Radioisotope production:

From nuclear physics to nuclear medicine

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Nuclear science and medicine:
an old common history

1895 – Discovery of X-rays by W. Roëntgen

First images using X-rays made few month later

1896 – Discovery of natural radioactivity by H. Becquerel

1901 – P. and M. Curie use radioactive matter on accessible tumor tissues.

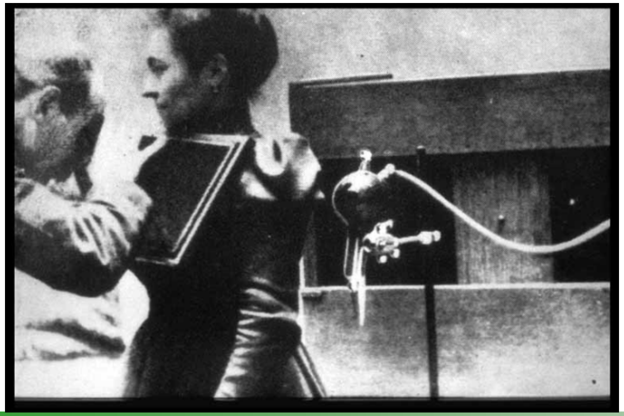
In the 20's, radium is used to treat patients

1930 – Building of the first cyclotron by E. Lawrence

1934 – Discovery of the induced radioactivity by I. et F. Joliot Curie

1938 – Production of iode-131

1941 – First treatment using radioactive Iodine



Nuclear Medicine

Definitions

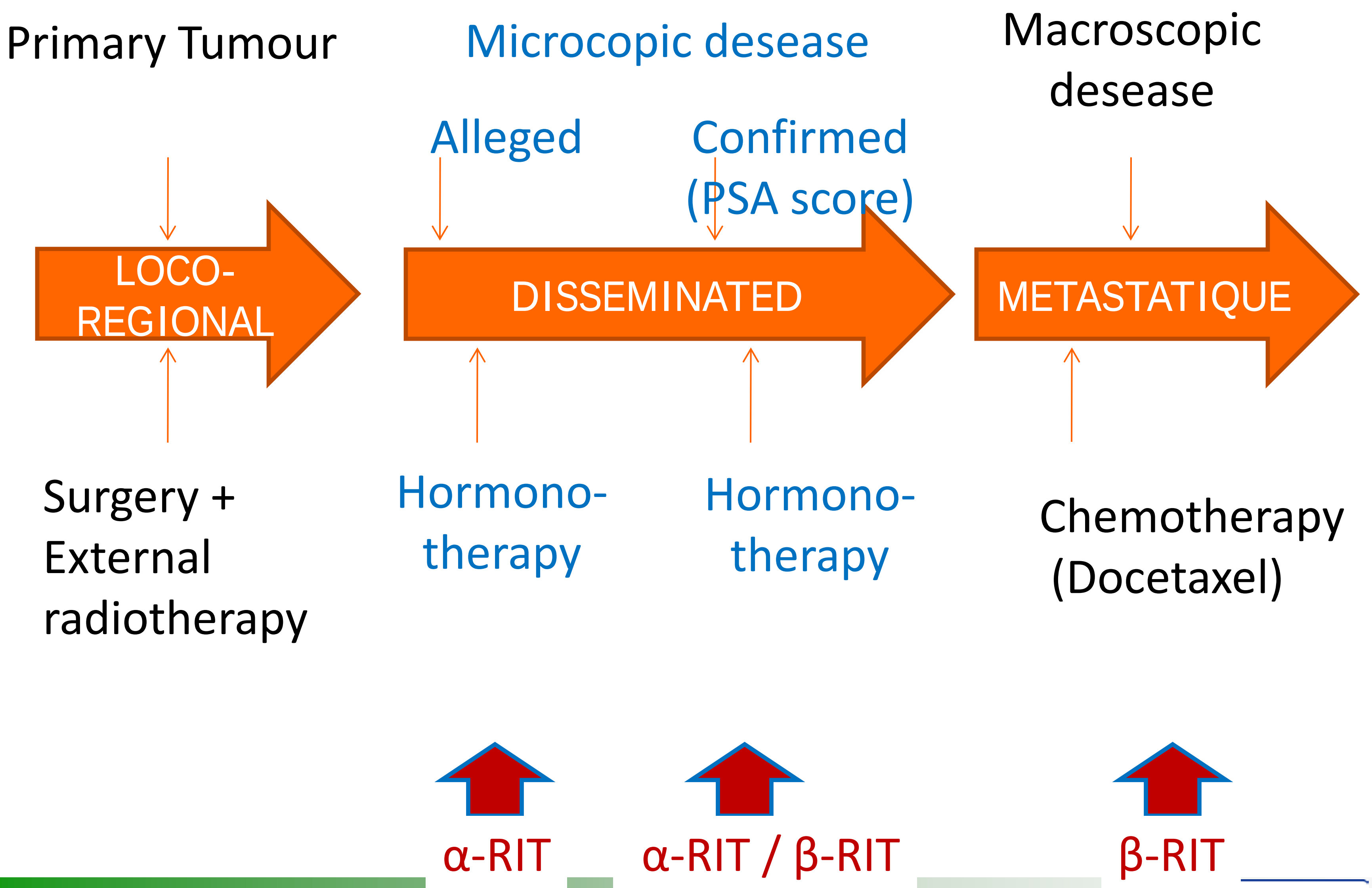
Nuclear medicine is a medical specialty which deals with **radionuclide** use **as open sources**.

Must not be confused with other medical specialties:

- **Radiology** which uses **X-rays** for imaging or closed radioactive sources for therapy
- **External radiotherapy** which uses external beam of ionizing radiation

Nuclear medicine is one of the tools to fight cancer and is used most of the time in complement **to surgery**, **chemotherapy**, **radiotherapy**

Prostate cancer



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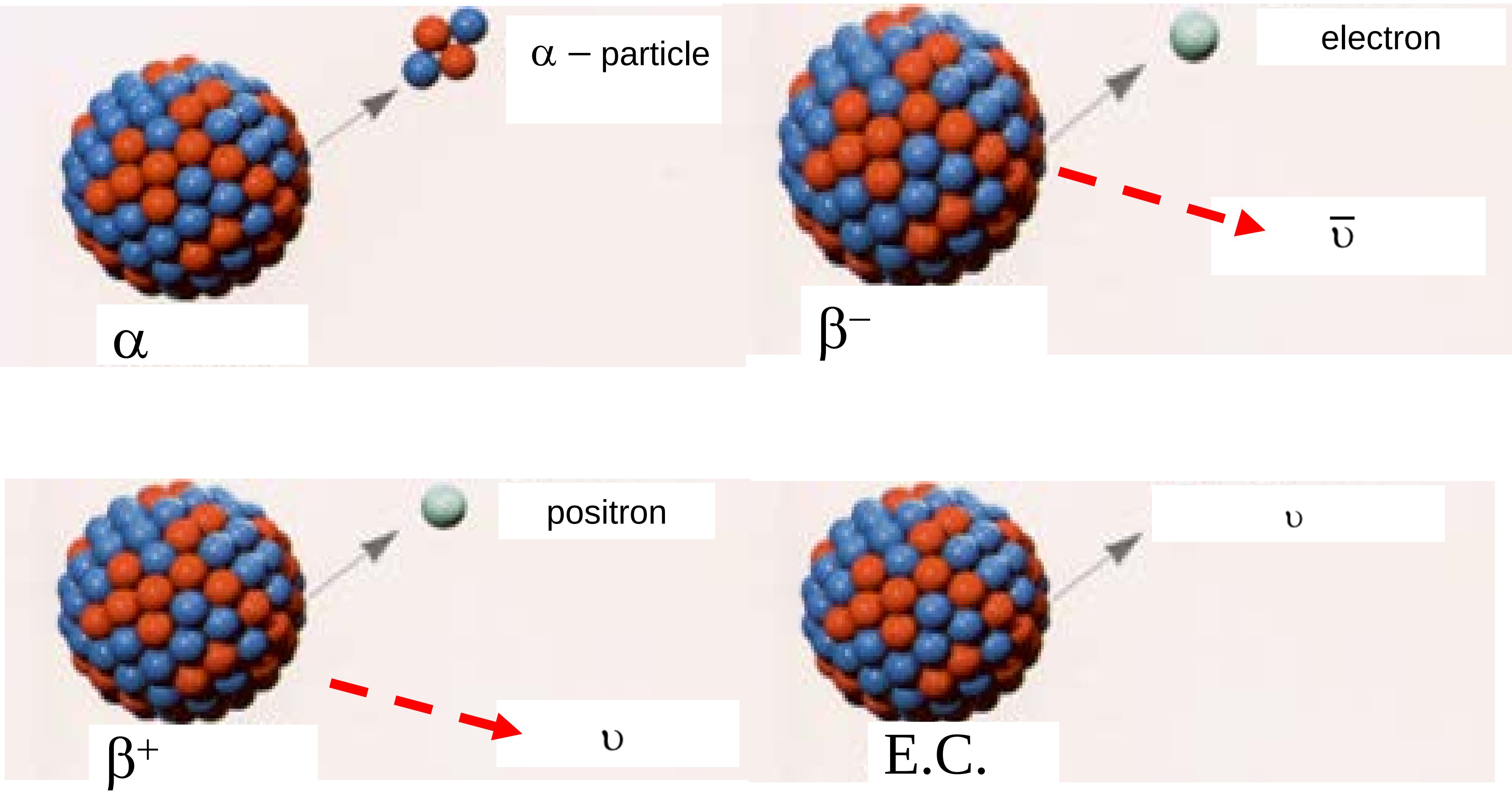
30 Million of nuclear medicine procedure performed worldwide each year.

In France:

220 centers of nuclear medicine

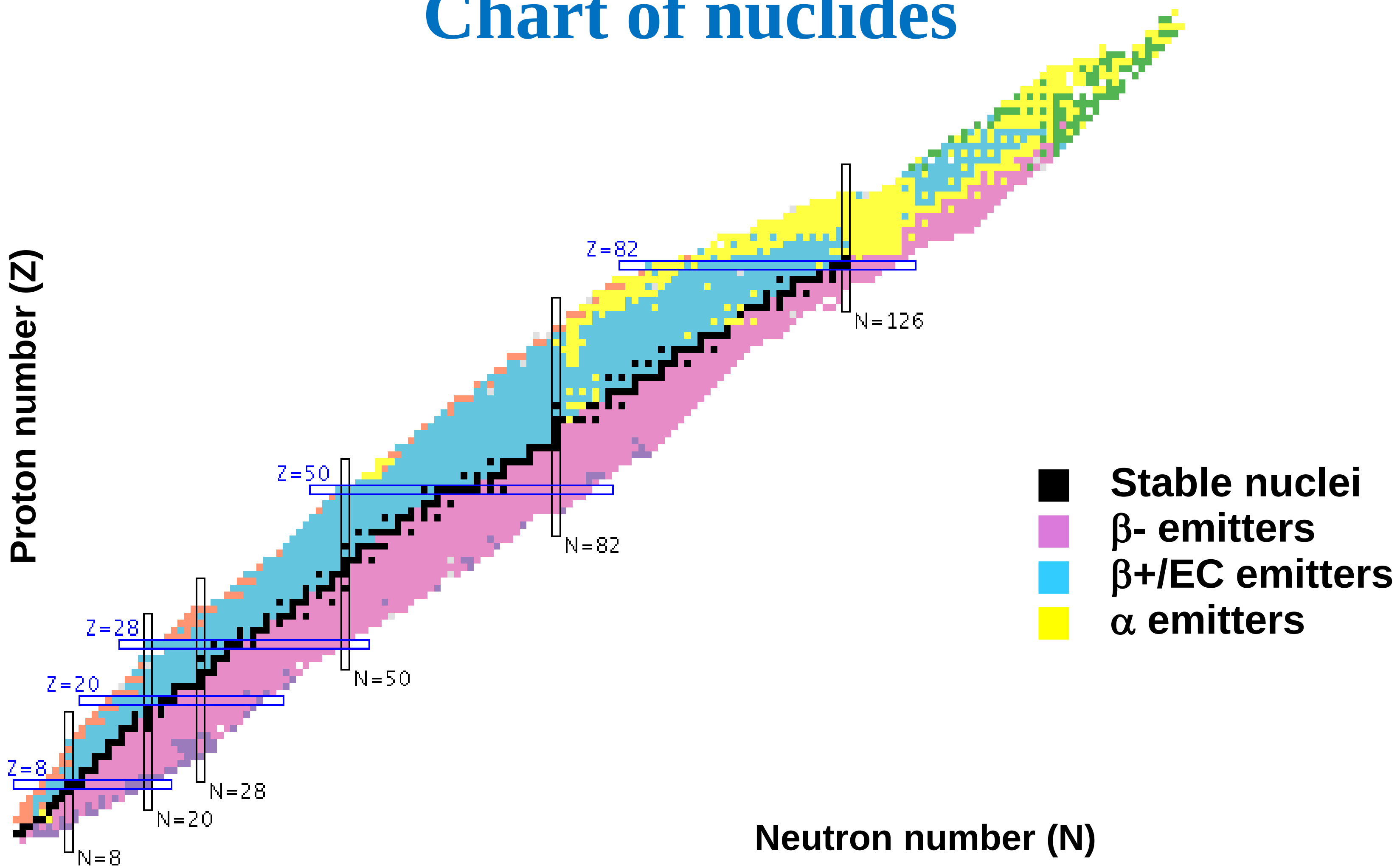
Most often used radionuclide: Tc-99m, F-18, I-131

Radioactive decay



EC and β+ processes are in competition

Chart of nuclides



Two nuclei having the same Z are:

are **isotopes** of the **same chemical element**

have the same chemical properties

Associated phenomena

γ emission/ internal conversion :

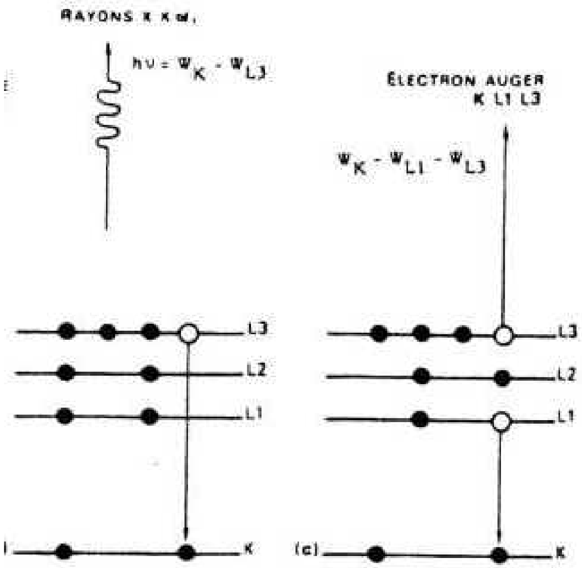
After a radioactive decay, a nucleus is often in an excited state.

→ The excess of energy can be realesed using either photon emissions or electron emission.

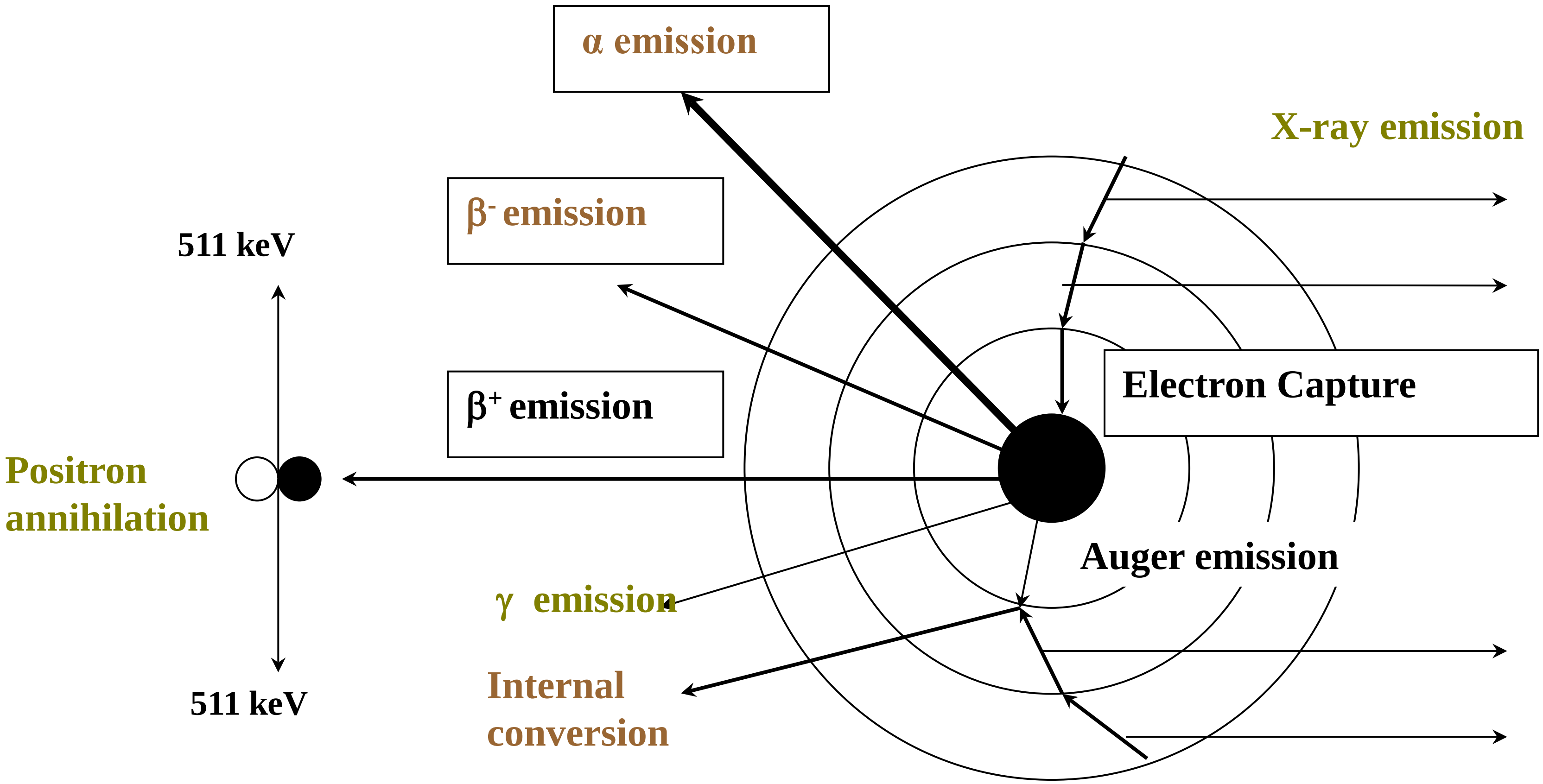
The electron cloud of the atome is disrupted:

Two mechanisms are competing to correct that:

- X-ray emission
- Auger emission



Available radiation from radioactive decay



Nuclear medicine uses the interaction properties of these radiation with matter.

- *Highly penetrating* radiation are used **for imaging and diagnosis** (X, γ , β+)
- *Low penetrating* radiation are used for **therapy (α, β-,e-Auger)**

Nuclear medicine

Therapy - Diagnostics

Theranostics

It is a treatment strategy that combines therapeutics with diagnostics.

→ To select patient that will response to a given treatment

→ To make dosimetry prior therapy

→ To assess treatment efficacy

In **breast cancer,** there is **3 different types with different treatment strategy**

Which radionuclides?

- **Radionuclide** with radiations for both imaging and therapy (^{117m}Sn)
- R**adionuclides of the same element** (^{64}Cu/^{67}Cu, ^{124}I/^{131}I, …)
- R**adionuclides** with comparable properties (^{99m}Tc / ^{188}Re)

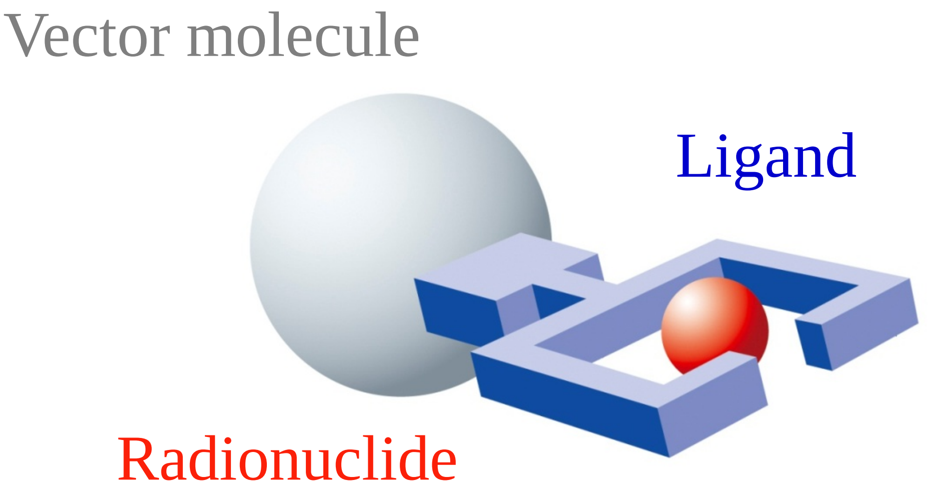
What is a radiopharmaceutical?

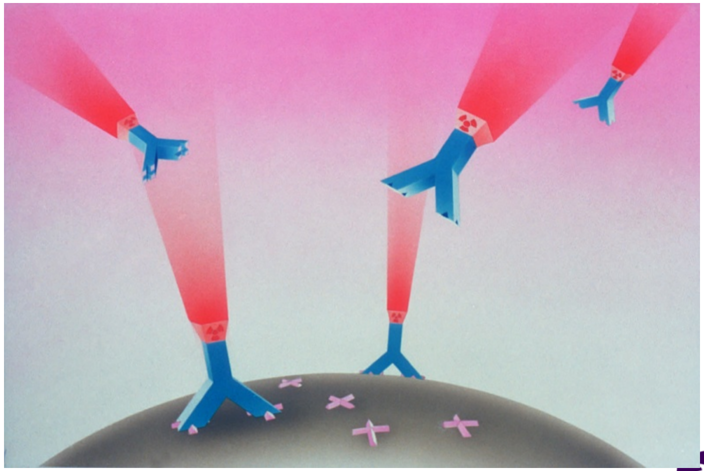
A radiopharmaceutical is a radioactive drug that targets the cells of interest

In some cases, the radionuclide can be injected directly:

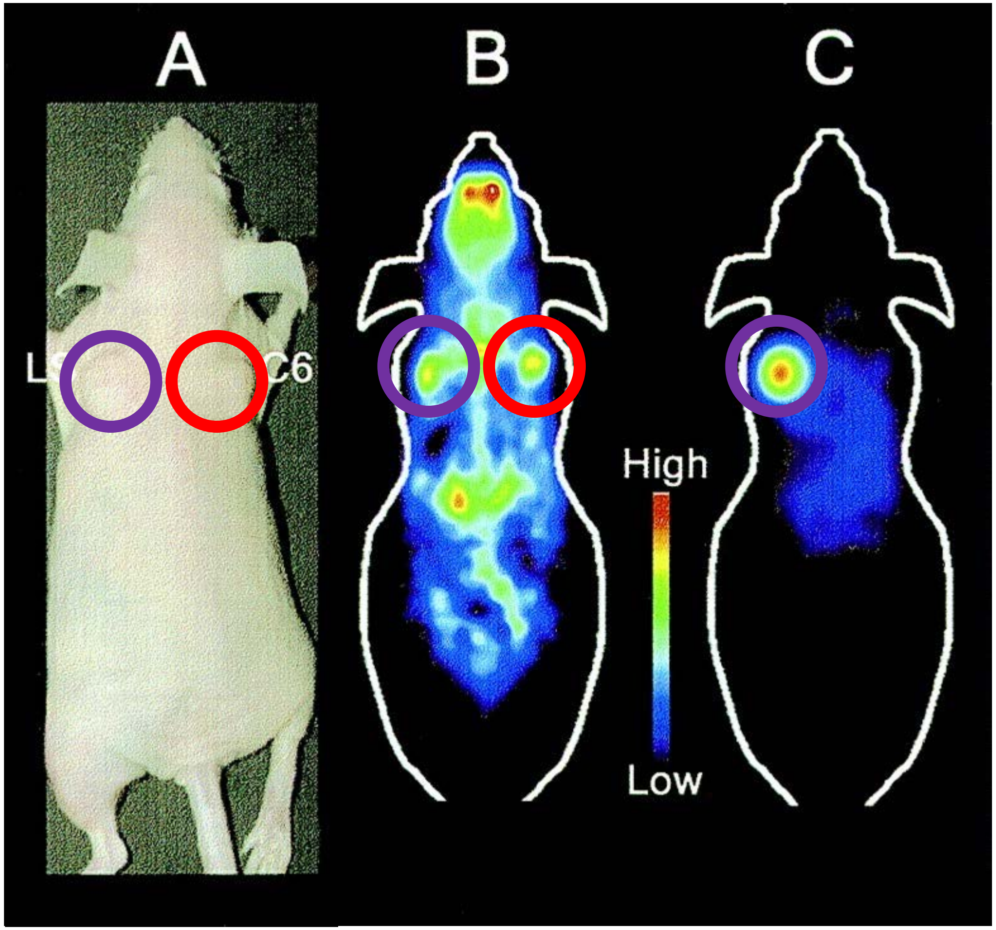
- Iodine-131 goes directly to the thyroide
- Rubidium-82 as an analogue of Potassium is accumulating ion the heart
- Radium-223 as an analogue of calcium goes to the bones.

In most cases, a vector molecule is needed to target the cells of interest.





