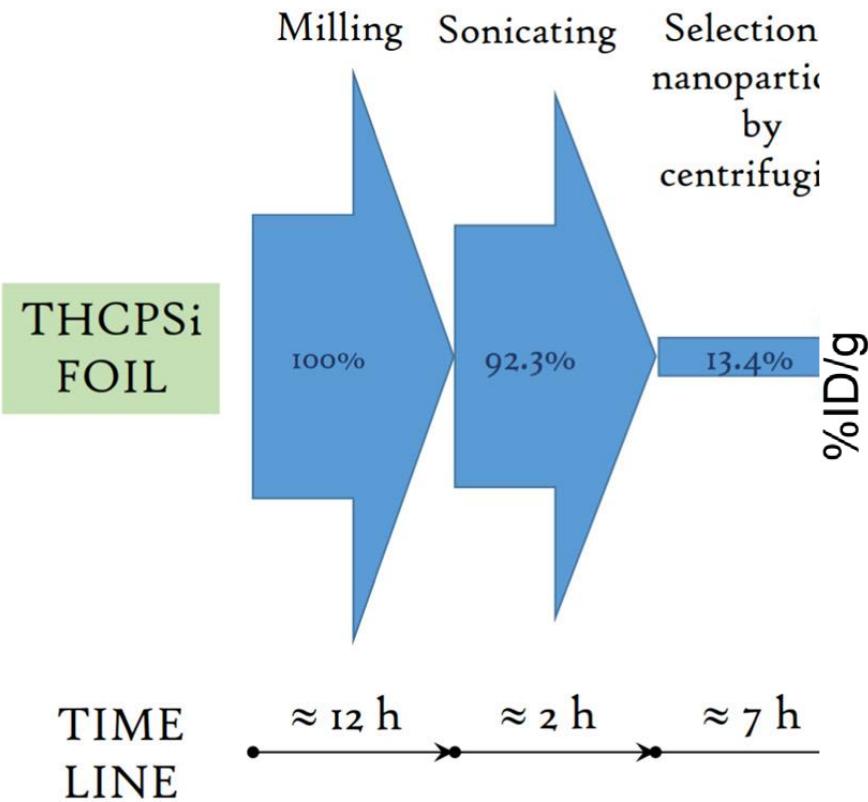
Resonance Ionization Laser Ion Source



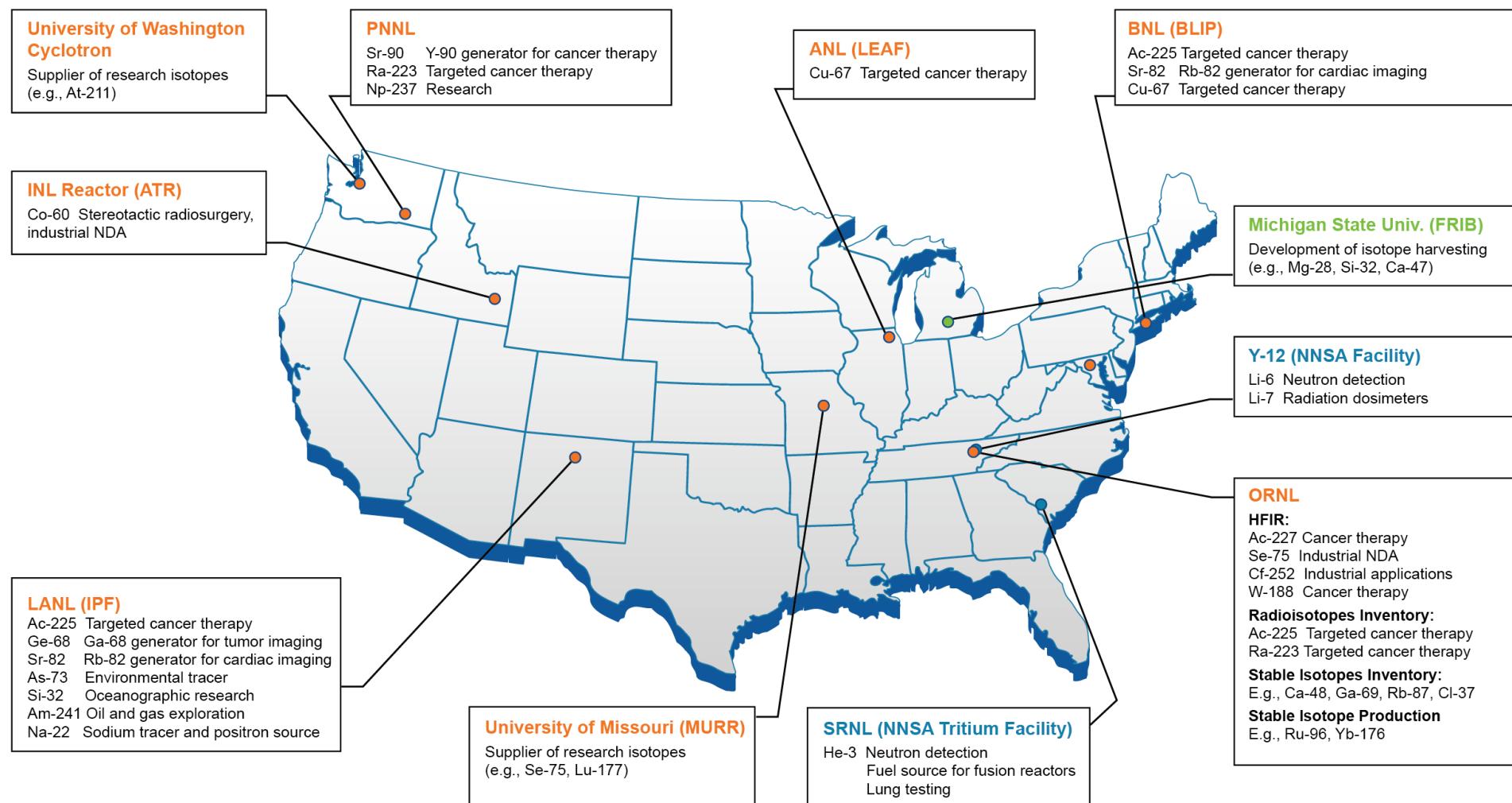
Laser Ionization



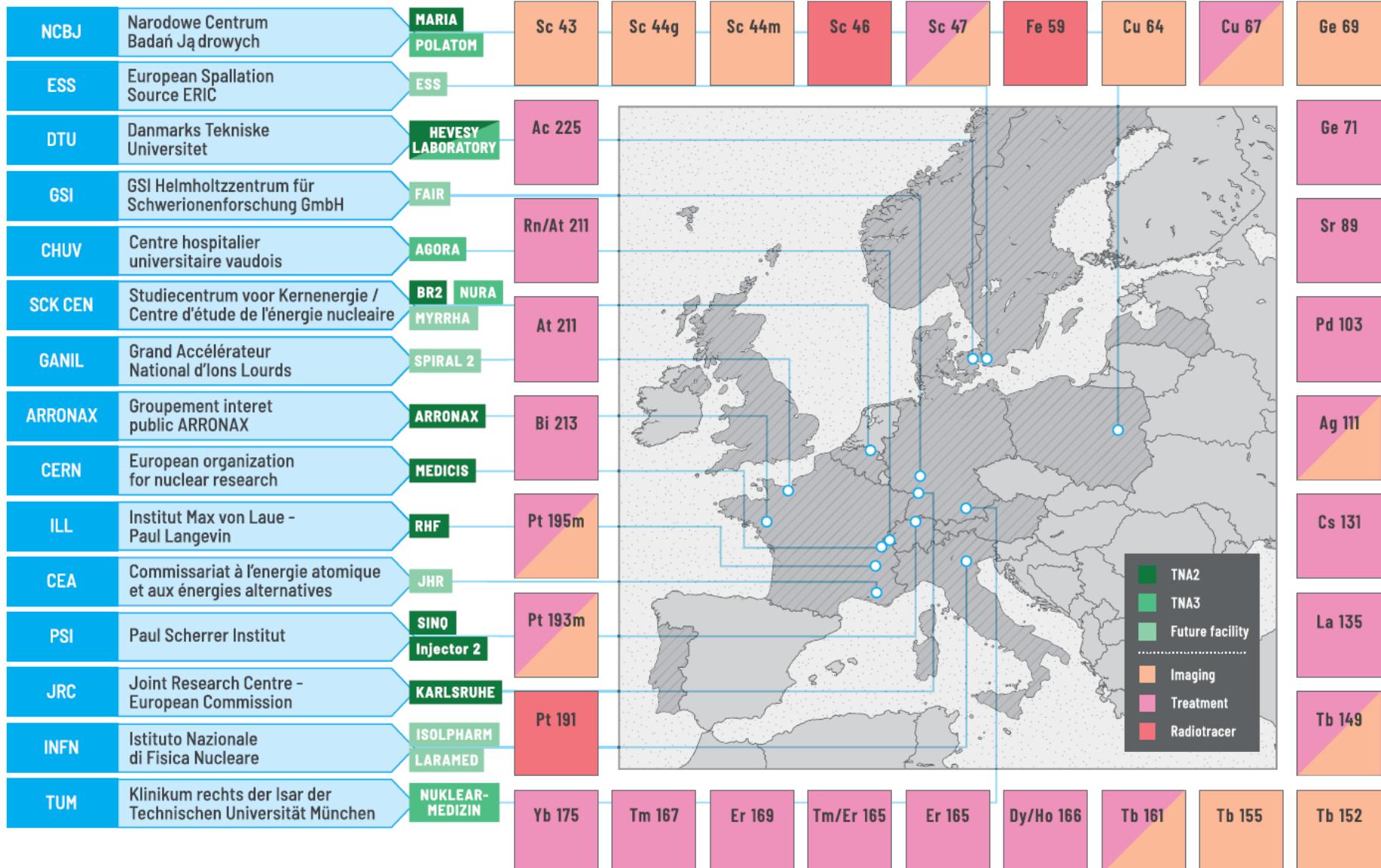
Radiolabeling of nanoparticles with ^{155}Tb



A great model: the US DOE Isotope Program

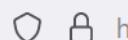


PRISMAP: towards a European Isotope Center



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008571 (PRISMAP).

