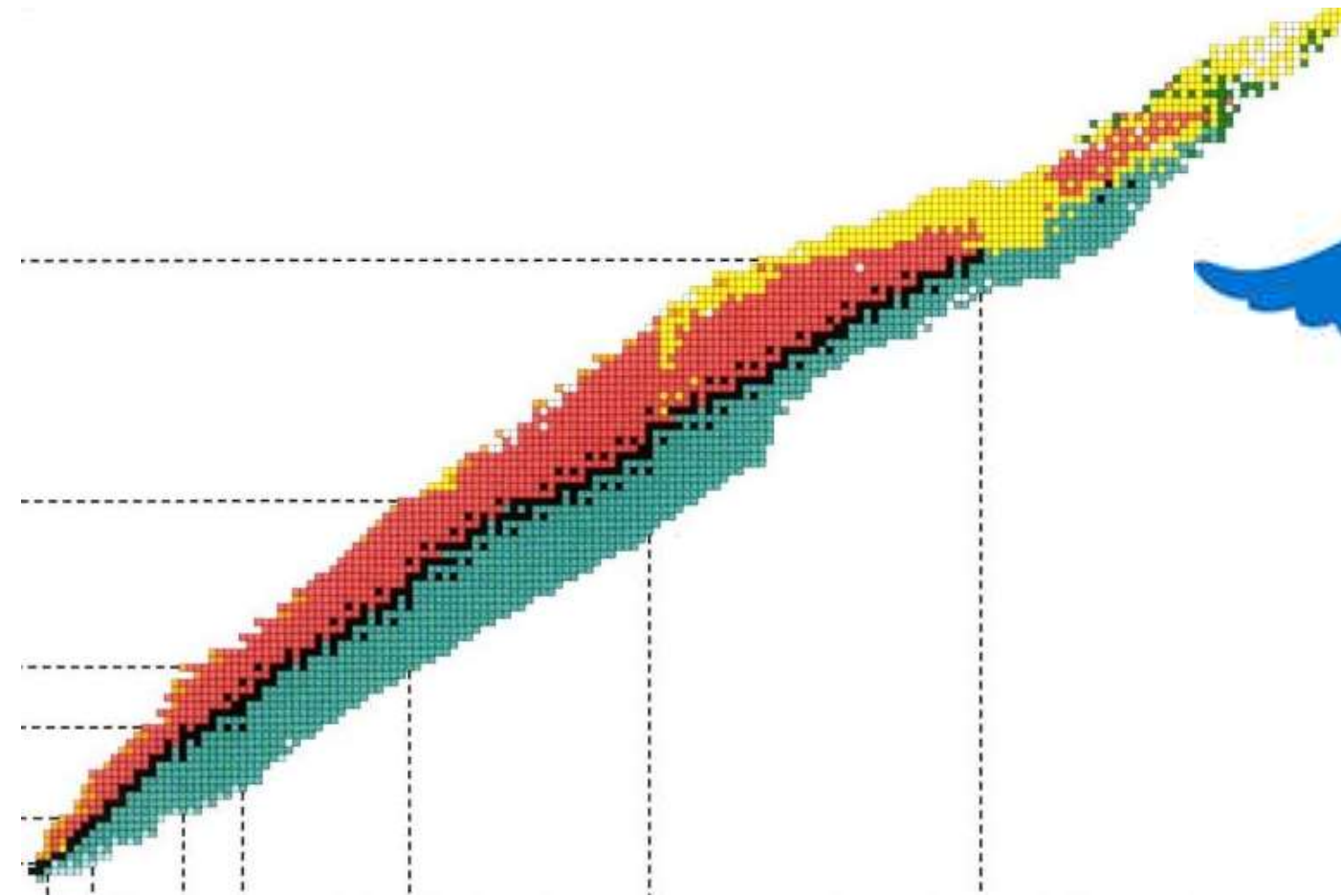


Medical Isotope Production



Ulli Köster

ILL & UGA, Grenoble, France

Theranostics

=

Personalized
medicine

=

Precision
medicine

Cure

Companion
diagnostic

Therapy

Symptomatic
treatment

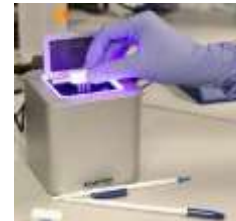
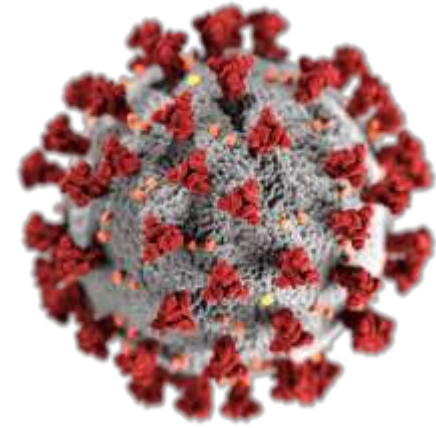
Diagnostic

Prevention

“Medical”

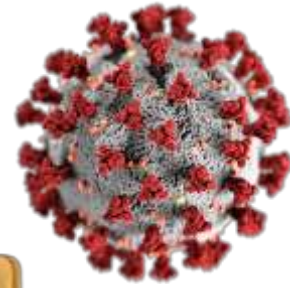
MD (Miracle Drug)

MD's efficacy
predictor



Theranostics
=
Personalized
medicine
=
Precision
medicine

“Medical”



Cure

10k **Miracle Drug** *



= 0.85 G\$

Companion
diagnostic

25k MD's efficacy
predictor



= 0.08 G\$

Therapy

25k 



= 0.08 G\$

Symptomatic
treatment



Diagnostic

20M 



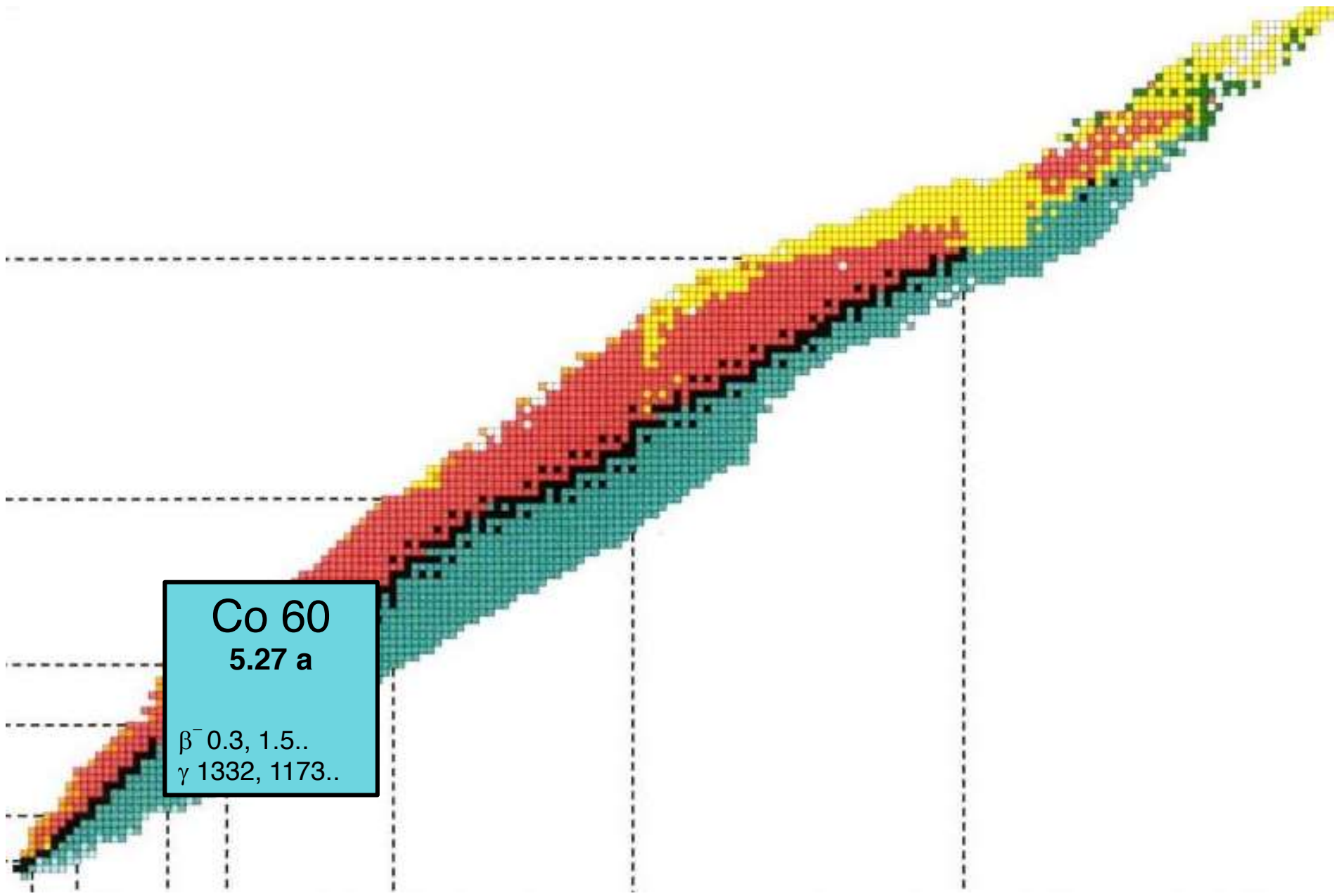
= 1 G\$

Prevention

38M * 500  * 

= 2 G\$

Radionuclides for Medicine



Radiation sterilization of medical material

- Single use consumables (surgical threads, gloves, etc.)
- Human tissues
- Implantable devices
- Pharmaceuticals

RADIATION MODALITIES



GAMMA

Exposes product to Cobalt 60 radiation

38%



ELECTRON BEAM

Exposes product to high-energy electrons

7%



X-RAY

Uses ionizing energy from electron beams

GAS MODALITIES



ETHYLENE OXIDE

Exposes product to gaseous sterilant

50%



VHP

Low temp gas process under deep vacuum

OTHER



MOIST HEAT (STEAM)

High temp, high pressure with vacuum or gravity conditioning



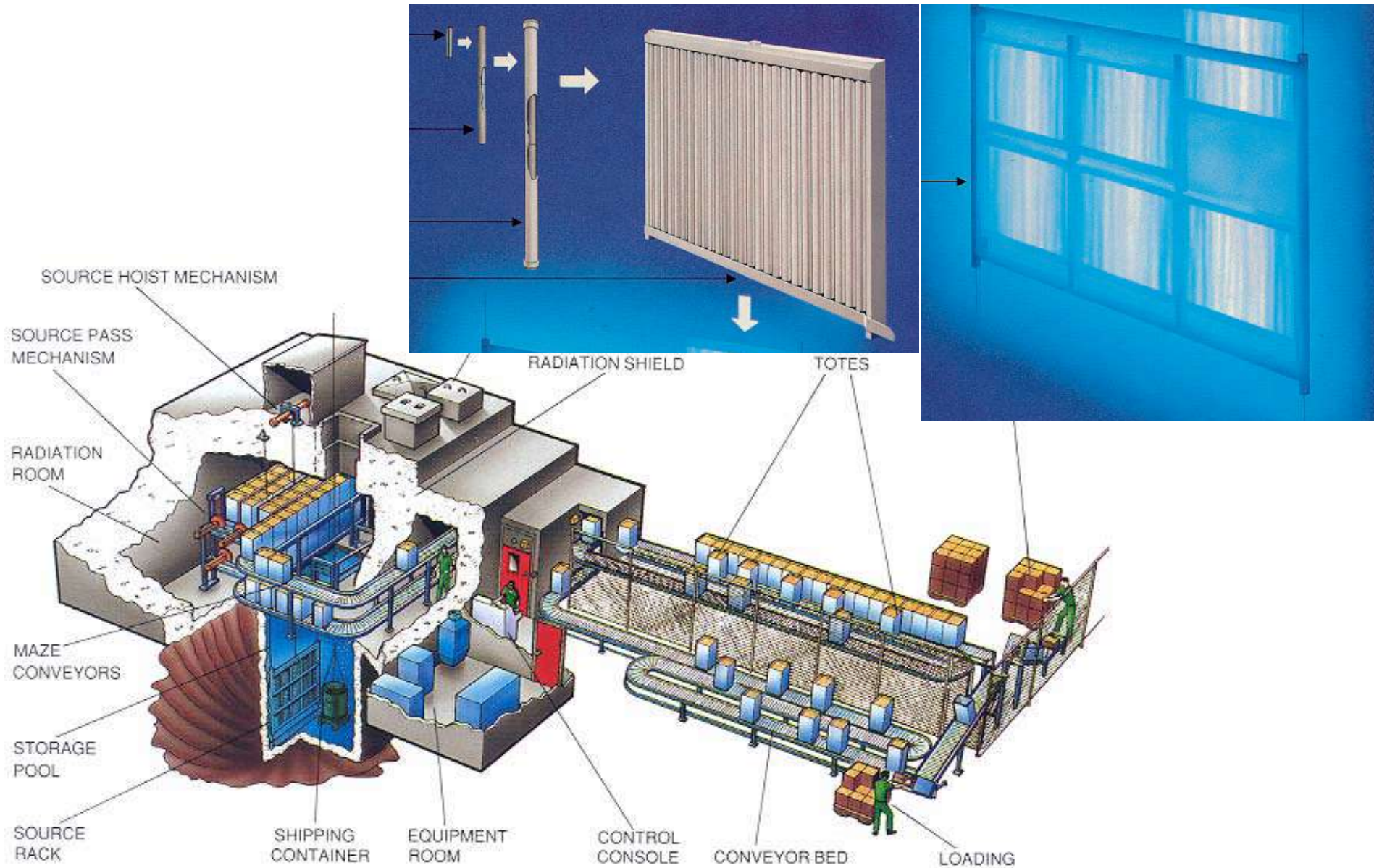
LABORATORIES

Provides microbiological and analytical testing

Market for gamma ray sterilization: ≈ 1 G\$/year

Total ^{60}Co activity in use: $\approx 10^{19}$ Bq ≈ 0.3 GCi

Radiation Sterilization of Medical Devices



1 MCi = 37 PBq ^{60}Co sterilizes 650 kg/hour at 25 kGy

Theranostics

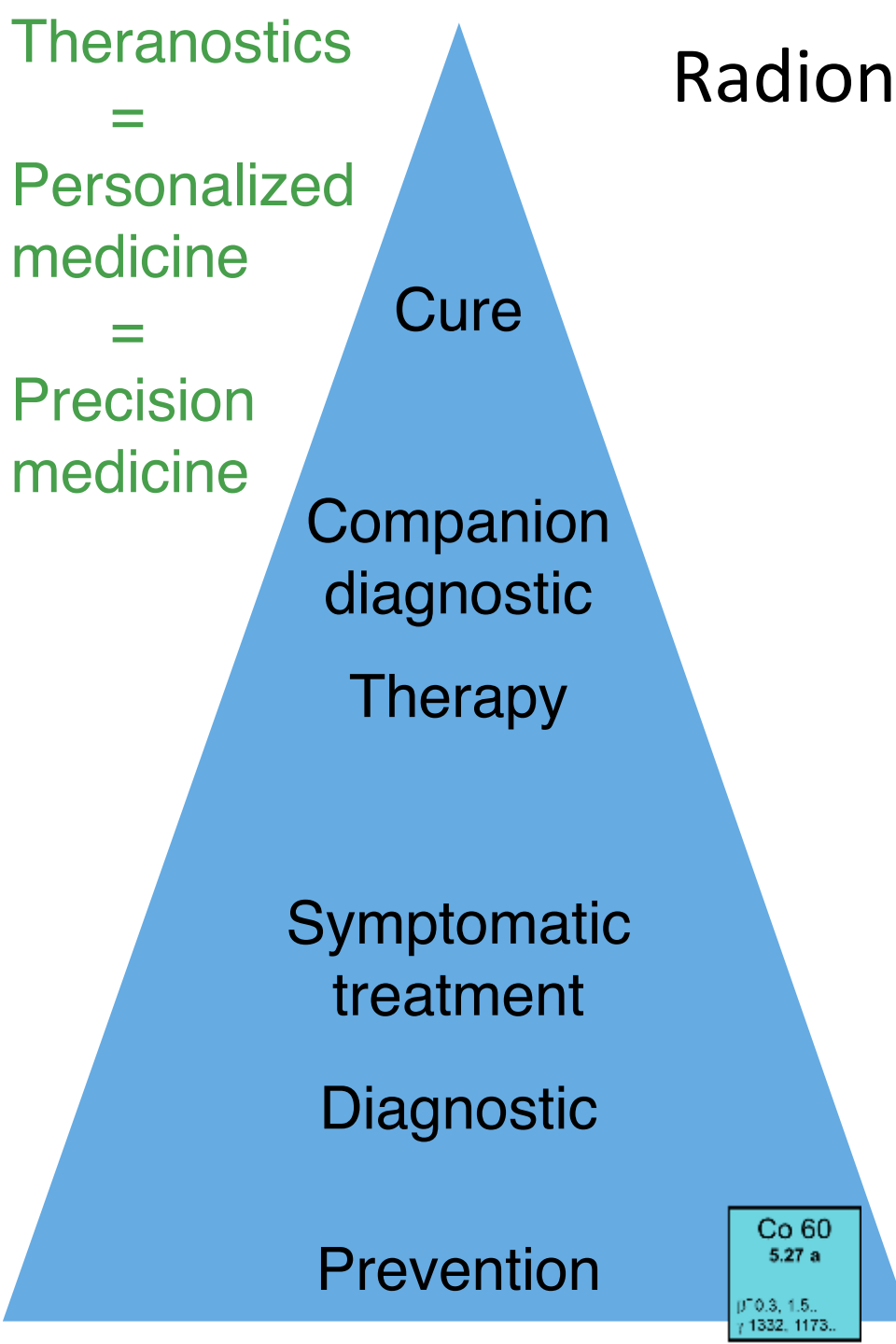
=

Personalized
medicine

=

Precision
medicine

Radionuclides



Cure

Companion
diagnostic

Therapy

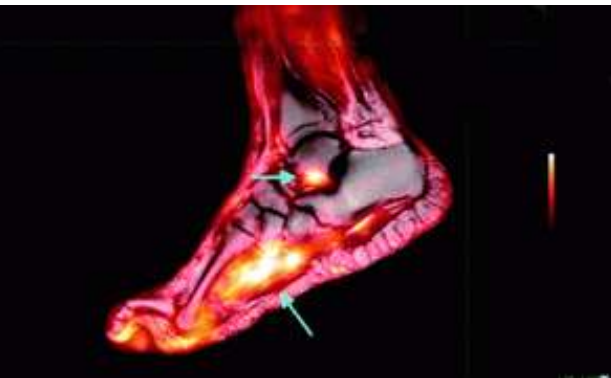
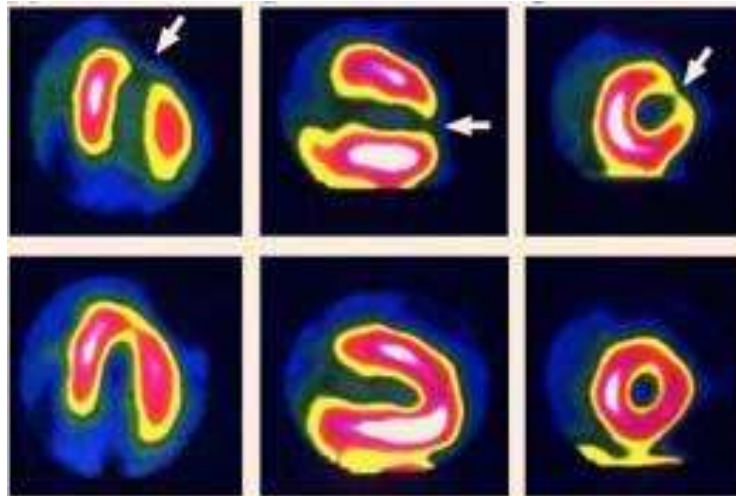
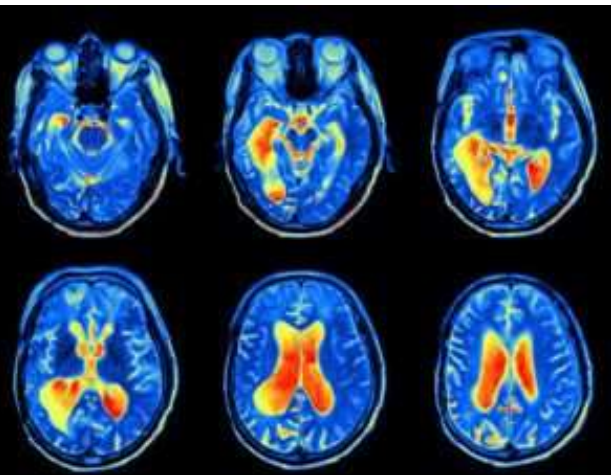
Symptomatic
treatment

Diagnostic

Prevention

Co 60
5.27 a
μ⁺ 0.3, 1.5..
γ 1332, 1173..