Targeting is working pretty well



(A) : Tumours LS and C6

(B) : PET using ^{18}F-FDG

LS and C6 can be seen – FDG is not specific

(C) : Targeted-TEP using an anti –CEA antibody to target LS

source : G. Sundaresan, *Journal of Nuclear Medicine*

Renewing interest coming from progress in biology and chemistry

- ⌘ Many antibodies (humanized) are available form Big Pharma
  → allowing to target specific biological site

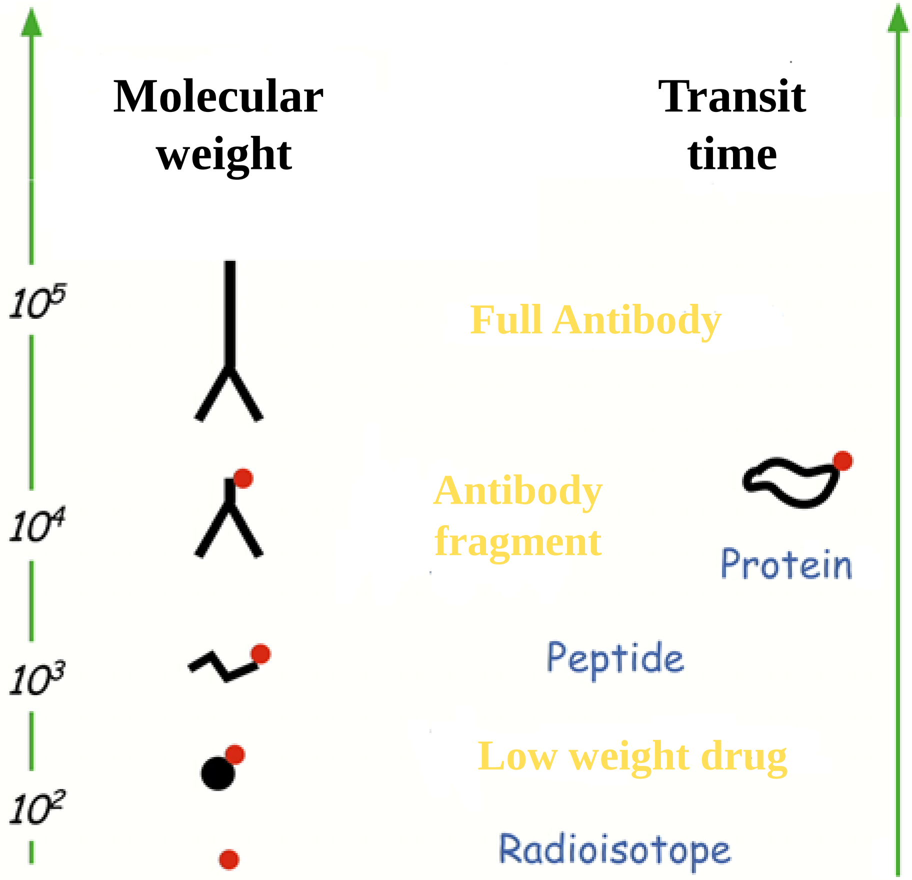
- ⌘ Peptide therapy can be also developed

New concepts:

Pre targeting / Click chemistry

Vector Type

The vector can be of different type: a small molecule, a peptide or an antibody



Zr-89 $T_{1/2}$ = 78.4 hr
I-124 $T_{1/2}$ = 4.18 j …

Cu-64 $T_{1/2}$ = 12.7 hr;
Ga-68 $T_{1/2}$ = 1.13 hr

→ Need of numerous radionuclide to Adapt $T_{1/2}$ to the vector transit time

Renewing interest coming from progress in biology and chemistry

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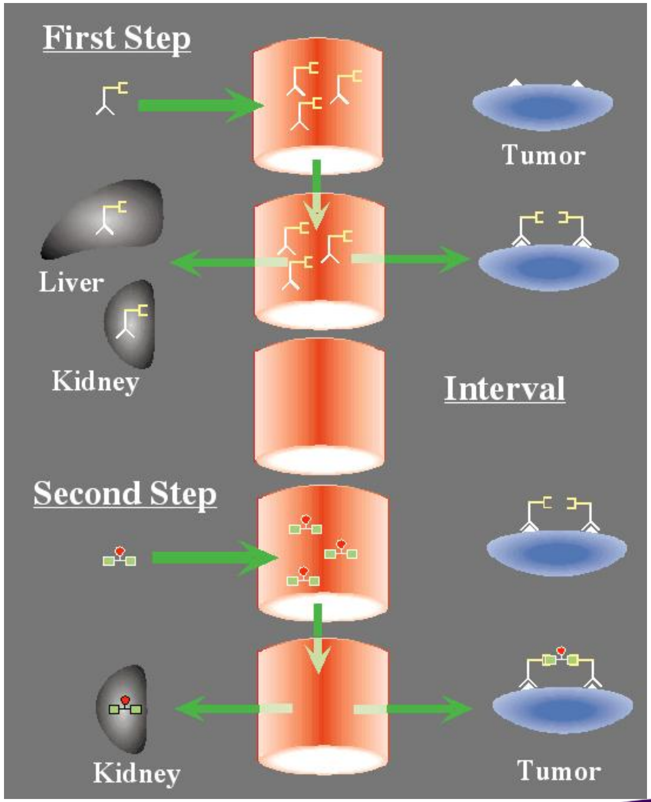
New concepts:

Pre targeting / Click chemistry



Need of numerous radionuclide with different chemical properties to ease chemistry

Nuclear imaging

Some numbers (*2013 – French association of nuclear medicine SFMN*)

In France, there is 460 gamma caméras (half being coupled with CT scan) and aroune 118 PET coupled with CT scan

Over 1 million scintigraphiy and 250 000 PET exams are performed each year.

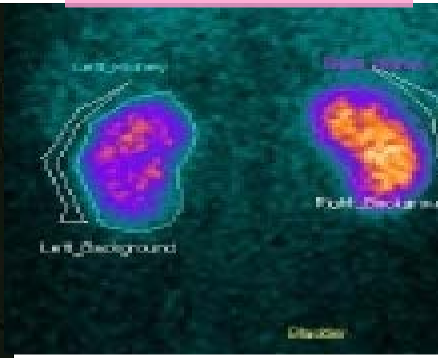
Several imaging modality exit (example of the kidney)

Ultrasound

MRI

CT scan

SPECT – PET



Non ionizing imaging

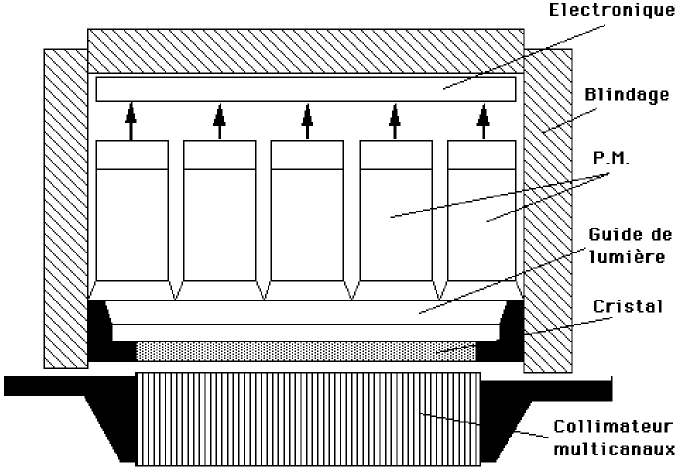
Ionizing imaging

anatomical imaging

Functional imaging

Radionuclide of interest for Gamma cameras

Gamma cameras

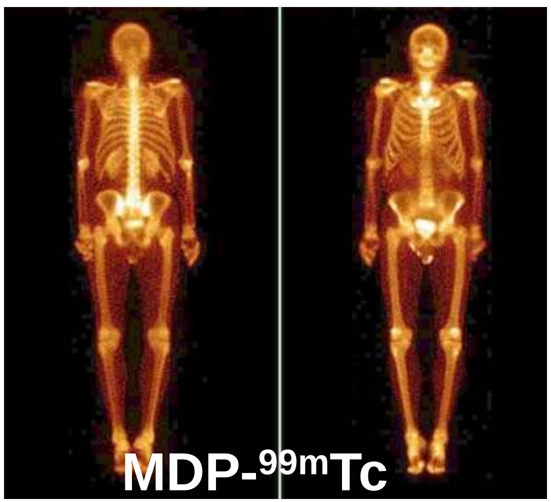


Isotope	Energie	Période
Emetteurs de photons γ		
Technétium 99m	140 keV	6 heures
Iode 123	159 keV	13 heures
Thallium 201	71 keV	73 heures

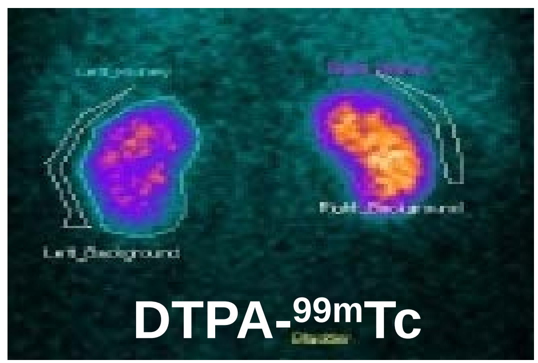
Photon energy between 70 keV and 200 keV

Different applications

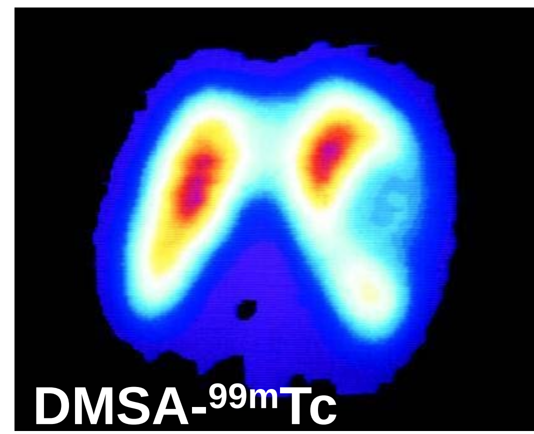
Changing the vector molecule allow to use the same radionuclide for different applications:



Skeleton



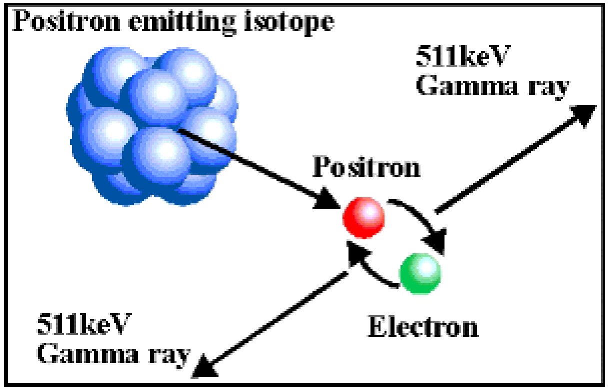
Kidney

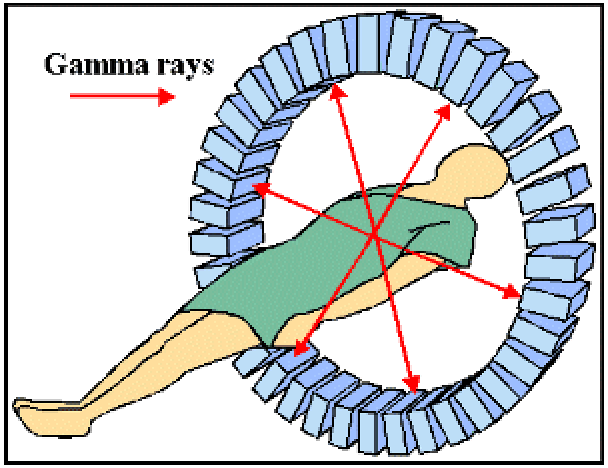


Thyroïd

One radioisotope – Several radiopharmaceuticals

Positron Emission Tomographie (PET)





PET Camera +
CT Scan

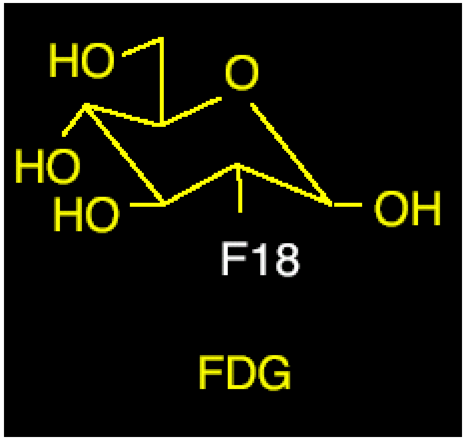
Radionuclide of interest for PET

Main positron emitters

Oxygen-15	2mn
Nitrogen-13	10 mn
Carbon-11	20mn
Fluorine-18	110mn

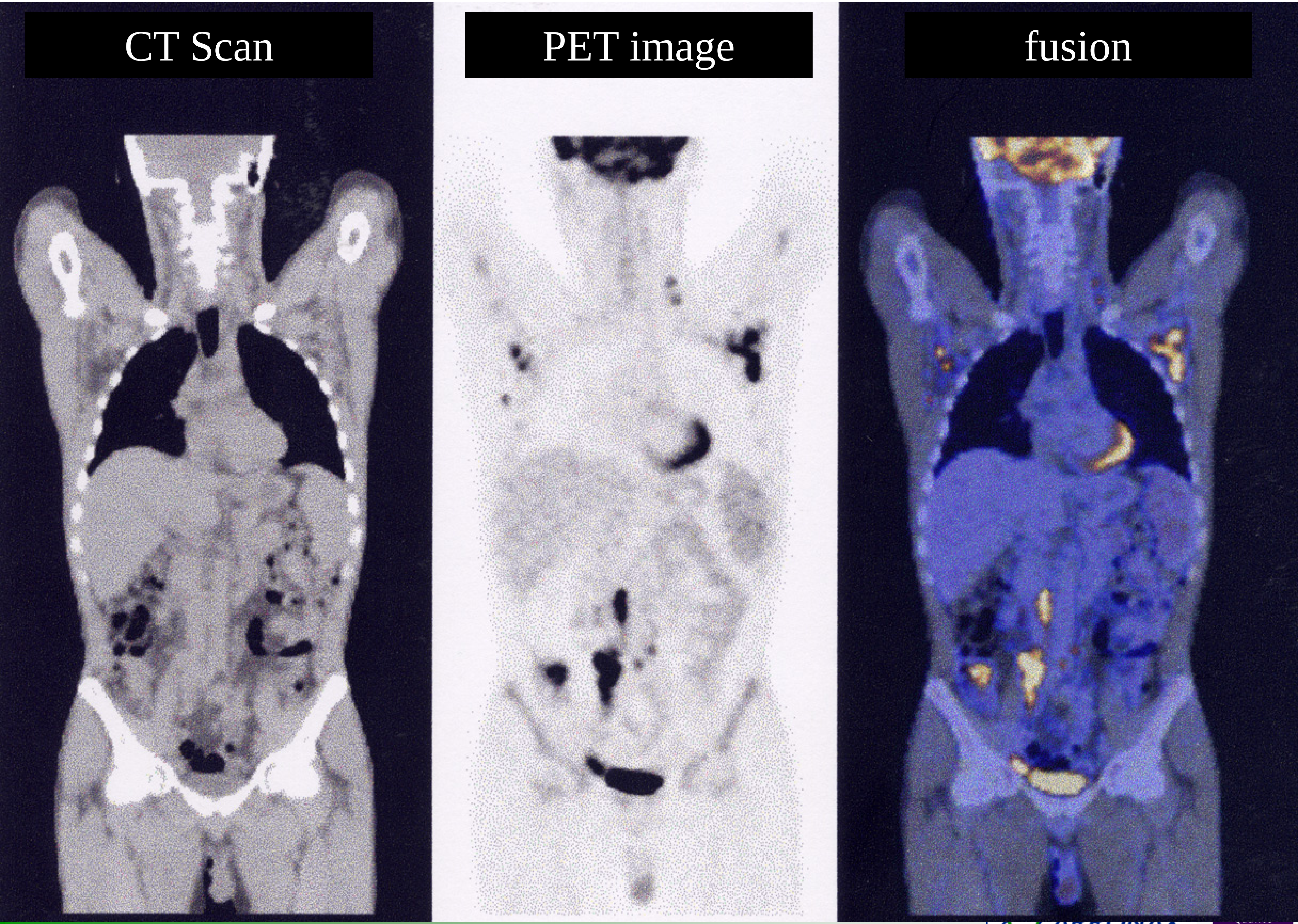
Other can be selected with respect to $T_{1/2}$, branching ratio, associated radiation, positron energy,…
Sc-44, Cu-64, Zr-89, I-124, Tb-152, …

The most used one is **^{18}F** with ***Fluorodeoxyglucose***

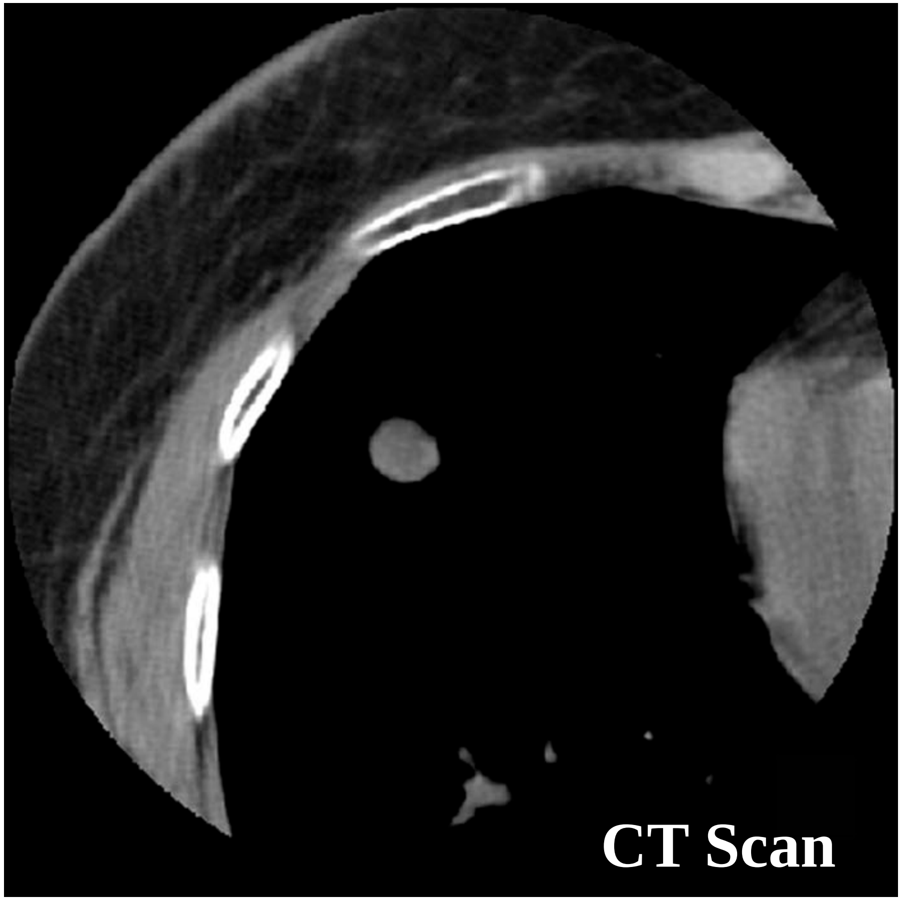


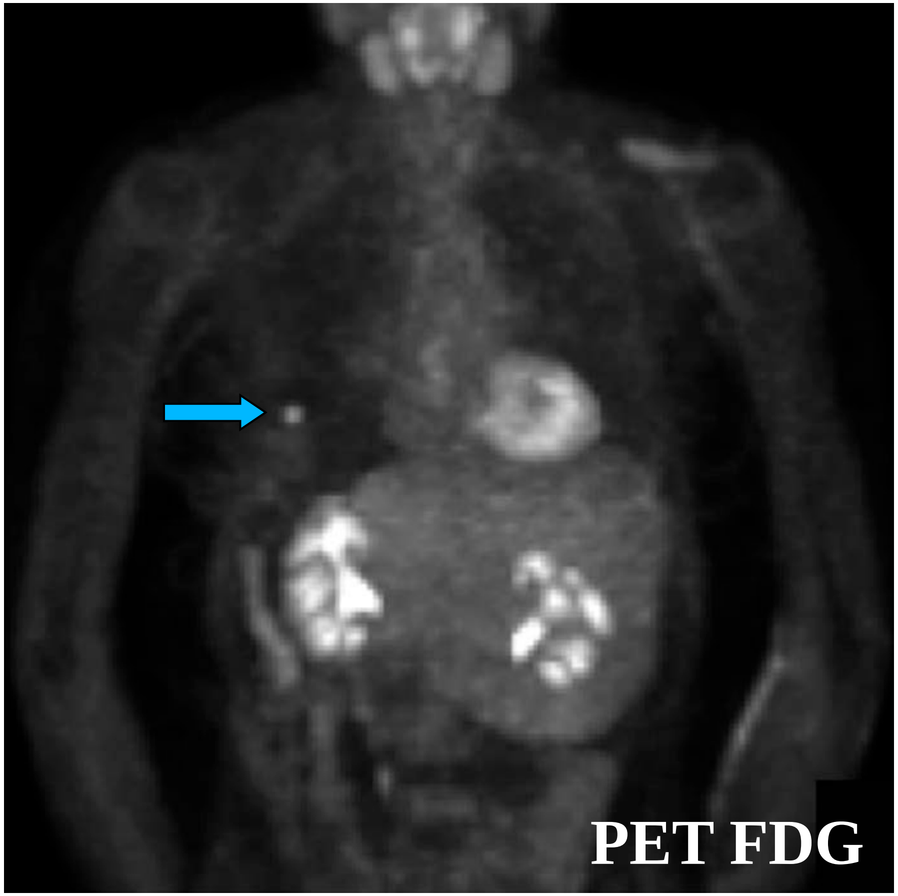
Principle:
FDG is an analogue of sugar
Cancer cells are hyperactive and use more sugar than normal cells.

FDG accumulate in cancer cells but also in certain organs (brain, heart,…)


CT Scan
PET image
fusion

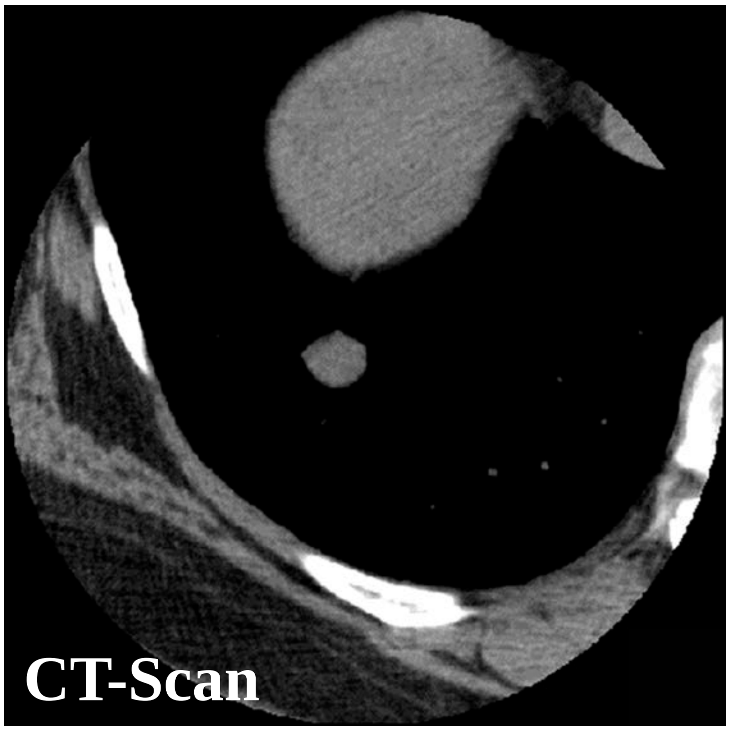
An example of the Added value of PET
Cancerous nodule in the lung

