PARTICLE ACCELERATORS FOR THE PRODUCTION OF MEDICAL RADIOISOTOPES

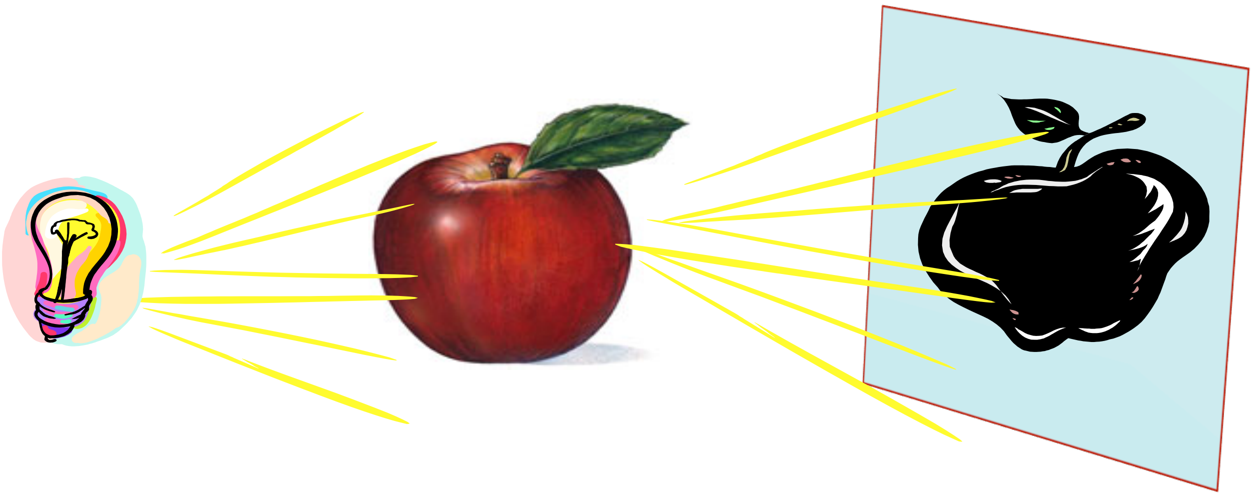
Adriano Duatti
Department of Chemical and Pharmaceutical Sciences
University of Ferrara
Via L. Borsari, 46, 44121 Ferrara, Italy
dta@unife.it
adriano.duatti@unife.it

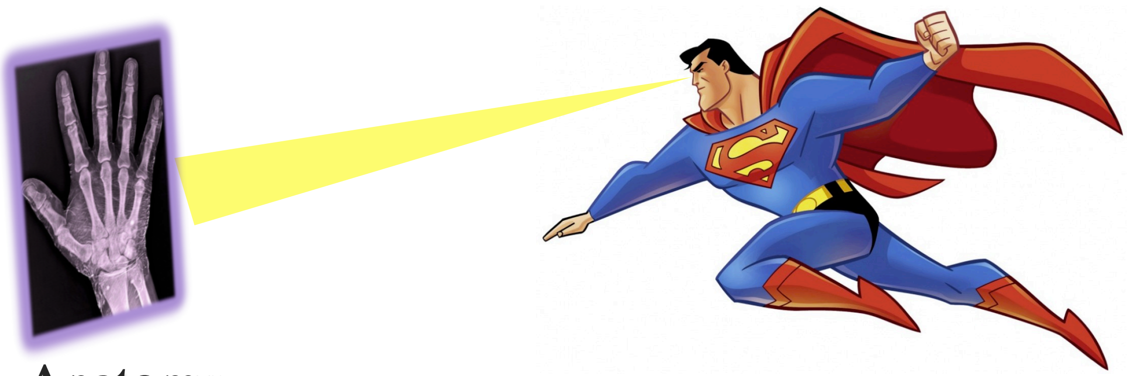
Summary

- Molecular imaging.
- Radionuclides as imaging tools.
- Examples of relevant medical radionuclides.

WHAT'S MOLECULAR IMAGING?