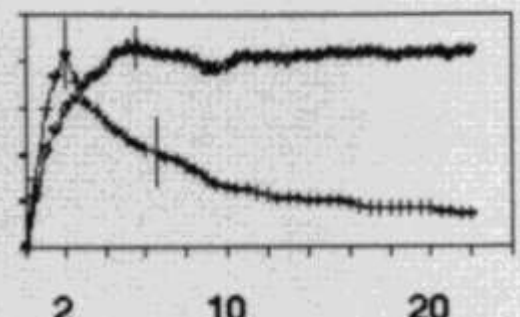
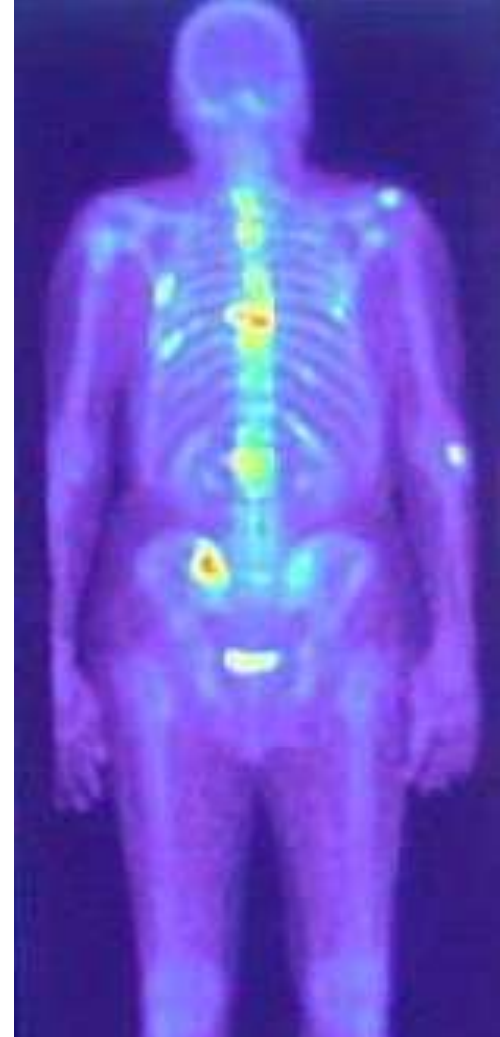
Molecular imaging



Ventilation:



Perfusion



Theranostics

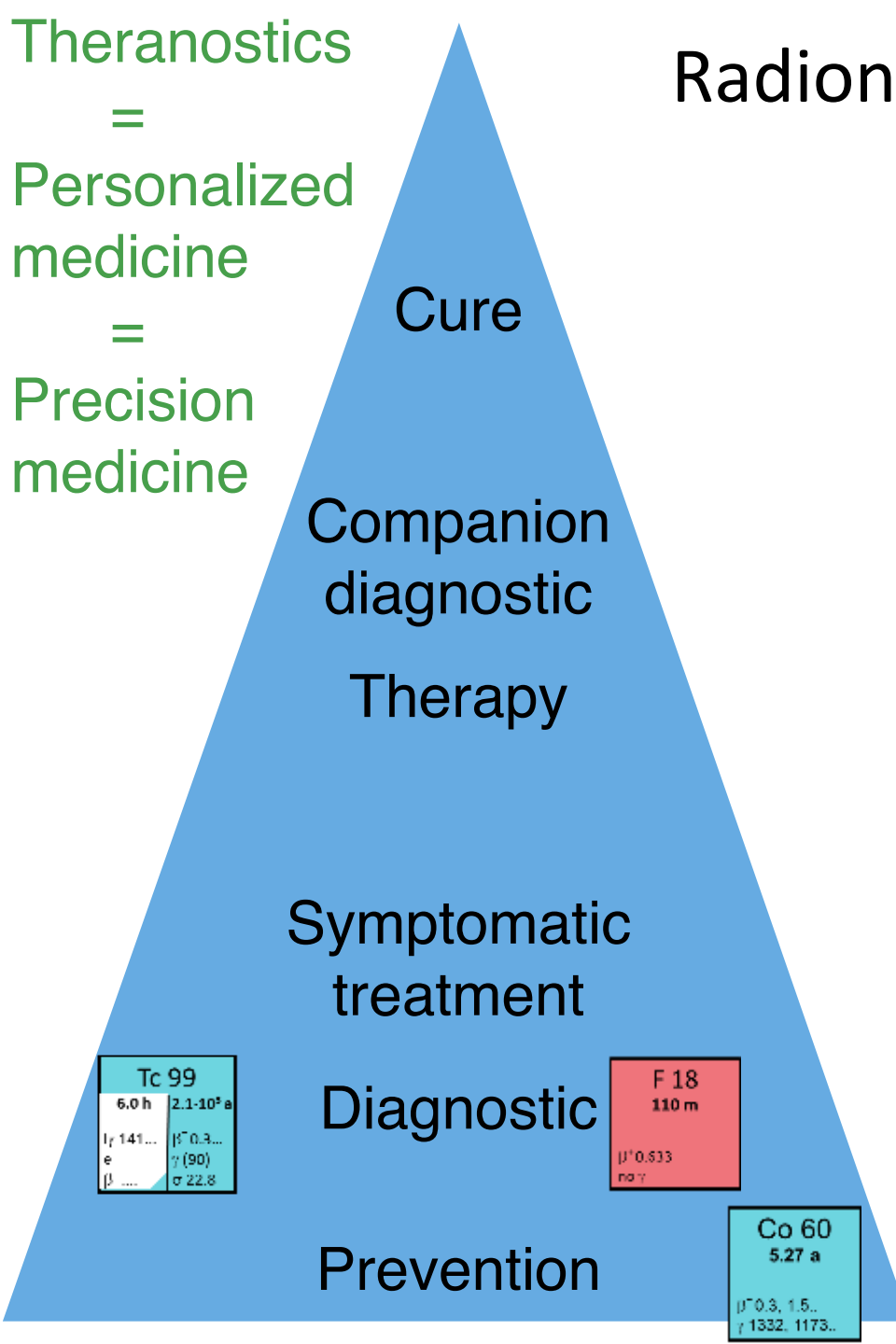
=

Personalized
medicine

=

Precision
medicine

Radionuclides



Cure

Companion
diagnostic

Therapy

Symptomatic
treatment

Diagnostic

Prevention

Tc 99	
6.0 h	2.1·10 ⁵ a
I _γ 141...	β ⁻ 0.3...
e	γ (90)
β ⁻ ...	σ 22.8

F 18	
110 m	
μ ⁺ 0.633	no γ

Co 60	
5.27 a	
μ ⁺ 0.3, 1.5...	γ 1332, 1173...

Discontinued radium applications



zum Essen und Trinken
(NACH DR. SENFTNER O.R.P.)

Sind Sie gesund, so erhalten Sie dadurch Ihr kostbares Gut, sind Sie leidend, so erhöhen Sie Ihre Aussicht, wieder gesund zu werden!

Versuchen Sie auch die übrigen Burkbraun-Edelerzeugnisse: Kakao, Schokolade, Pralinen, Sie werden darin Ihre Marke finden, denn alles, was den Namen Burkbraun trägt, ist einzigartig köstlich!

BURK & BRAUN
KAKAO-U.SCHOKOLADENFABRIK
C O T T B U S



MÉTHODE THO-RADIA

EMBELLISSANTE PARCE QUE CURATIVE

4°

DENTIFRICE THO-RADIA

A BASE DE SELS DE THORIUM

FORMULE du Docteur Alfred CURIE

Astringent et bactéricide, il stérilise la cavité buccale, évite et combat les gingivites, prévient la carie et les pyorrhées alvéolaires. Il assainit les dents, laisse dans la bouche une délicieuse impression de fraîcheur, conserve l'éclat, la blancheur et l'incrépité de la dentition.

Le grand tube 6 francs

Pas de joli sourire sans de jolies dents

CHEZ LES PHARMACIENS EXCLUSIVEMENT



CRÈME POUVRE THO-RADIA

EMBELLISSANTES PARCE QUE CURATIVES
à base de thorium et de radium selon la formule du
DOCTEUR ALFRED CURIE
EXCLUSIVEMENT CHEZ LES PHARMACIENS

Brochure gratuite sur demande à THO-RADIA, 20 RUE DES CAPUCINES, PARIS

Évitez et combattez la **TUBERCULOSE**
par la **TUBÉRADINE**
(Antiseptique pulmonaire radioactif)

Jáchymov Jáchymov

Trade **RADIUMCHEMA** mark

Radio-active compress
Radiumchema

Large size: 6/8 in.
The activity of this compress is constant.

Contents of Radium: 0.1 mg

Directions for use inside.
The genuineness and the contents of Radium are guaranteed only so long as the original outer remains intact.

Chemical Works Kôlin-Jáchymov (Czechoslovakia), Radiumchema Department.

THREE RUBBER PROPHYLACTICS
No. 33 Rolled

Sold for protection against disease
"GET NEXT TO NUTEX"
Ask for them by name

RADIUM NUTEX are fine quality prophylactics... They are carefully inspected and tested.
SOLD IN DRUG-STORES
Manufactured by
THE NUTEX COMPANY
Sales Office Philo., Pa.
Made in U. S. A.

3 for 50c Doz. \$1.50

LE RADIUM RÉGÈNÈRE L'ÉPIDERME

PLUS DE RIDES TEINT VÉLOUTÉ

LA CRÈME RAMEY
RADIACÉE
CONTIENT DU RADIUM

Theranostics

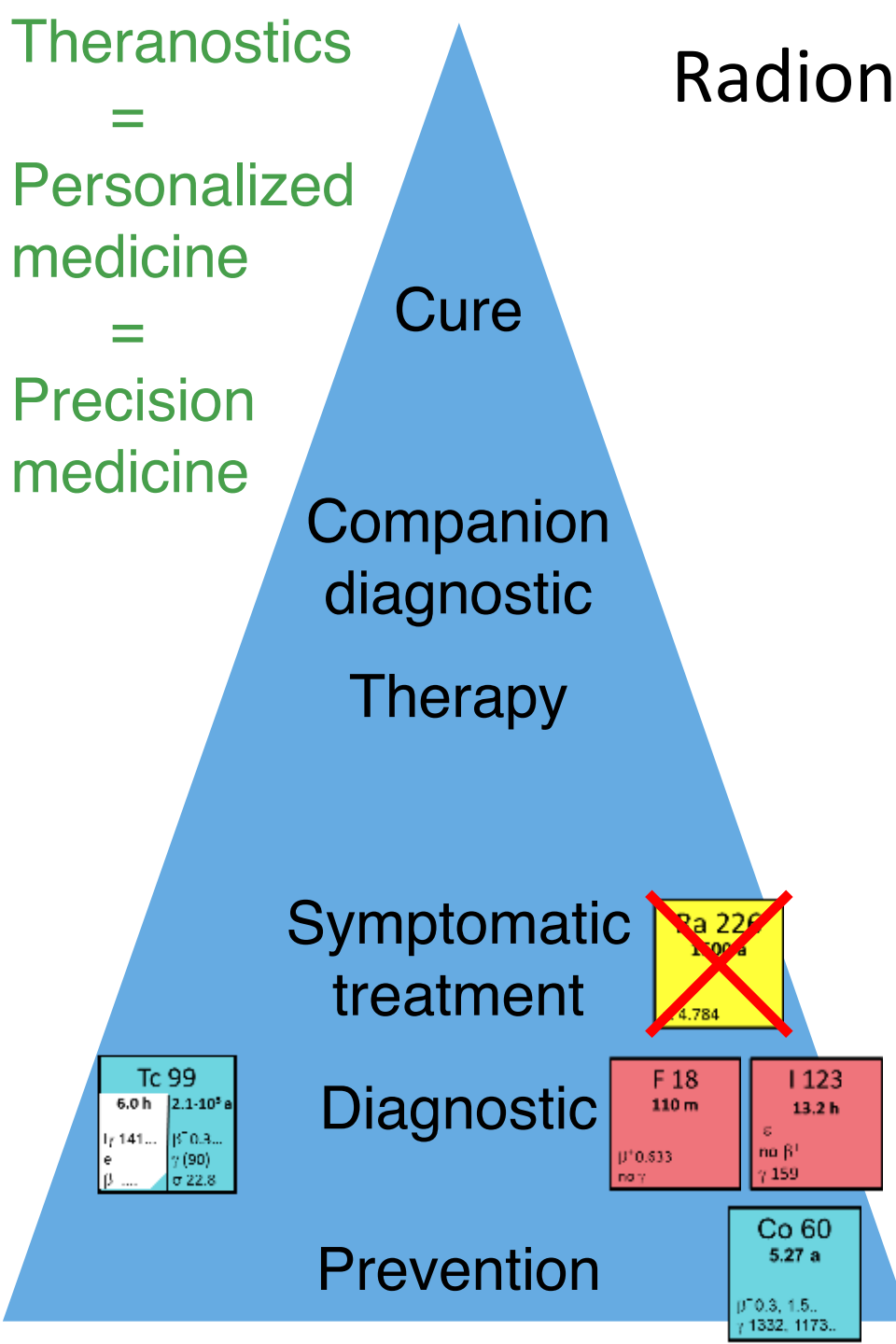
=

Personalized
medicine

=

Precision
medicine

Radionuclides



Cure

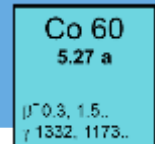
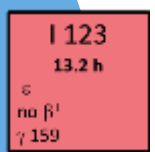
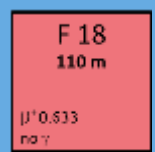
Companion
diagnostic
Therapy

Therapy

Symptomatic
treatment

Diagnostic

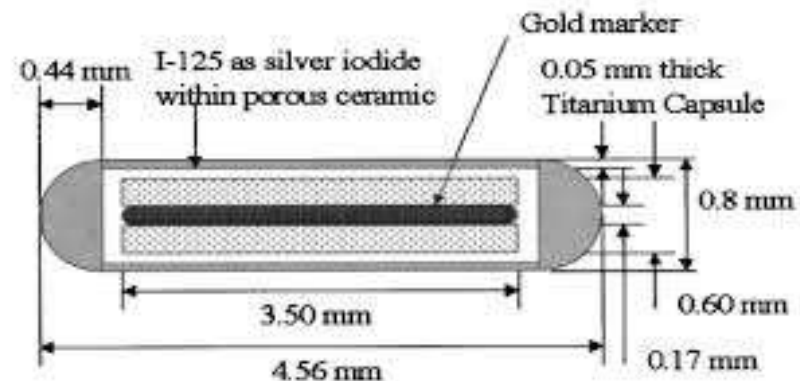
Prevention



Brachytherapy

High Dose Rate (HDR) brachytherapy
short-term insertion of ^{60}Co , ^{137}Cs ,
 ^{169}Yb or ^{192}Ir sources

Low Dose Rate (LDR) brachytherapy
long-term insertion of ^{32}P , ^{103}Pd , ^{125}I ,
 ^{131}Cs , etc. sources (“seeds”)



Theranostics

=

Personalized
medicine

=

Precision
medicine

Radionuclides

Cure

Companion
diagnostic

Therapy

Symptomatic
treatment

Diagnostic

Prevention

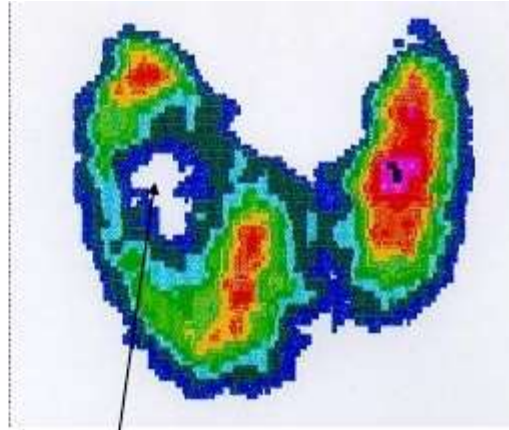
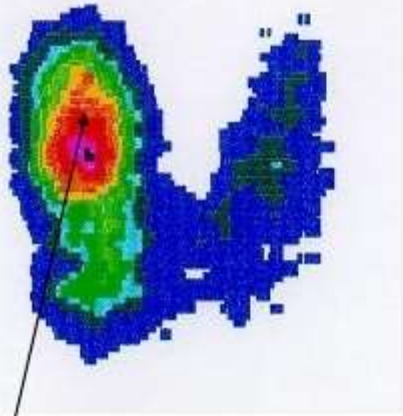
Co 60	
5.27 a	
β^- 0.3, 1.5...	
γ 1332, 1173...	

Tc 99	
6.0 h	2.1-10 ⁵ a
I_{γ} 141...	β^- 0.3...
e	γ (90)
β ...	σ 22.8

F 18	
110 m	
β^+ 0.633	
γ	

Co 60	
5.27 a	
β^- 0.3, 1.5...	
γ 1332, 1173...	