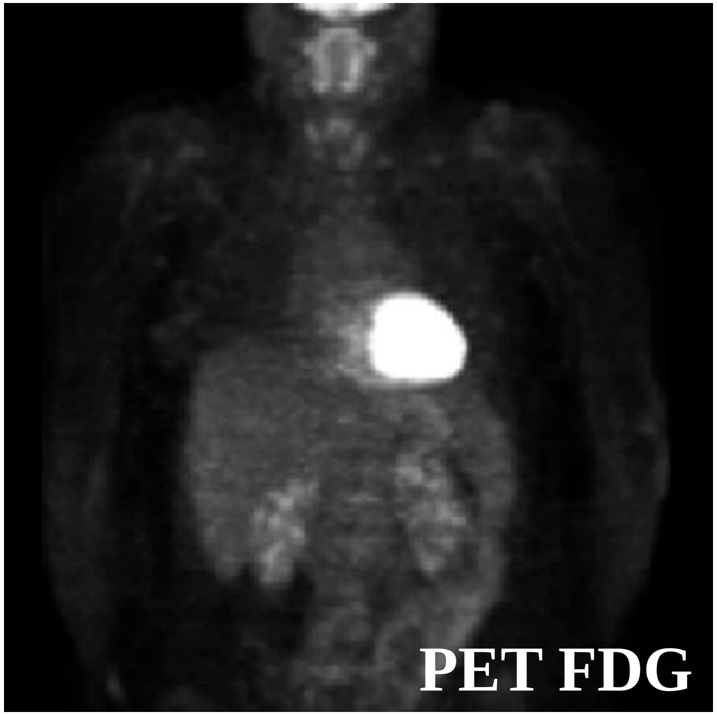




Christensen, J. A. et al. Am. J. Roentgenol. 2006;187:1361-1367

An example of the Added value of PET
Benign nodule in the lung



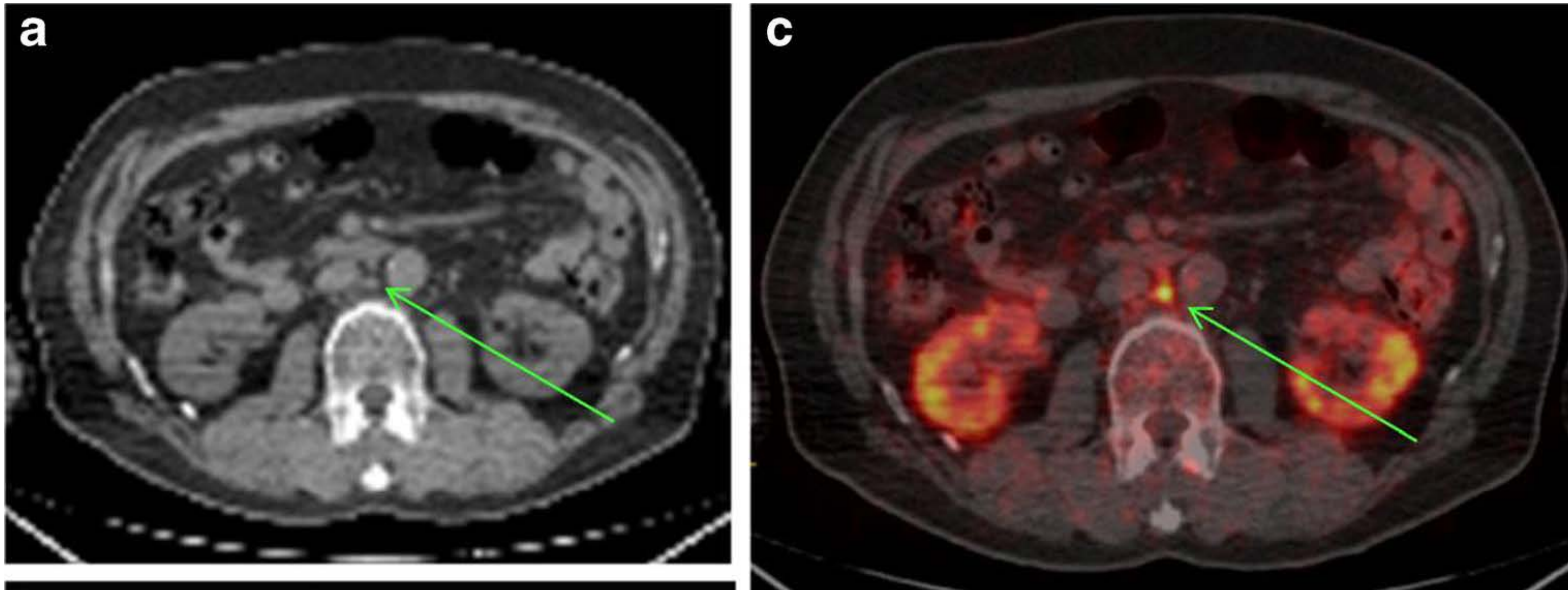


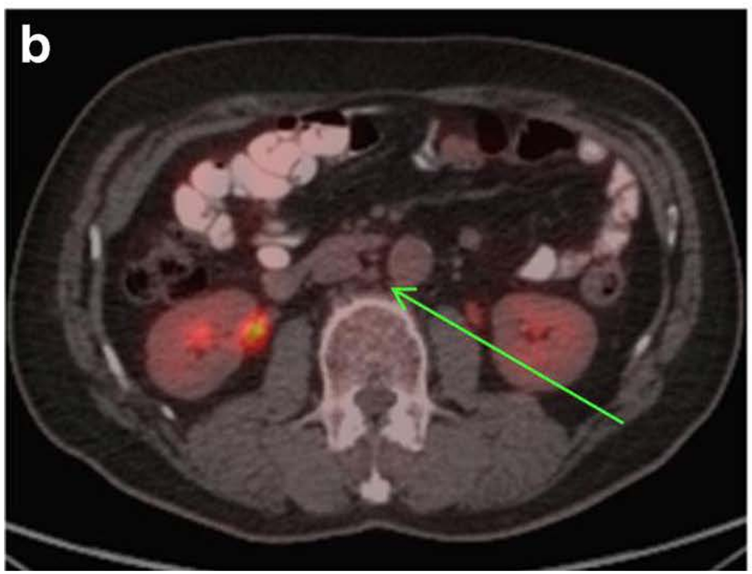
AJR

Christensen, J. A. et al. Am. J. Roentgenol. 2006;187:1361-1367

An example of the Added value of PET

nodule in the prostate





An antibody coupled to Zr-89

Nodule diameter <1cm

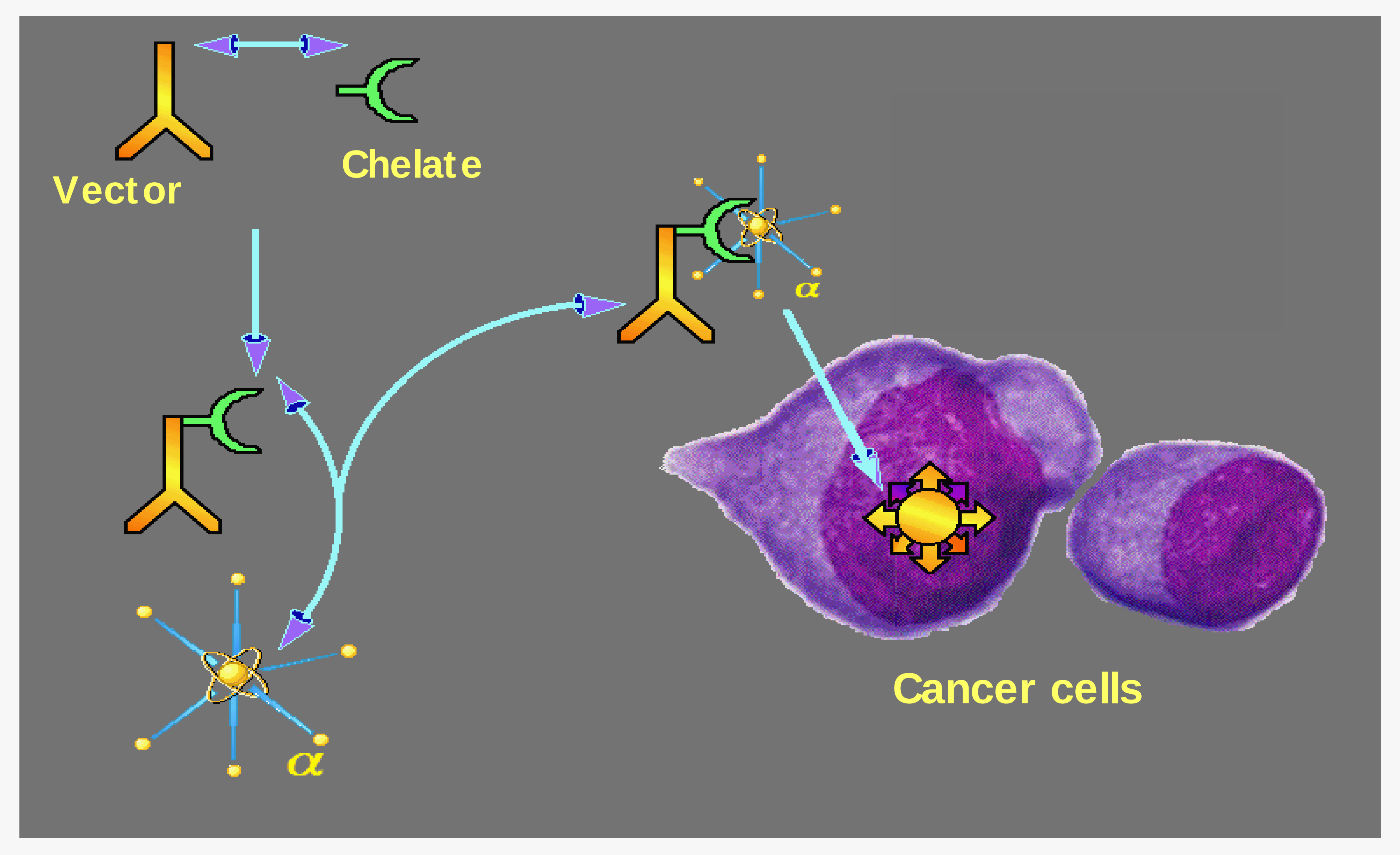
→No suspicion in CT Scan

PET exam shows the nodule uptake is high

→ cancerous

Therapy

Targeted therapy



Radiations emitted by the radionuclide act locally

Targeted therapy

Several radiopharmaceuticals are available which use β- emitters:

Bexxar® uses ^{131}I (*antibody*)

Zevalin® uses ^{90}Y (*antibody*)

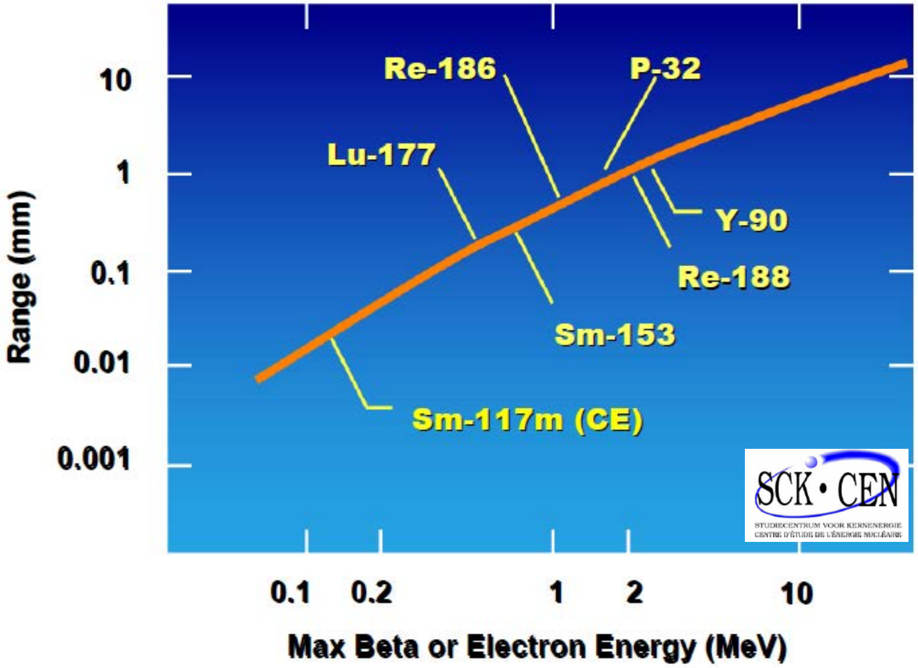
Lutathera® uses ^{177}Lu (*peptide*)

Why several β- emitters are used ?

•Associated radiation (γ and X-rays)
→radiation safety constraints

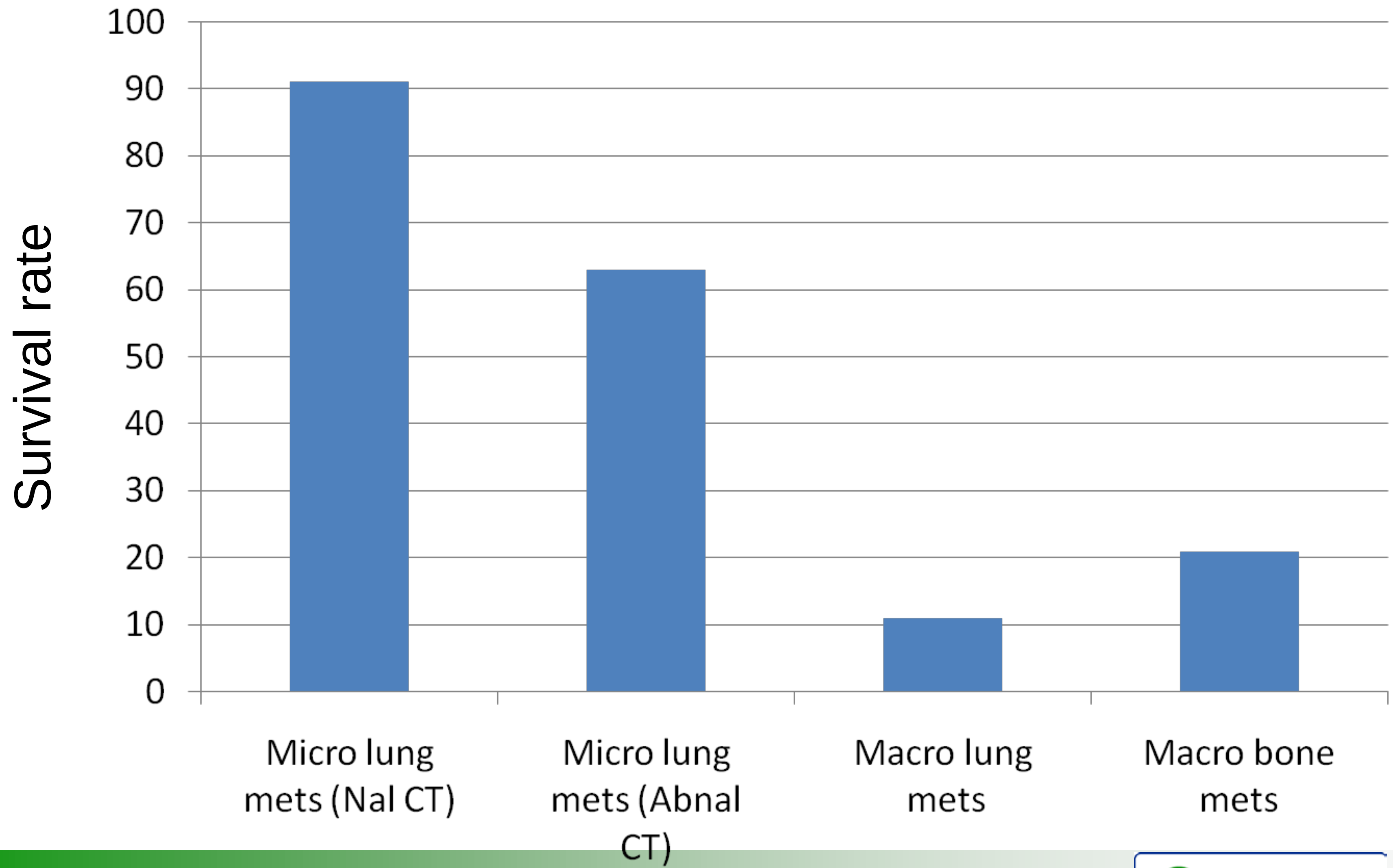
• half lives are differents

•β- energies are differents
→Range in matter will be different
→Linear energy transfer (LET) will be different



Metastatic differentiated thyroid cancer treated with ^{131}I

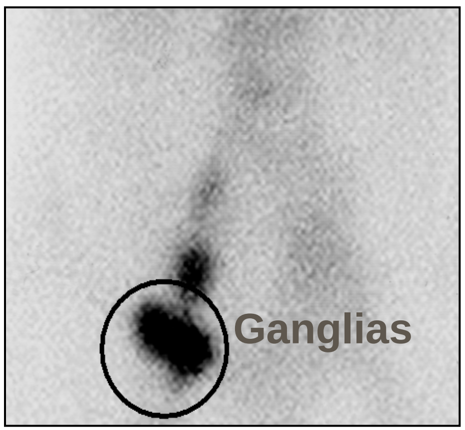
10-year survival rate



Radio-immunotherapy for lymphoma

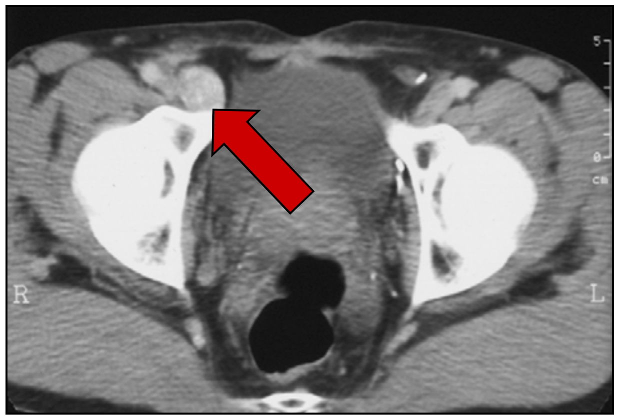
a theranostic approach

Scintigraphy with In-111 is used to evaluate the response of the patient.

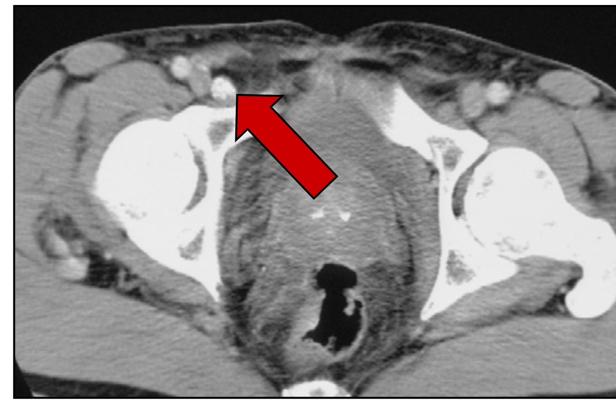


Zevalin ®

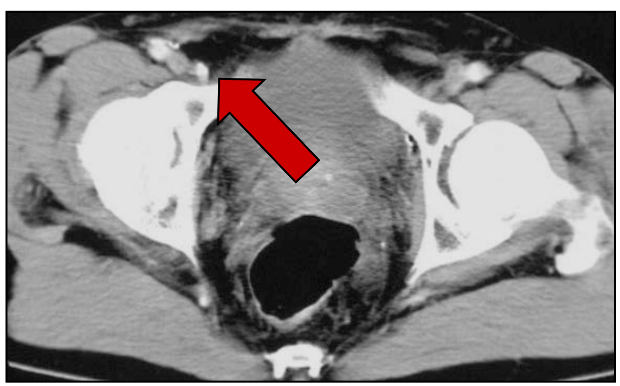
3 mars 2000 (Before RIT)



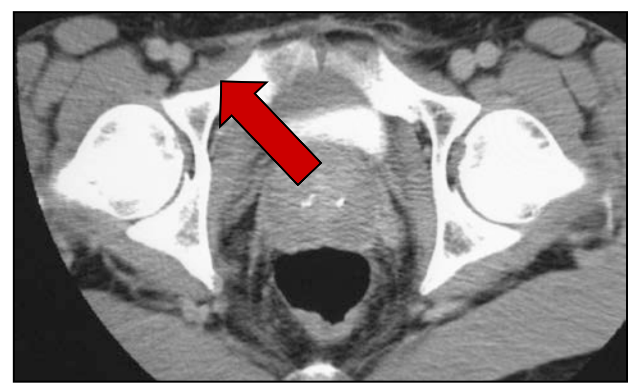
5 avril 2000 (one month after RIT)



9 mars 2001 (One year after RIT)



25 septembre 2001 (18 months after RIT)



ARRONAX

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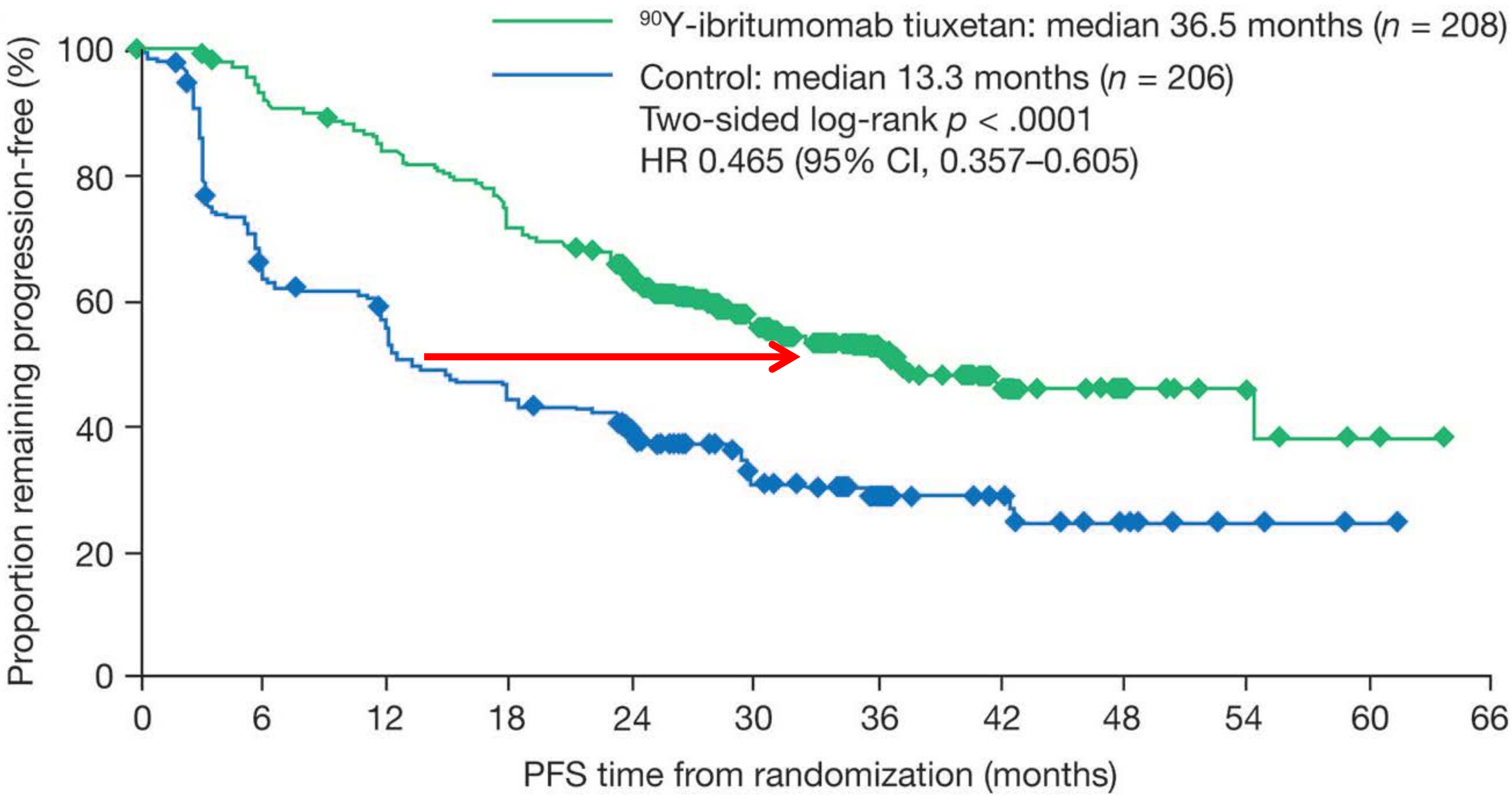
Compared progression-free survival in a phase III study of patients treated with consolidation using Zevalin® after induction treatment vs induction treatment alone (control group)



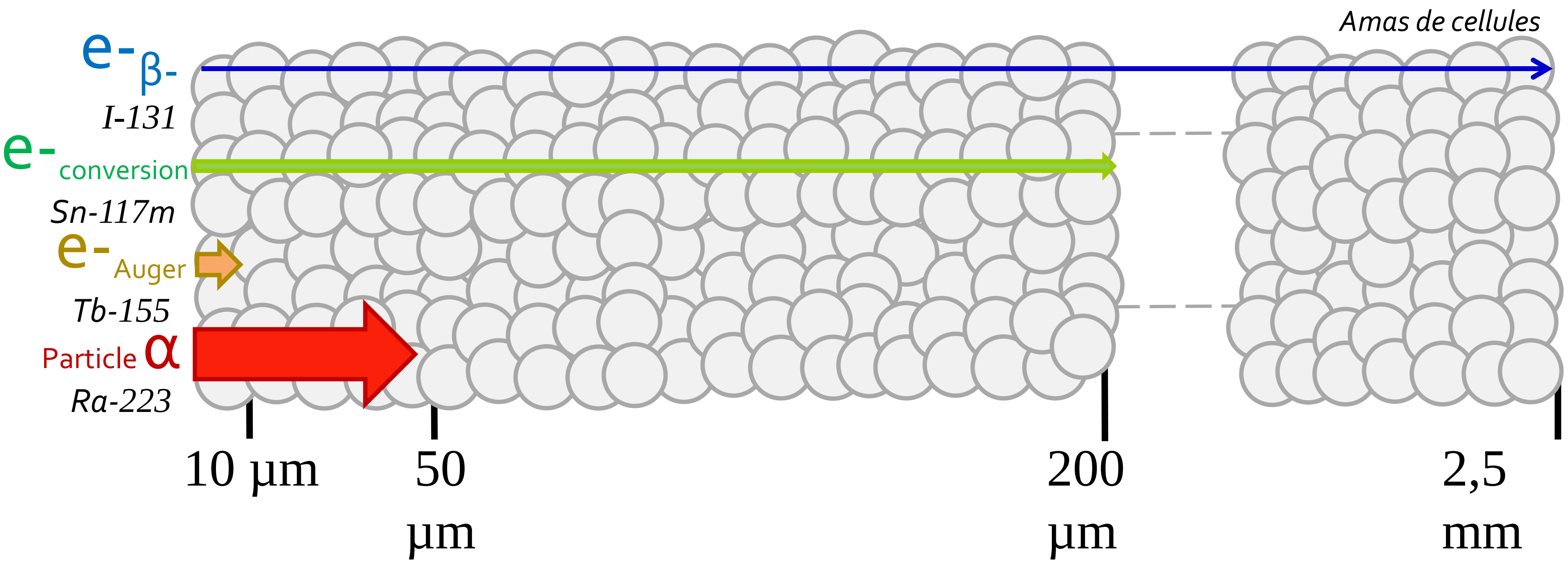
Morschhauser F et al. The Oncologist 14 (suppl 2): 17-29 2009

Linear Energy Transfer (LET)