Radiology



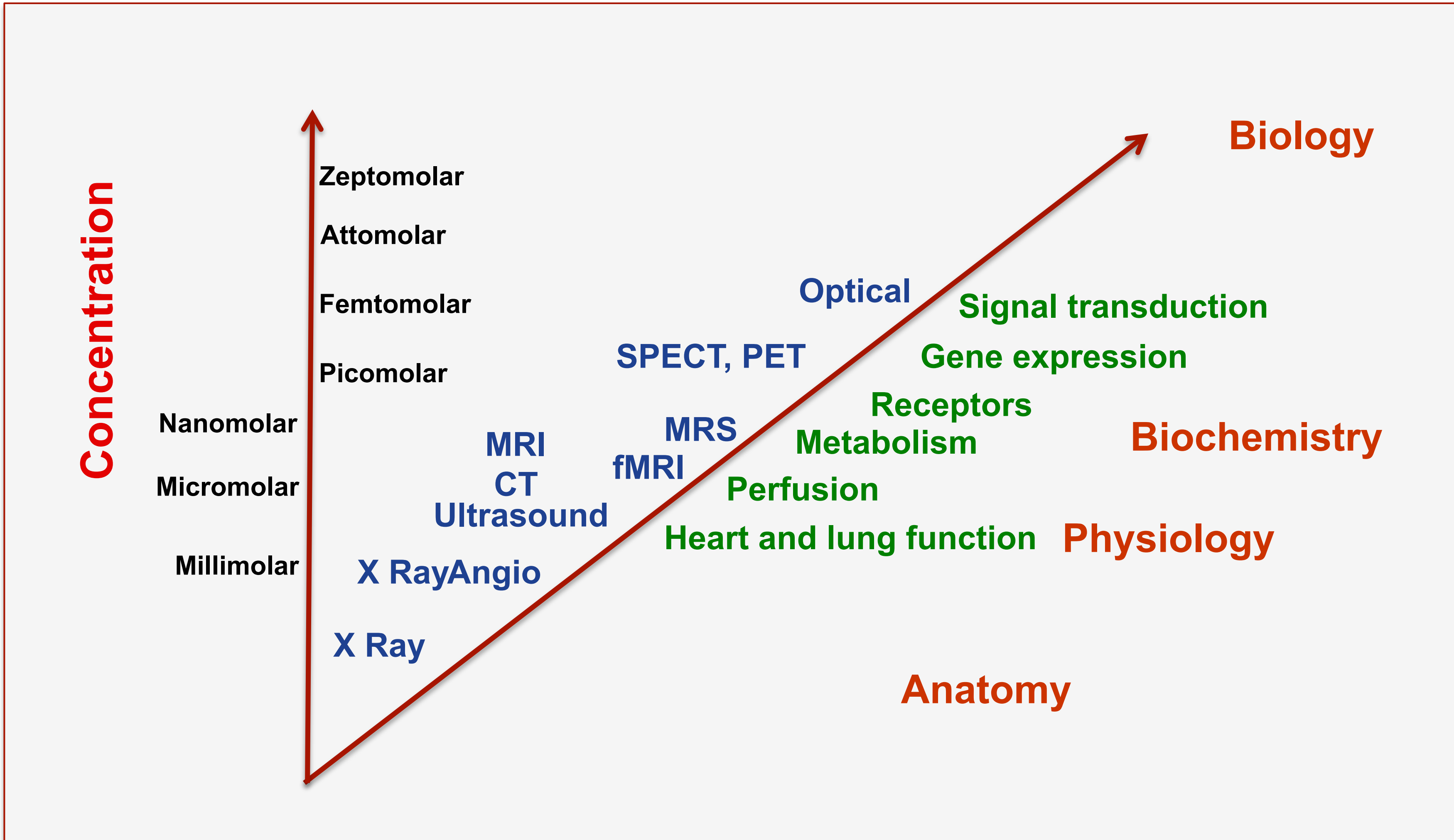


Anatomy

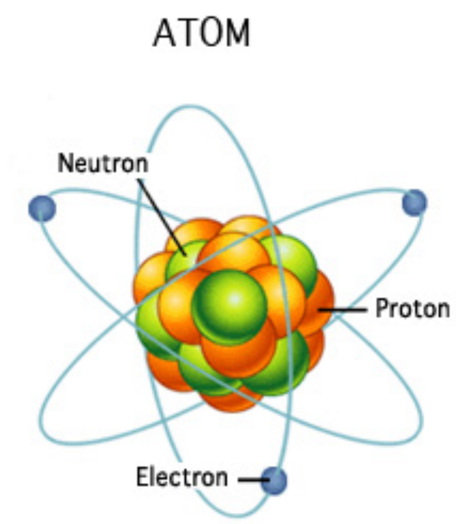
Molecular imaging

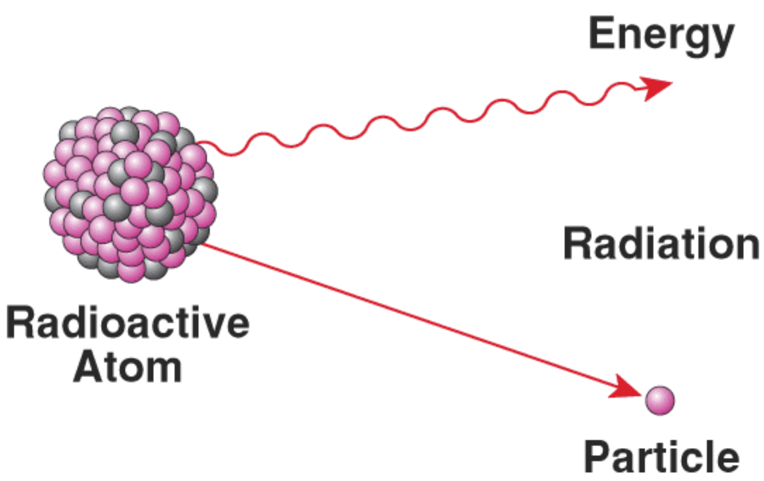
- Molecular imaging is broadly defined as in vivo imaging of biological processes 'at the molecular' level.
- In principle, this can be accomplished by imaging the in vivo distribution of 'single molecules' interacting with the process.
- Nuclear imaging is a methodology using 'radiolabeled single-molecule probes' for collecting in vivo, diagnostic information.