Thyroid scintigraphy and therapy



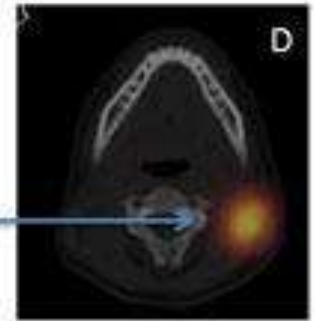
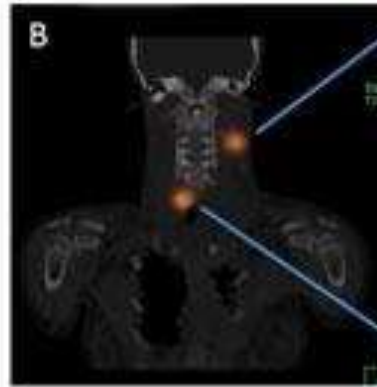
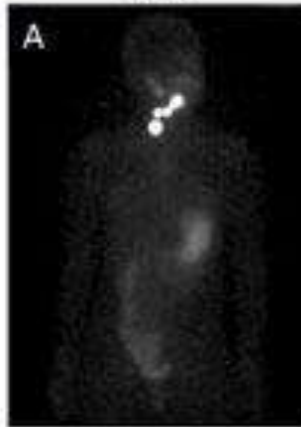
I 123
13.2 h
 ϵ
no β^+
 γ 159

Hot nodule - Rt. lobe

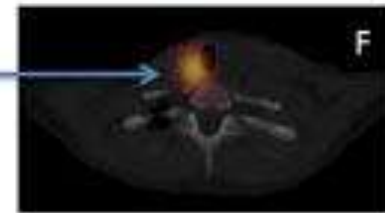
Cold nodule - Rt. lobe

¹²³I Diagnostic Whole Body Scan

¹²³I DxWBS with SPECT-CT



I 131
8.0 d
 β^- 1.0, 1.8,...
 γ 364, 637...



$^{123}\text{I}^-$, $^{131}\text{I}^-$ or $^{99\text{m}}\text{TcO}_4^-$ for scintigraphy

$^{131}\text{I}^-$ for therapy

(papillary) thyroid cancer has the **highest survival** of all malignant cancers !

Theranostics

=

Personalized
medicine

=

Precision
medicine

Radionuclides

Cure

Companion
diagnostic

Therapy

Symptomatic
treatment

Diagnostic

Prevention

Co 60
5.27 a
β^- 0.3, 1.5...
γ 1332, 1173...

I 131
8.0 d
β^- 1.0, 1.8, ...
γ 364, 637...

Tc 99
6.0 h
$2.1 \cdot 10^5$ a
γ 141...
β^- 0.3...
γ (90)
σ 22.8

F 18
110 m
β^+ 0.633
no γ

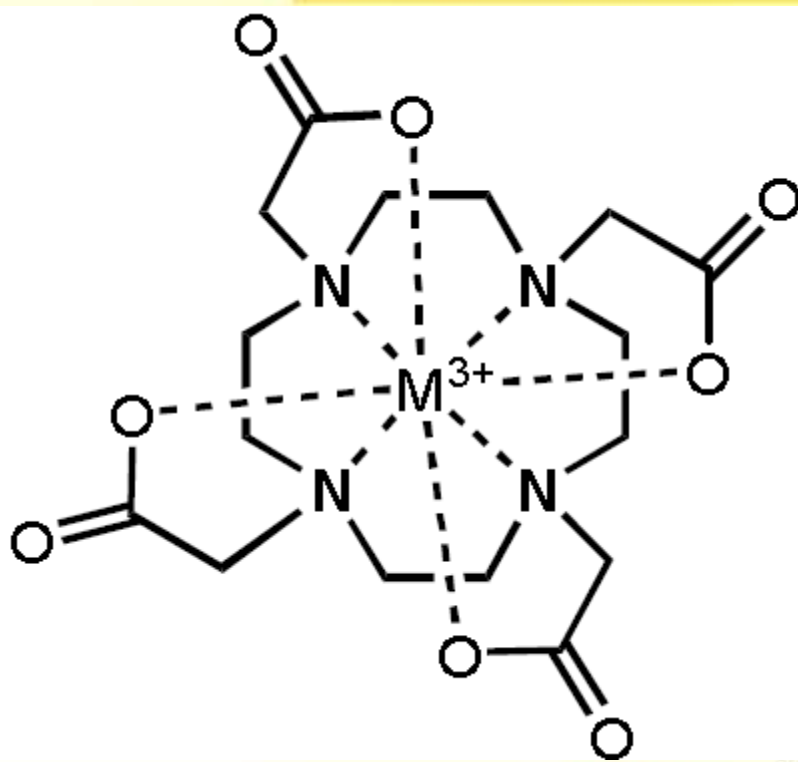
I 123
13.2 h
ϵ
no β^+
γ 159

Co 60
5.27 a
β^- 0.3, 1.5...
γ 1332, 1173...

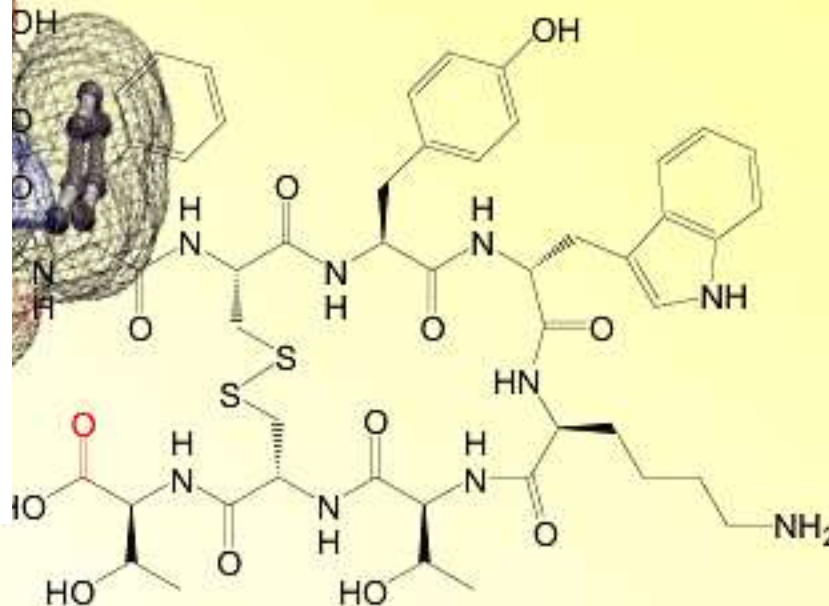
How can one treat such patients?



Structural Formula of DOTA-TOC/TATE



DOTA-TATE



1,4,7,10-tetraazacyclododecantetraacetate

^{111}In

^{90}Y

^{67}Ga

^{177}Lu

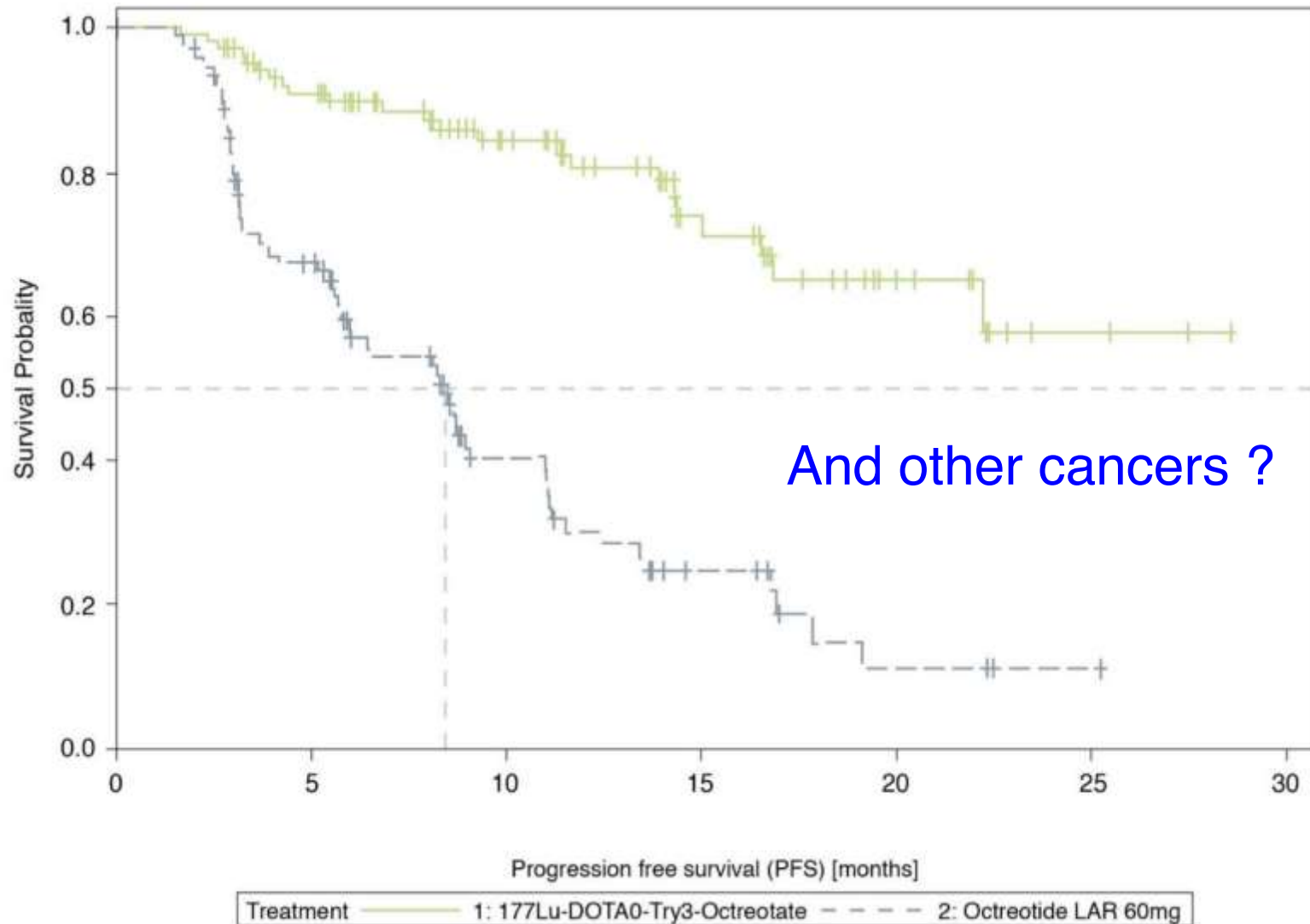
^{68}Ga

^{213}Bi

$\text{IC}_{50} (\text{Y}^{\text{III}}) = 1.6 \pm 0.4 \text{ nM}$

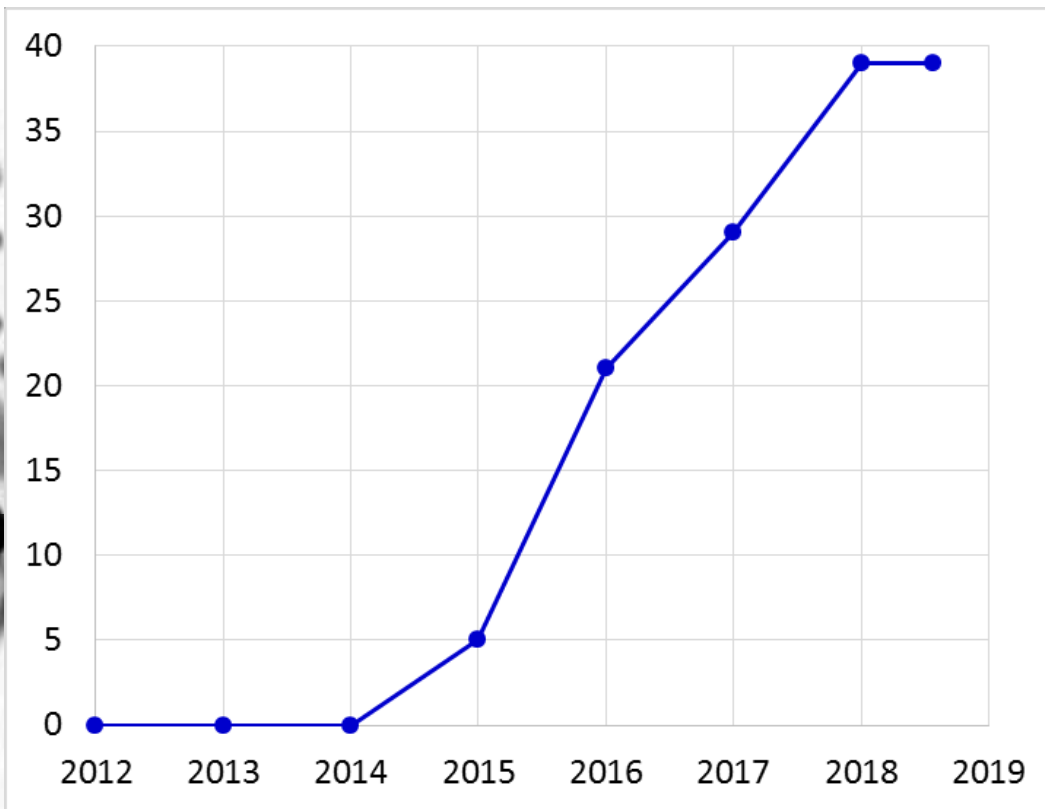
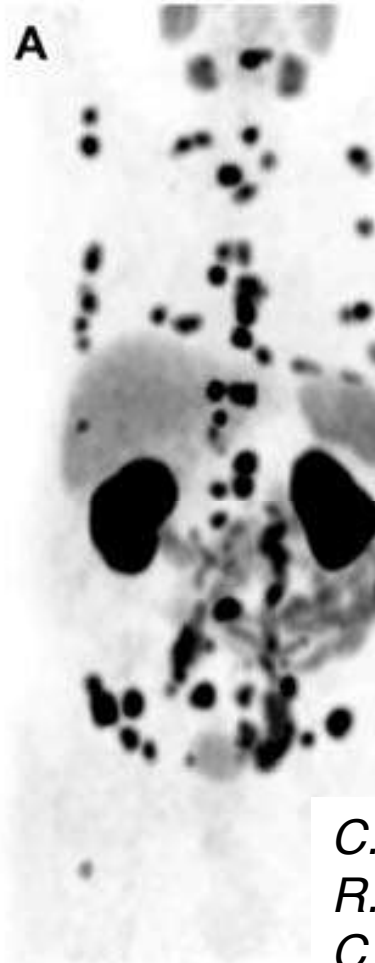
Helmut Maecke, EANM-2007.

^{177}Lu -Peptide Receptor Radionuclide Therapy of midgut neuroendocrine tumors



J. Strosberg et al., N Engl J Med 2017;376:125.

^{177}Lu -radioligand therapy of advanced prostate cancer



C. Kratochwil et al., Eur J Nucl Med Mol Imaging 2015;42:987.

R.P. Baum et al., J Nucl Med 2016;57:1006.

C. Kratochwil et al., J Nucl Med 2016;57:1170.

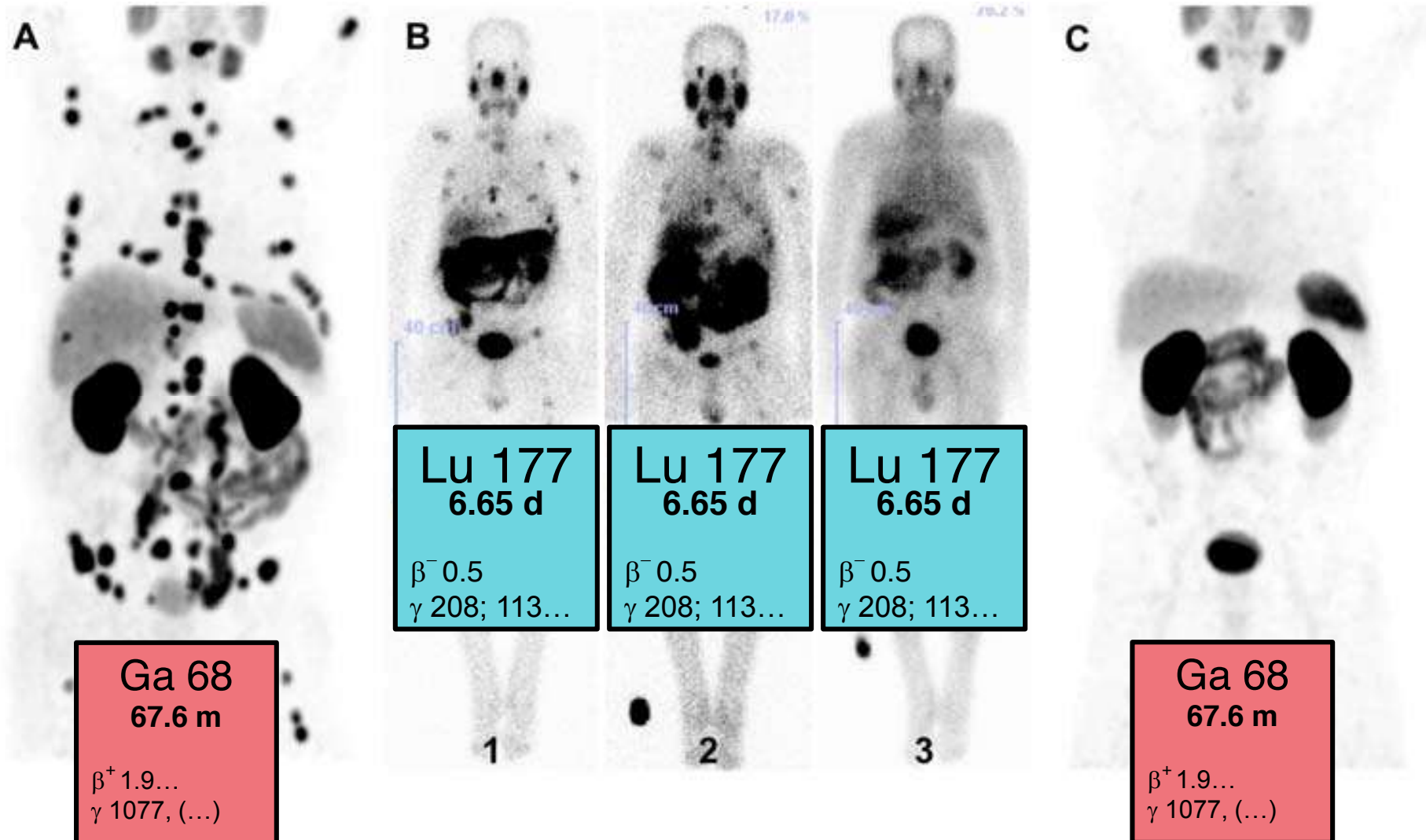
K. Rahbar et al., J Nucl Med 2017;58:85.

M.S. Hofman et al., Lancet Oncol 2018;19:825.