Radiation consecutive to radioactive decay have

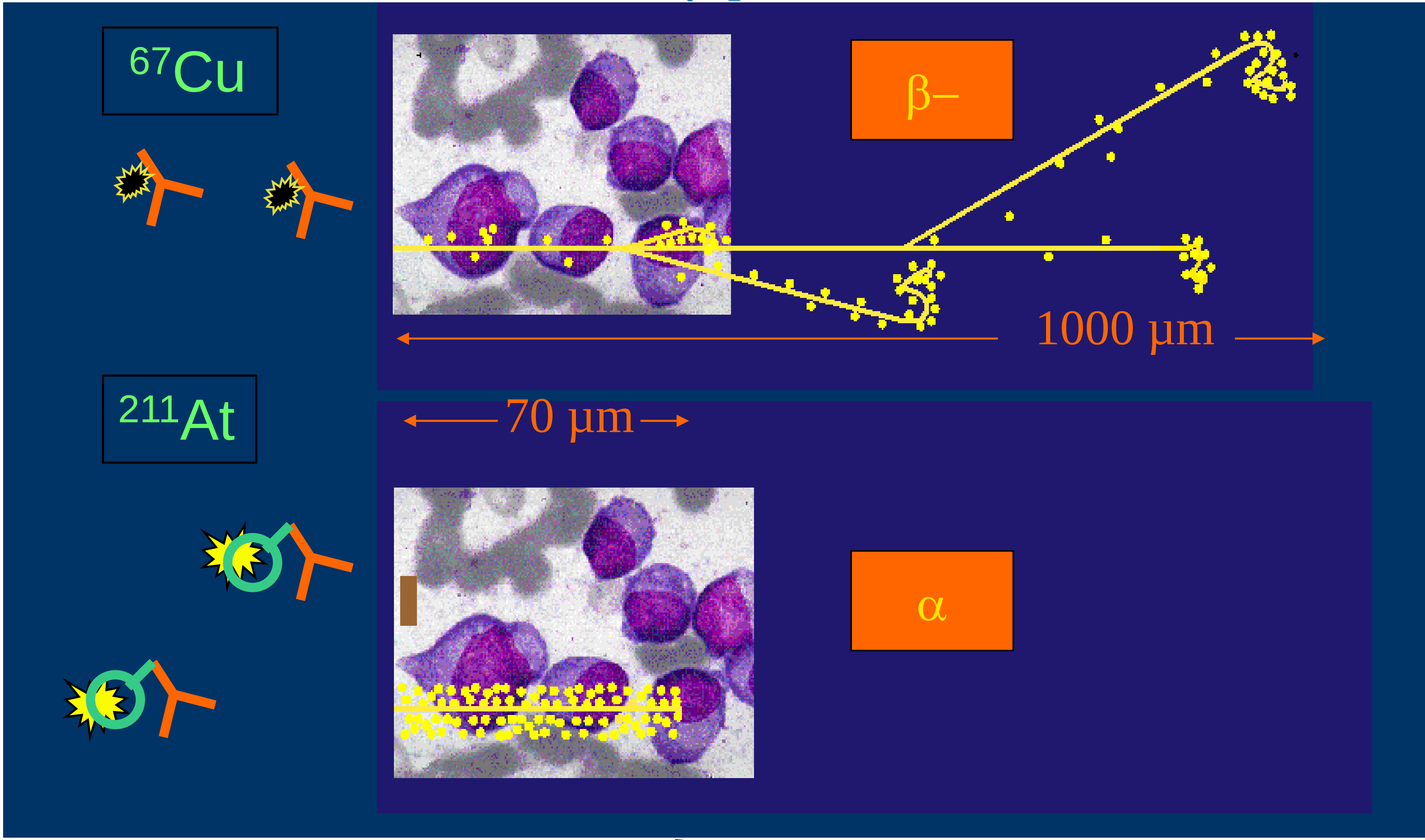
→ Different range in matter

→ Different initial energy



Leading to different Linear Energy Transfer

α versus β particles

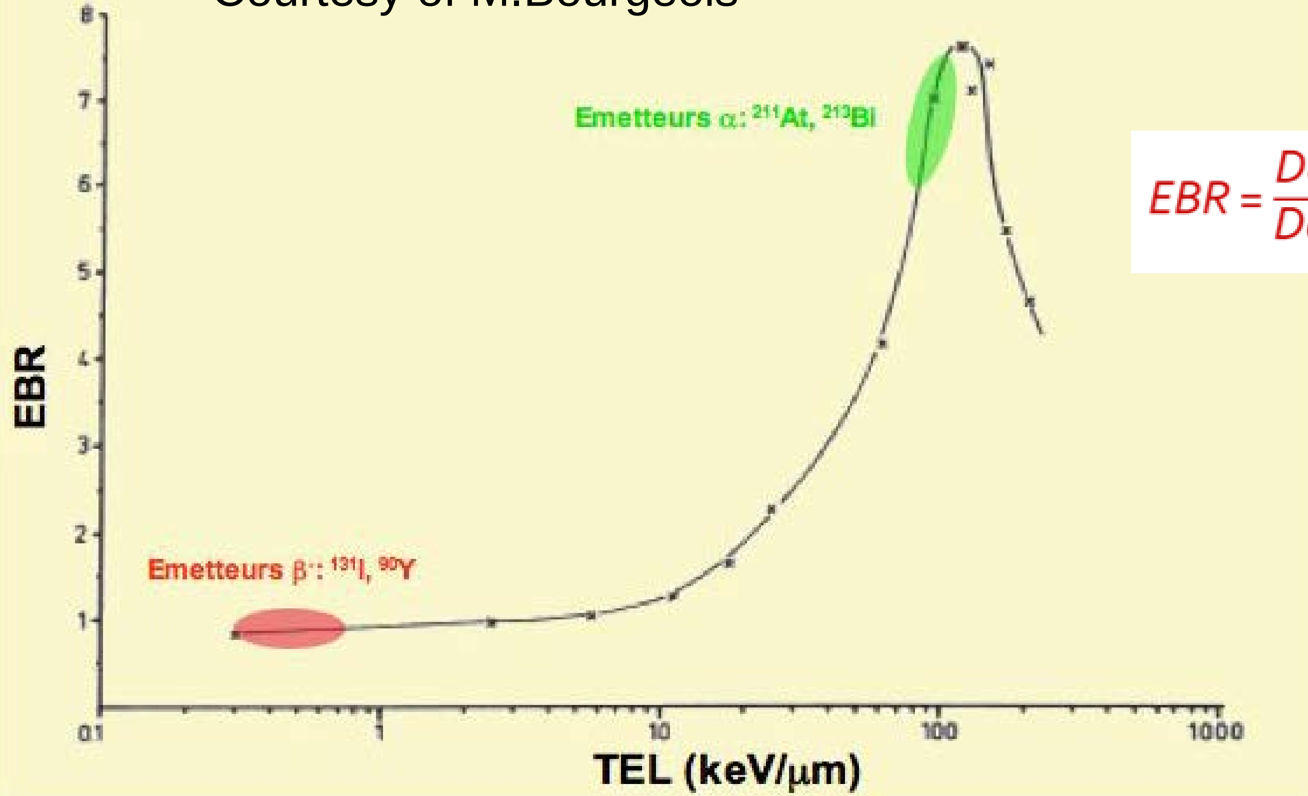


Shorter range for α particles
Higher energy deposition density

→ Higher LET than β

Benefit from high LET particles

Courtesy of M.Bourgeois



$$EBR = \frac{Dose\ photons\ X\ (250\ kV)}{Dose\ rayonnement\ testé}$$

A lower dose is needed to get the same effect

High LET produce double-strand DNA breaks--with little chance of cell repair and survival.

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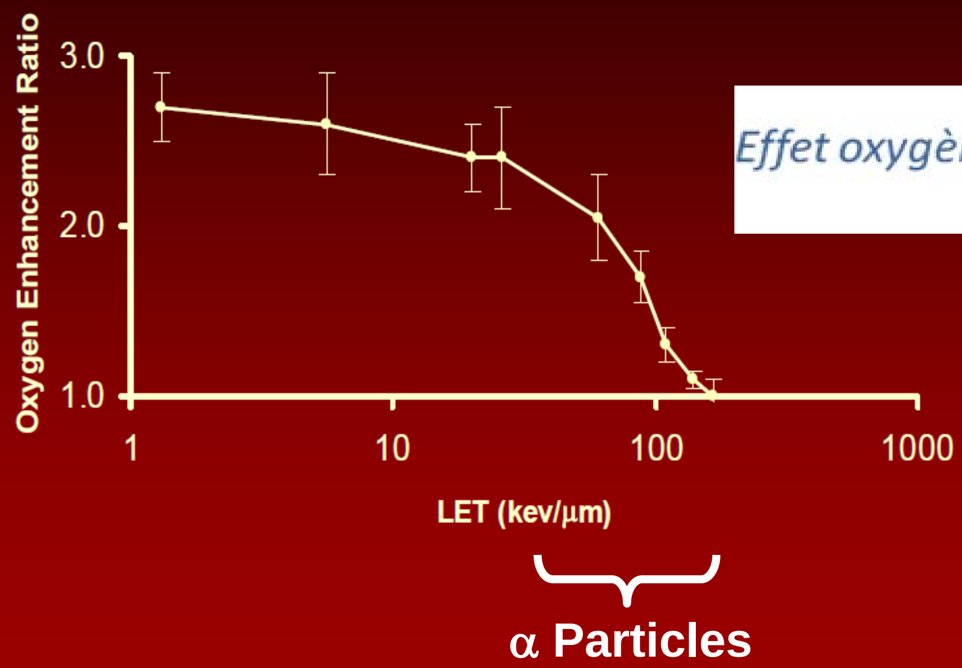
Benefit from high LET particles

Courtesy of G. Sgouros



$$\text{Effet oxygène} = \frac{\text{Dose – cellule en hypoxie}}{\text{Dose – cellule normalement oxygénée}}$$

(Barendsen, et al., Int J Radiat Biol 10:317-327, 1966.)

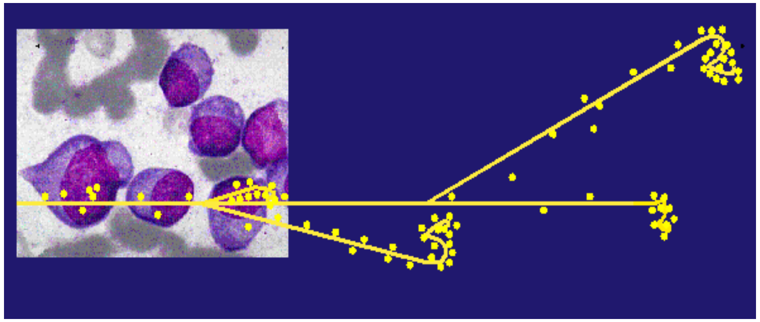
Hypoxic cells require 2-3 times more radiation than normal cells to be destroyed

Normal and hypoxic cells react the same way to α radiation

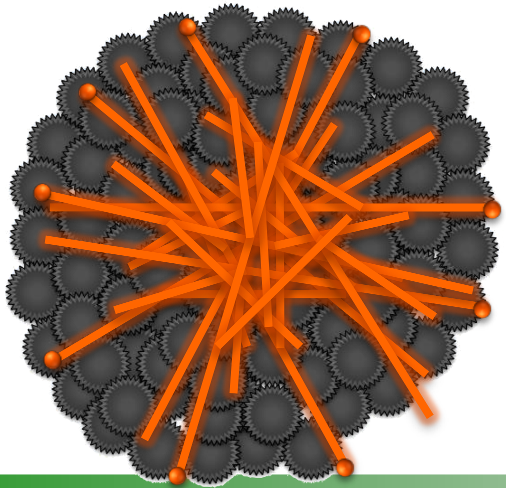
α and β radiations are complementary

β emitter

- <1 MeV dissipated over 1 to 10 mm
- energy deposited outside the target cell

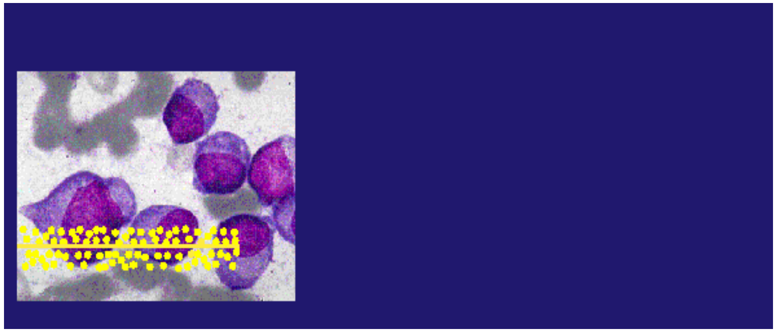


- TARGET: macro-clusters

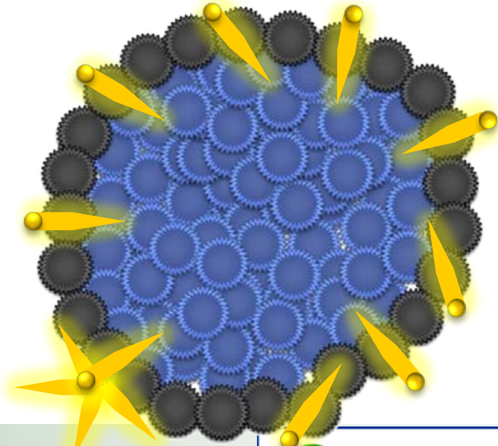


α emitter

- 5-6 MeV dissipated over 0.1 mm
- Energy deposited within the target cells



- TARGET: isolated cells / micro-clusters



How can we get radionuclide for medical applications?

Some are available in our environement

➢ Some radioisotopes are created by interaction of cosmic rays with the atmosphere.

→ **None are useful for medical application**

➢ Radioisotopes from decay chain of long lived radioisotopes (^{238}U decay chain for example).

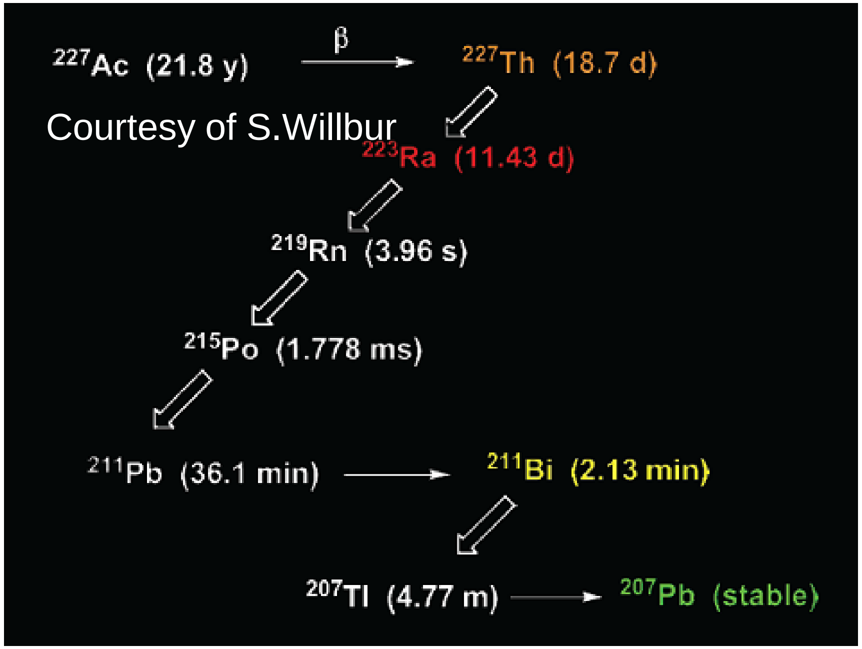
→ **Few are used for medical application**

Radioisotopes of medical interest present in in our environment

Radium-223:

Belongs to the ^{235}U decay chain

4 consecutive α particles are emitted during the decay



One radiopharmaceutical is registered in USA and Europe (2013): Xofigo® (^{223}RaCl)

As an analog of calcium, radium tends to concentrate on bones

→ Xofigo is used for the treatment of bone metastasis

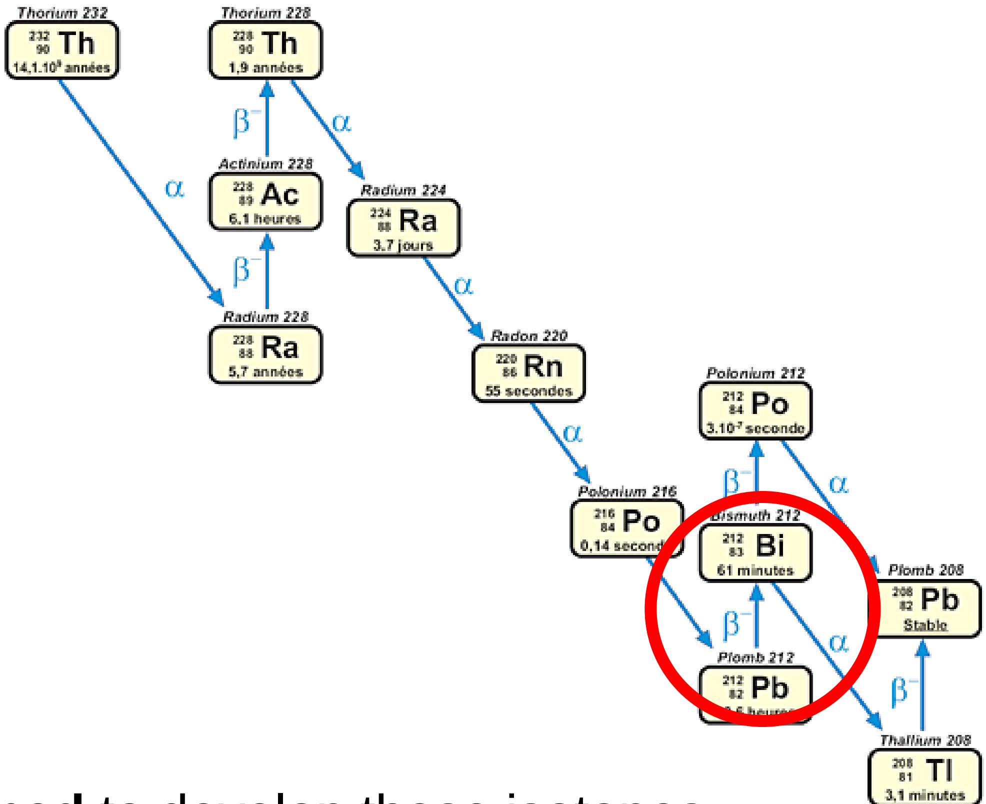
Radioisotopes of medical interest present in in our environment

^{212}Pb/212Bi:

Belongs to the ^{232}Th decay chain

Indeed, one can use either :

- ^{212}Bi directly
- ^{212}Pb to act as a in-vivo generator



Stocks of ^{232}Th exist in the world.

Areva has set a subsidiary **Areva med** to develop these isotopes

A small factory is in operation close to Limoges (France)
A large factory is in project in Caen (France)

Most of the radioisotopes are artificially created

Nuclear Physics step
Selection of the most approriate nuclear reaction

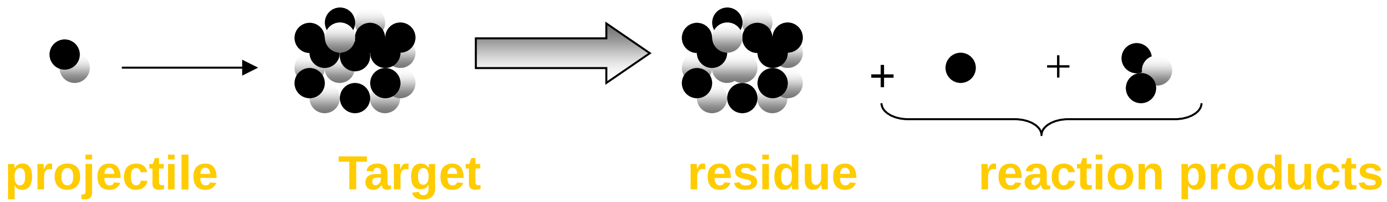
Target

projectile

Radiochemistry Step
Extraction and Purification

Radioisotope
with the proper purity

Artificially Induced Radioactivity



Many different nuclear reactions can be used:

$$p + {}^{18}O \rightarrow {}^{18}F + n$$

$$\alpha + {}^{209}Bi \rightarrow {}^{211}At + 2\,n$$

$$n + {}^{176}Yb \rightarrow {}^{177}Yb + \gamma$$

$$\gamma + {}^{68}Zn \rightarrow {}^{67}Cu + p$$

$$n + {}^{235}U \rightarrow \text{fission}$$

Nuclear reactors or **particle accelerators** can be used depending of the desired reaction mechanism

Thick target yield

Irradiation conditions

Reaction Cross section

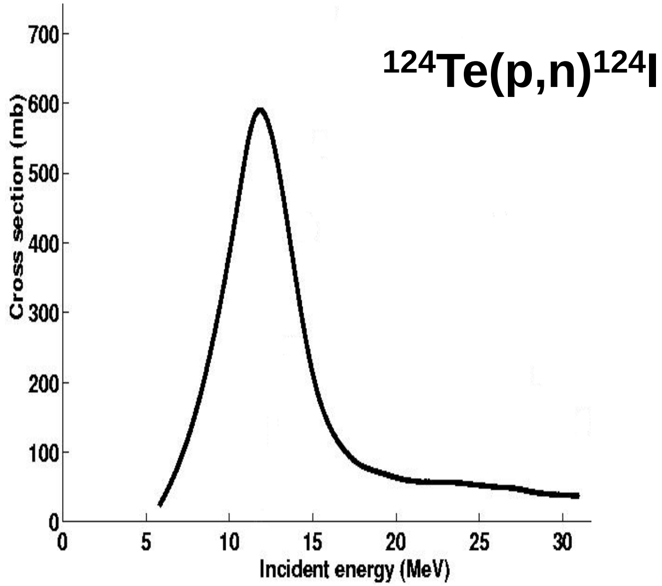
Produced Activity:

$$Act = \Phi \cdot \chi \cdot \frac{Na \cdot \rho}{A} \cdot \left(1 - \exp(-\lambda \cdot t_{irr})\right) \cdot \int_{E_{fin.}}^{E_{in.}} \frac{\sigma(E)}{\frac{dE}{dx}} \cdot dE$$

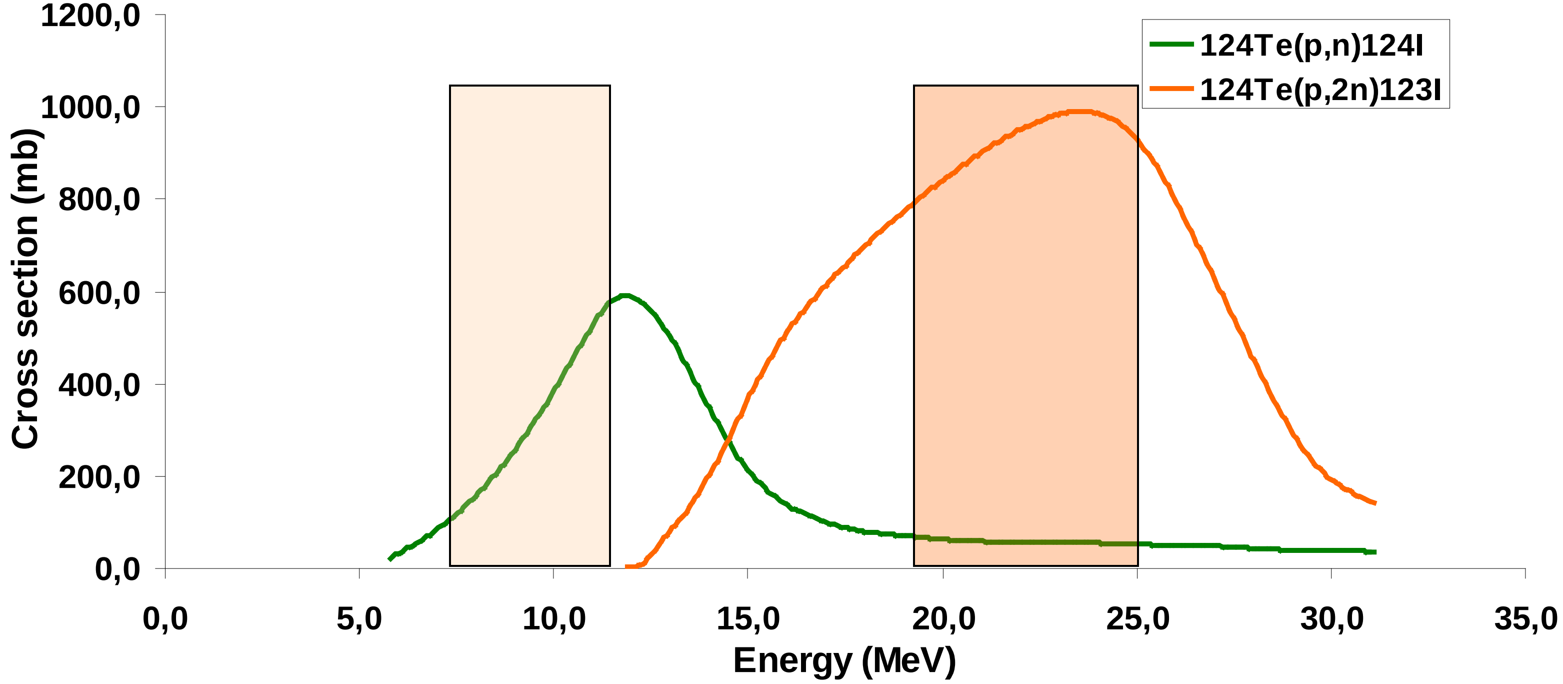
Radioactive decay

Target characteristics

including enrichment



Carrefully select the nuclear reaction and the projectile energy.



By a smart choice of the incident energy and target thickness, one can:

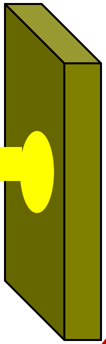
Maximizes the production yield

Minimizes the production of contaminants.