Sensitivity of Imaging Methods in Biology

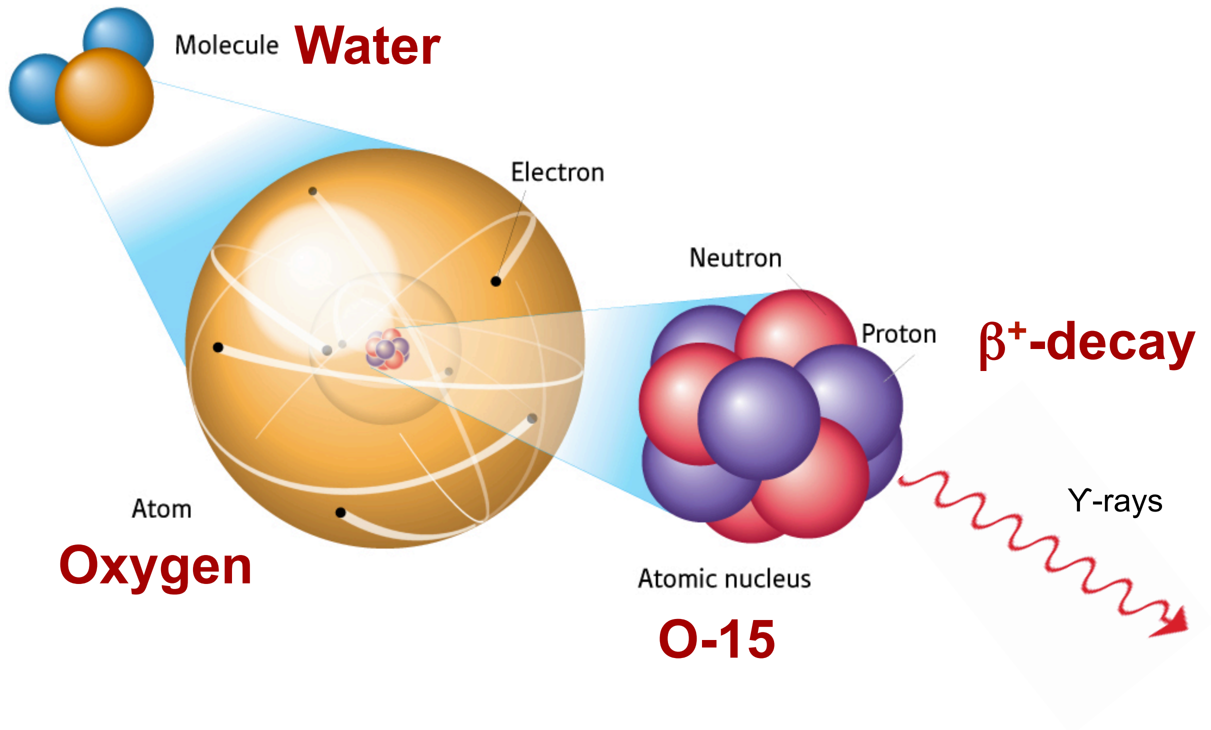


What Do We Need?

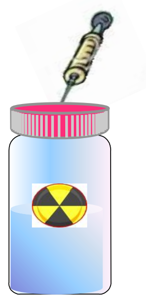




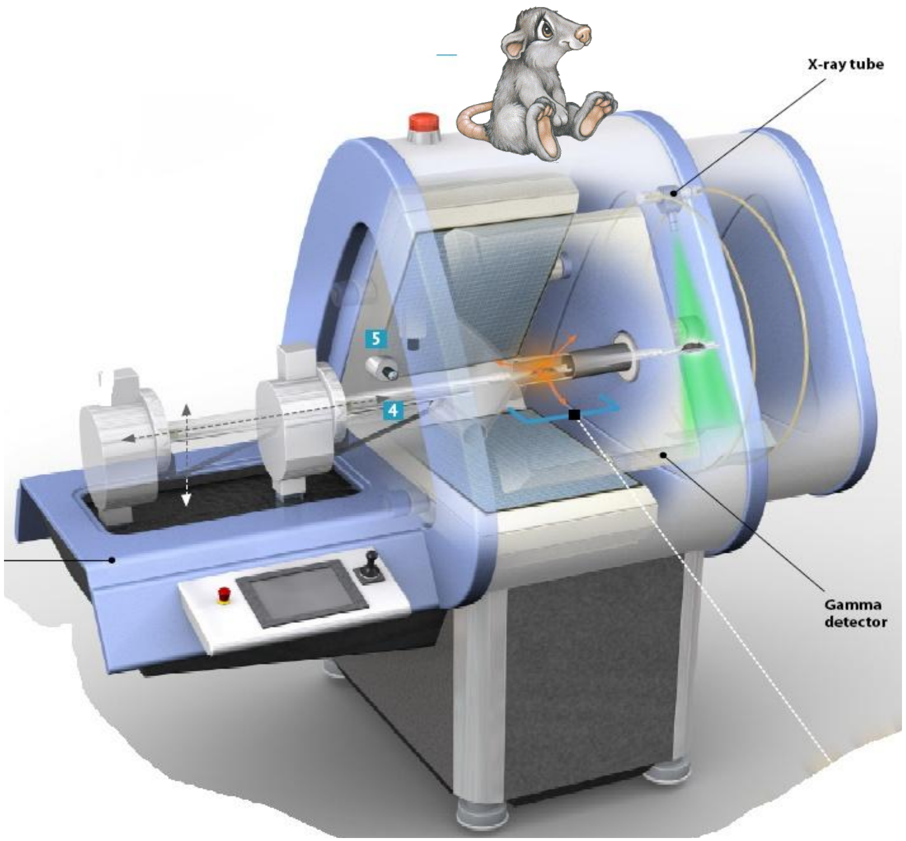
The Machinery of Molecular Nuclear Imaging