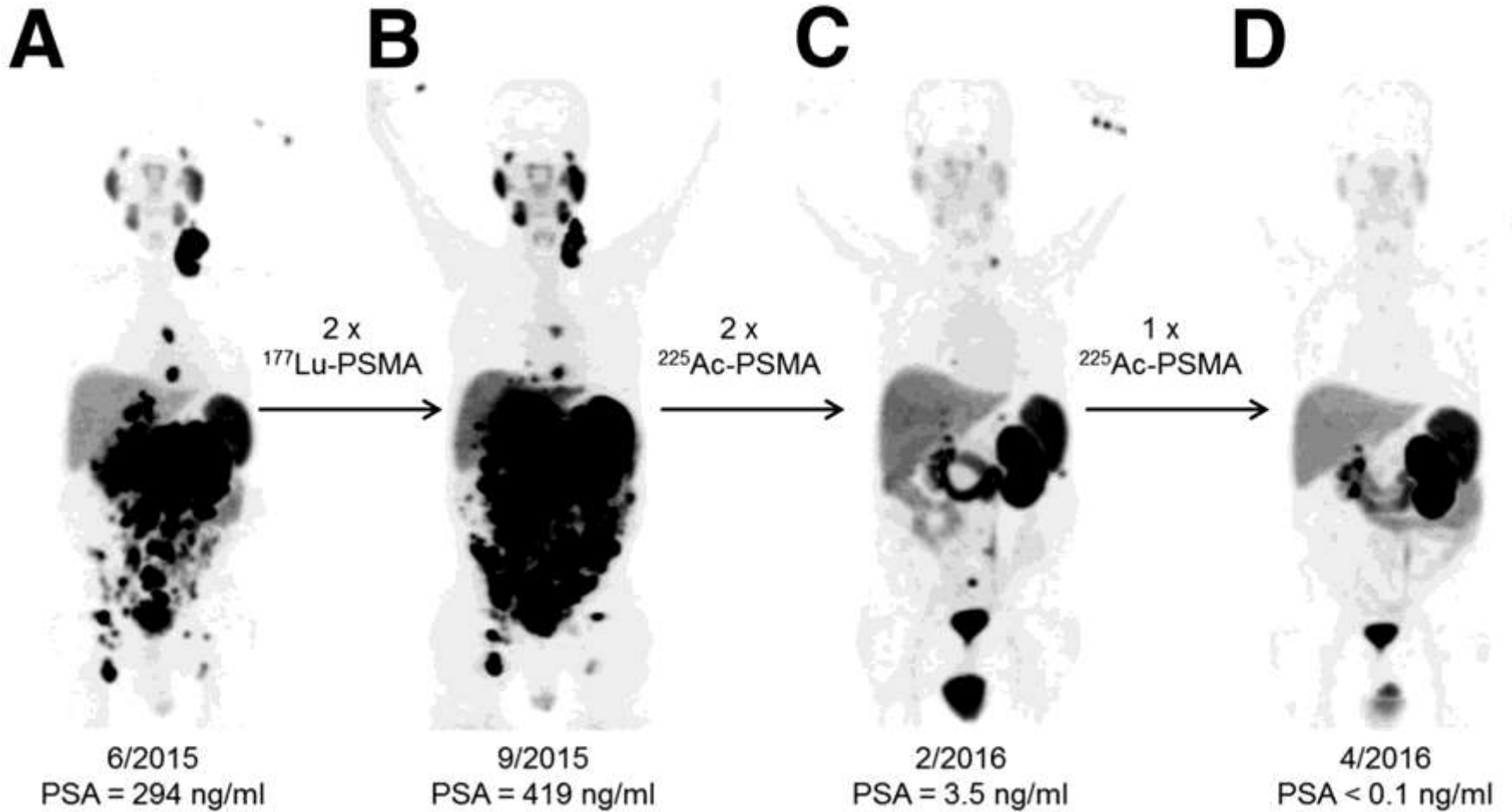
M.M. Heck et al., Eur Urol 2019;75:920.

T.W. Barber et al., J Nucl Med 2019; 60:955.

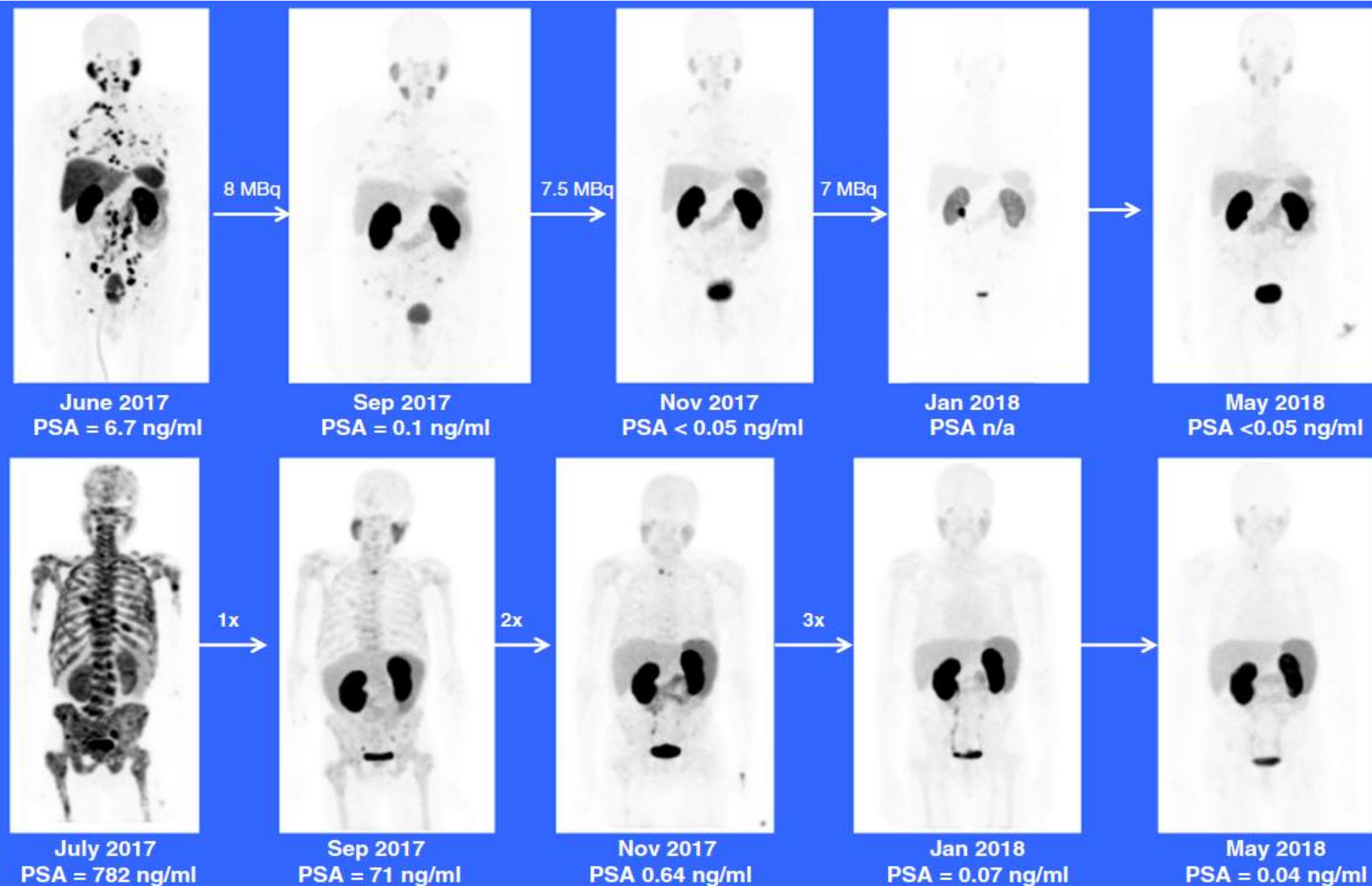
^{177}Lu -radioligand therapy of advanced prostate cancer



Targeted therapy with ^{225}Ac



Targeted therapy with ^{225}Ac



Theranostics

=

Personalized
medicine

=

Precision
medicine

Radionuclides

Ac 225
9.9 d
 α 5.830; 5.797...
 γ 100; 150...
 e^-

Lu 177
6.65 d
 β^- 0.5
 γ 208; 113...

Cure

Ga 68
67.6 m
 β^+ 1.9...
 γ 1077, (...)

Companion
diagnostic

Therapy

Co 60
5.27 a
 β^- 0.3, 1.5...
 γ 1332, 1173...

I 131
8.0 d
 β^- 1.0, 1.8...
 γ 364, 637...

Ra 223
11.4 d
 α 5.716, 5.606...
 γ 269; 154; 124...
 σ 130

Symptomatic
treatment

Tc 99
6.0 h | $2.1 \cdot 10^5$ a
 $I\gamma$ 141... | β^- 0.3...
 e^- | γ (90)
 β^- ... | σ 22.8

Diagnostic

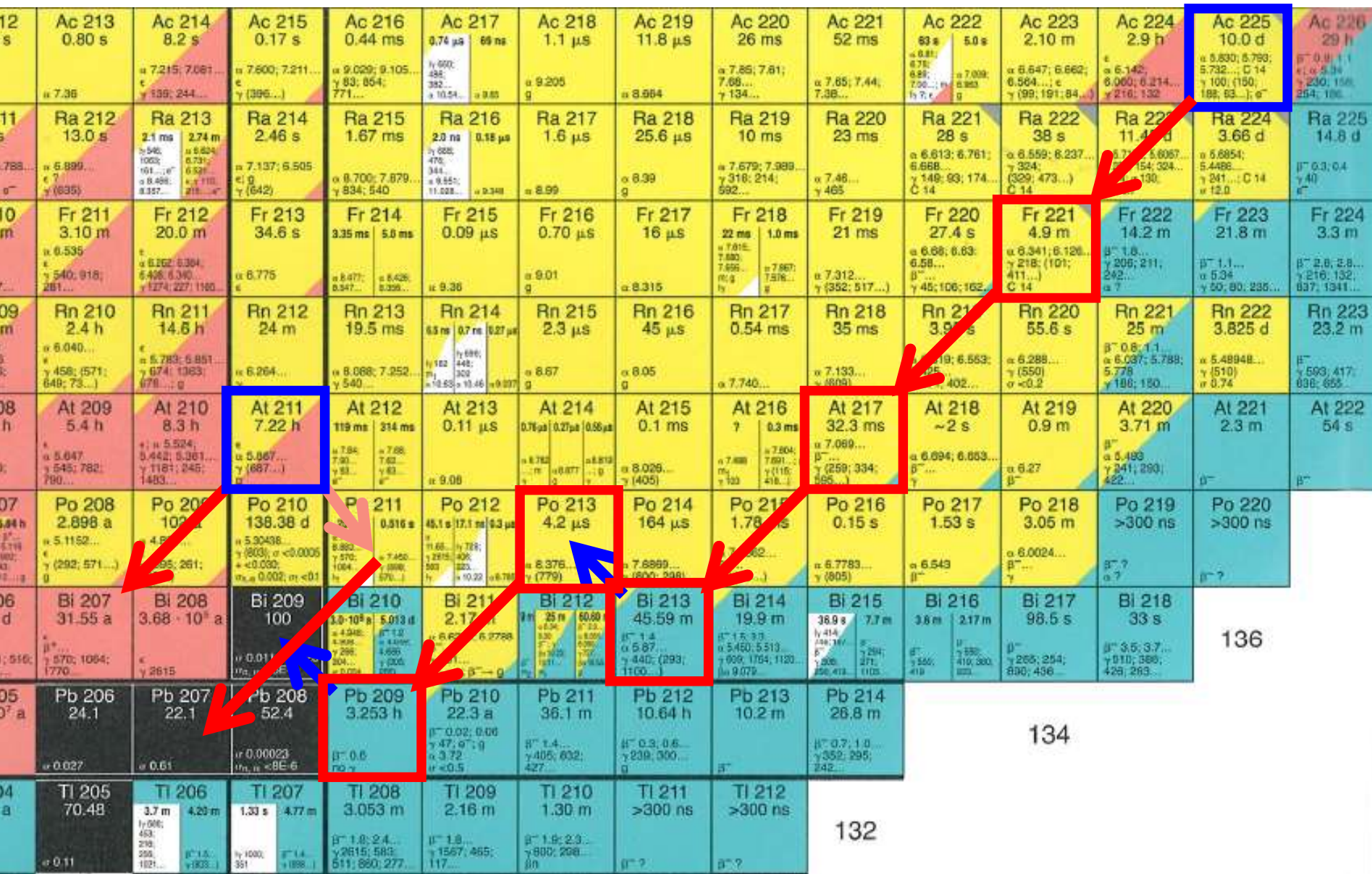
F 18
110 m
 β^+ 0.633
no γ

I 123
13.2 h
 e^-
no β^+
 γ 159

Prevention

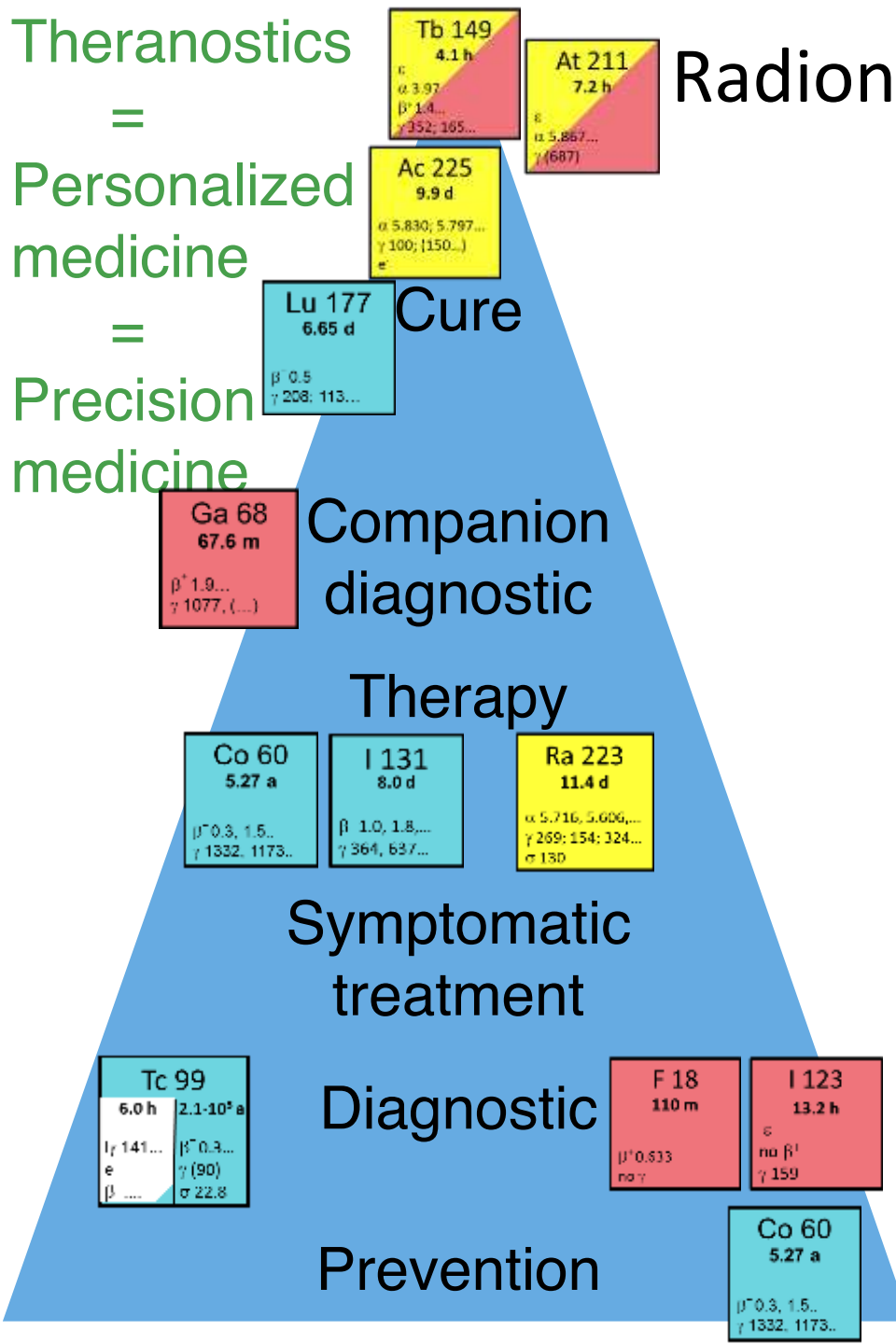
Co 60
5.27 a
 β^- 0.3, 1.5...
 γ 1332, 1173...

Isotopes for targeted alpha therapy



Theranostics = Personalized medicine = Precision medicine

Radionuclides



Tb 149
4.1 h
α 3.97
β⁻ 1.4...
γ 152; 165...

At 211
7.2 h
α 5.867...
γ (687)

Ac 225
9.9 d
α 5.830; 5.797...
γ 100; (150...)
ε

Lu 177
6.65 d
β⁻ 0.5
γ 208; 113...

Ga 68
67.6 m
β⁺ 1.9...
γ 1077, (...)

Co 60
5.27 a
β⁻ 0.3, 1.5...
γ 1332, 1173...

I 131
8.0 d
β⁻ 1.0, 1.8...
γ 364, 637...

Ra 223
11.4 d
α 5.716, 5.606...
γ 269; 154; 124...
σ 130

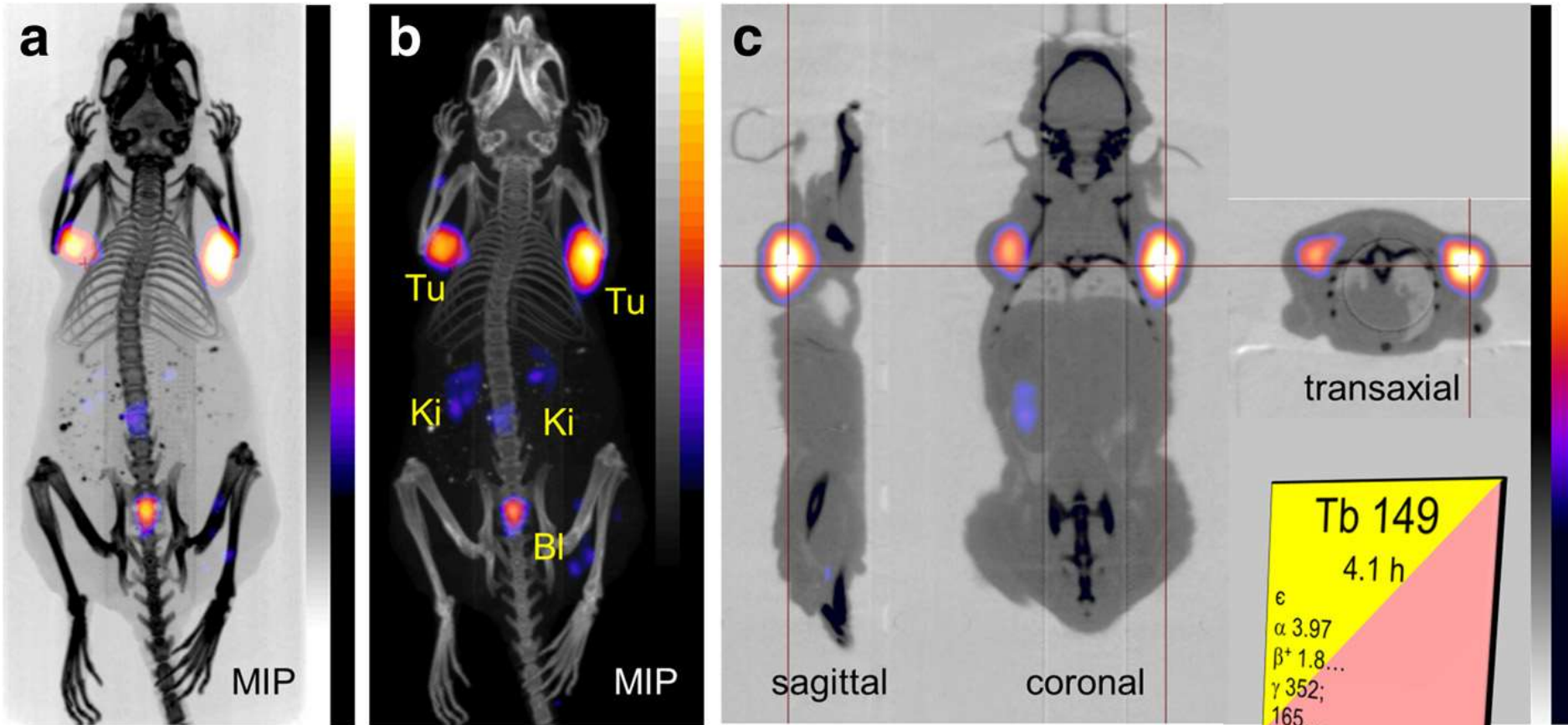
Tc 99
6.0 h | 2.1·10⁵ a
I_γ 141... | β⁻ 0.3...
e | γ (90)
β⁻ ... | σ 22.8

F 18
110 m
β⁺ 0.633
no γ

I 123
13.2 h
ε
no β⁺
γ 159

Co 60
5.27 a
β⁻ 0.3, 1.5...
γ 1332, 1173...