Development of a radiopharmaceutical

Nuclear Physics step
Selection of the most approriate
nuclear reaction

Target

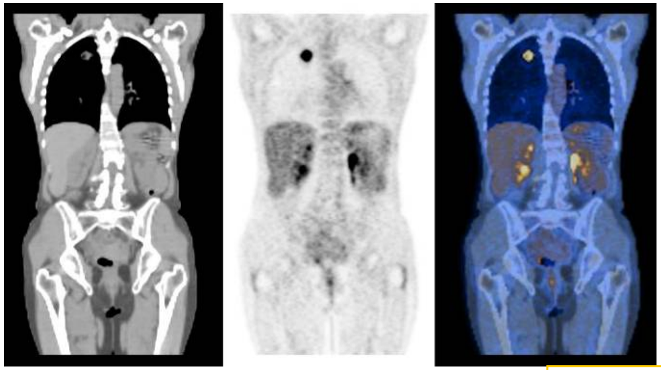


projectile

Radiochemistry Step
Extraction and
Purification

Radiopharmacy Step
Radiolabeling

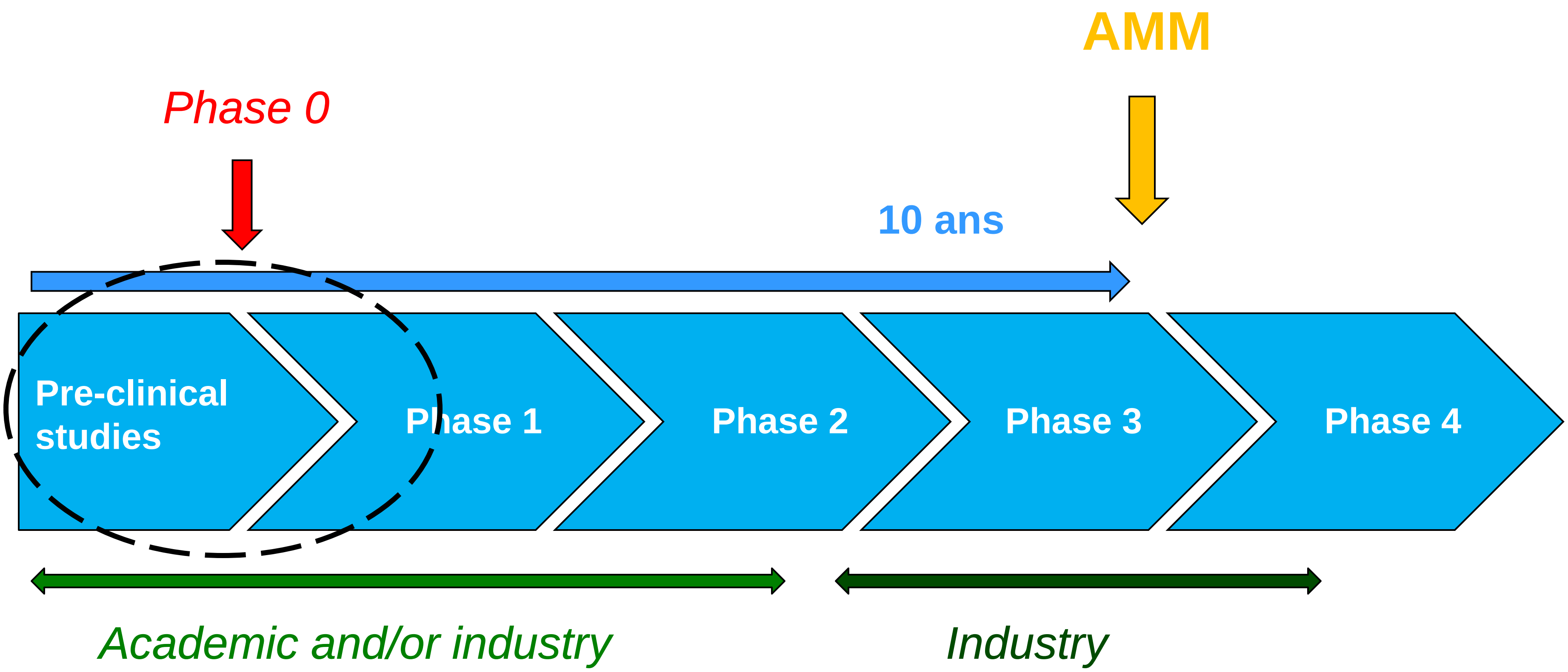
Medical validation



Radiopharmaceutical

Development of a radiopharmaceutical

A long process

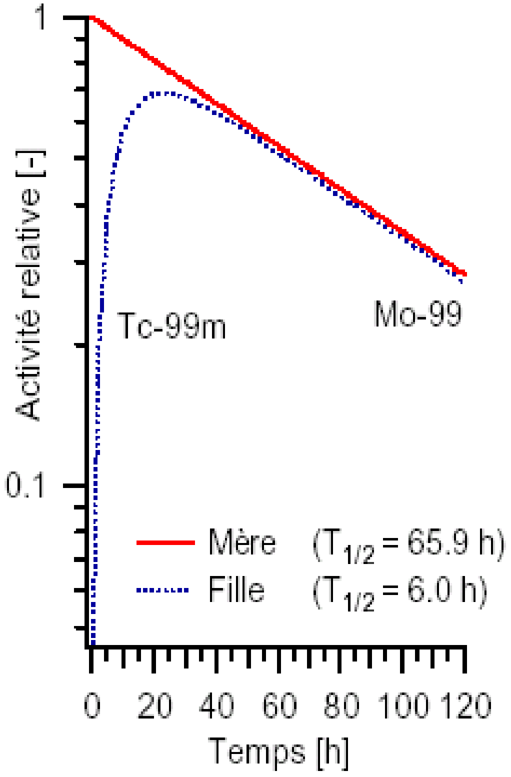


Radionuclide production

Radionuclide from generator

In some cases, the radionuclide of interest can be obtained through the decay of its mother nuclei.

Particularly interesting if $T_{1/2}$ of the mother nuclei >> $T_{1/2}$ of the daughter nuclei. → **Secular equilibrium**



A generator is a source of radionuclide available on site at demand for several days or weeks

→ No logistic constraints

Radionuclide from generator

Several generators exist:

^{99}Mo/ ^{99m}Tc	**2.7d /6h**	**most used in the world**
^{82}Sr /^{82}Rb	25.5d/1.3mn	used in USA for cardiology
^{68}Ge/^{68}Ga	271d /68mn	β+
^{225}Ac/^{213}Bi	10 d / 45mn	α
^{212}Pb/^{212}Bi	10,6h / 60mn	α
^{188}W/^{188}Re	69j/16.9h	β–
^{44}Ti /^{44}Sc	60 ans/ 4h	research
^{72}Se/^{72}As	8.4 j/26 h	research

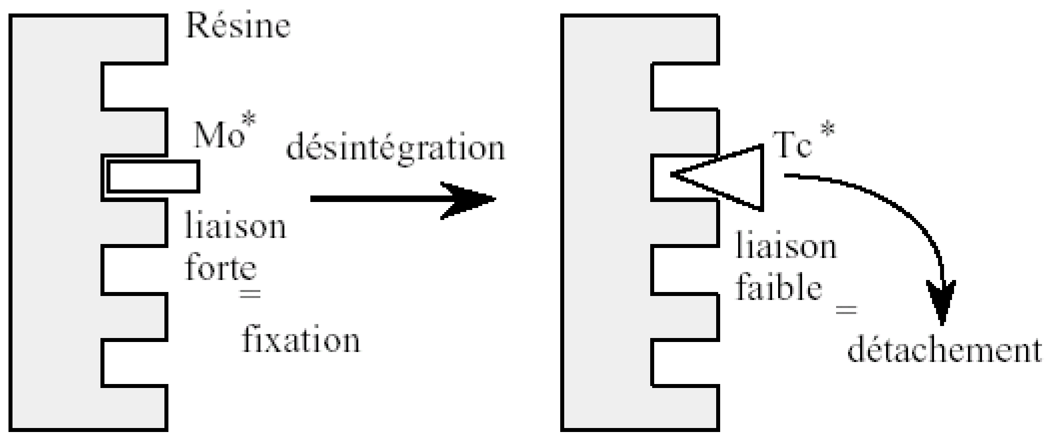
……

A generator example: ^{99}Mo/ ^{99m}Tc

$$ {}^{99}_{42}Mo \xrightarrow[T_A=67\ h]{} {}^{99m}_{43}Tc \xrightarrow[T_B=6\ h]{} {}^{99}_{43}Tc \xrightarrow[T_C=2{,}1.10^5\ ans]{} {}^{99}_{44}Ru $$

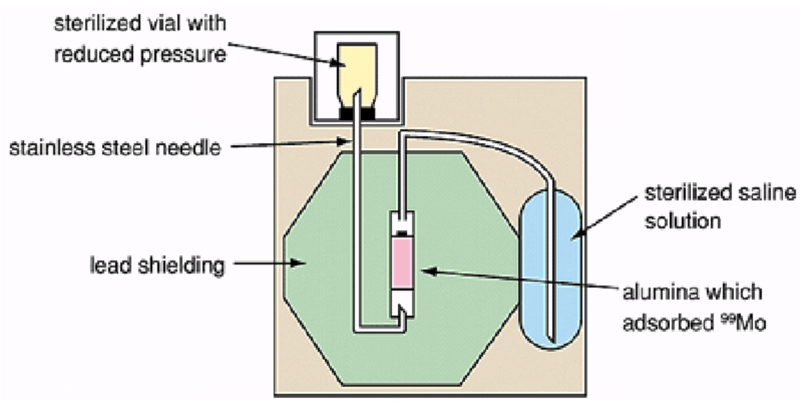
Schéma de principe :

Mo is adsorbed on a resin



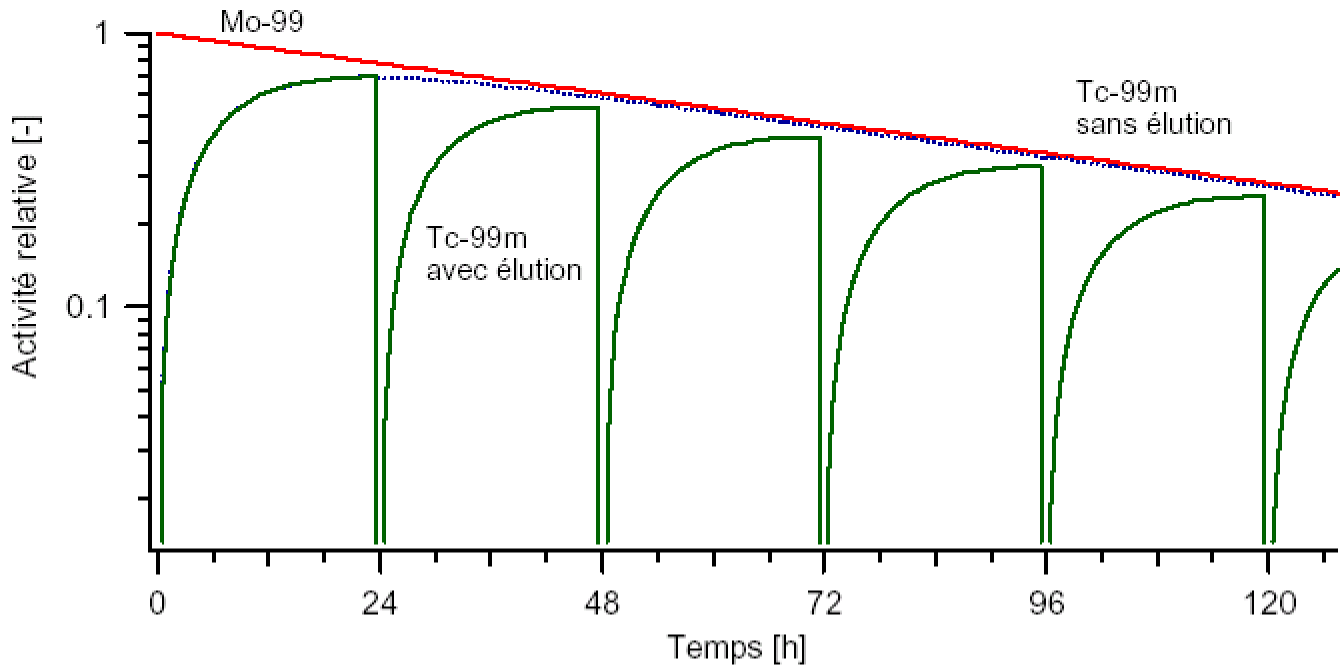
Tc-99m obtained through the decay of Mo is loosely bound to the resin.

Tc-99m is recovered by eluting the resin with NaCl 0.9%



an example of the structure of a generator on the market

A generator example: $^{99}Mo/ ^{99m}Tc$



Every 24 h, the maximum activity can be recovered

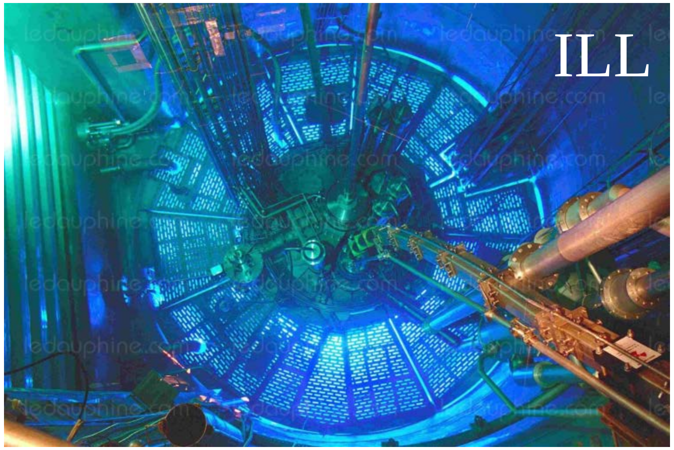
After one week, the total activity is divided by a factor 5.8.
Generator must be changed

Use of research reactor

Radionuclide production

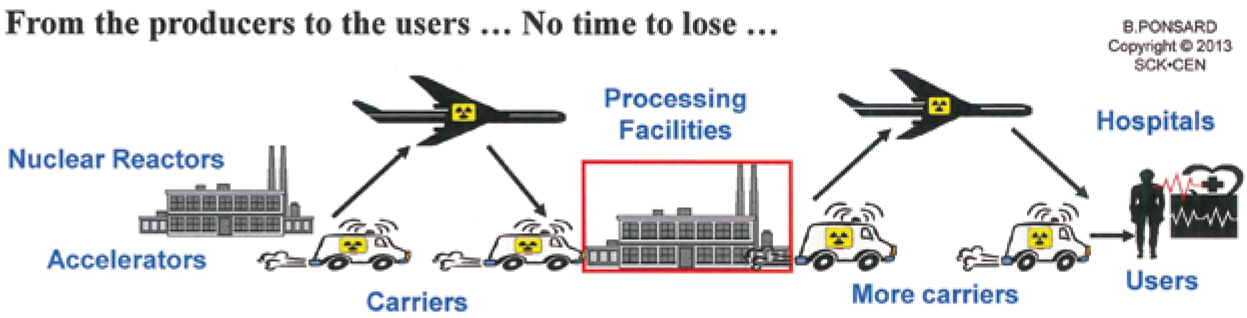
Reactors:

- neutron induced reaction
- Fission

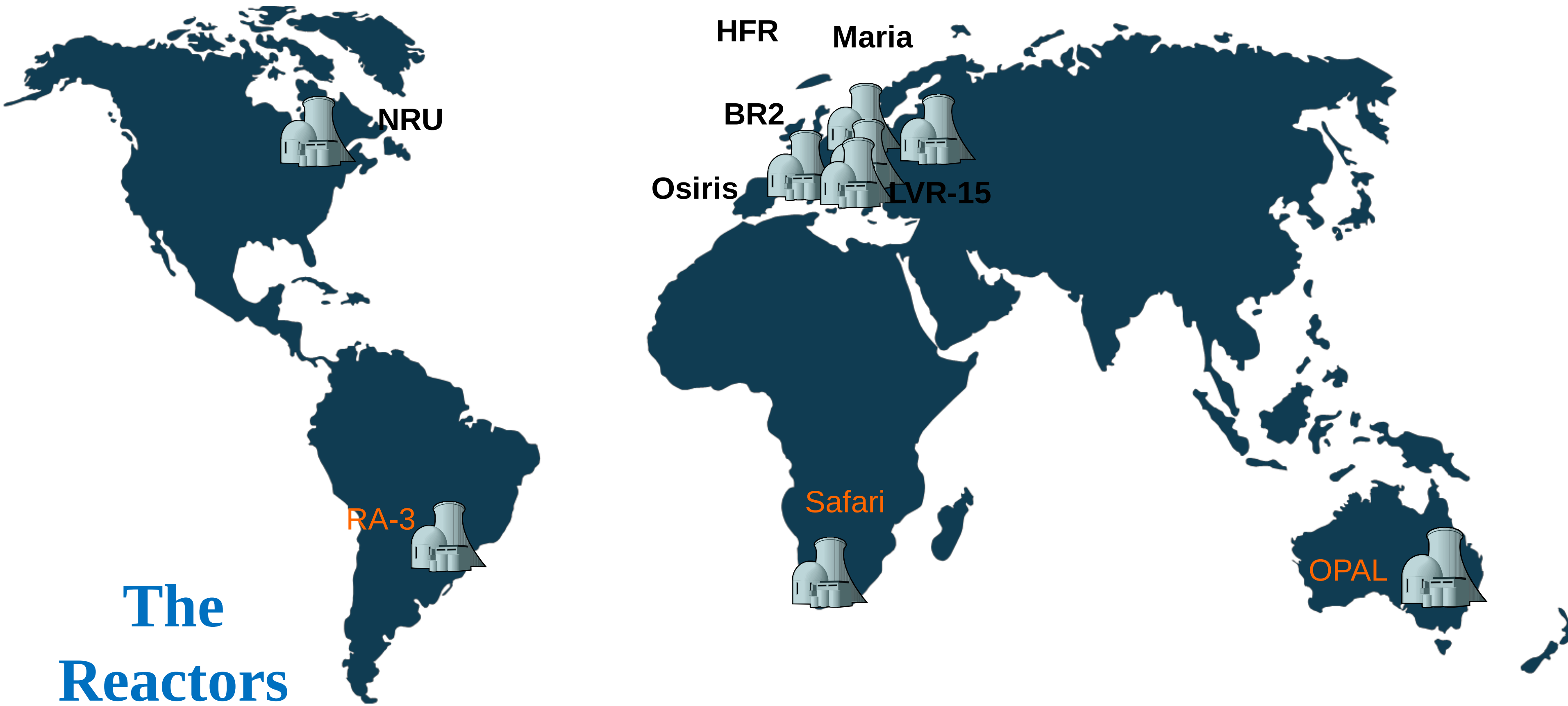


The number of this kind of facility is limited (expensive, dealing with sensitive material, …)

→ centralized production



Reactor production: Mo99



The Reactors

Mo-99	LEU - OPAL, RA-3, SAFARI
TARGETS	**HEU – BR2, HFR, LVR-15, Maria, NRU, Osiris**

Specific activity

Specific activity is **the measure of the activity per mass** (GBq/mg)

The number of selective site targeted by antibodies or peptide on cell is often limited → **high specific activity is required.**

In reactor, two main reaction mechanisms:

- **Fission**

  lots of radio isotopes are produced → Complex chemistry step.

  High specific activity

- **Neutron induced reaction:**

  Often low specific activity product (target and product are isotopes of the same element)

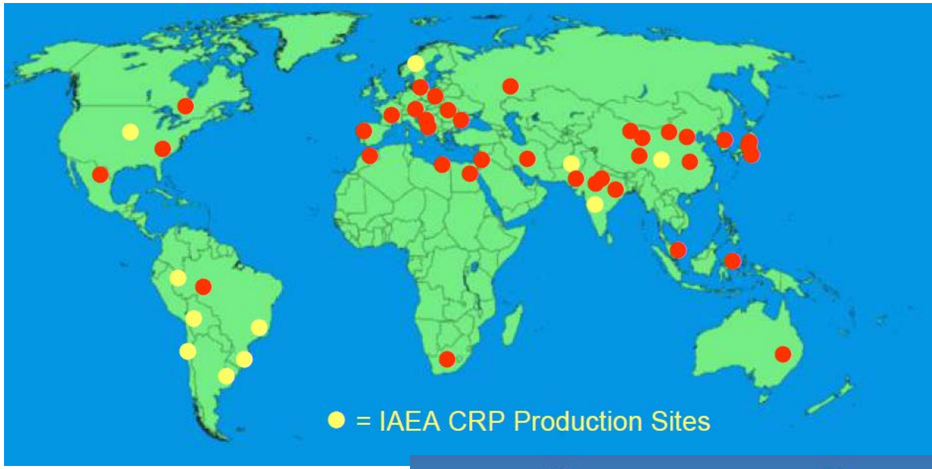
Lu-177: Direct production route

^{176}Lu $\xrightarrow{(n,\gamma)}$ ^{177}Lu + ^{177m}Lu

enrichie — σ = 2090 barn — 6,647 j — 160.44 j

Advantages:

- High production yield
- Large number of production site
- Easy chemical separation



> 1 X 10^{13} NEUTRONS/CM^{2}/SEC

Drawbacks:

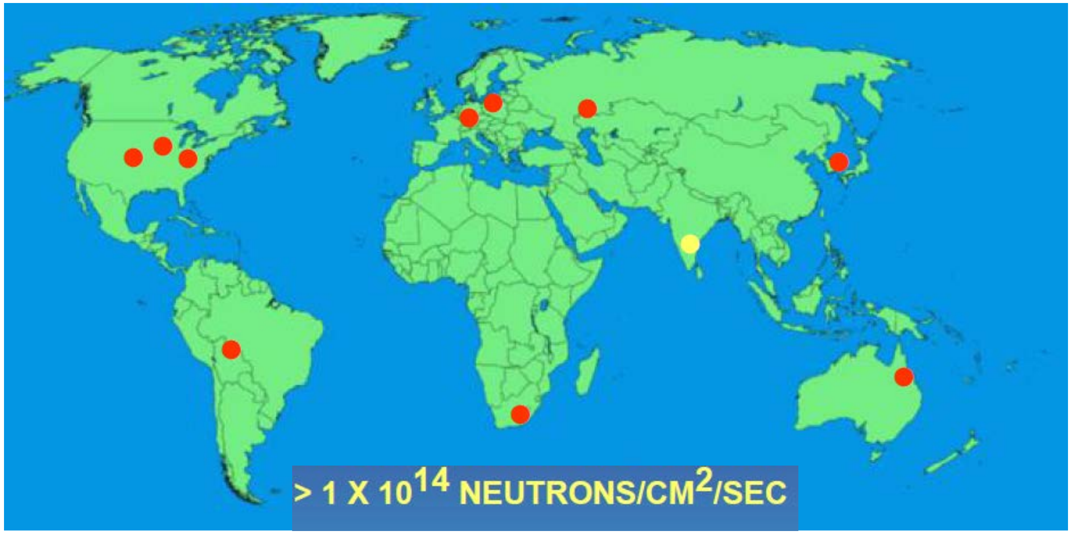
- Low specific activity (<**30 Ci/mg Lu)**
- co-production of long lived ^{177m}Lu

  → potential waste management issue in hospital

With a ^{177m}Lu contamination of the order of 0,02%, a typical dose of 7 - 9 GBq, approximately 1.4 – 1.8 MBq ^{177m}Lu

Lu-177: Indirect production route

^{176}Yb enrichie —(n,γ), σ = 2,85b barn→ ^{177}Yb 1,9 h —β→ ^{177}Lu 6,647 j



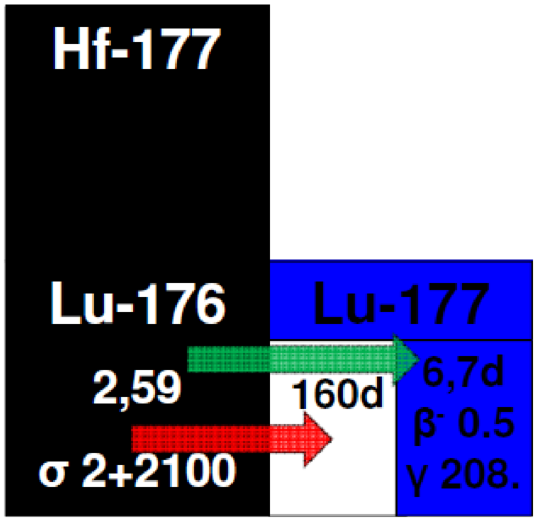
Advantages:

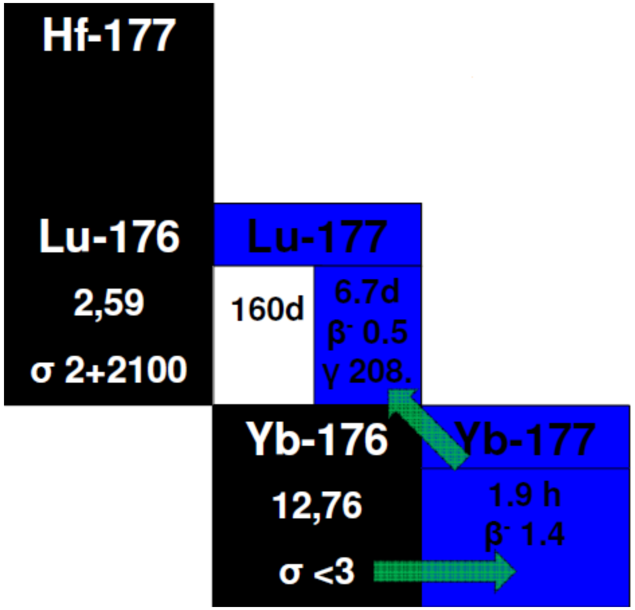
- No stable Lutetium
- No ^{177m}Lu

Drawbacks:

- Low production yield → High flux reactor is required.
- Chemical separation is complex (Yb / Lu separation)

Which route is the best one?





Depends :

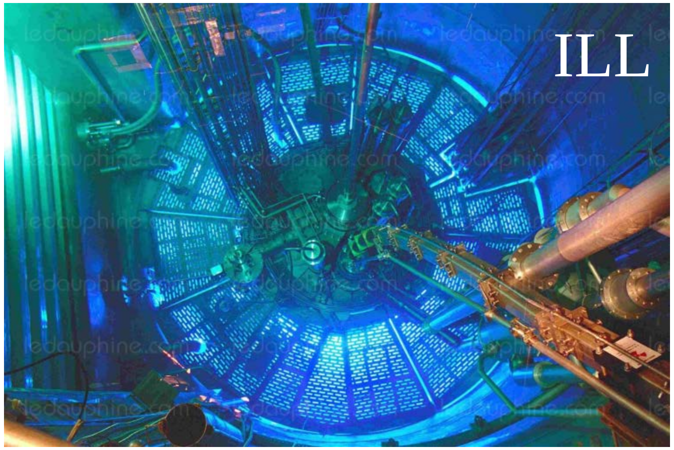
If one wants the best purity → indirect route

If one wants low prices to be able to make it available worldwide
→ direct route.

Radionuclide production

Reactors:

- neutron induced reaction
- Fission



Accelerators

- Electrons to produce gamma
- Proton, deuterons, alpha particles
- Heavy ions
- Secondary neutrons

Figure 2. A compact superconducting accelerator used for radioisotope production

Different types and sizes

^{82}Sr, ^{117m}Sn,...

^{67}Ga, ^{111}In, ^{123}I,
^{201}Tl, ^{68}Ge

^{11}C, ^{13}N,
^{15}O, ^{18}F,
^{64}Cu

11 MeV

30 MeV

70 MeV

Linear accelerator
160 MeV

^{82}Sr, ^{117m}Sn, ^{225}Ac...