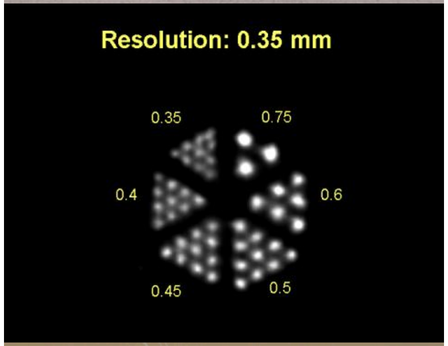


Scintigraphic Imaging

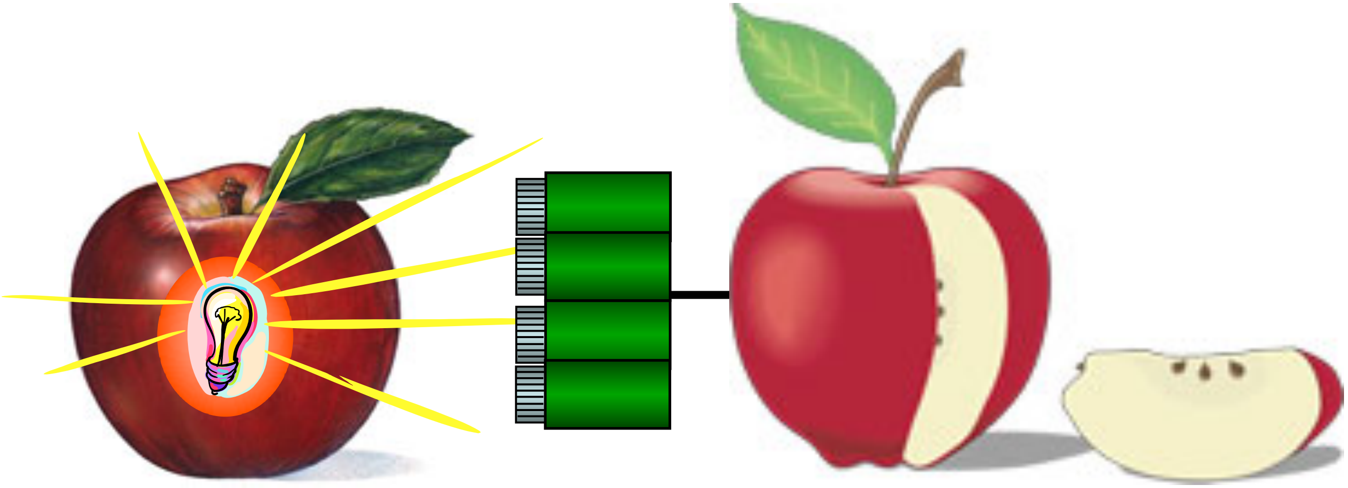


Small-Animal Scanners





Scintigraphy



EXAMPLES OF RADIONUCLIDES HAVING INTRINSIC BIOLOGICAL PROPERTIES

Rubidium-82

Rb^+

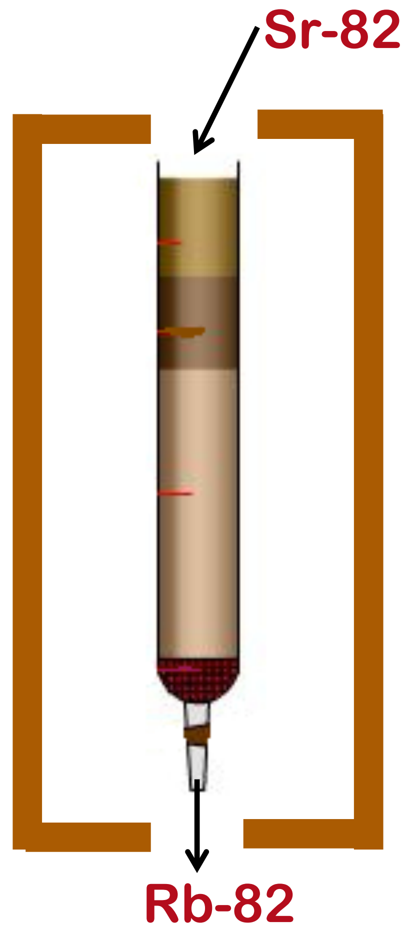
- **Rubidium-82 (Rb-82) is produced by decay of Strontium-82 (Sr-82)**
- **75 second T½**
- **Kinetics:**
  - **Potassium analog**
  - **High extraction fraction at high flow rates**
- **Defects visualized 2-7 minutes after injection**

Strontium-82

Nuclear Reaction	Target	Projectile Energy (MeV)	Comment
^{89}Y(p, spallation)	Yttrium oxide	60-240	Low radiopurity& yield
^{nat}Mo(p, spallation)	Mo metal	500-700	Low radiopurity, high cost
^{nat}Rb(p,xn)	RbCl or Rb metal	40-90	Preferred
$^{nat}Kr(\alpha$,pxn)	Kr gas	20-120	Low radiopurity, low yield, little availability
$^{nat}Kr(^{3}He$,xn)	Kr gas	20-90	Low radiopurity, low yield, very little availability