The PRISMAP “Day 1 Radionuclide” Portfolio



<https://www.prismap.eu/radionuclides/portfolio/>



Most Visited



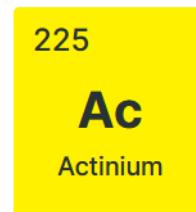
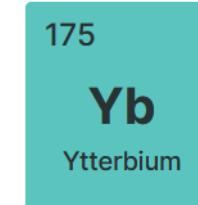
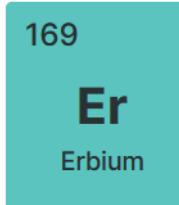
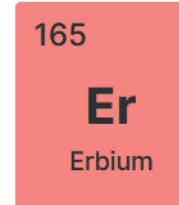
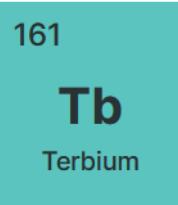
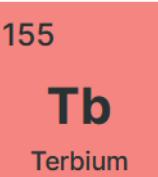
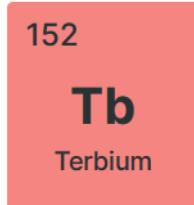
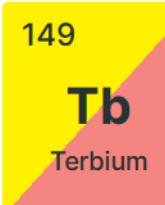
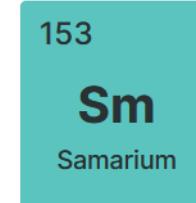
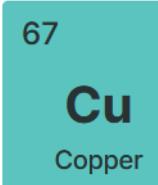
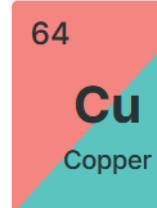
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Consortium

Access platform

Medical radionuclides

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Tb 161

6.95 d

 β^- 0.5, 0.
 γ 26, 49,
 e^- [Home](#) [Consortium](#) [Access platform](#) [Medical radionuclides](#)