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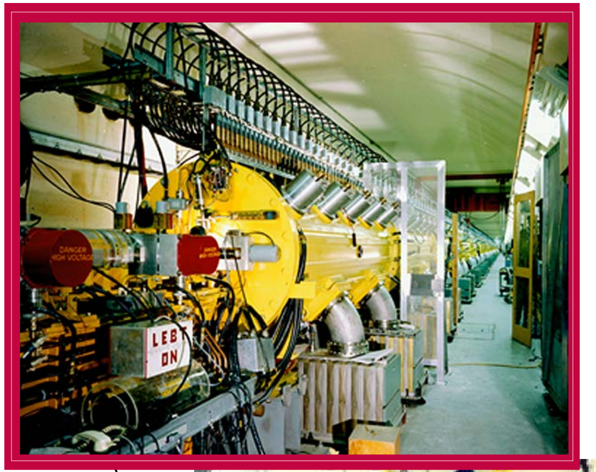
Long lived Radionuclide: Centralized production

Sr-82 ($T_{1/2}$ = 25.5 d):

- LANL, USA –100 MeV, 200µA
- BNL, USA –200 MeV, 100µA
- INR, Russia –160 MeV, 120µA

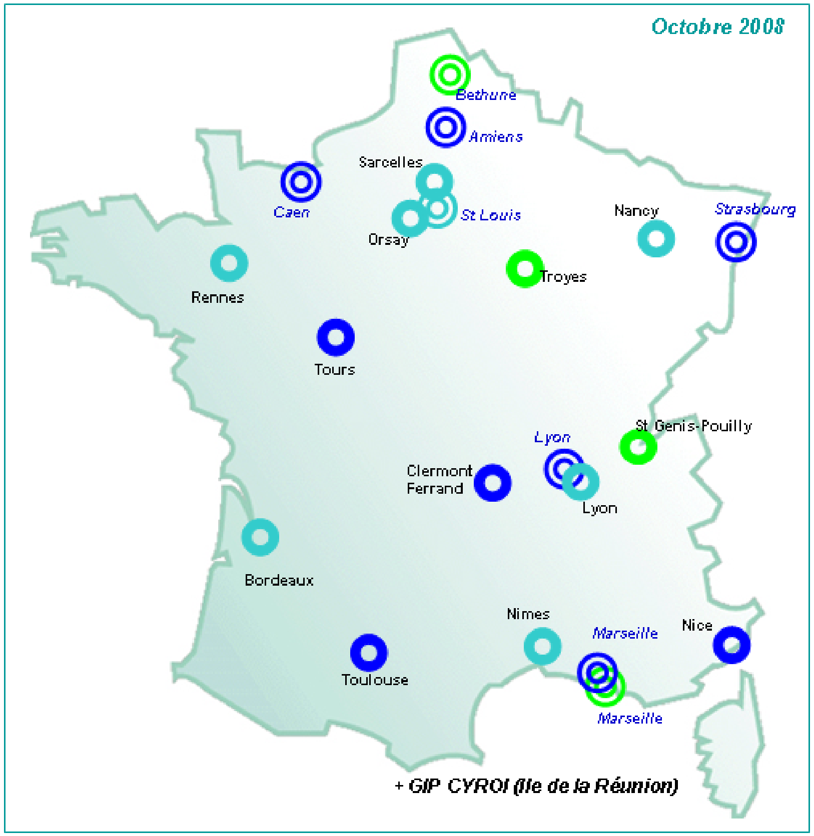


BLIP

- iThemba, South Africa –66 MeV, 250µA
- TRIUMF, Canada –110 MeV, 70 µA
- ARRONAX, France – 70 MeV, 2*100µA

Short lived radionuclide: localized production

(^{18}F production in France)



iba Molecular

Orsay
Rennes
Sarcelles
Bordeaux
Lyon
Nimes
Nancy
Paris (St Louis)

CYCLOPHARMA LABORATOIRES

Clermont-Ferrand
Nice
Toulouse
Tours
Strasbourg
Amiens
Lyon
Caen
Marseille

Advanced Accelerator Applications

St Genis-Pouilly
Troyes
Béthune
Marseille

Opérationnel — *Projet en cours*

A large number of accelerator available worldwide

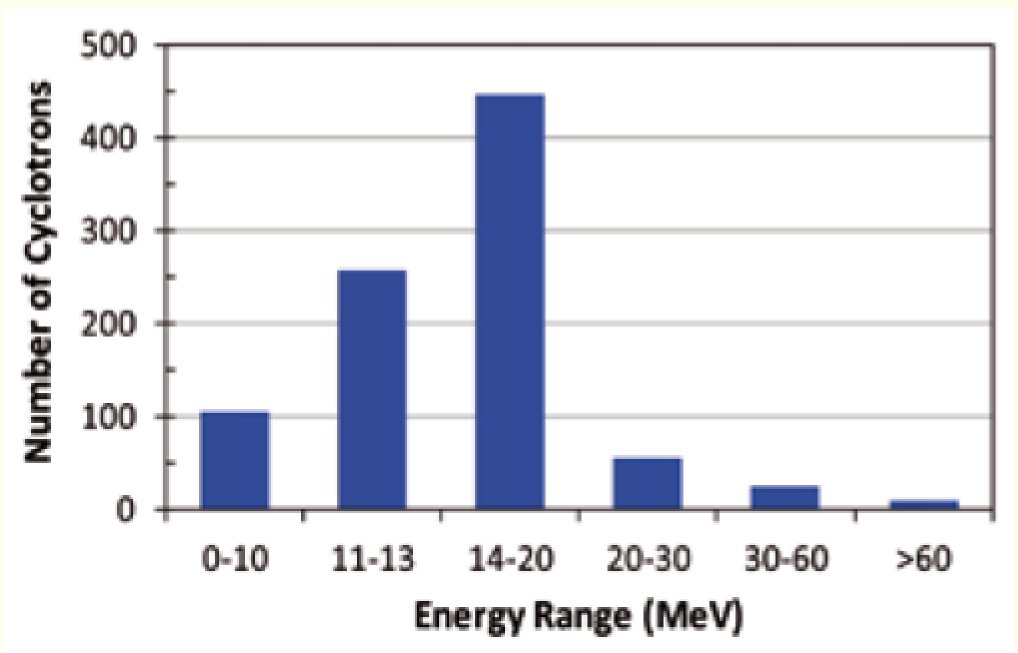


Figure 2.6. Number of cyclotrons operational worldwide in 2013 against their maximum proton beam energy.

NUPECC, Nuclear physics for medecine, report 2014

Several 70 MeV cyclotrons under construction by both

Research entities:

LNL –Italy

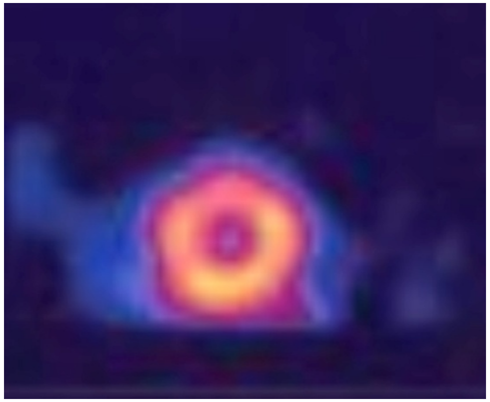
Private entities:

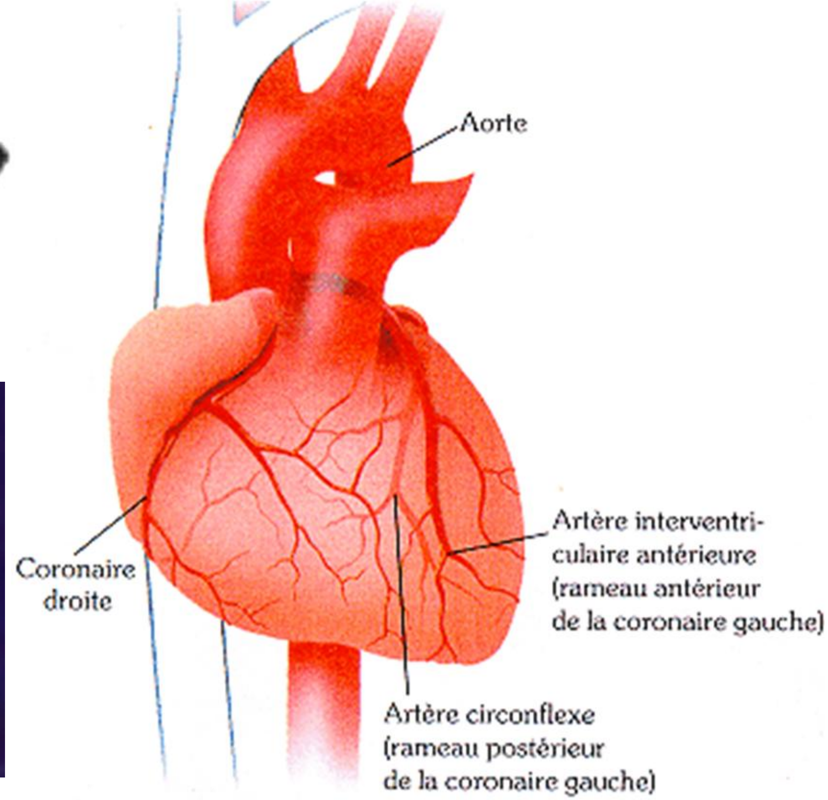
Zevacor (USA)

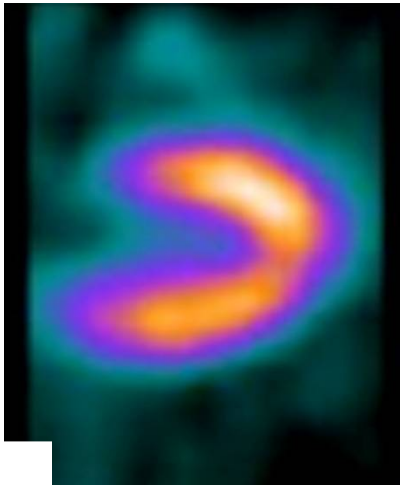
CDNM (Russia)

Multi-particle accelerators now available from accelerator providers (30 MeV and 70 MeV)

Rubidium-82 (^{82}Rb): PET imaging in cardiology







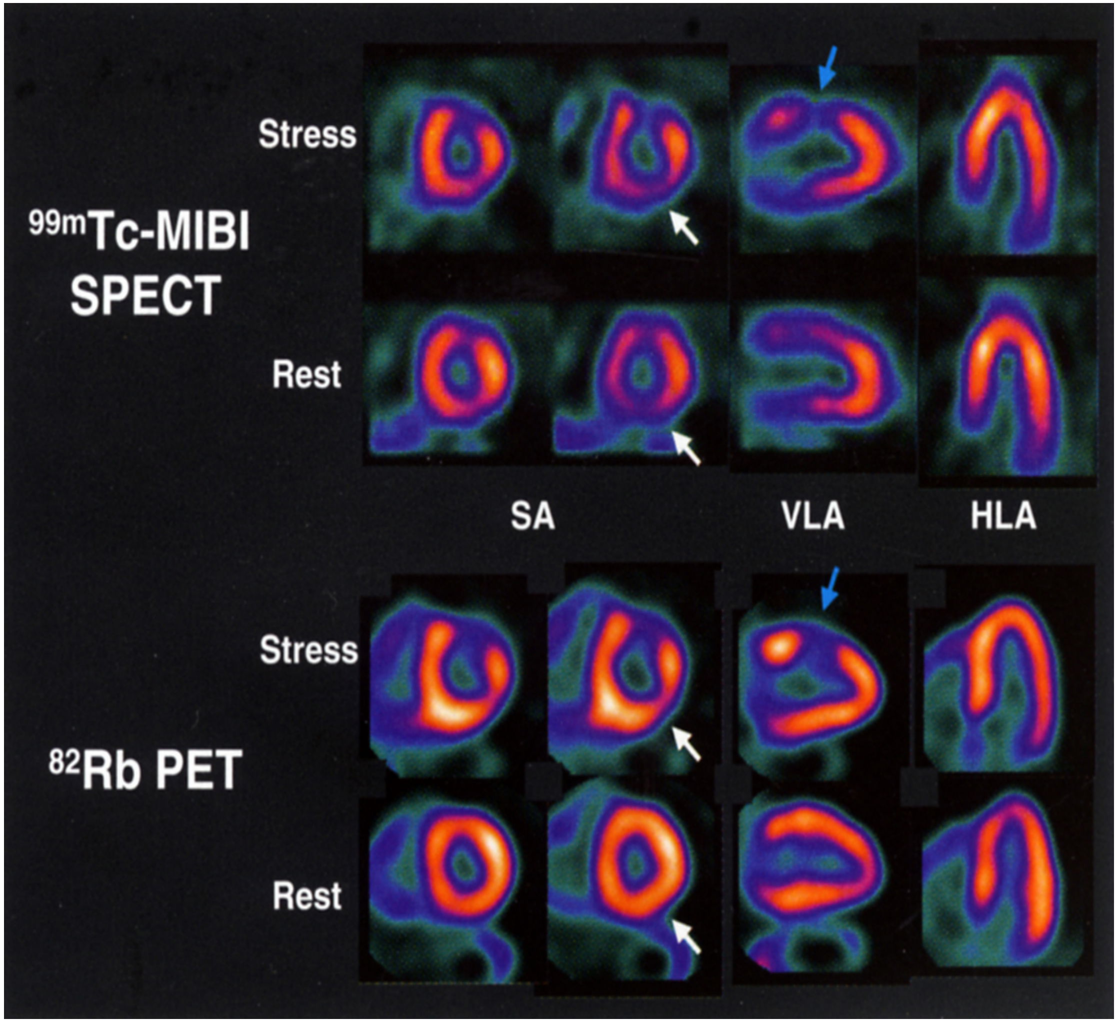
Rb 82 (40 – 60 mCi) → 90-120 sec (rest)

Rb 82 (40 – 60 mCi) → 90-120 sec (stress)

Transmission	90-120 sec	Gated Rest	Dipyridamole Adenosine	90-120 sec	Gated Stress	Transmission
4-10 minutes		5 minutes	4-6 minutes		5 minutes	4-10 minutes

9 Di Carli MF. Major achievements in nuclear cardiology:XI. Advances in positron emission tomography. J Nucl Cardiol. 2004;11:719-732

Rubidium-82 (82Rb): PET imaging in cardiology

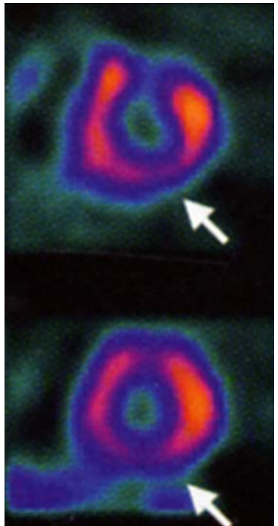


Same patient

Different results

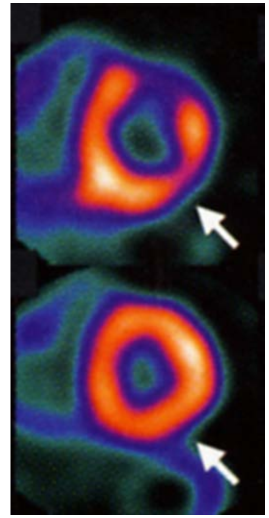
Rubidium-82 (^{82}Rb): PET imaging in cardiology

^{99m}Tc-MIBI SPECT



Bad corrections

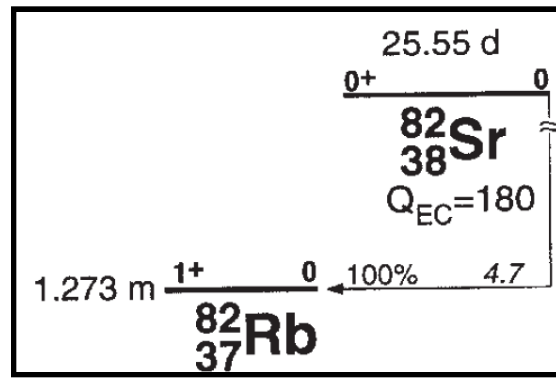
^{82}Rb-PET



D. Le Guludec et al, Eur J Nucl Med Mol Imaging 2008; 35: 1709-24

Several advantages:

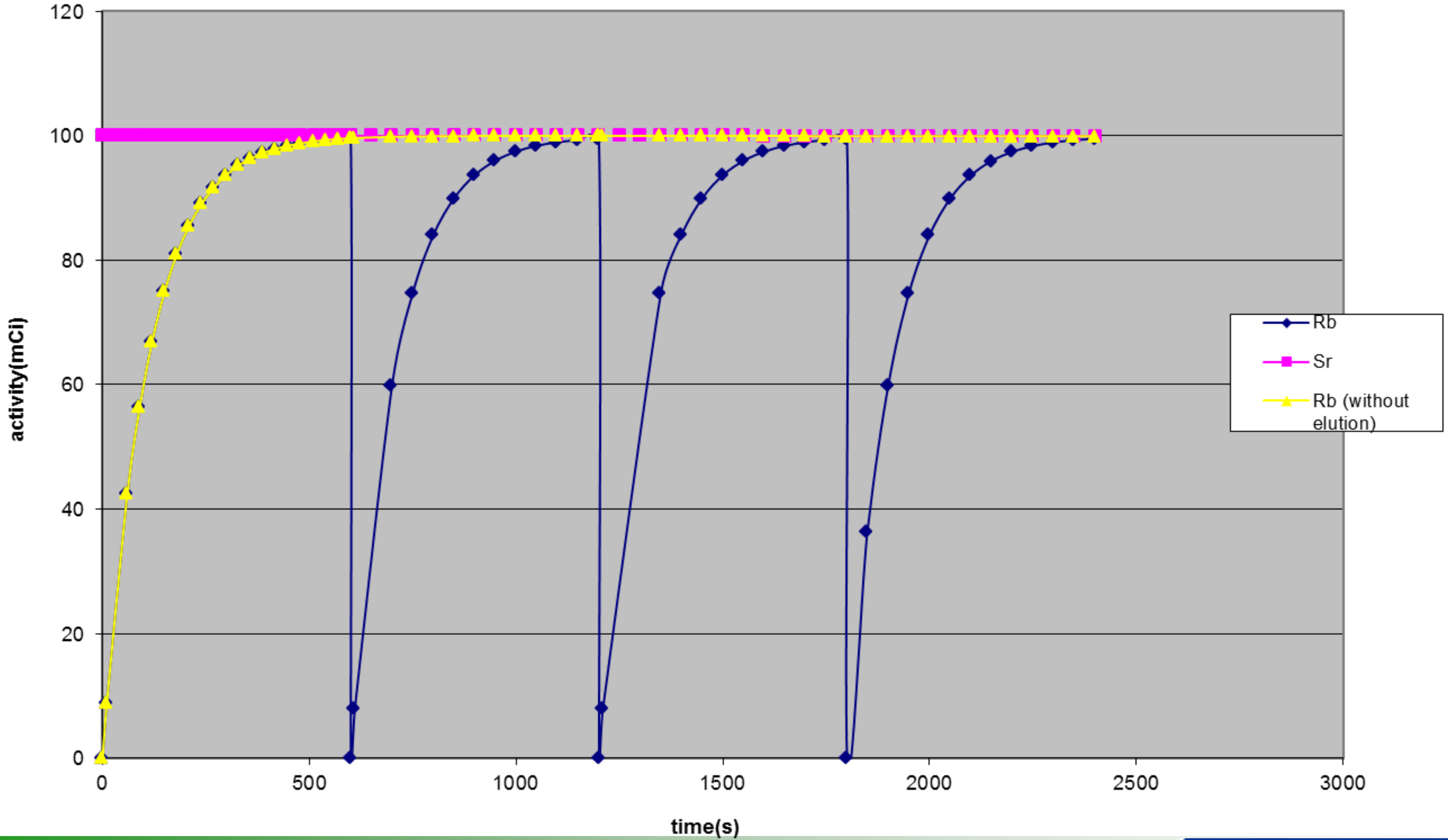
- Better corrections
- Quantification
- Shorter duration of the exam
- Lower dose to patient



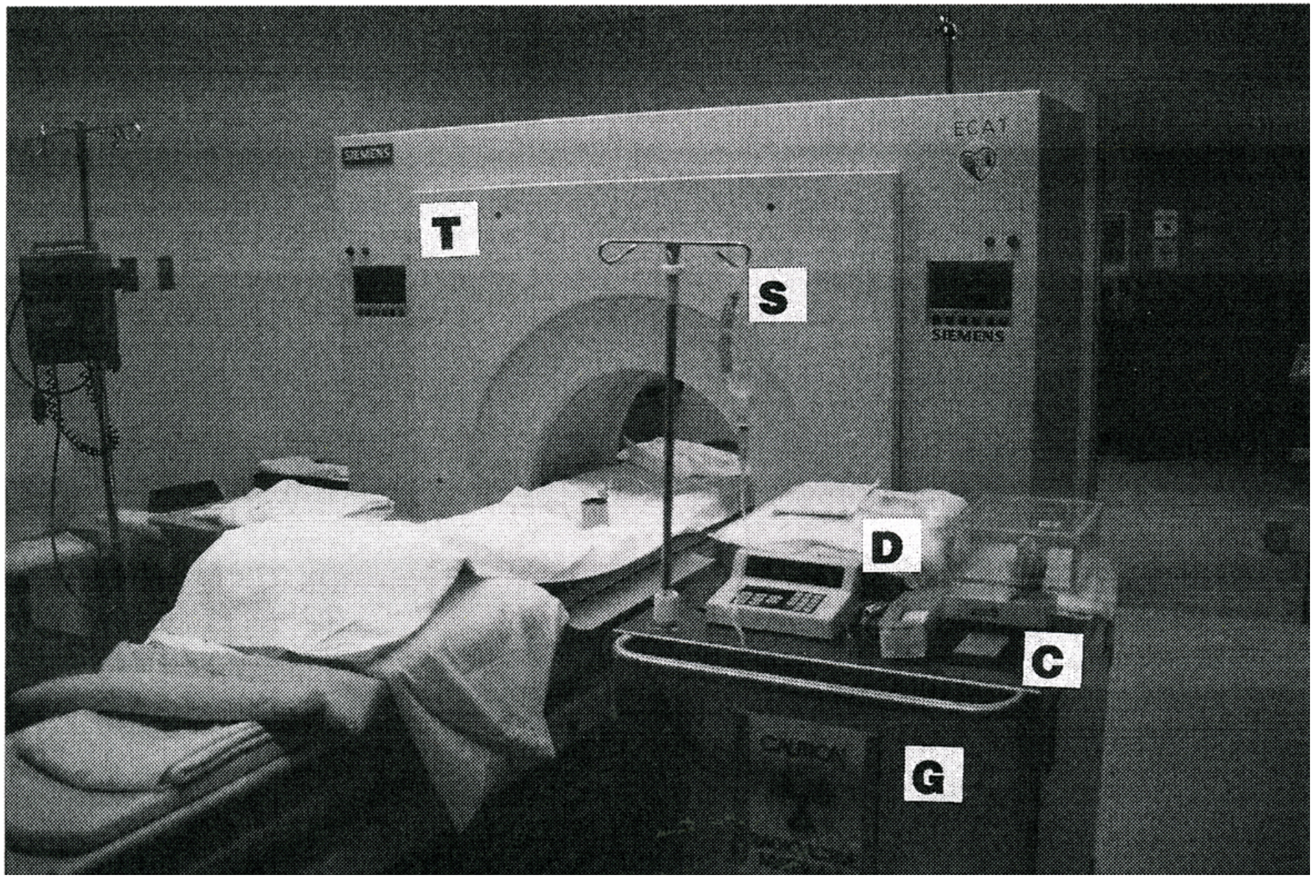
^{82}Sr/^{82}Rb generator

Rubidium-82 (^{82}Rb): PET imaging in cardiology

$$^{82}Sr \xrightarrow{\lambda_1} {}^{82}Rb \xrightarrow{\lambda_2} {}^{82}Kr \text{ (stable)}$$



Rubidium-82 (^{82}Rb): PET imaging in cardiology



Generator ^{82}Sr/^{82}Rb

Infusion system

T = PET Scanner
S = NaCl solution
G = Chart containing the Sr82/Rb82 generator
D = Automatic infusion system
C = Control computer

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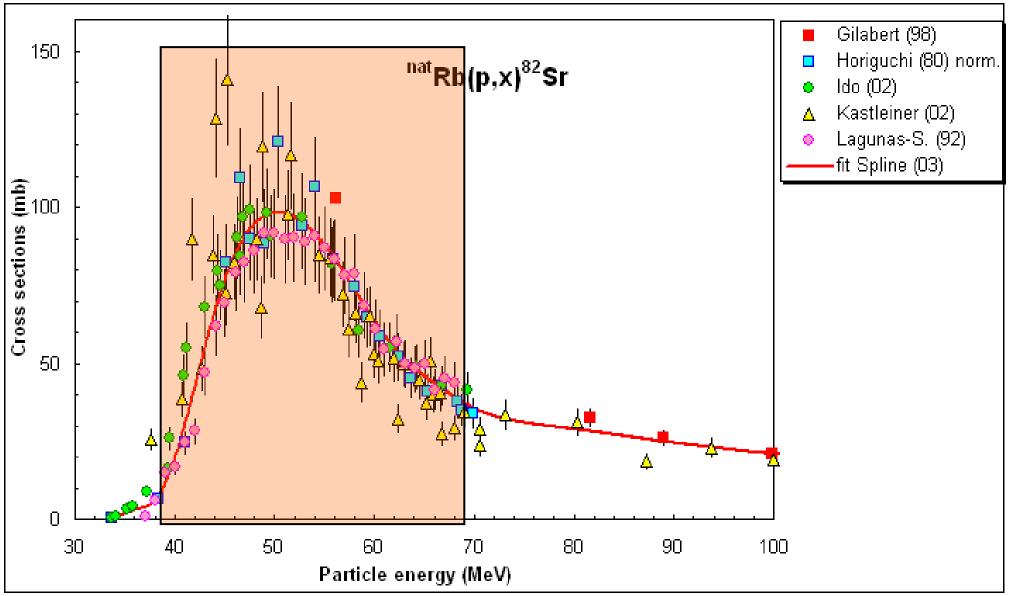
^{82}Sr production