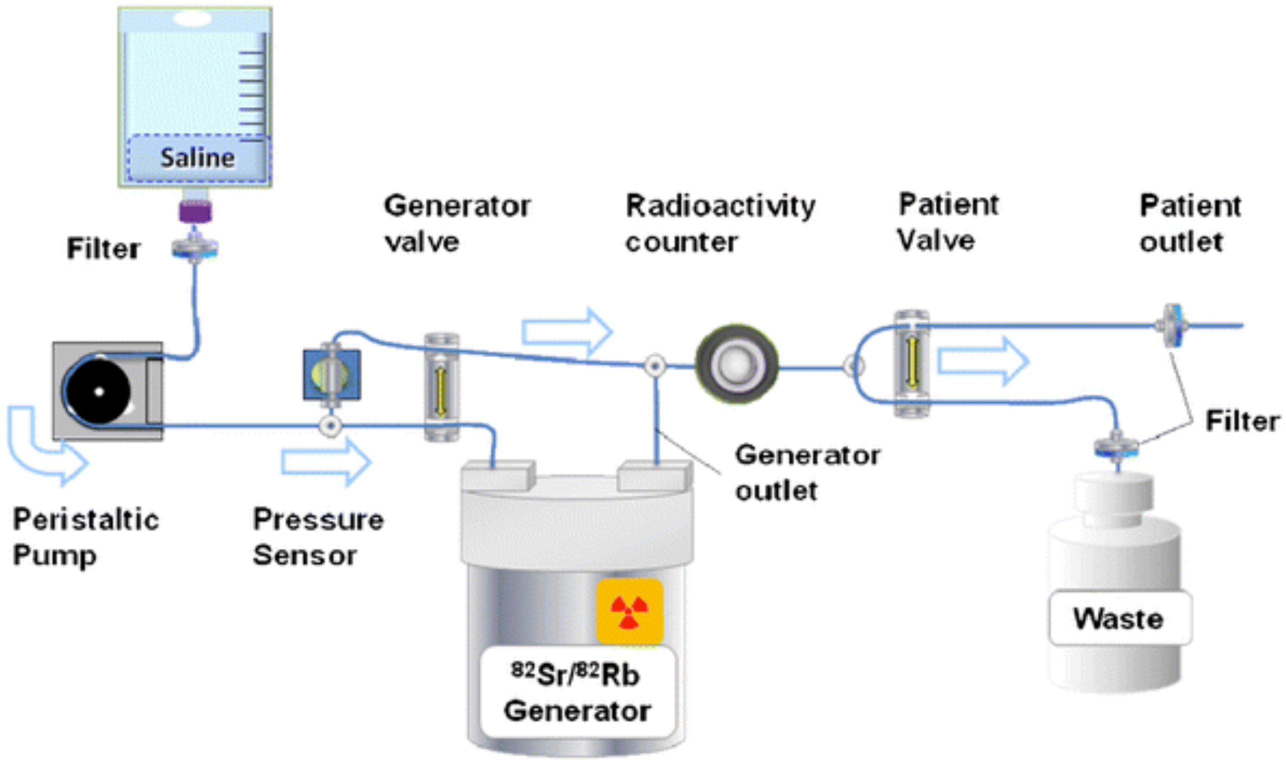
CardioGen-82®

(Rubidium Rb 82 Generator)