Parameter	Specification
Half-life	6.95 d
Daughter	Dy-161 (stable)
Branching Ratio/Decay	100% β^-
Production	Gd-160(n,γ)Gd-161(β^-)Tb-161
Purification	2-step column separation
Chemical Form	In 0.05 M HCl (evaporation to dryness is also possible)
Specific Activity	>20 GBq/mg (PSI), t.b.d. (SCK CEN and NCBJ)
Radionuclide Purity	>99.99% (<0.01% Tb-160)
Radioisotopic Purity	>99.99% (<0.01% Tb-160)
Radiochemical purity	Labelling up to 100 MBq/nmol DOTANOC, DOTATATE or p-SCN-Bn-DOTA
Chemical Purity	t.b.d.
Identification	48.9 keV and 74.6 keV lines present
Appearance	Clear and colourless solution
pH	1-2
Activity available	~GBq (depends on PRISMAP lab)
Availability	Monthly (planning in advance)
Grade	Preclinical grade, n.c.a.
Other information	with/without analysis certificate

[Apply for this medical radionuclide](#)

Purity grades available

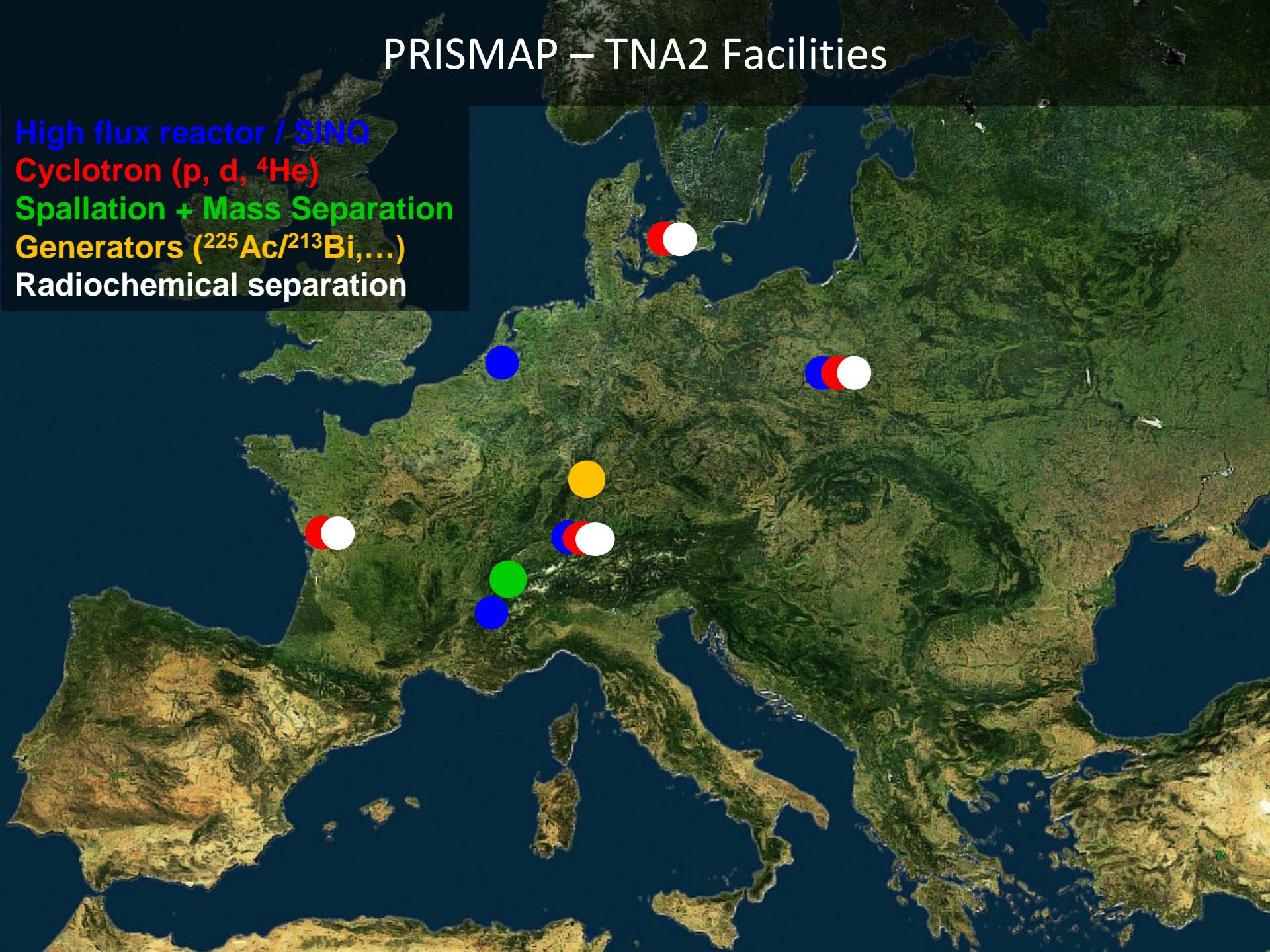
PRECLINICAL**No carrier added (n.c.a.)**