• Reaction and Cross section $^{nat}Rb + p \rightarrow {}^{82}Sr + x$



Low cross section

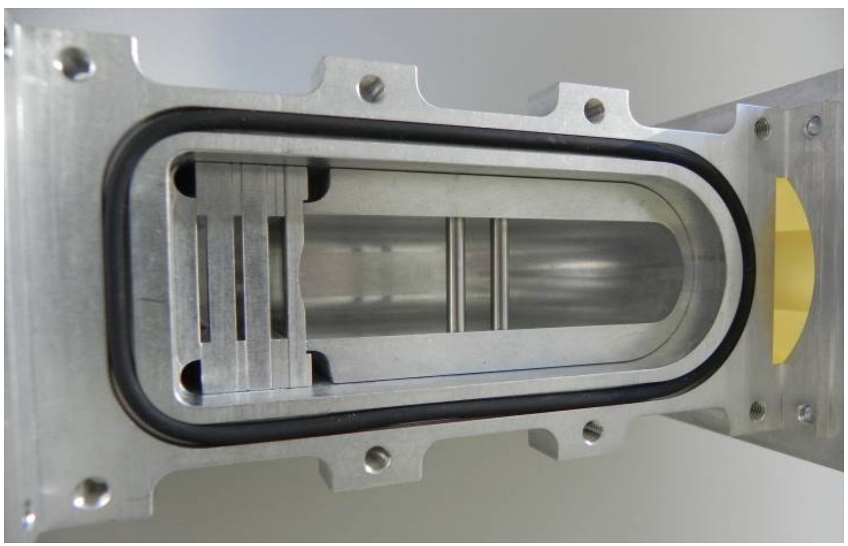
Energy range of interest
40 MeV-70 MeV

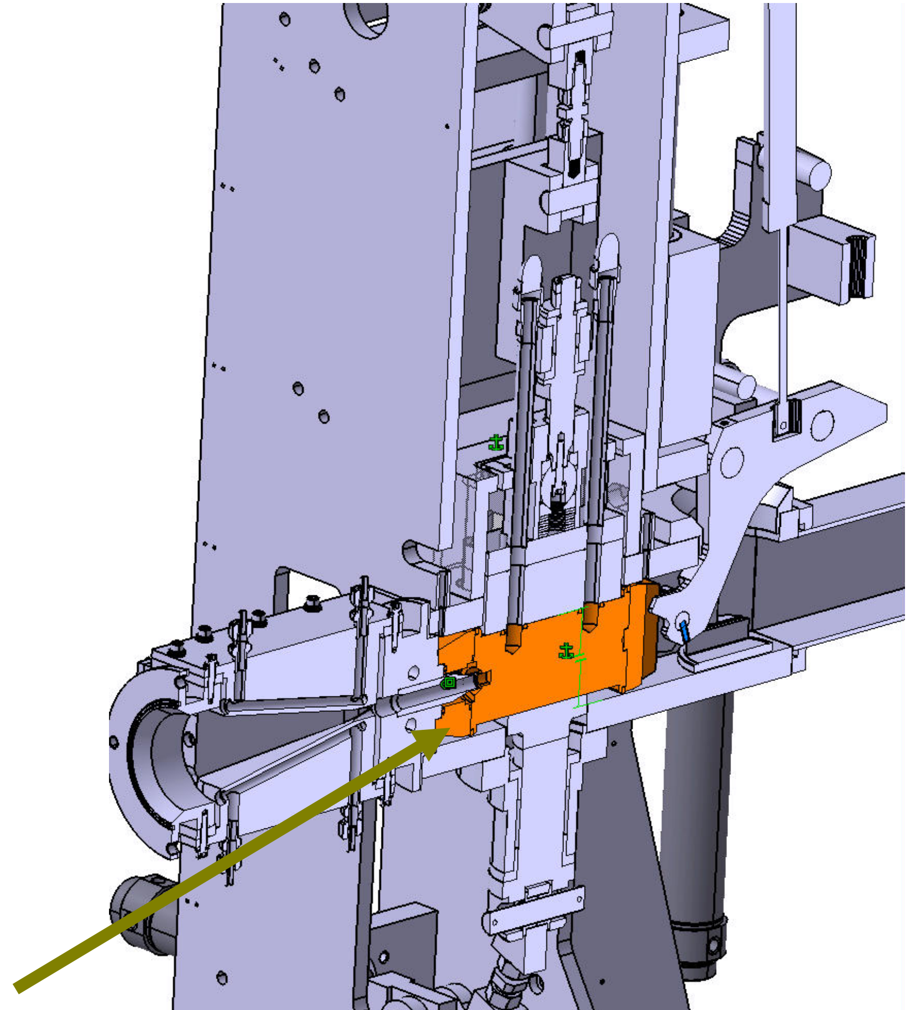
Production needs high energy machines and high intensity beams

ARRONAX irradiation station

Pressed pellet of RbCl

Encapsulated RbCl

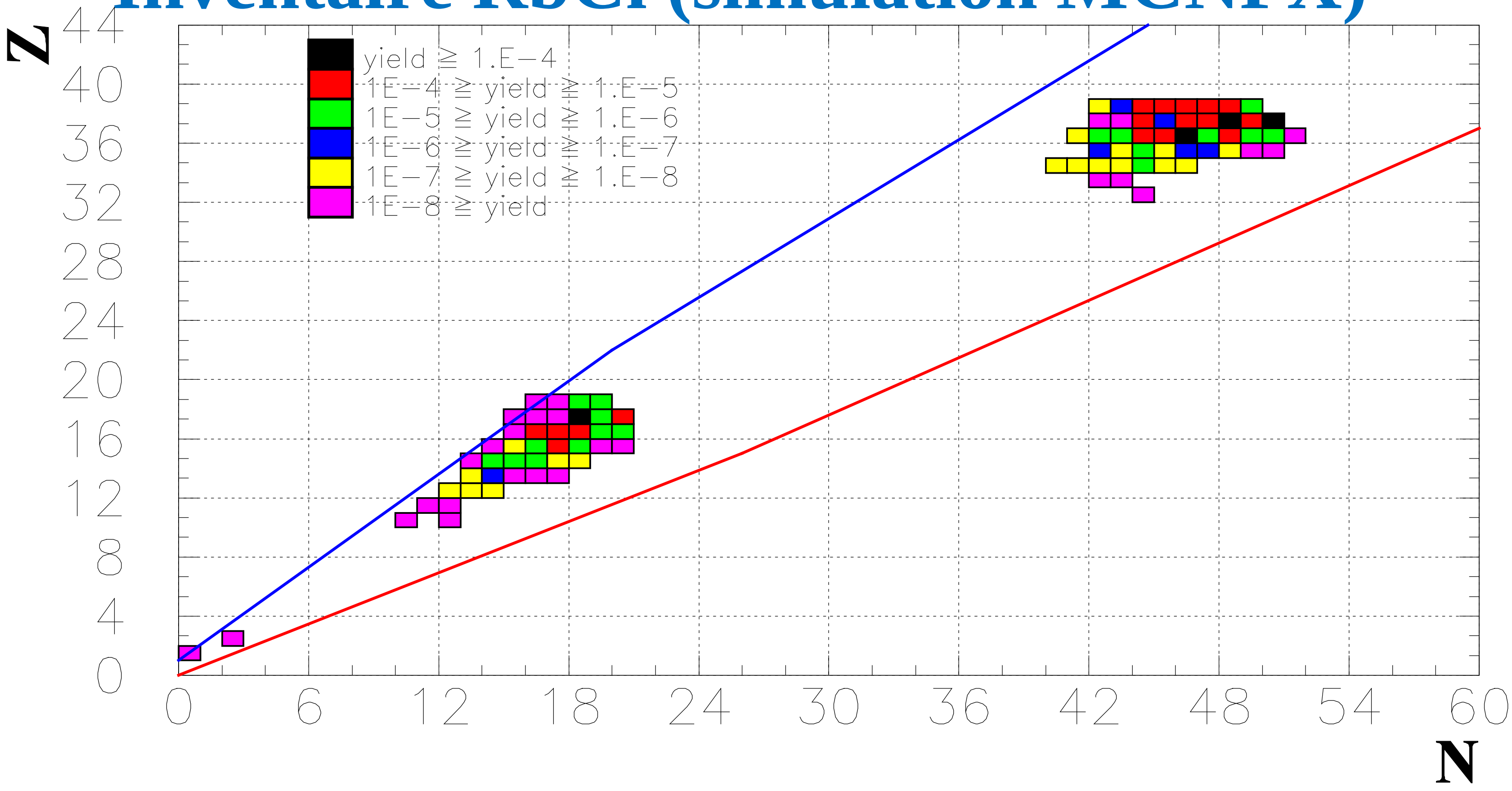




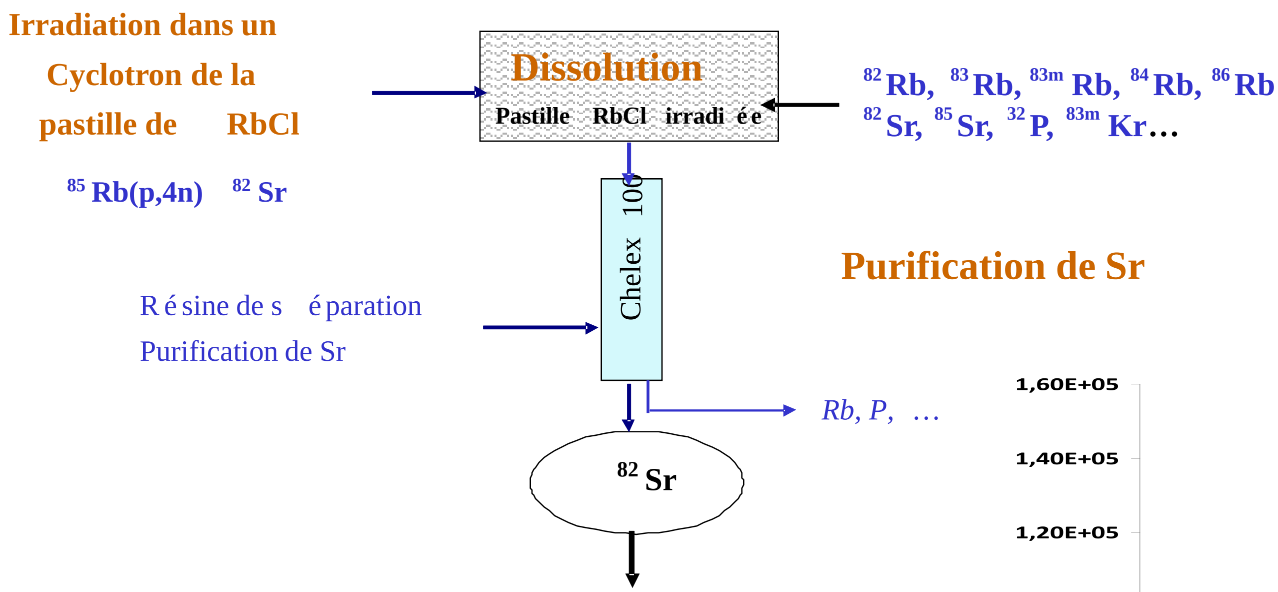
Rabbit

We have achieved 100µA on RbCl target for 100 h @ 70 MeV

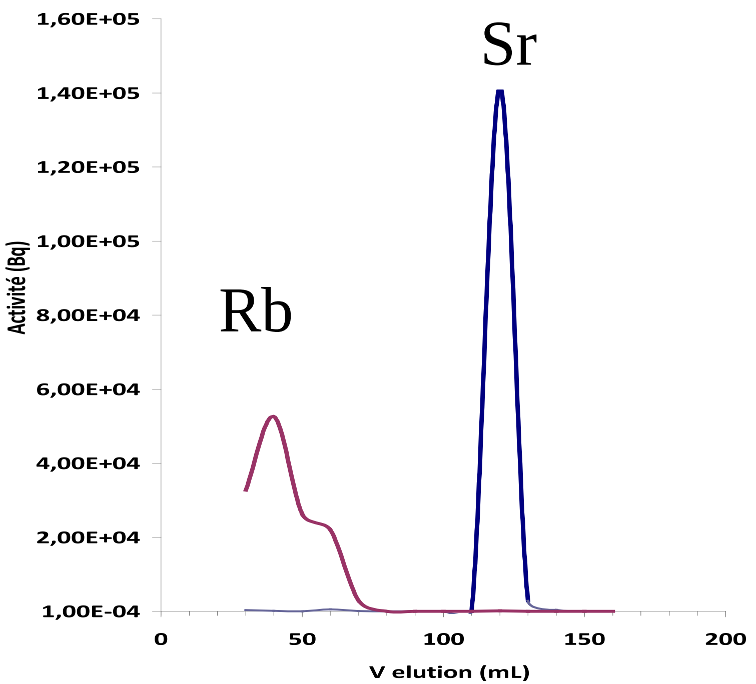
Inventaire RbCl (simulation MCNPX)



Extraction and purification



Purification de Sr



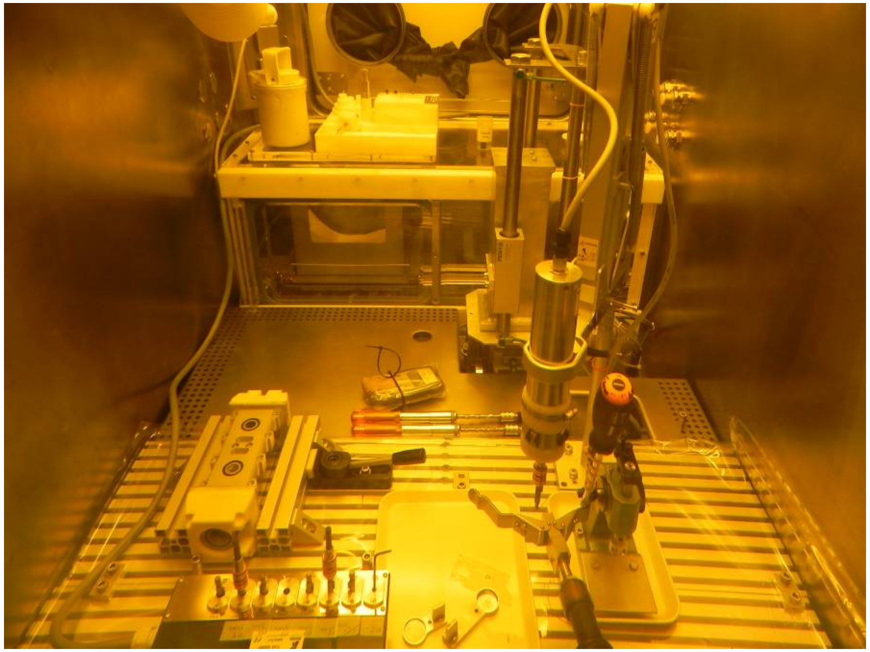
Good separation

Reproducibility verified

Extraction yield = 92.9 % ± 3.7% (k=2)

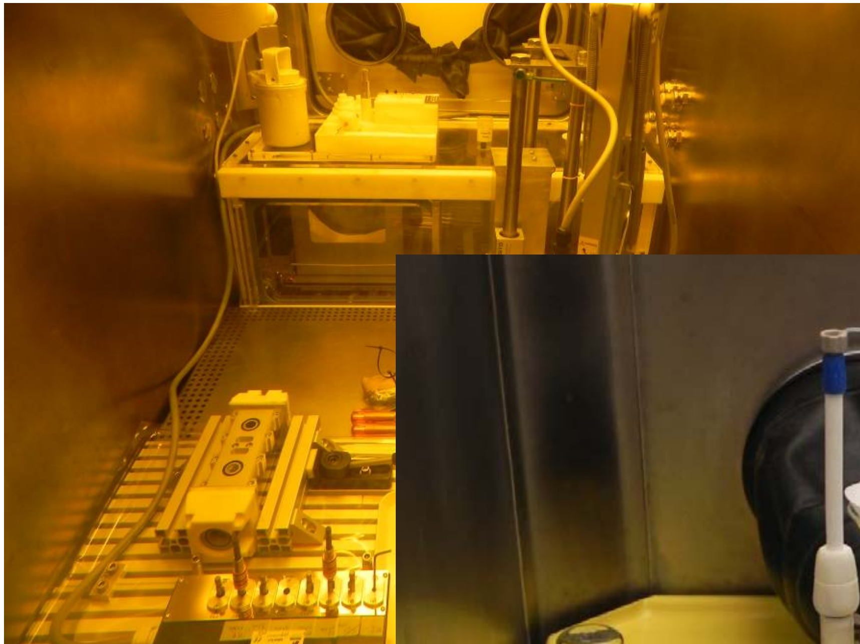
Purity of the product fulfills regulatory requirements.

Processing in hot cells

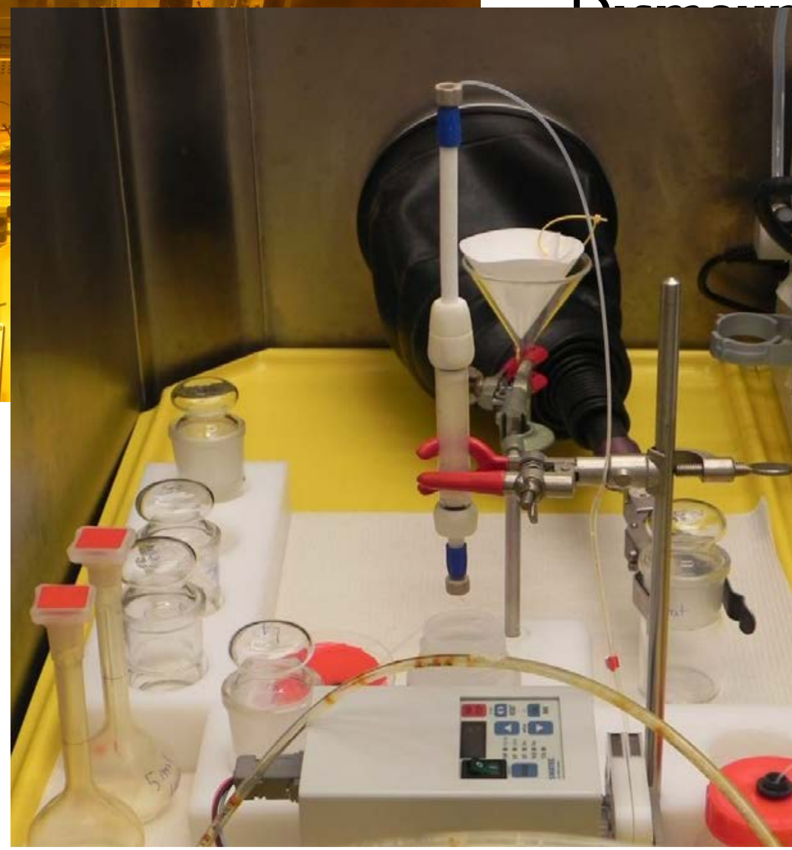


Dismounting the rabbit

Processing in hot cells

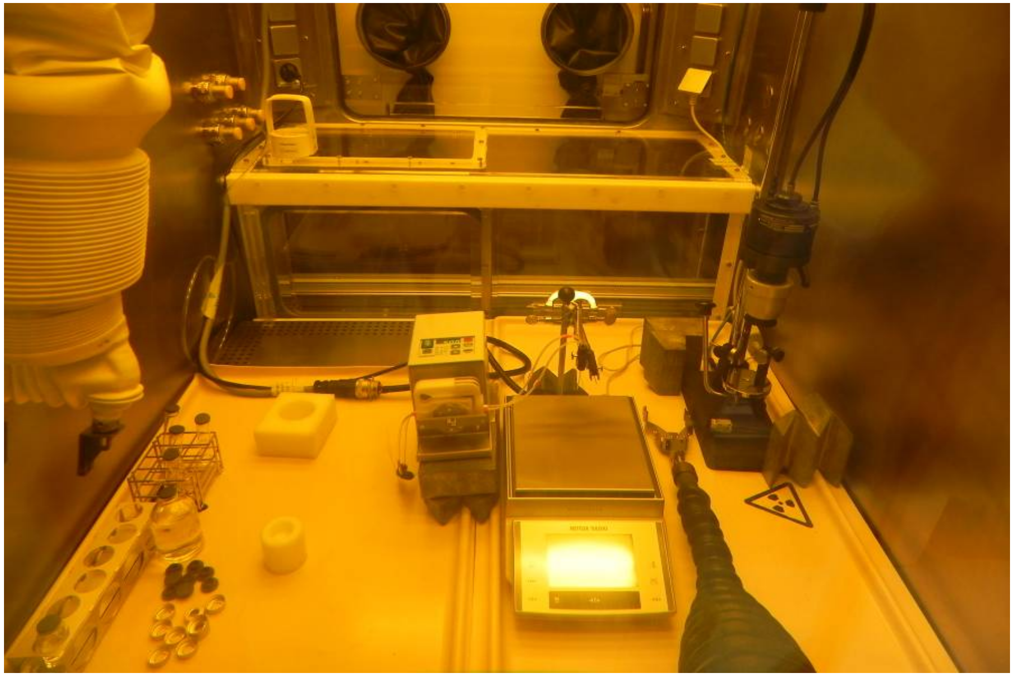


Dismounting the rabbit



Chemical separation

Dispensing and quality control



Quality control:

- γ -Spectroscopy
- ICP-OES

Shipment

Remaining Challenges

- Alternative production route for well established radionuclides
- Use of high LET particles (alpha emitters or Augers emitters)
- New isotopes for new concept
- New development in accelerator: linac or compact cyclotrons
- High purity radioisotopes
  Mass separation, Medicis@CERN
- Targetry for high intensity beams/Beam diagnostics/Activation /maintenance
- Neutron production without reactor
- Isotope production using electron beams

Alternative production route for established radionuclide

Different solutions are being explored for Mo99/ Tc99m:

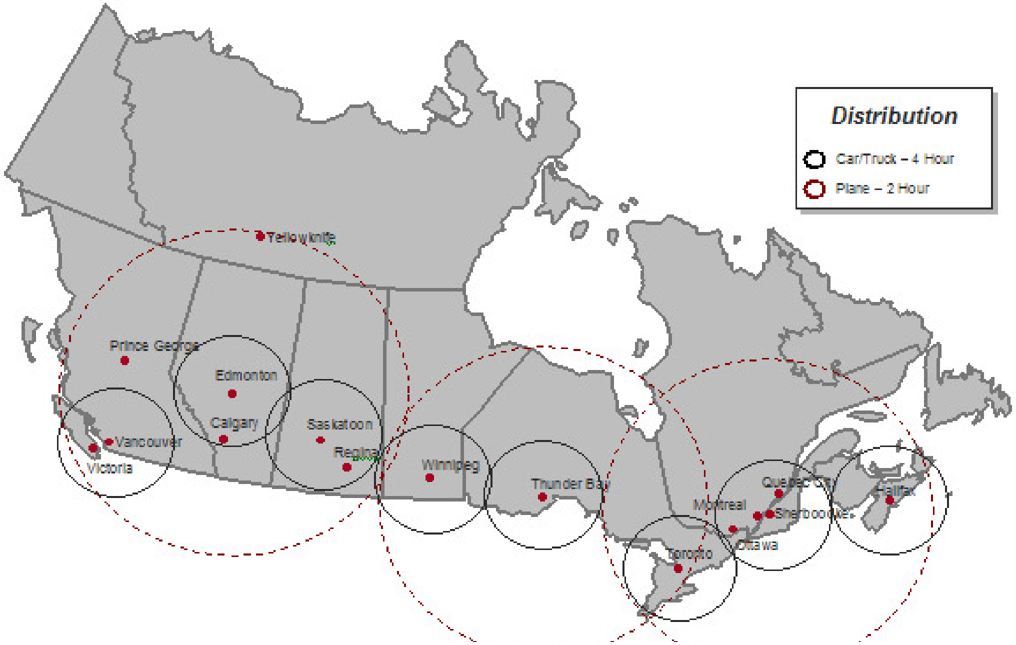
- Optimization of ^{99}Mo/ ^{99m}Tc use in hospital
- Conversion of existing reactors to ^{99}Mo production (OPAL, RA-3,MARIA…)
- Full cost recovery
- New reactors being built (Jules Horowitz in France)
- New processing facility being built (ANSTO in Australia)

^{99m}Tc production in cyclotron

$P + {}^{100}Mo \rightarrow {}^{99m}Tc + 2n$

24 MeV cyclotron

Already tested on patients in **Canada**

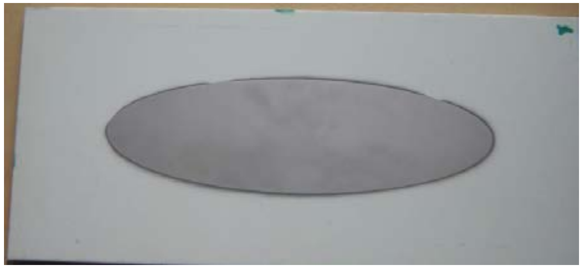


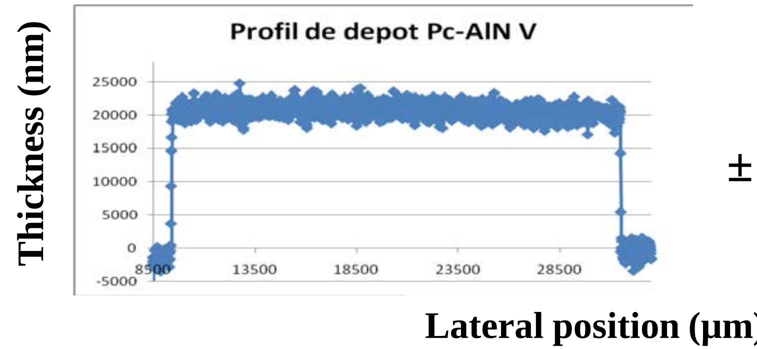
http://www.advancedcyclotron.com/news/ACSI-N