Alpha-PET with ^{149}Tb



7 MBq ^{149}Tb -DOTANOC 2 h p.i.

ISOLDE

PAUL SCHERRER INSTITUT

PSI

ETH zürich

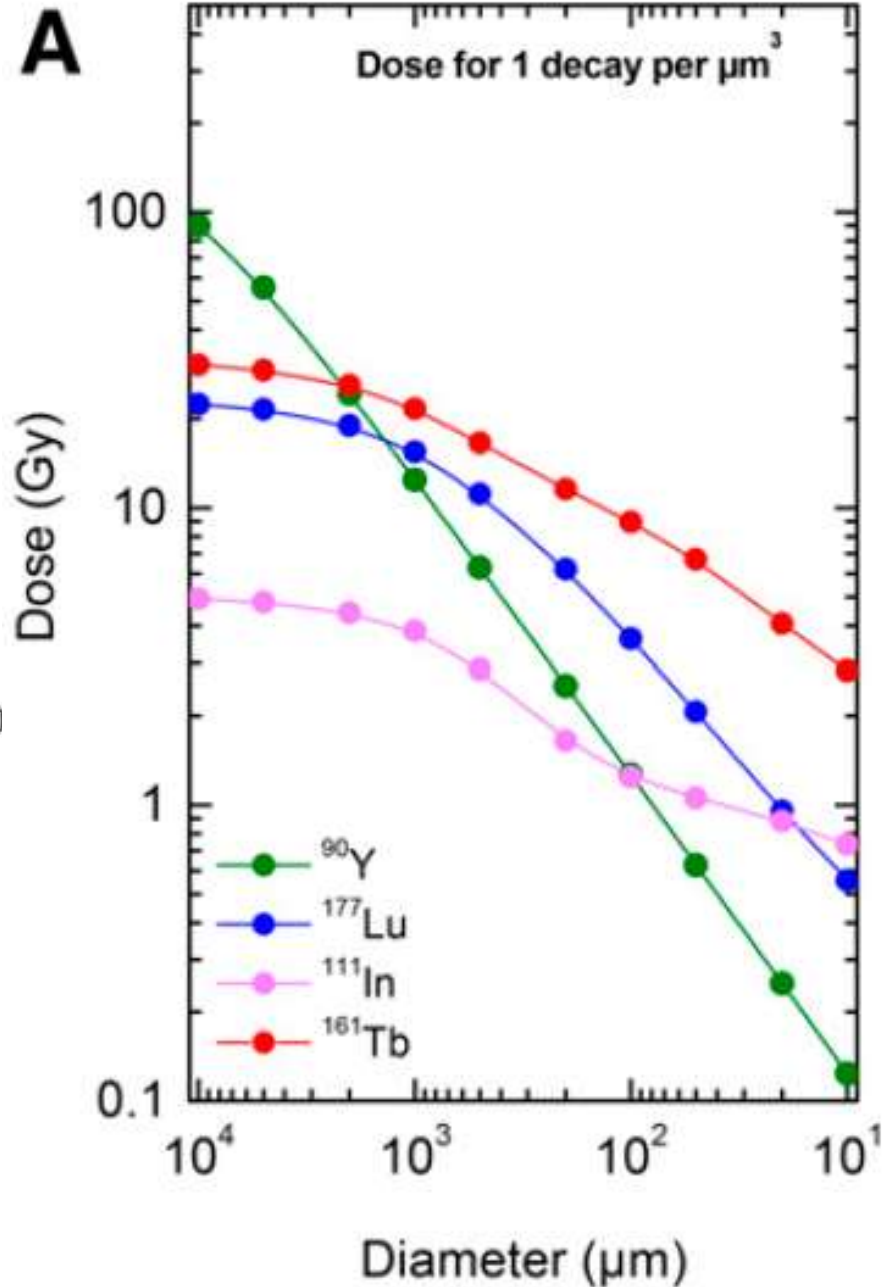
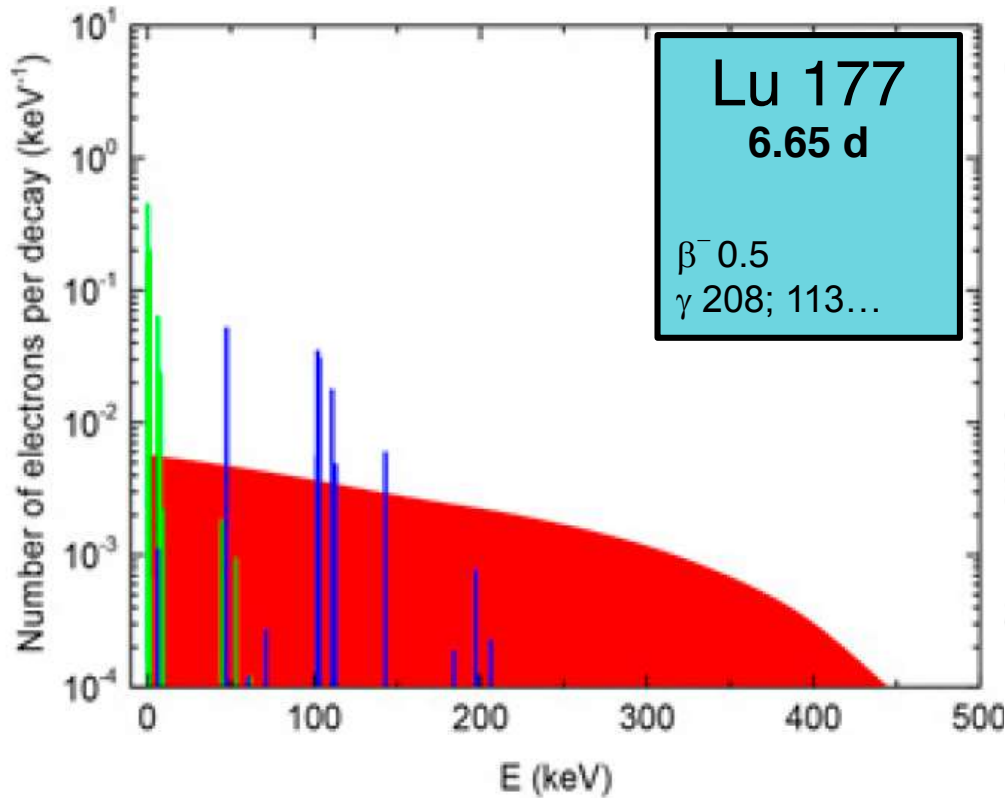
ILL

NEUTRONS
FOR SOCIETY

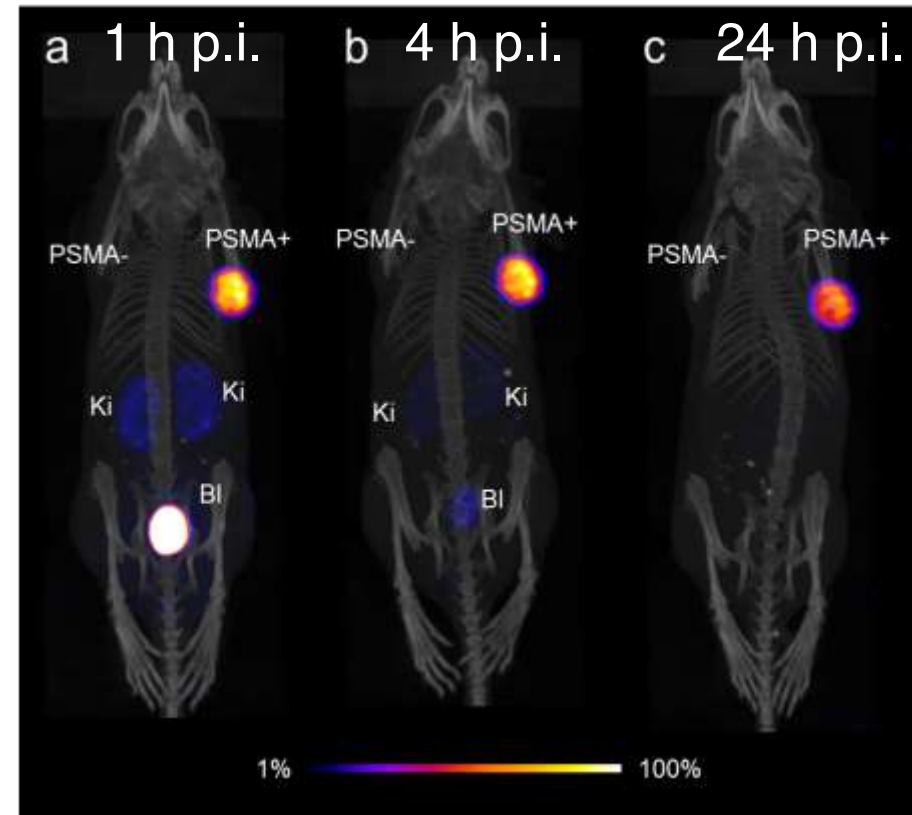
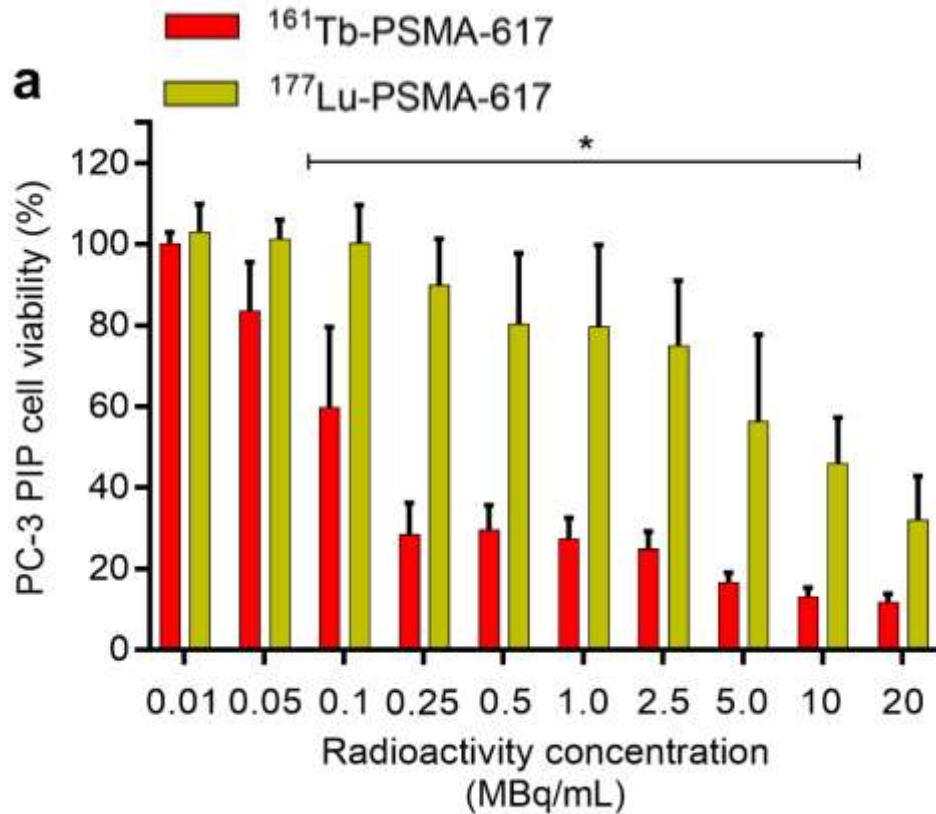
u^b

UNIVERSITÄT
BERN

^{161}Tb versus ^{177}Lu



Terbium-161 for PSMA-targeted radionuclide therapy of prostate cancer



C. Müller et al., Eur J Nucl Med Mol Imaging 2019;46:1919.

Theranostics = Personalized medicine = Precision medicine

Radionuclides

Tb 149
4.1 h
e
α 3.97
β⁻ 1.4...
γ 152; 165...

At 211
7.2 h
e
α 5.867...
γ (687)

Ac 225
9.9 d
α 5.830; 5.797...
γ 100; (150...)

Tb 161
6.9 d
β⁻ 0.5; 0.6
γ 26; 49; 75...
e

Lu 177
6.65 d
β 0.5
γ 208; 113...

Cure

Ga 68
67.6 m
β⁺ 1.9...
γ 1077, (...)

Companion diagnostic

Therapy

Co 60
5.27 a
β⁻ 0.3, 1.5...
γ 1332, 1173...

I 131
8.0 d
β 1.0, 1.8...
γ 364, 637...

Ra 223
11.4 d
α 5.716, 5.606...
γ 269; 154; 124...
σ 130

Symptomatic treatment

Tc 99
6.0 h
2.1·10⁹ a
I_γ 141...
e
β⁻ 0.3...
γ (90)
σ 22.8

Diagnostic

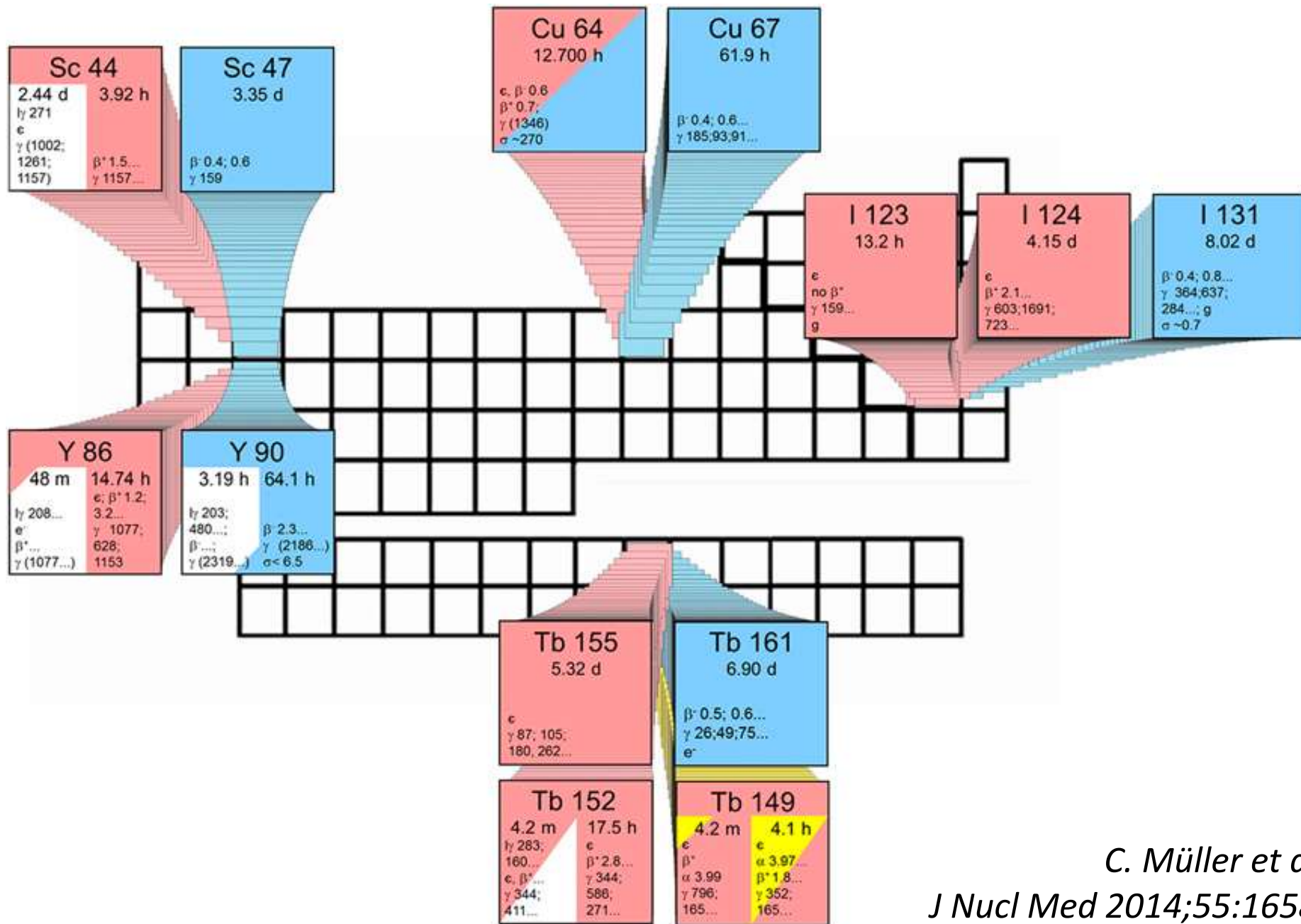
F 18
110 m
β⁺ 0.633
no γ

I 123
13.2 h
e
no β⁺
γ 159

Prevention

Co 60
5.27 a
β⁻ 0.3, 1.5...
γ 1332, 1173...

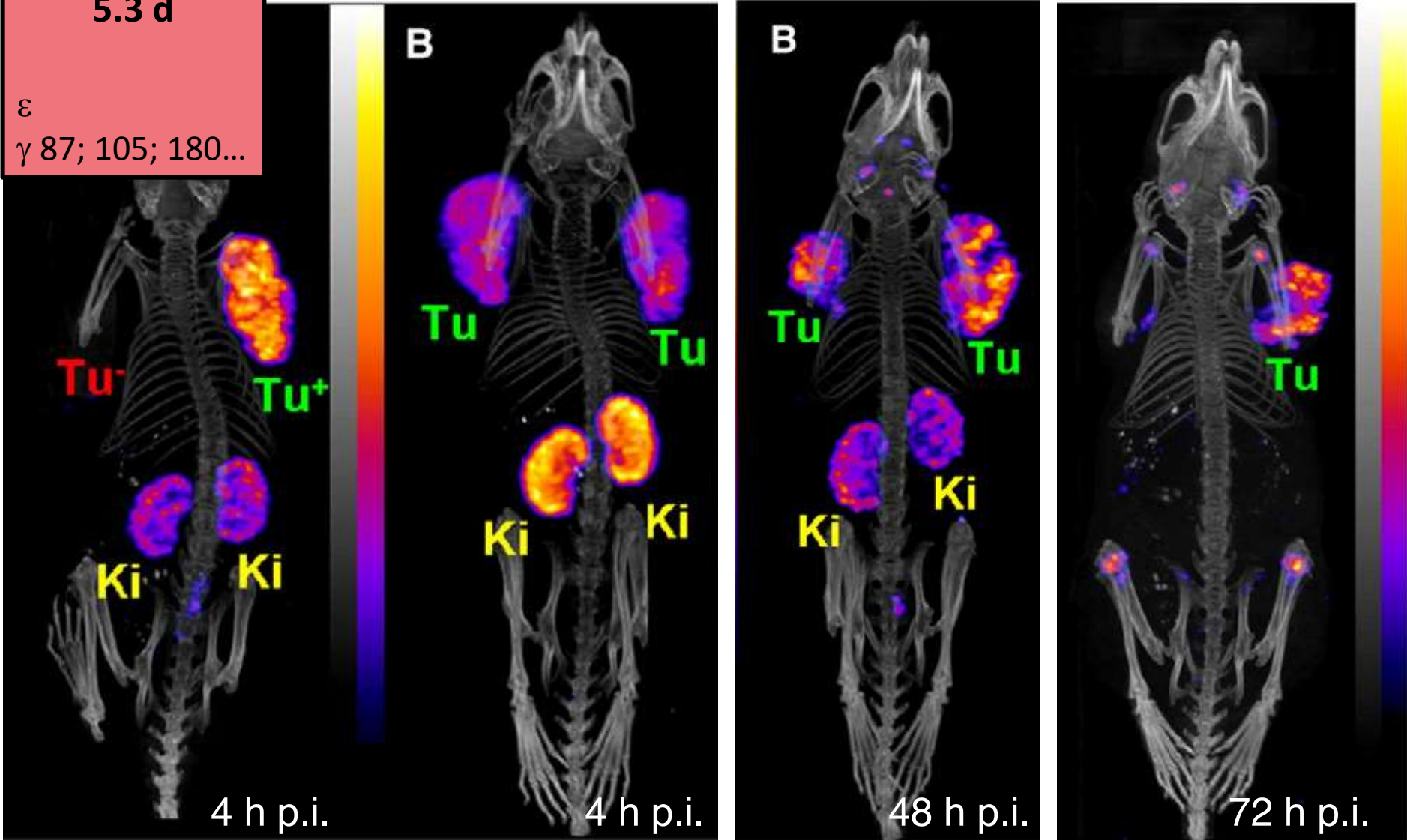
Matched pairs for theranostics



Tb 155
5.3 d

ϵ
 γ 87; 105; 180...