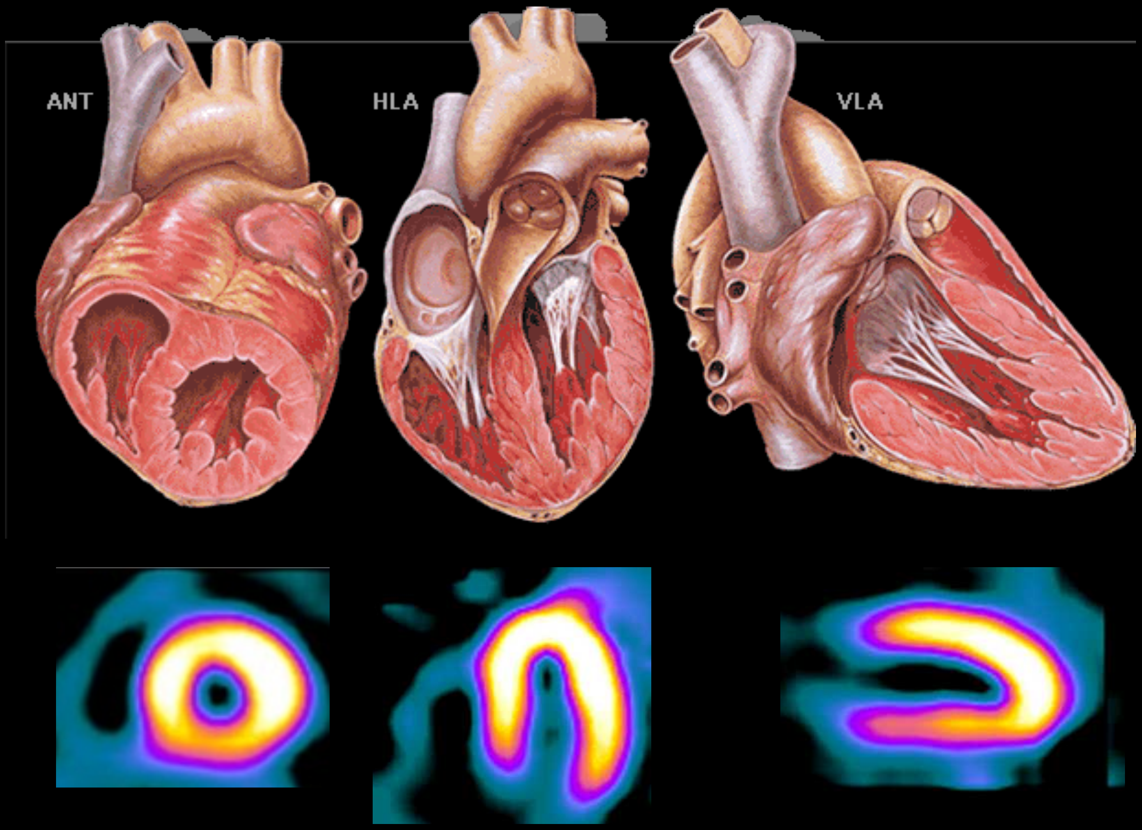


CardioGen-82®

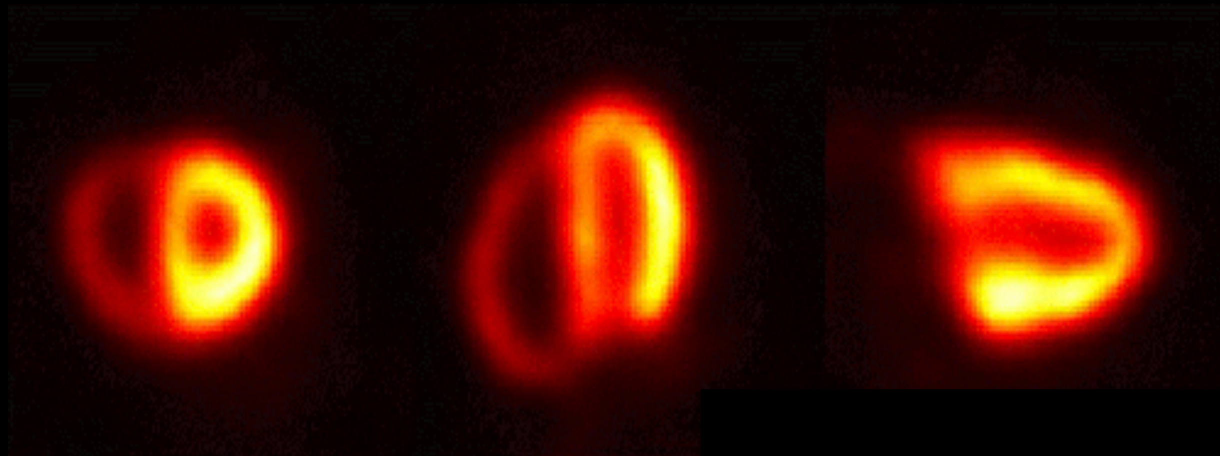
(Rubidium Rb 82 Generator)