Use of high LET particles

Production route: $^{209}Bi + \alpha \rightarrow {}^{211}At + 2n$

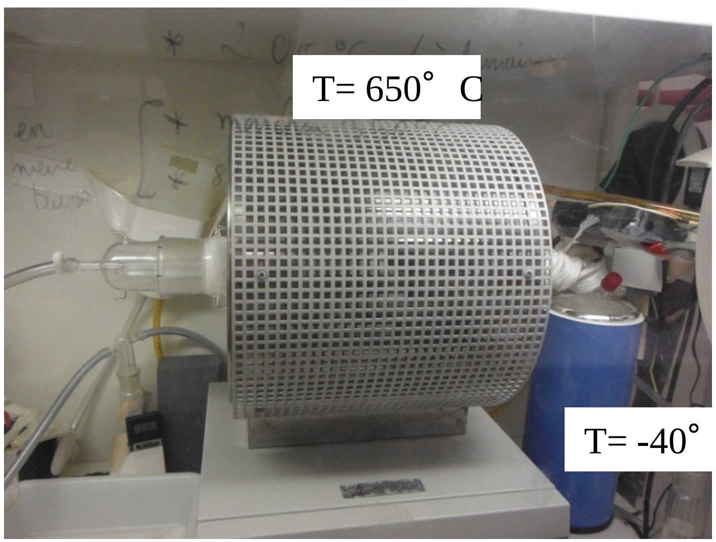
Target preparation (deposition under vacuum)

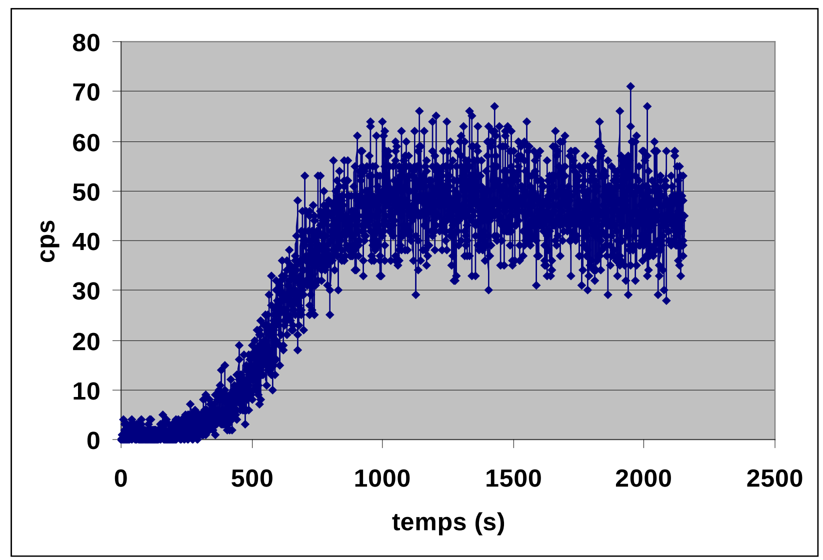




± 5 %

Dry extraction method





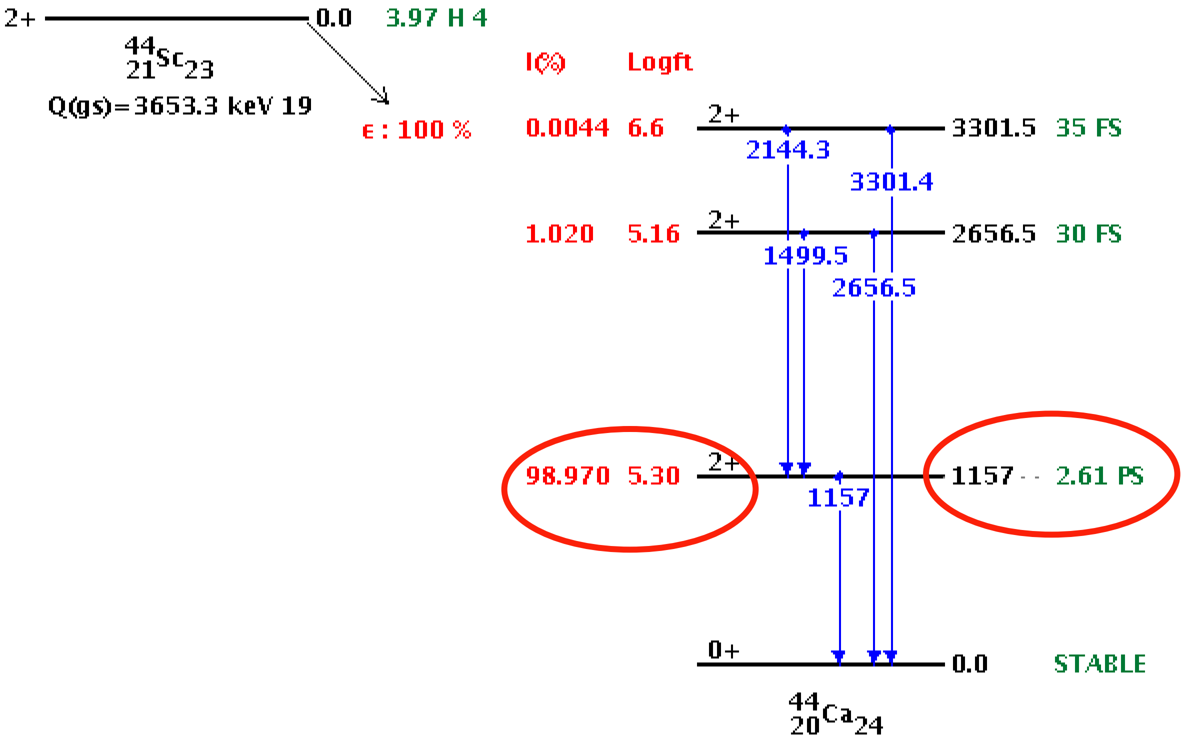
Astatine output: few minutes – extraction time around ≈ 2 h – Extraction yield: >80%

Use newly available radioisotopes for developing new concept

^{44}**Sc**: β+ /γ emitter

$T_{1/2}$=3,97 h

$$^{44}_{21}\mathrm{Sc} \xrightarrow{\beta^+\ 94.3\ \%} {}^{44}_{20}\mathrm{Ca} + e^+ + \nu_e$$



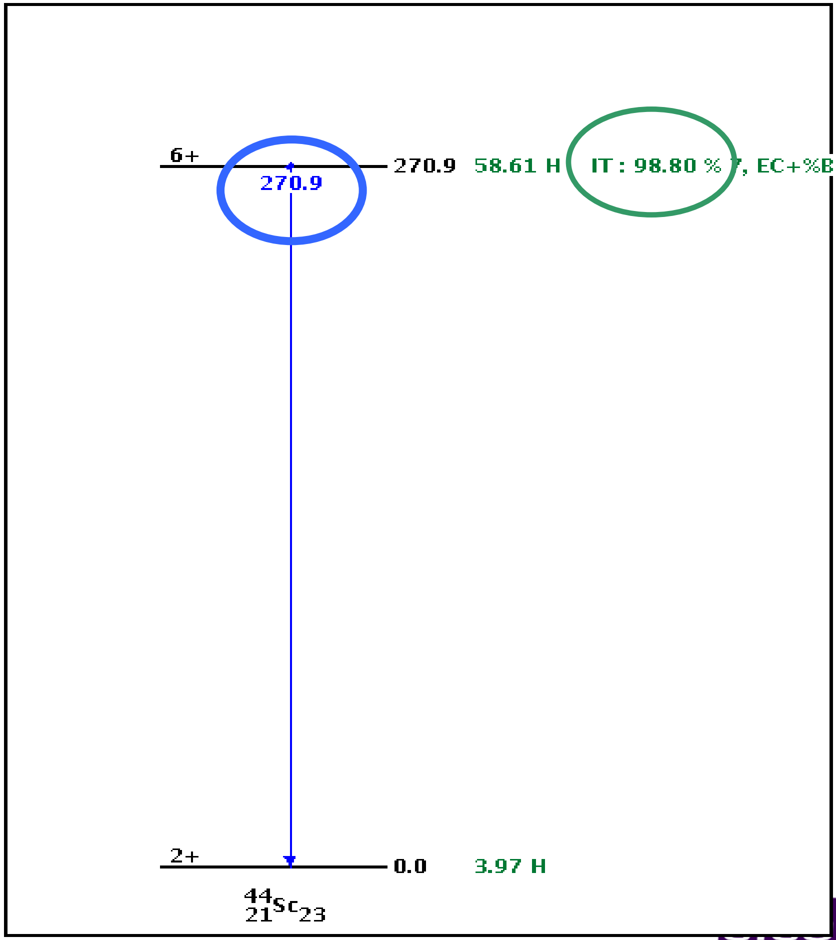
3-photons camera

^{44m}Sc: $T_{1/2}$=58,61 h

decay to ^{44}Sc by γ (270,9 keV)

Small recoil energy

In-vivo generator concept works



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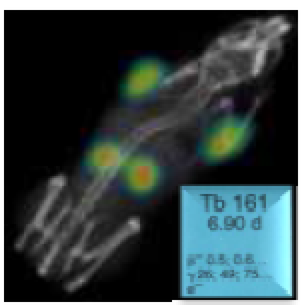
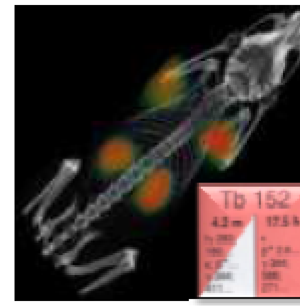
R&D isotopes

^{149}Tb-therapy

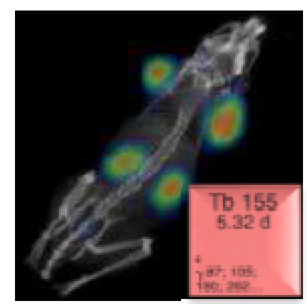
^{161}Tb-therapy & SPECT



^{152}Tb-PET



^{155}Tb-SPECT



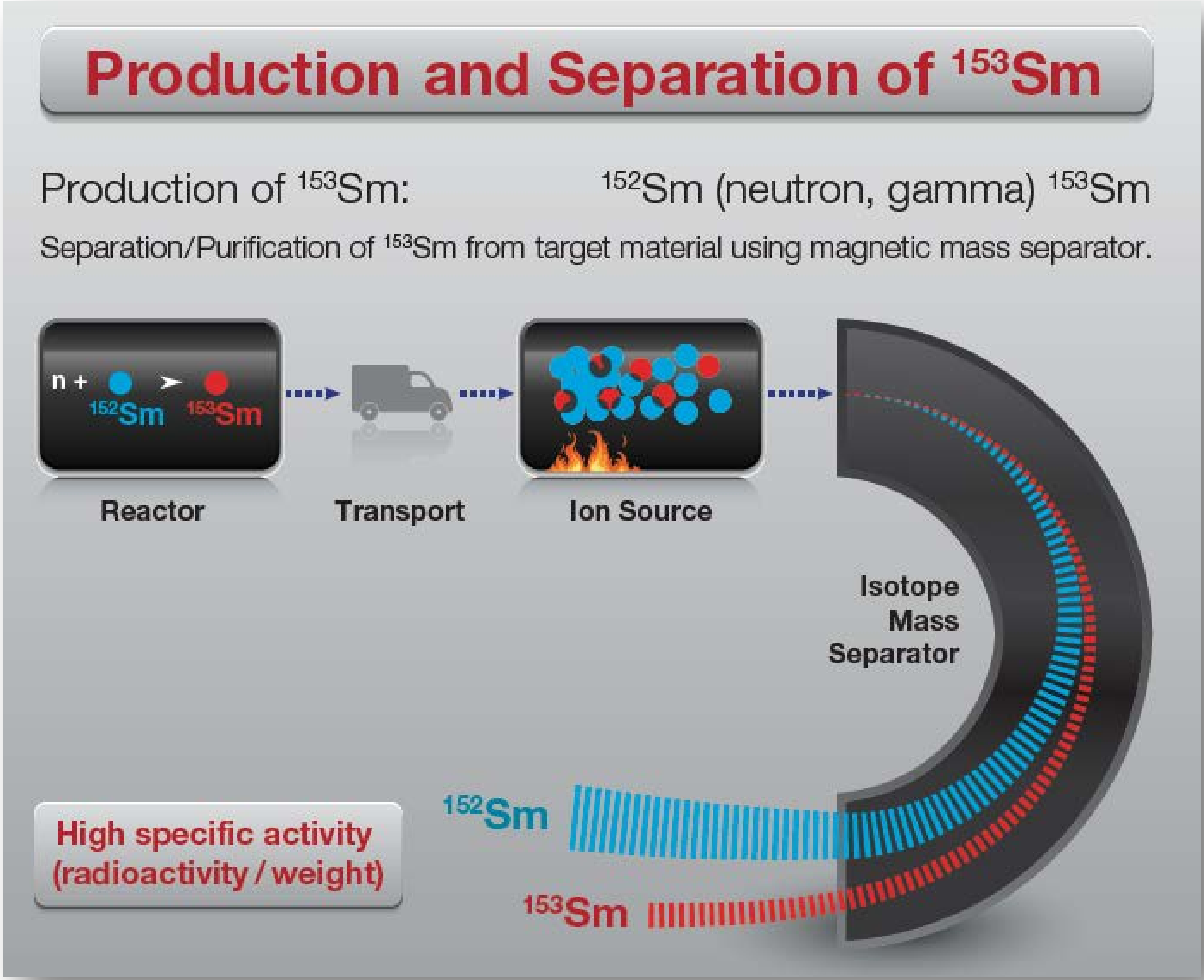
Courtesy of U. Koester

New development in accelerator: linac or compact cyclotrons

The PT 600 prototype (7.8 MeV) from GE

A 7 MeV Proton linac from ACCSys. [http://www.accsys.com]

High purity radioisotopes - Mass separation

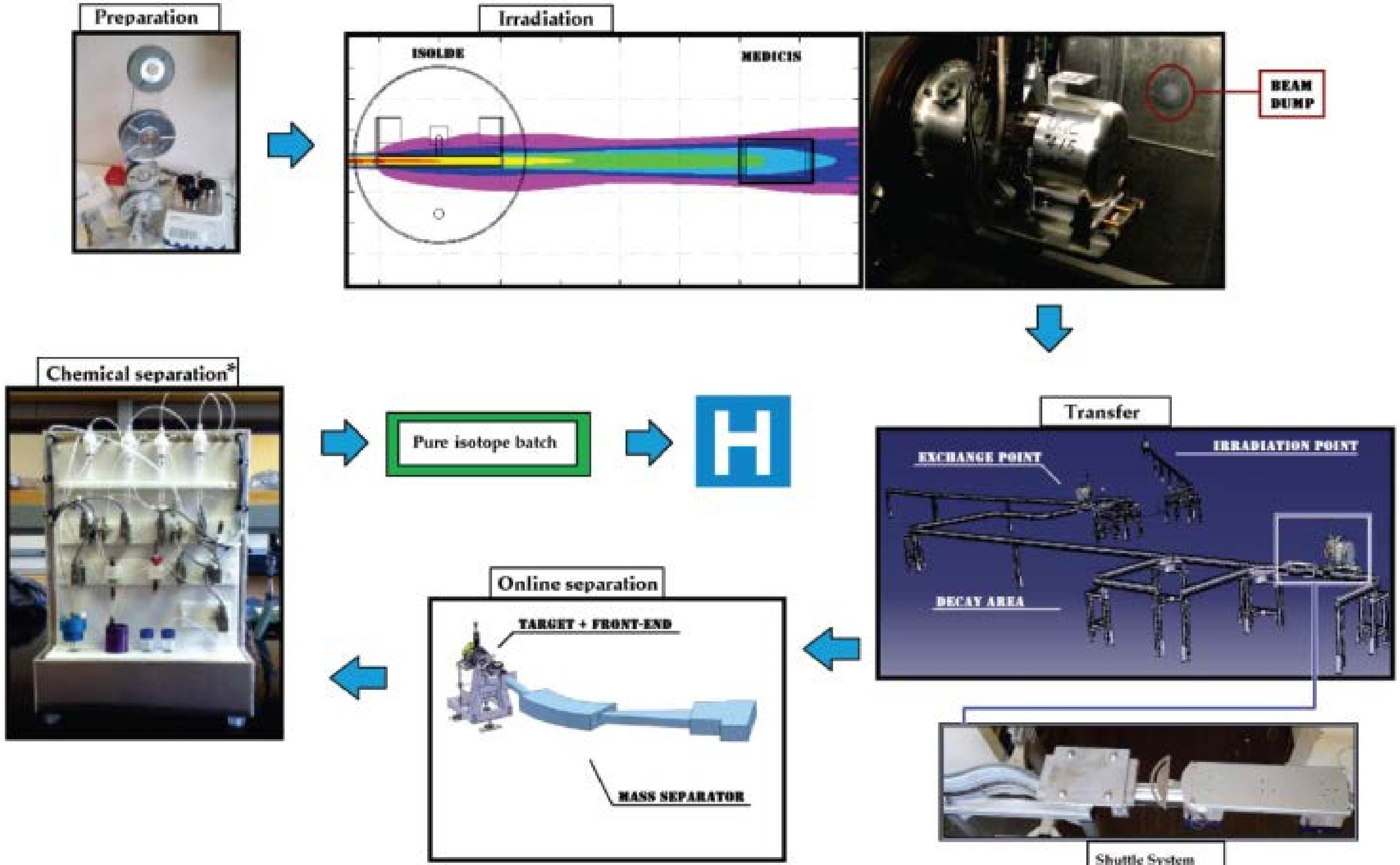


Dr. John D'Auria IsoTherapeutics Group LLC and Simon Fraser University

High purity radioisotopes - Medicis@CERN

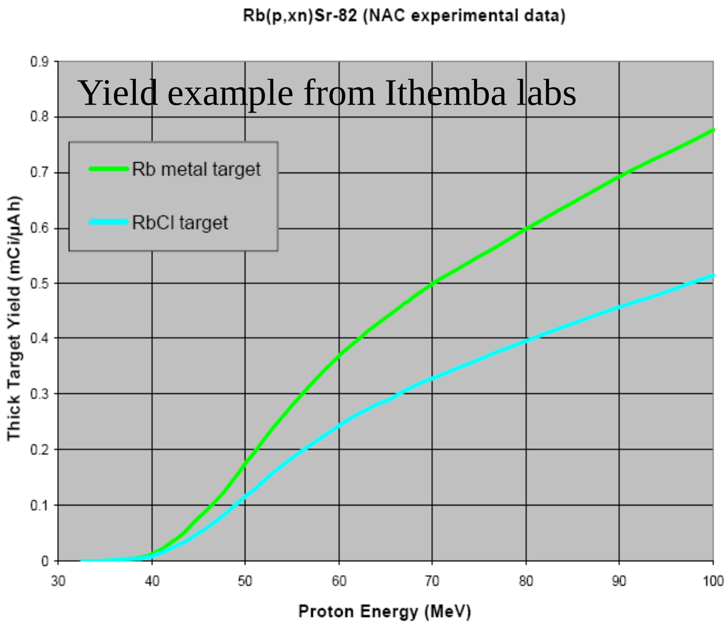
MEDICIS: ***Medical Isotopes Collected from ISOLDE***

Principle: Use protons (~90%) normally lost into the Beam Dump



Targetry for high intensity beams/Beam …

^{82}Sr Targetry: From RbCl to Rb metal



Better yield

Better thermal conductivity
→ Higher beam current on target

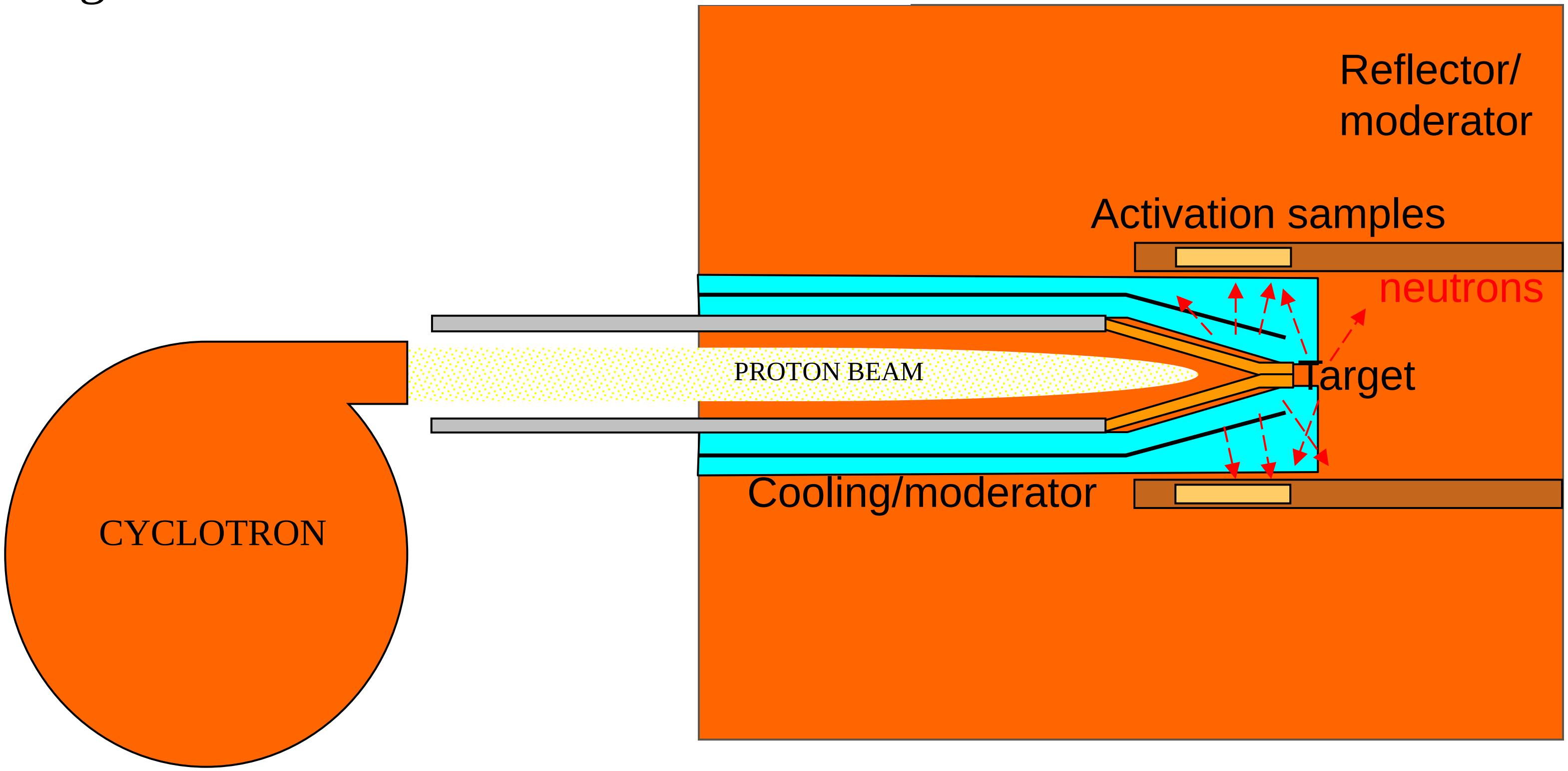
Rb metal far more reactive than RbCl

A collaboration with INR Troitsk (Russia) has been set.

Our recent achievement: 70 MeV - **150 µA on target (10.5 kW)**
Strontium extraction done without problem
Increase of the production yield as expected

Secondary neutron production

- A proton beam is generated by a cyclotron
- Protons interact with a solid target
- Fast (high energy) neutrons are generated
- Neutrons are moderated (water)
- Neutrons are reflected and further moderated
- Samples are activated by moderated neutrons



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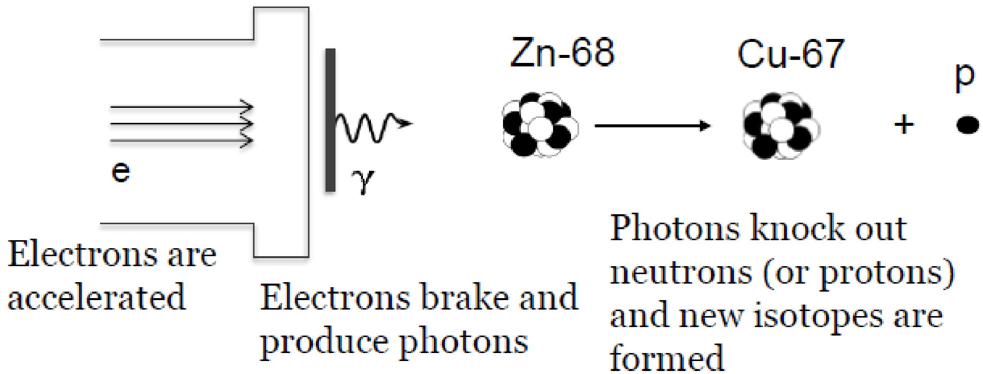
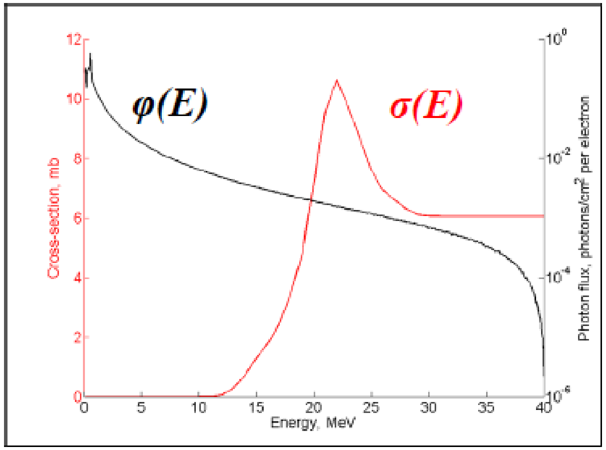
Isotope production using electron beams

Photo-production of Isotopes

NIOWAVE
www.niowaveinc.com



$$Y = N \int_{E_{th}}^{E_{max}} \varphi(E) \cdot \sigma(E) dE$$



Mo99, Cu-67, Ac-225, …

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Conclusions

- Old field with early applications
- Exciting fields with new techniques and new isotopes
- Direct applications of new developments made in nuclear physics

Thank you for your attention

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- the **Université de Nantes**
- the **French government** (CNRS, INSERM)
- the **European Union**.

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