^{155}Tb for SPECT



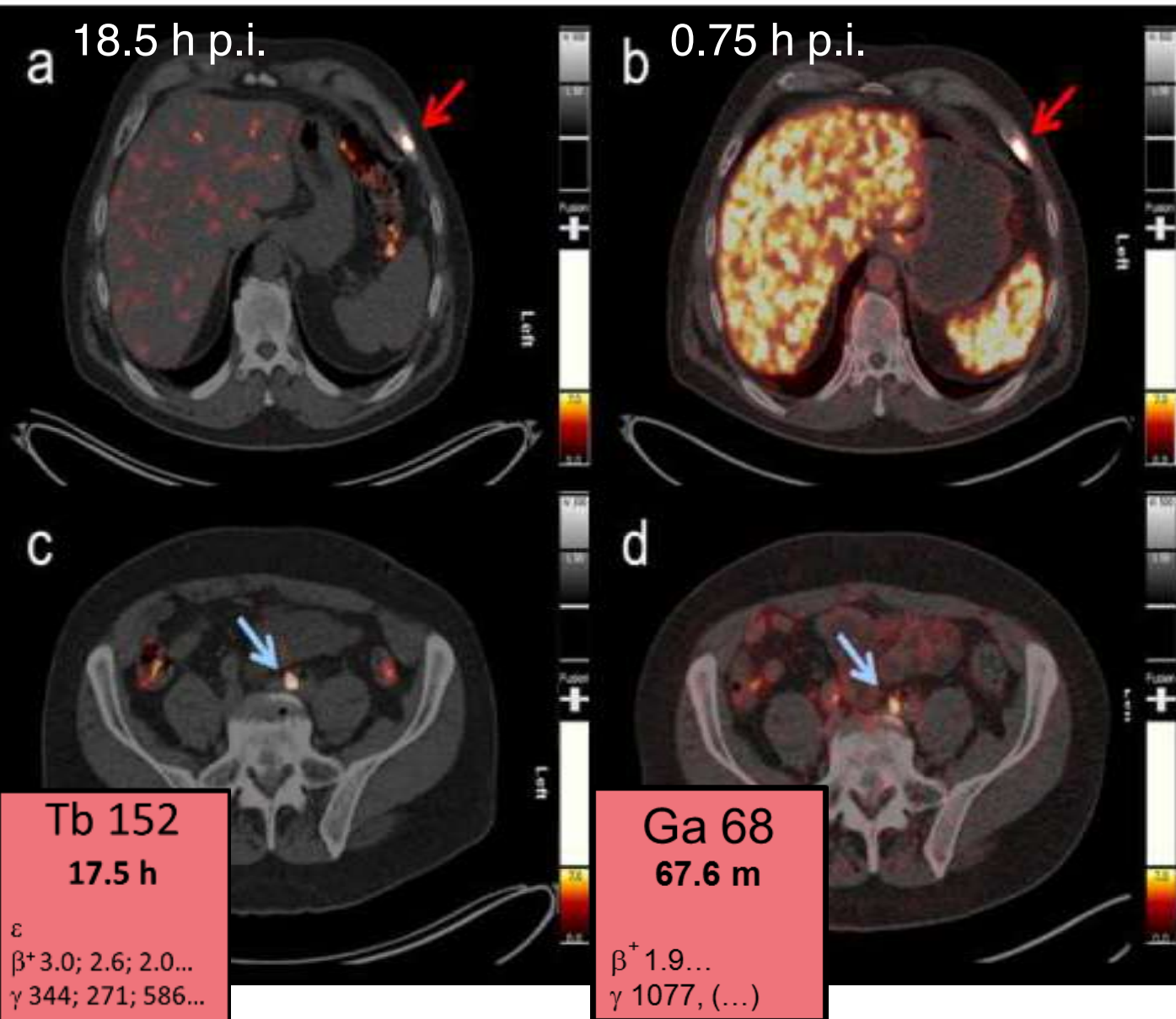
minigastrin
A431 tumor

DOTATATE
A431 tumor

cm09
IGROV-1 tumor

chCE7
SKOV-3ip tumor

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



Zentralklinik Bad Berka

PAUL SCHERRER INSTITUT
PSI

ETH zürich

ISOLDE

ILL
NEUTRONS
FOR SOCIETY

ENSAR²

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...



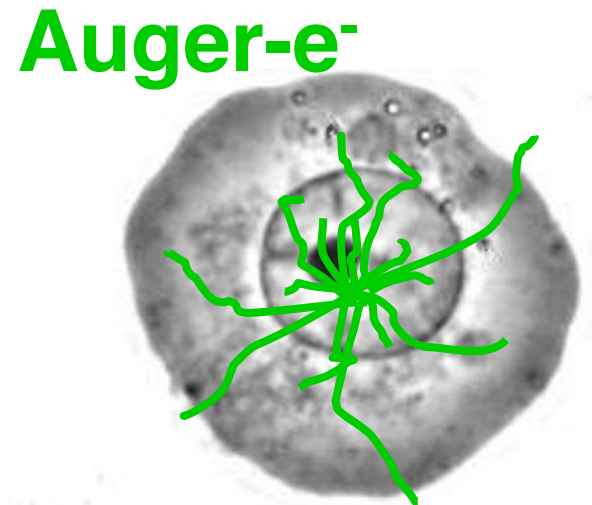
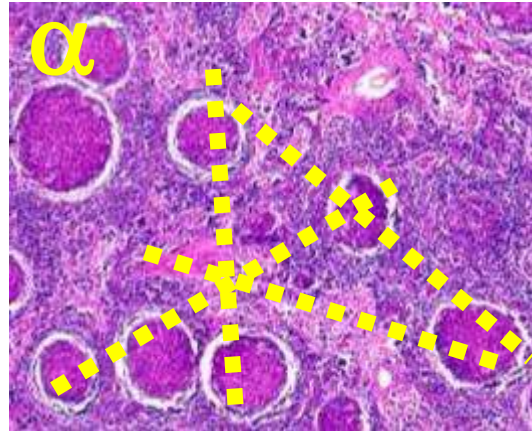
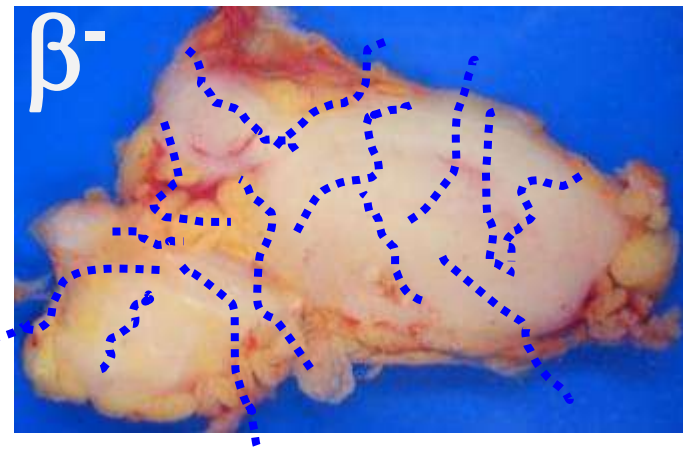
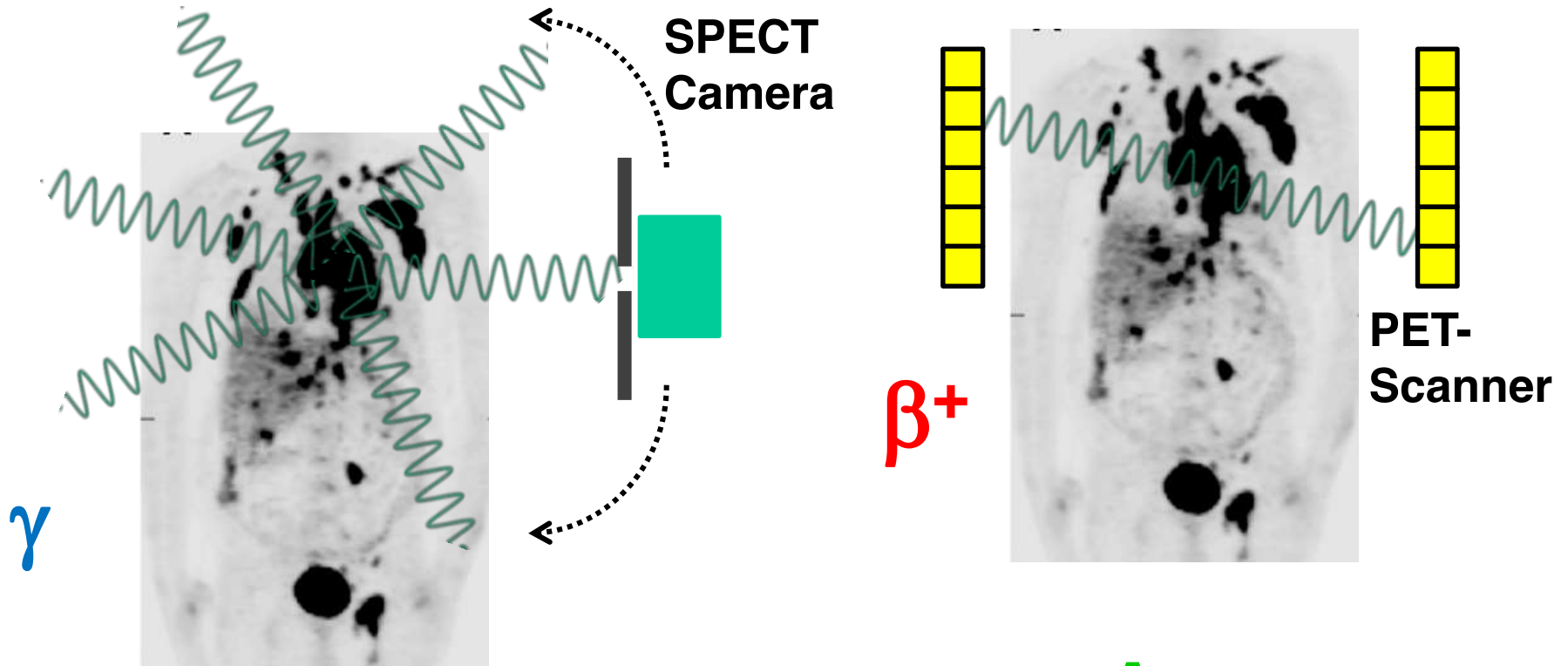
Tb 161
6.9 d

β^- 0.5; 0.6
 γ 26; 49; 75...
 e^-

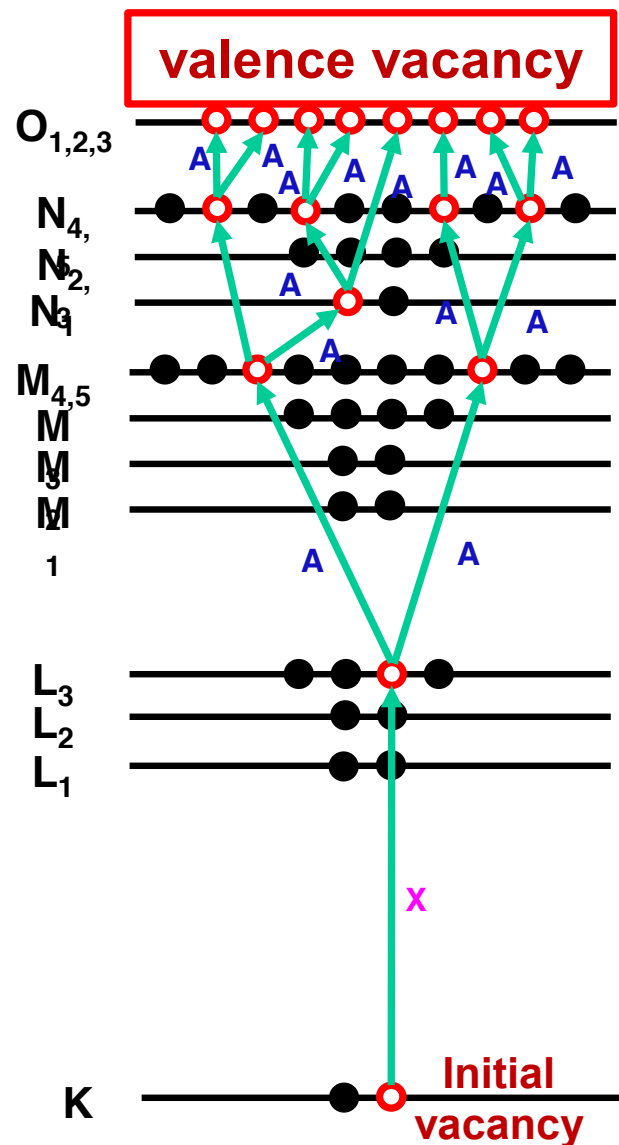
Tb 149
4.1 h

ϵ
 α 3.97
 β^+ 1.4...
 γ 352; 165...

The Nuclear Medicine Alphabet



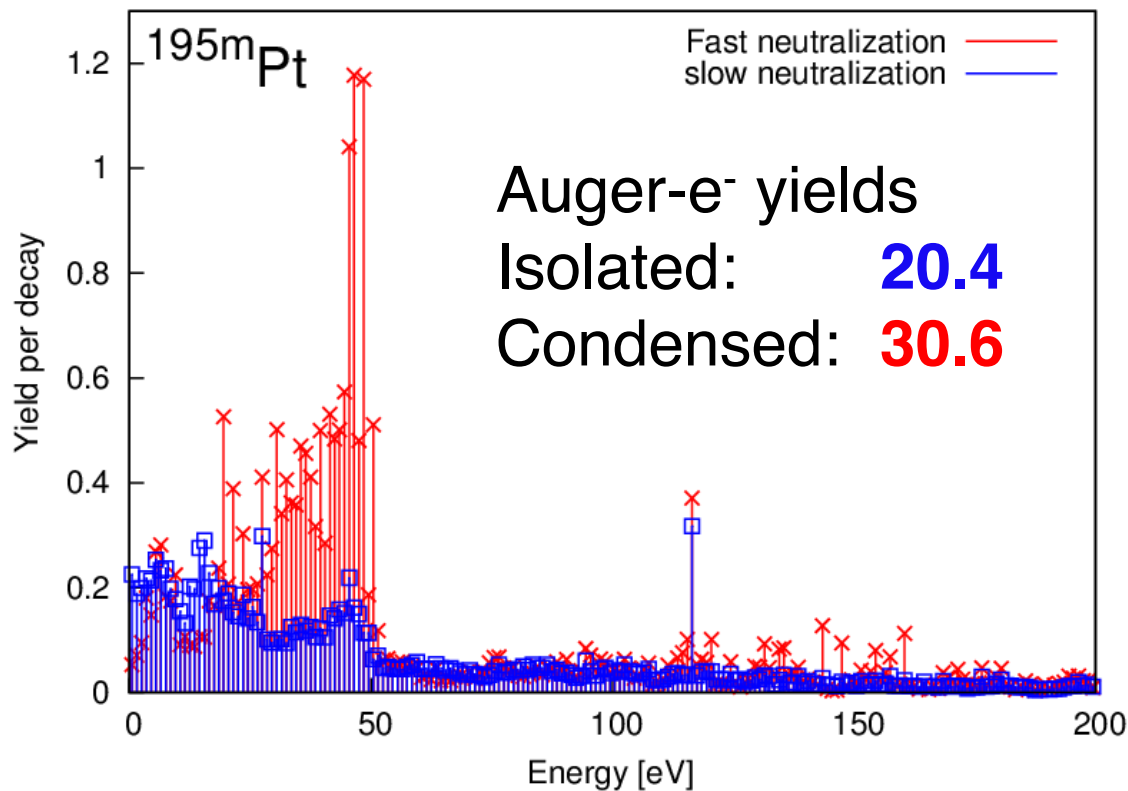
BrIccEmis: Simulation of Auger electron spectra



Two approaches:

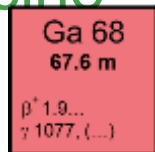
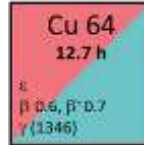
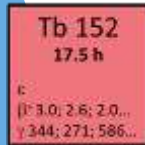
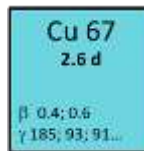
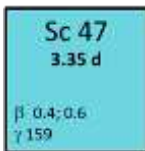
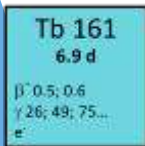
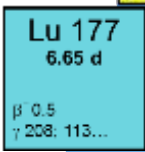
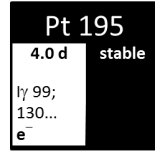
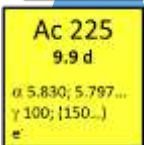
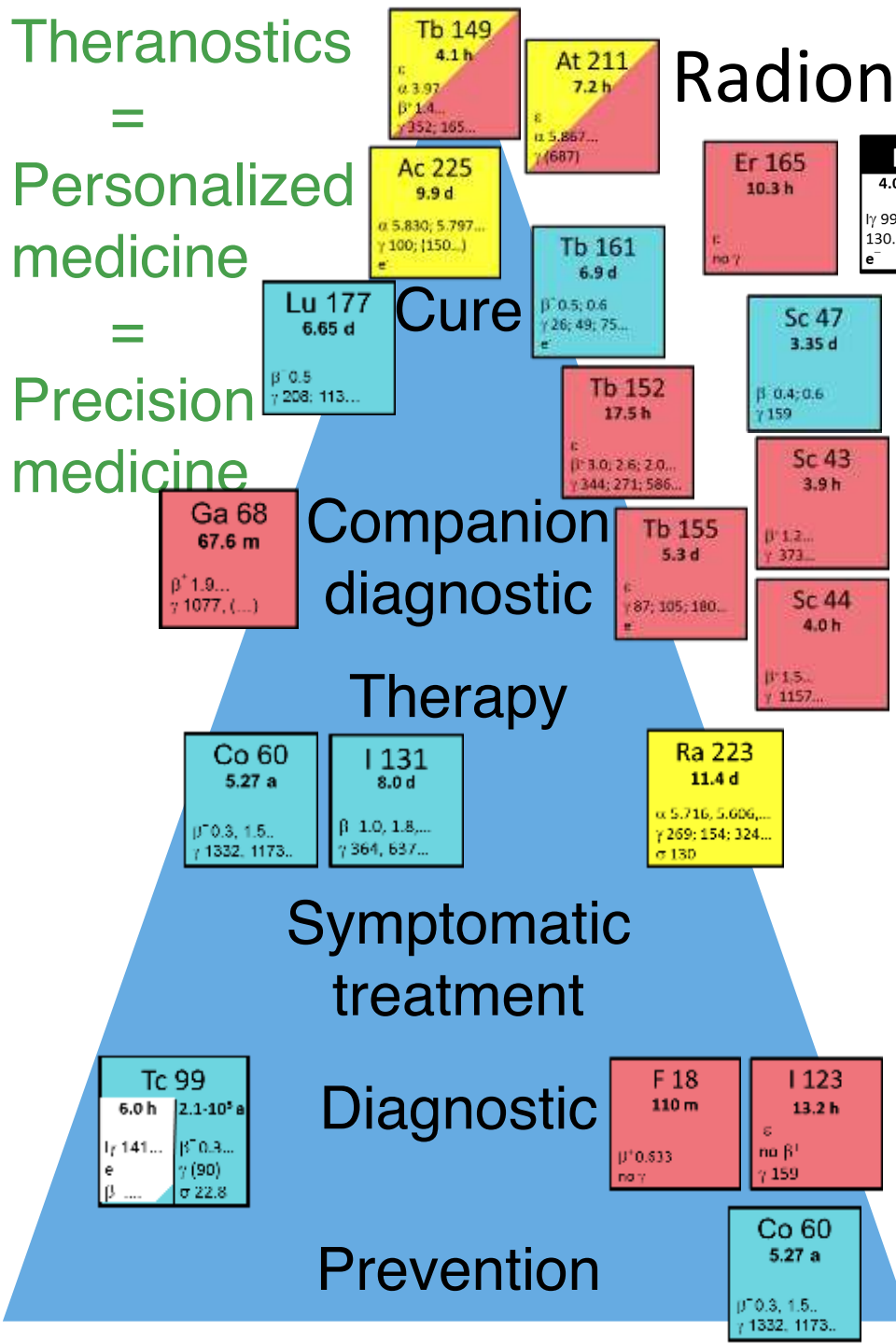
1. No neutralization during Auger cascade (**slow**) isolated atom
2. Valence vacancy immediately neutralized (**fast**) condensed phase

Pt 195	
4.0 d	stable
ly 99; 130...	
e ⁻	

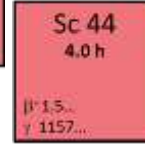
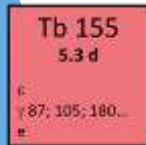


Theranostics
 =
 Personalized
 medicine
 =
 Precision
 medicine

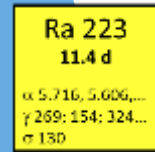
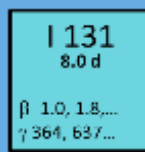
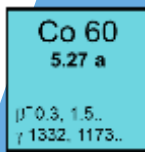
Radionuclides



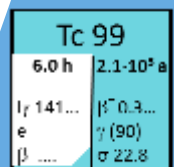
Companion
 diagnostic



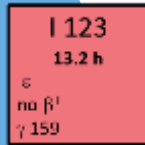
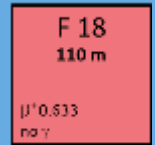
Therapy



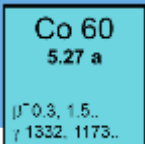
Symptomatic
 treatment



Diagnostic



Prevention



Prospects of targeted radionuclide therapies ?

2014	Algeta	⇒ Bayer	2.4 G\$
2018	AAA	⇒ Novartis	3.9 G\$
2018	Sirtex	⇒ CGE/CDH	1.4 G\$
2019	Endocyte	⇒ Novartis	2.1 G\$
2019	Blue Earth	⇒ Bracco	0.5 G\$
2019	BTG	⇒ Boston Scientific	4.2 G\$
Sum over 5 years			14.5 G\$



Bayer HealthCare



NOVARTIS



远大健康
CGE HEALTHCARE



Boston
Scientific
Advancing science for life™

SANOFI



oranomed



Theranostics

=

Personalized medicine

=

Precision medicine

Radionuclides

Tb 149
4.1 h
α 3.97
β⁻ 1.4...
γ 152; 165...

At 211
7.2 h
α 5.867...
γ (687)

Er 165
10.3 h
ε
no γ

Pt 195
4.0 d stable
γ 99;
130...
e

Ac 225
9.9 d
α 5.830; 5.797...
γ 100; (150...)
e

Tb 161
6.9 d
β⁻ 0.5; 0.6
γ 26; 49; 75...
e

Lu 177
6.65 d
β 0.5
γ 208; 113...

Cure



Sc 47
3.35 d
β 0.4; 0.6
γ 159

Cu 67
2.6 d
β 0.4; 0.6
γ 185; 93; 91...

Tb 152
17.5 h
ε
β⁻ 3.0; 2.6; 2.0...
γ 344; 271; 586...

Sc 43
3.9 h
β⁻ 1.2...
γ 373...

Cu 64
12.7 h
ε
β 0.6, β⁻ 0.7
γ (1346)



Ga 68
67.6 m
β⁺ 1.9...
γ 1077, (...)

Companion diagnostic

Tb 155
5.3 d
ε
γ 87; 105; 180...
e

Sc 44
4.0 h
β⁺ 1.5...
γ 1157...



Therapy

Co 60
5.27 a
β⁻ 0.3, 1.5...
γ 1332, 1173...

I 131
8.0 d
β 1.0, 1.8...
γ 364, 637...

Ra 223
11.4 d
α 5.716, 5.606...
γ 269; 154; 124...
e 150

Symptomatic treatment

Tc 99
6.0 h 2.1·10² a
I_T 141... β⁻ 0.3...
e γ (90)
β ... σ 22.8

Diagnostic

F 18
110 m
β⁺ 0.633
no γ

I 123
13.2 h
ε
no β⁺
γ 159

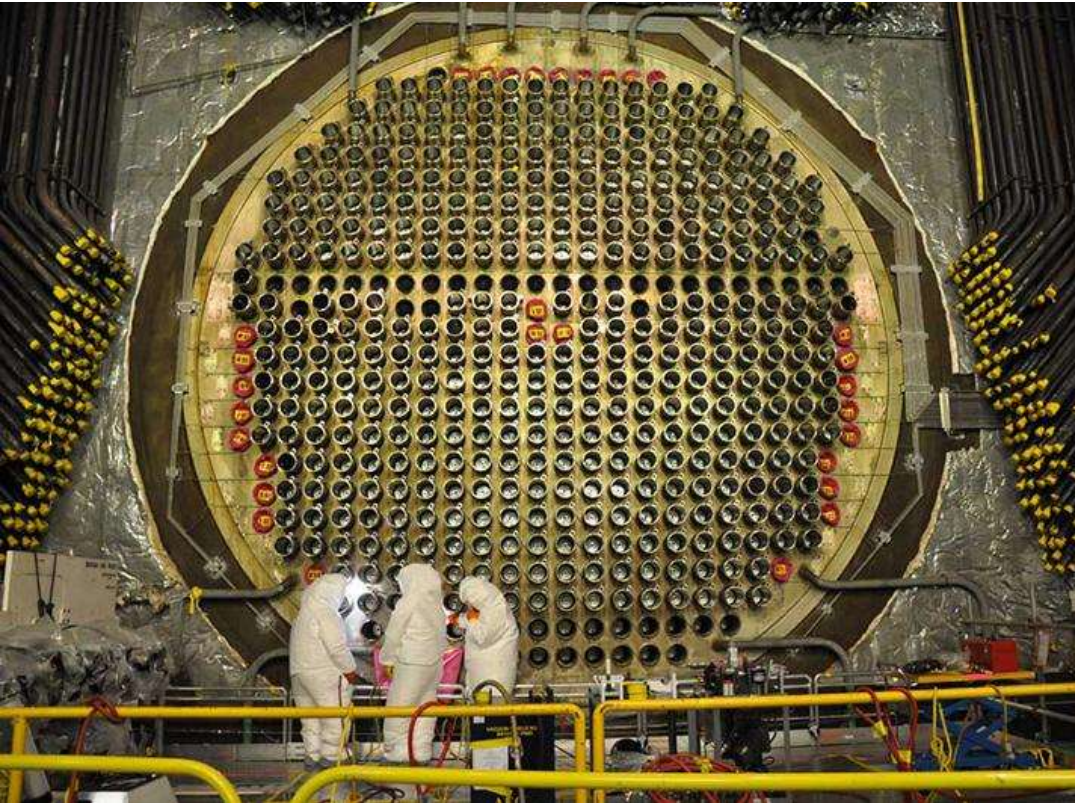


Prevention

Co 60
5.27 a
β⁻ 0.3, 1.5...
γ 1332, 1173...



^{60}Co production in CANDU reactors



$\Phi \approx 1\text{E}14 \text{ cm}^{-2}\text{s}^{-1}$ over many m^2

“particle current” $\approx 16 \text{ p}\mu\text{A}/\text{cm}^2$

Total “particle current” $\approx 40 \text{ A}$
easily usable $\gg 100 \text{ mA}$



Different ways to ^{60}Co (as a theoretical case study)

Cu 58 3.20 s β^+ 7.5... γ 1454, 1448 40...	Cu 59 82 s β^+ 3.8... γ 1302, 878 339, 465...	Cu 60 23 m β^+ 2.0, 3.9... γ 1332, 1792 826...	Cu 61 3.4 h β^+ 1.2... γ 283, 656, 67 1186...	Cu 62 9.74 m β^+ 2.9... γ (1173...)	Cu 63 69.15 σ 4...	Cu 64 12.7004 h β^- 0.6, β^+ 0.7 γ (1346) σ ~270	Cu 65 30.85 σ 2.17
Ni 57 36 h β^+ 0.8... γ 1378, 1920 127...	Ni 58 68.077 σ 4.6 $\sigma_{n,t} < 3E-5$	Ni 59 $7.5 \cdot 10^4$ a σ , β^+ ..., no γ σ 77.7, $\sigma_{n,t}$ 14 $\sigma_{n,p}$ 2, σ_{abs} 92	Ni 60 26.223 σ 2.9	Ni 61 1.1399 σ 2.5 $\sigma_{n,t}$ 1.5	Ni 62 3.6346 σ 1...	Ni 63 100 a β^- 0.07 no γ σ 20	Ni 64 0.9255 σ 1.6
Co 56 77.236 d β^- , β^+ 1.5... γ 847, 1038 2598, 1038...	Co 57 271.80 d σ 122, 136, 14	Co 58 8.94 h 70.86 d $t_{1/2}(25)$ σ 140000	Co 59 100 σ 20.7 + 16.5	Co 60 10.5 m 5.27 a σ 58 σ 2.0	Co 61 1.65 h β^- 1.2... γ 67, 909...	Co 62 14.0 m 1.5 m β^- 2.9... γ 1173 β^- 4.1... γ 1173 γ 1173 1163 2302 2003... 1129...	Co 63 27.5 s β^- 3.6... γ 87, 982...
Fe 55 2.73 a no γ σ 13 $\sigma_{n,t}$ 0.01	Fe 56 91.754 σ 2.8	Fe 57 2.119 σ 1.4	Fe 58 0.282 σ 1.3	Fe 59 44.494 d β^- 0.5, 1.6... γ 1099, 1292... σ < 10	Fe 60 $2.62 \cdot 10^6$ a β^- 0.2 m	Fe 61 6.0 m β^- 2.6, 2.8... γ 1205, 1027 298...	Fe 62 68 s β^- 2.5 γ 506 g

$^{59}\text{Co}(n,\gamma)^{60}\text{Co}$: 1 n \approx 1 atom ^{60}Co

$^{59}\text{Co}(d,p)^{60}\text{Co}$: 40 MeV d \approx $1.2E-3$ ^{60}Co

$^{nat}\text{Ni}(p,*)^{60}\text{Co}$: 30 MeV p < $1E-5$ ^{60}Co

$^{nat}\text{Fe}(p,*)^{60}\text{Co}$: 30 MeV p \approx $1.2E-3$ ^{60}Co

$^{nat}\text{Cu}(p,*)^{60}\text{Co}$: 500 MeV p \approx 0.015 ^{60}Co

$^{nat}\text{Ni}(\gamma,*)^{60}\text{Co}$: 30 MeV e^- < $1E-6$ ^{60}Co

“160 mA” = 1 EBq ^{60}Co

25000x SPIRAL2 = 1 EBq ^{60}Co

70000x TR30 = 1 EBq ^{60}Co equiv.

100000x main cyc. = 1 EBq ^{60}Co

^{177}Lu :

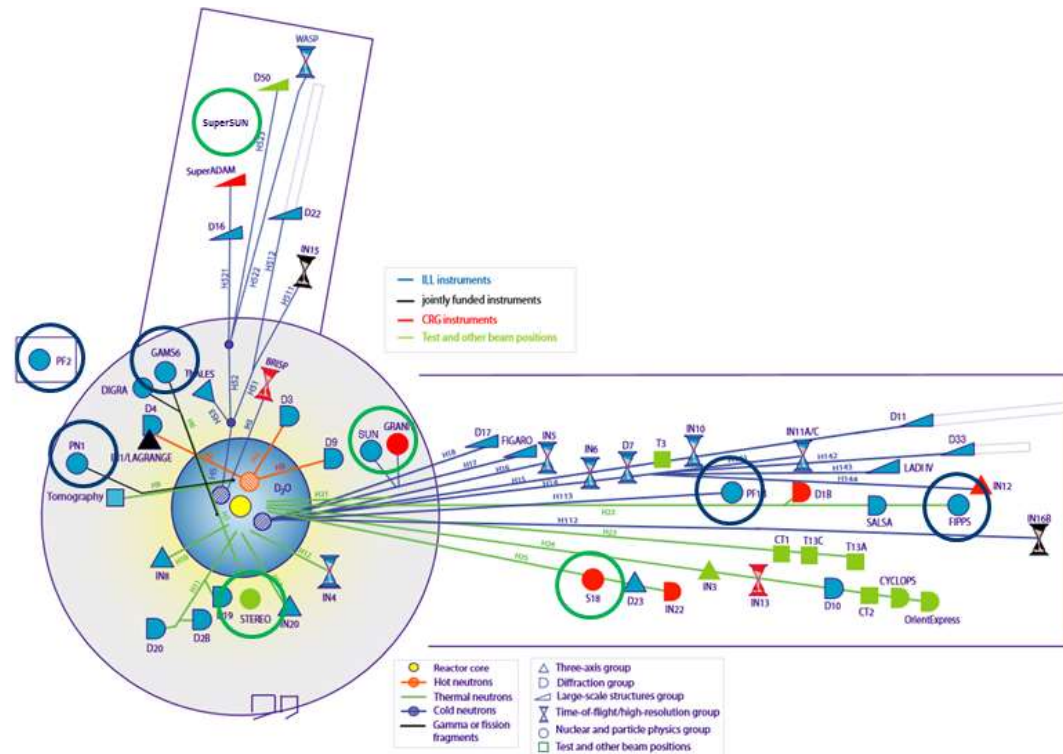
The “gold standard”
for radionuclide
therapy



Institut Laue-Langevin 2018:

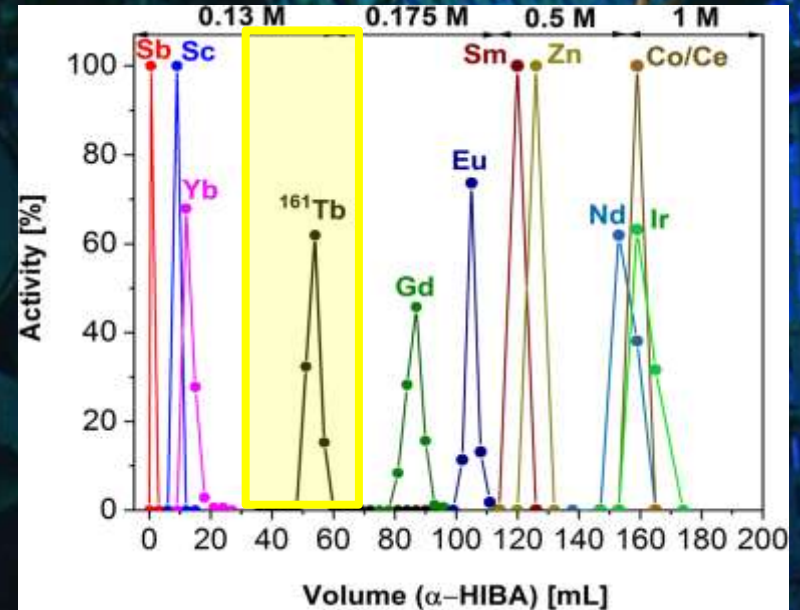
≈ **1600** scientific users at ILL

≈ **4000** patients get ^{177}Lu from ILL



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

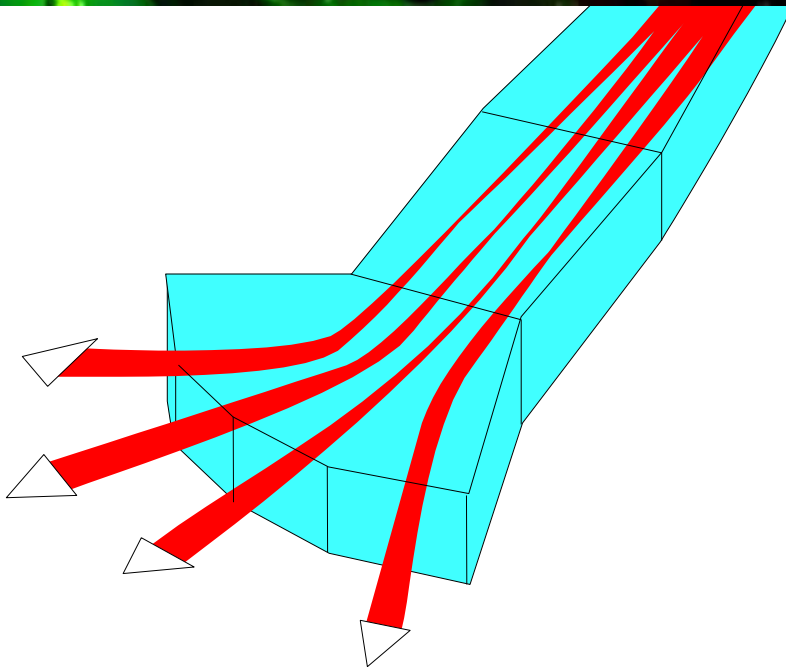
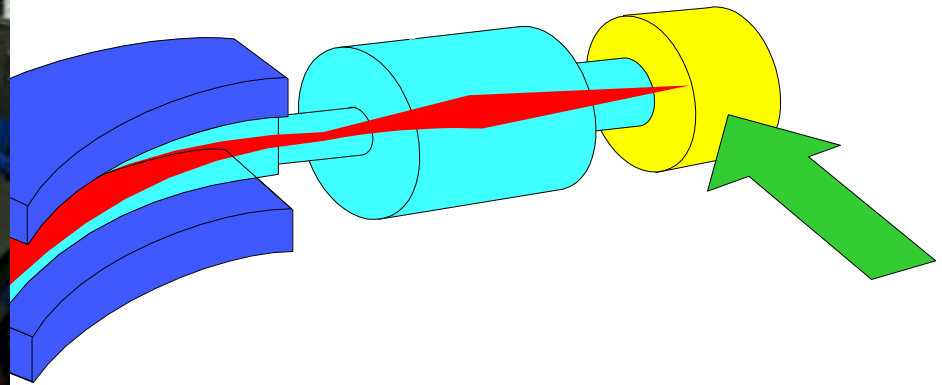
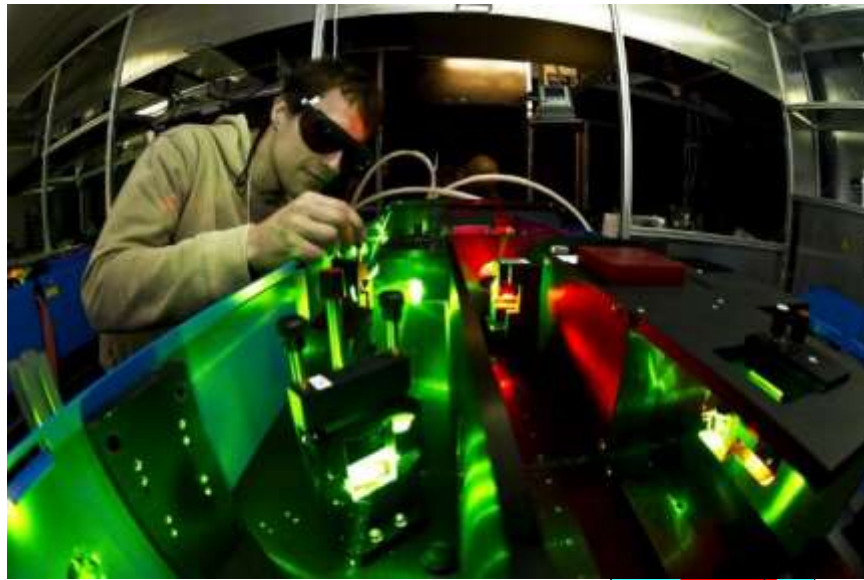
Dy 160 2.329 σ^{60} $\sigma_n, \alpha < 0.0003$	Dy 161 18.889 σ^{600} $\sigma_n, \alpha < 1\text{E-}6$	Dy 162 25.475 σ^{170}	Dy 163 24.896 σ^{120} $\sigma_n, \alpha < 2\text{E-}5$	Dy 164 28.260 $\sigma^{1610 + 1040}$
Tb 159 100 $\sigma^{23.2}$	Tb 160 72.3 d $\beta^- 0.6; 1.7\dots$ $\gamma 879; 299;$ 966... σ^{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...	Tb 163 19.5 m $\beta^- 0.8; 1.3\dots$ $\gamma 351; 390;$ 494...
Gd 158 24.84 $\sigma^{2.3}$	Gd 159 18.48 h $\beta^- 1.0\dots$ $\gamma 364; 58\dots$	Gd 160 21.86 $\sigma^{1.5}$	Gd 161 3.66 m $\beta^- 1.6; 1.7\dots$ $\gamma 361; 315;$ 102... σ^{20000}	Gd 162 8.2 m $\beta^- 1.0\dots$ $\gamma 442; 403\dots$



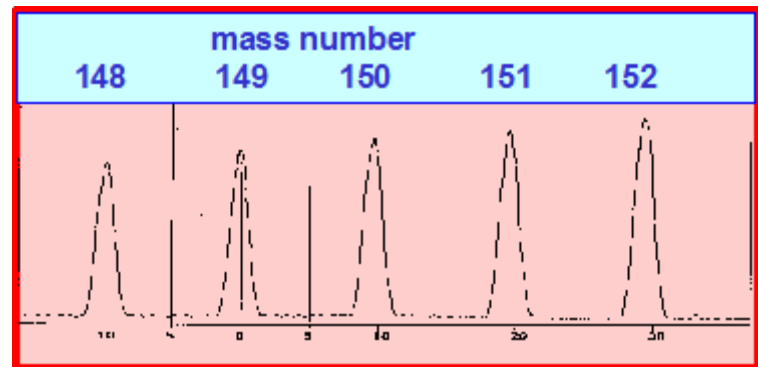
Irradiation at ILL & NeCSA, chemical separation at PSI

N. Gracheva et al., EJNMMI Radiopharm Chem 2019;4:12.

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



radioactive ion beams



Efficient parallel operation

HRS MAIN
HRS USER
GPS MAIN
CENTRAL MASS
LOW MASS
HIGH MASS

ISOLTRAP

152Tb

149Tb

155Tb

HRS setup

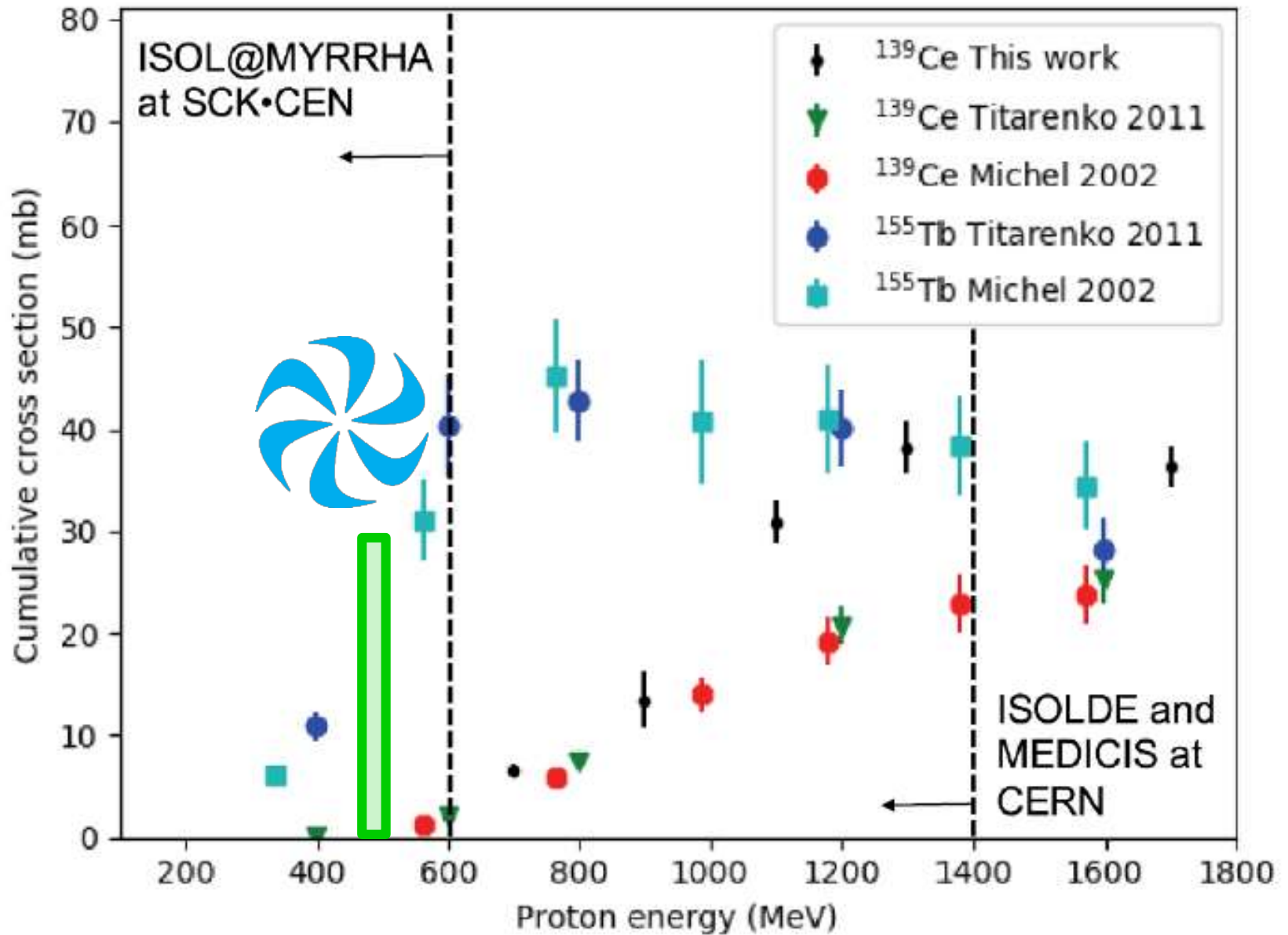
ISOLDE
CERN



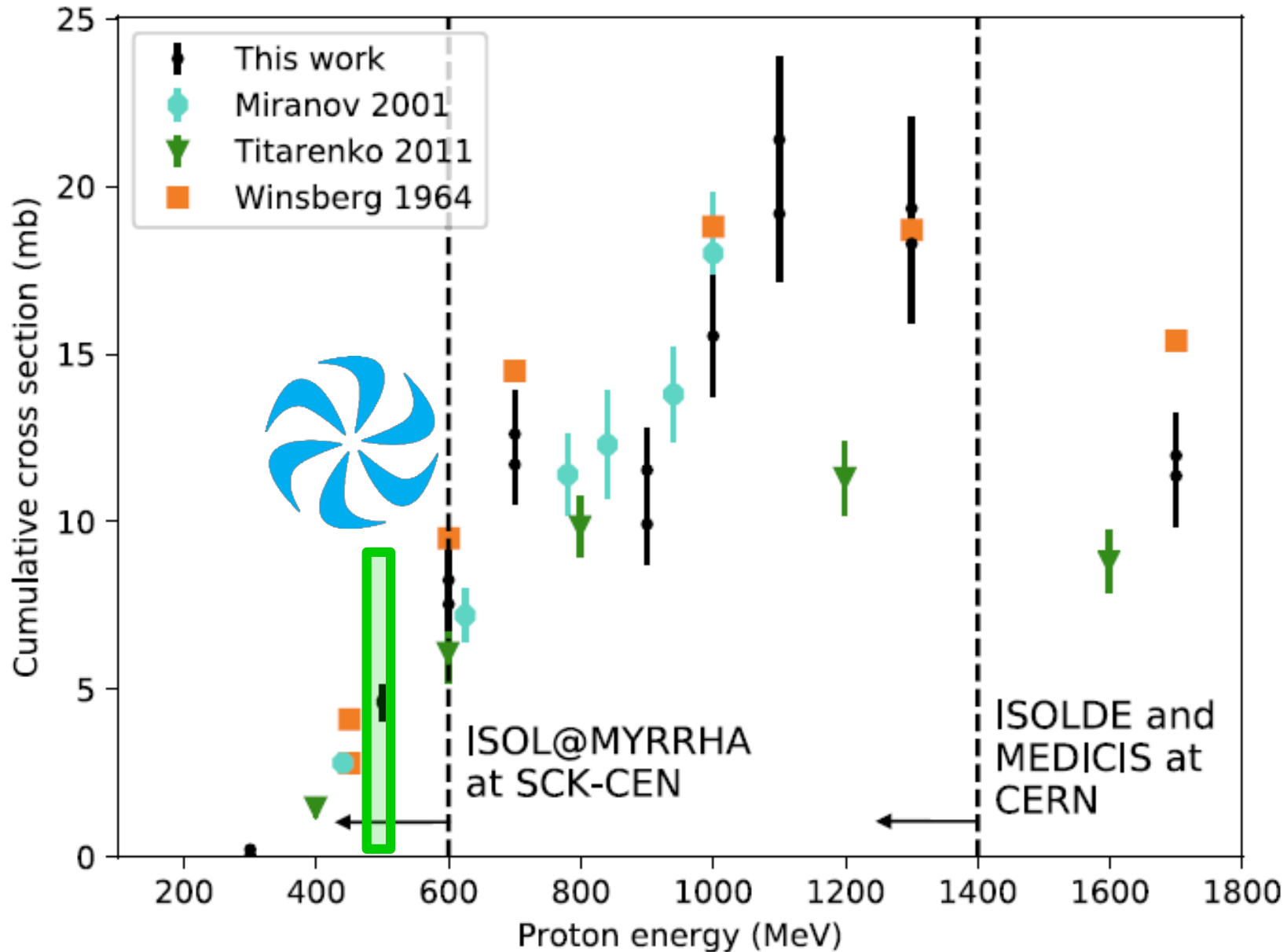
a very useful beam dump !



Spallation cross-sections: ^{155}Tb vs. ^{139}Ce



Spallation cross-sections: ^{149}Tb vs. ^{133}Ce



A great model: the US DOE Isotope Program

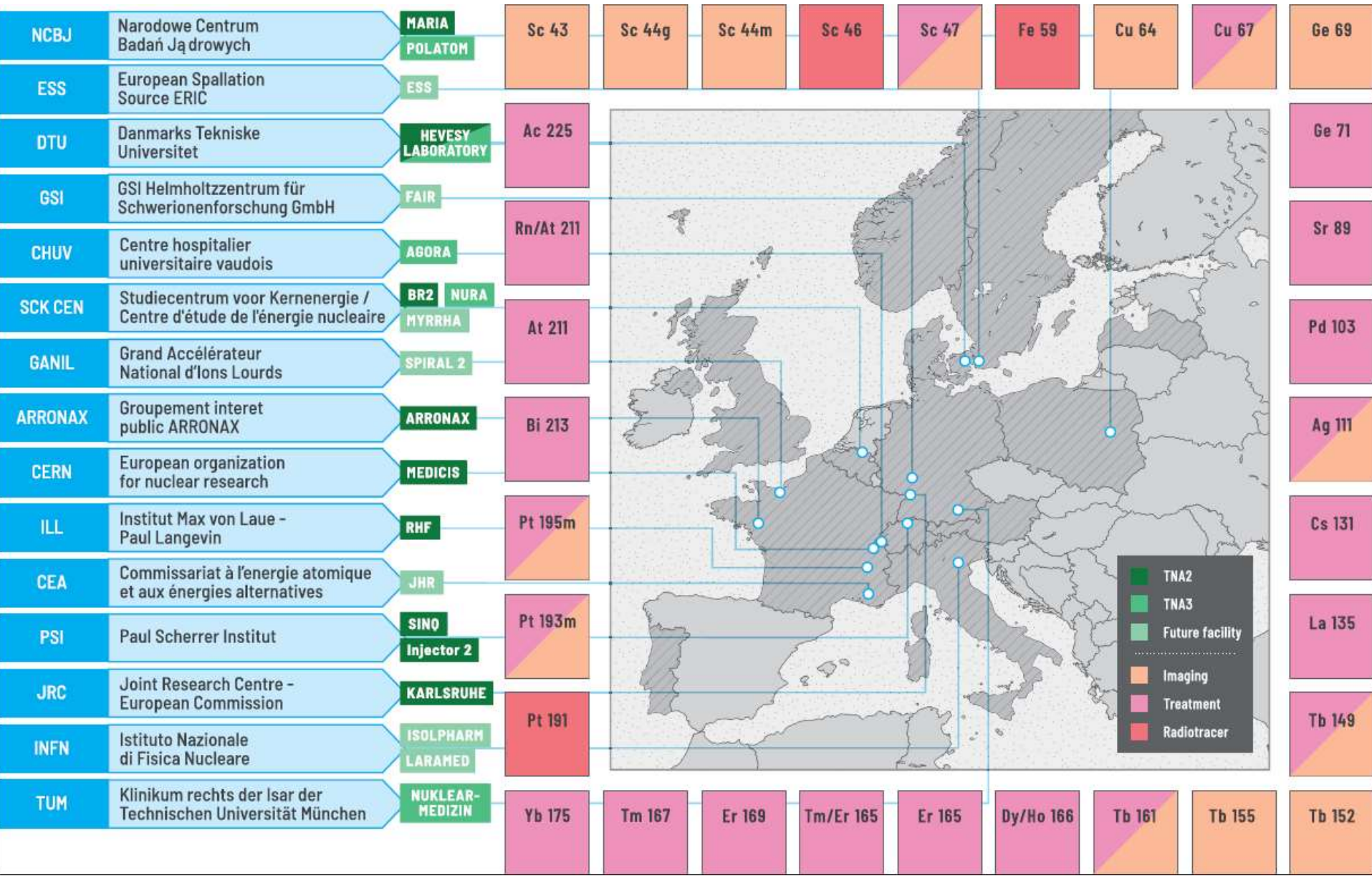


The image shows a screenshot of a web browser displaying the National Isotope Development Center (NIDC) website. The browser's address bar shows the URL <https://www.isotopes.gov>. The website header features the NIDC logo, which includes the text "NIDC" in large blue letters and "NATIONAL ISOTOPE DEVELOPMENT CENTER" in smaller blue letters to its right. To the right of the logo is the tagline: "the government source of isotopes for science, medicine, security, & other applications". Below the tagline is the U.S. Department of Energy logo and the text "Office of Science". A navigation bar below the header contains five menu items: "Product Catalog", "News", "Education & Outreach", "Isotope Production", and "About NIDC". Below the navigation bar are six thumbnail images: a glowing tube-like structure, a blue atomic model, a heart with a ^{82}Sr isotope symbol, a colorful medical scan of a heart, a skeletal scan of a human torso, and a grid of glowing blue circular patterns.

Welcome to the NIDC!

The **National Isotope Development Center (NIDC)** interfaces with the isotope user community and manages the coordination of isotope production across the facilities and business operations involved in the production, sale, and distribution of isotopes. A virtual center, the NIDC is funded by the [U.S. Department of Energy Isotope Program](#) within the [Office of Nuclear Physics](#) in the [Office of Science](#).

Proposed EU project PRISMAP: PRoduction of high purity Isotopes by mass Separation for Medical Application



Summary and Outlook

- Targeted Radionuclide Therapies (TRT) are transforming nuclear medicine
- Bright future for Theranostics, in particular in oncology
- NP research infrastructures can play an important role for supply of EMERGING and UNCONVENTIONAL radionuclides ($^{149/152/155/161}\text{Tb}$, ^{211}At , ^{67}Cu , $^{193\text{m}/195\text{m}}\text{Pt}$, ...)
- but medical applications using these radionuclides must be developed in parallel
- Research infrastructures are NOT competitive in production of “industrial” radionuclides
- PRISMAP: a European Isotope Development Center !

Specific ideas/wishes for TRIUMF



1. Logic choices for ISAC:

- Tb isotopes and other n-deficient lanthanides (Auger)
- ^{225}Ac , $^{211}\text{Rn}/^{211}\text{At}$
- regular harvesting of R&D isotopes
- needs shielded collection position(s)!

2. Prospects for ARIEL

- $^{226}\text{Ra}(\gamma, n)^{225}\text{Ra}(\beta^-)^{225}\text{Ac}$, $\text{Zn}(\gamma, p)^{67}\text{Cu}$..

3. Alpha beams (30-40 MeV)

- for production of ^{211}At , ^{43}Sc , $^{117\text{m}}\text{Sn}$, $^{195\text{m}}\text{Pt}$, $^{193\text{m}}\text{Pt}$, etc.
- NO ^4He beams in Canada: cyclotron or LINAC prototype?

4. Synergies with laser spec., hyperfine interactions

- fundamental spectroscopy of At-molecules
- TDPAC for chelator/labelling development (cf. β -NMR)