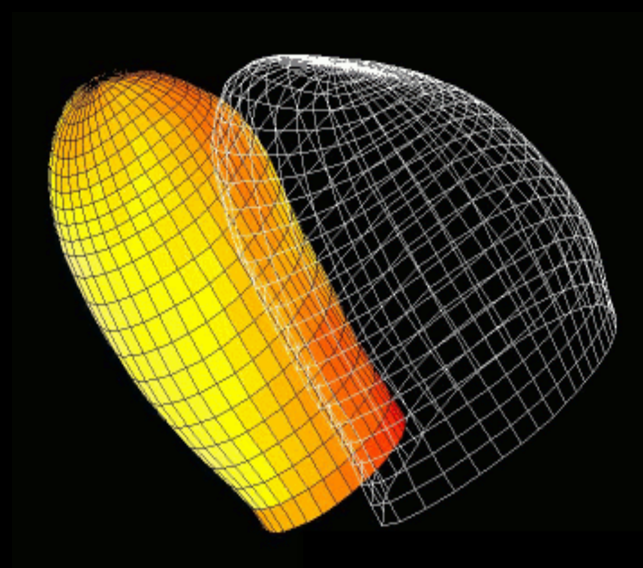


CARDIAC TOMOGRAPHY

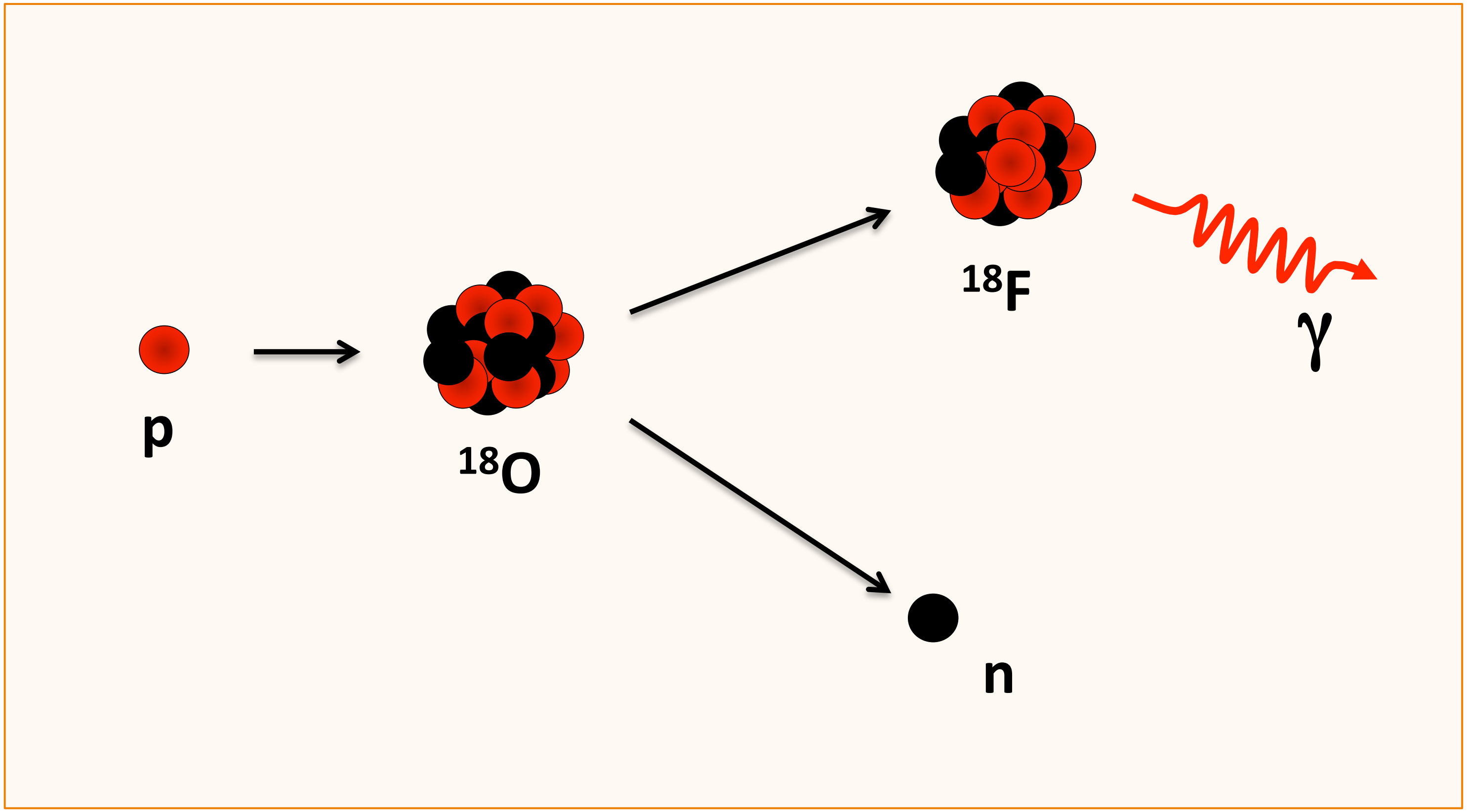


4D Cardiac Images

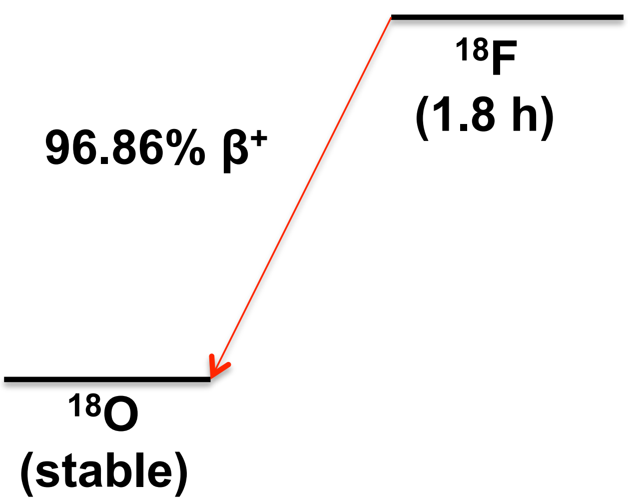




Production of Fluorine-18



Decay of F-18