Yes

[Full specifications](#)

PRISMAP – TNA2 Facilities

High flux reactor / SINQ
Cyclotron (p, d, ^4He)
Spallation + Mass Separation
Generators ($^{225}\text{Ac}/^{213}\text{Bi}, \dots$)
Radiochemical separation



The losers

Ir 191

4.9 s

I_{γ} 129...
 e^-

Kr 81

13.1 s

I_{γ} 190

P 32
14.3 d

β^- 1.7
no γ

Xe 133
5.25 d

β^- 0.3...
 γ 81...
 e^-

I 131
8.0 d

β^- 1.0, 1.8...
 γ 364, 637...

Ga 67
78.3 h

ε
no β^+
 γ 93, 185, 300,...

Tl 201
3.04 d

ε
 γ 167, 135...

Y 86
14.7 h

ε , β^+ 1.2, 3.2...
 γ 1077, 628,
1153...

La 132
4.59 h

ε , β^+ 3.2, 3.7...
 γ 465, 567,
663, 1910...

The winners

Lu 177

6.64 d

β^- 0.5

γ 208, 113...

Tb 161

6.96 d

β^- 0.5; 0.6

γ 26, 49, 75...

e^-

Cu 67

2.6 d

β^- 0.4; 0.6

γ 185; 93; 91...

Ac 225

9.9 d

α 5.830;

5.797...

γ 100; (150...)

At 211

7.2 h

ε

α 5.867...

γ (687)

Tb 149

4.1 h

ε

α 3.97

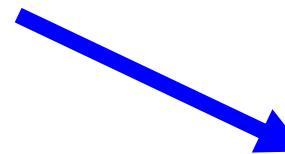
β^+ 1.4...

γ 352; 165...

PRISMAP — building a European network for medical radionuclides

PRISMAP is the European medical radionuclide programme on the production of high purity radionuclides (radioactive isotopes) by mass separation. We federate a European consortium of the key intense neutron sources, isotope mass separation facilities and high-power accelerators and cyclotrons, with leading biomedical and healthcare research institutes in the active translation of the emerging radionuclides into medical diagnosis and treatment.

PRISMAP will create a single-entry point for a fragmented user community distributed amongst universities, research centres, industry and hospitals, in a similar way as how the National Isotope Development Center (NIDC), supported by the Department of Energy (DOE), has provided radionuclide sources for users in the USA. PRISMAP brings together a consortium of 23 beneficiaries from 13 countries, one European Research Laboratory and an International Organisation. It receives support of leading associations and institutions in the field such as the European Association of Nuclear Medicine (EANM) and the International Atomic Energy Agency (IAEA).



ARE YOU A KEY PLAYER IN INDUSTRY, RESEARCH OR CLINICAL APPLICATION IN THE FIELD OF MEDICAL RADIONUCLIDES? HELP US SHAPE THE FUTURE FOR NOVEL AND EMERGING MEDICAL RADIONUCLIDES IN EUROPE BY TAKING PART IN OUR SURVEY!

Next proposal deadline: 31 March 2022