F-18-Fluoride

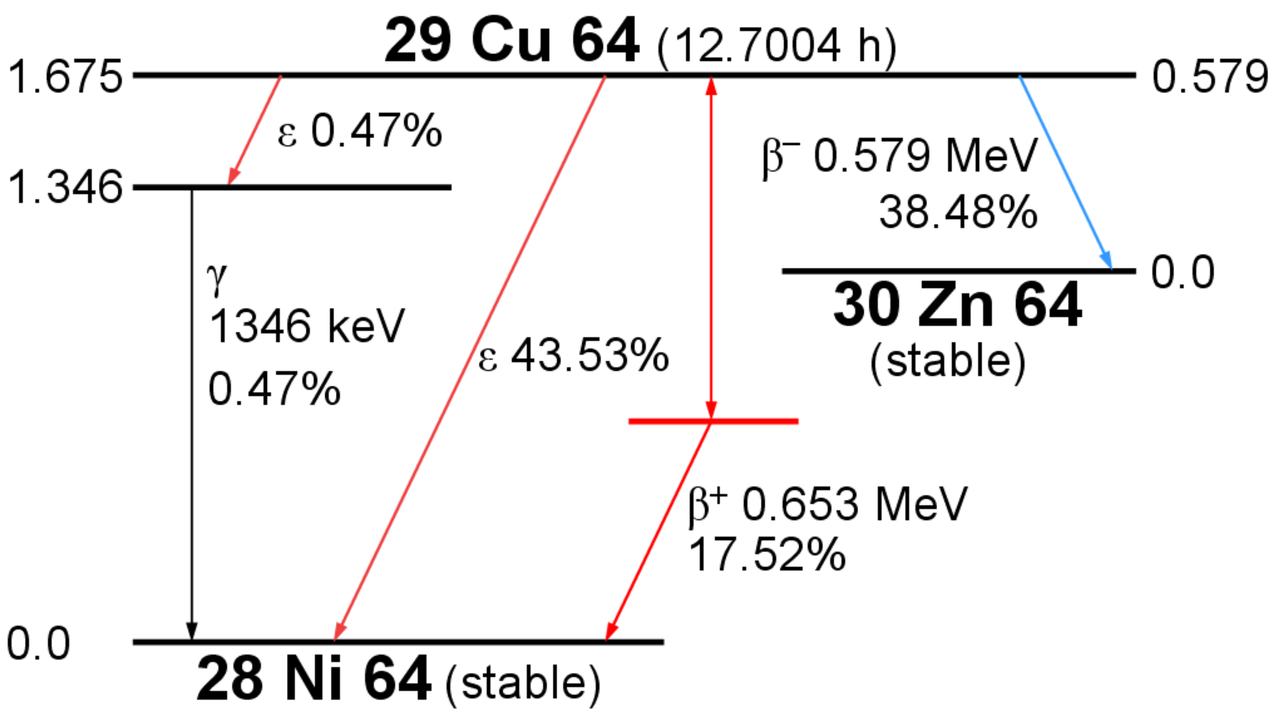
Copper-64

Production = $^{64}Ni(p,n)^{64}Cu$

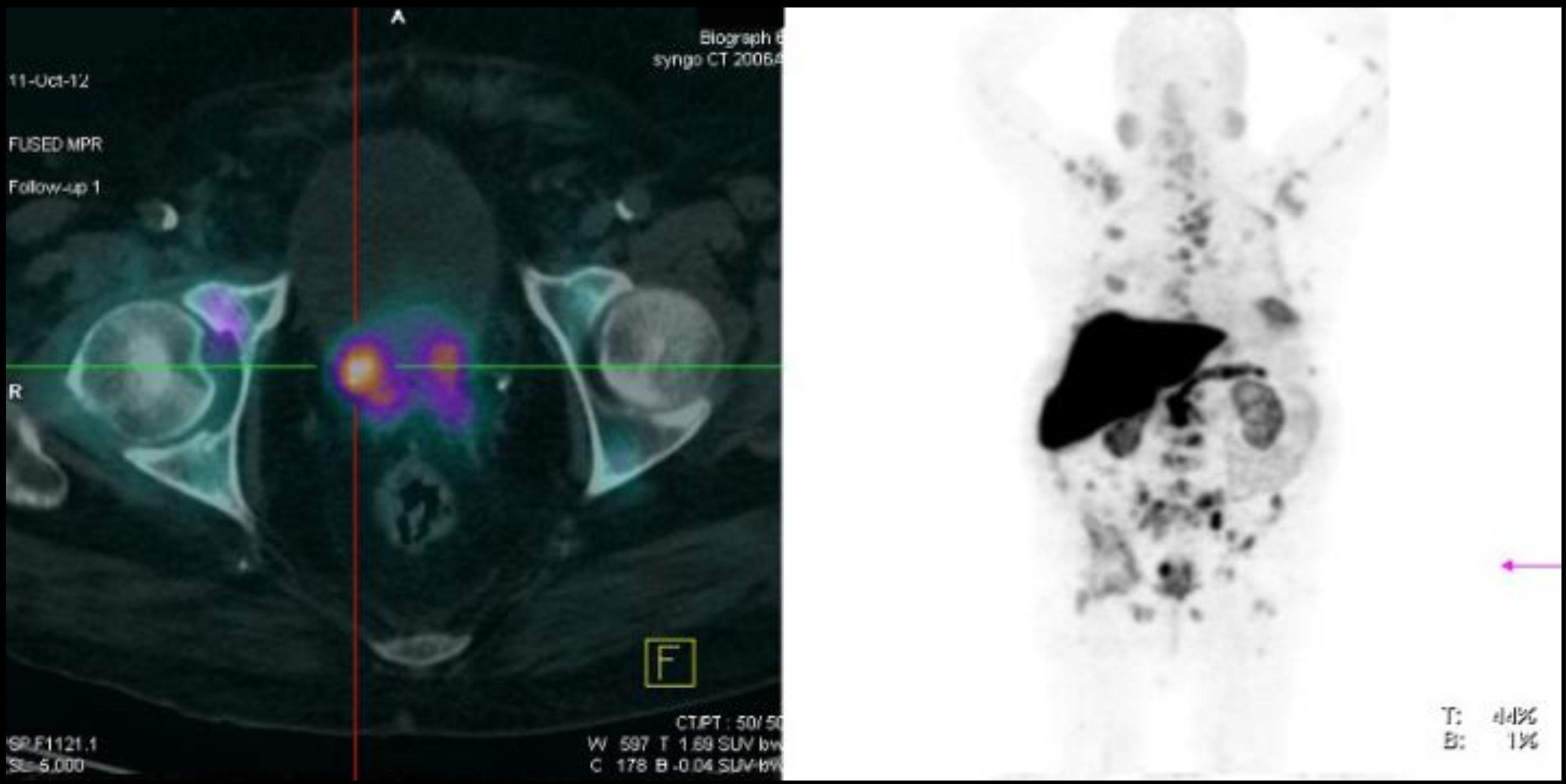
Modes of decay = β^{+} (17%), β^{-} (39%),

$\mathbf{t_{1/2}}$ = 12.701 h

Copper-64

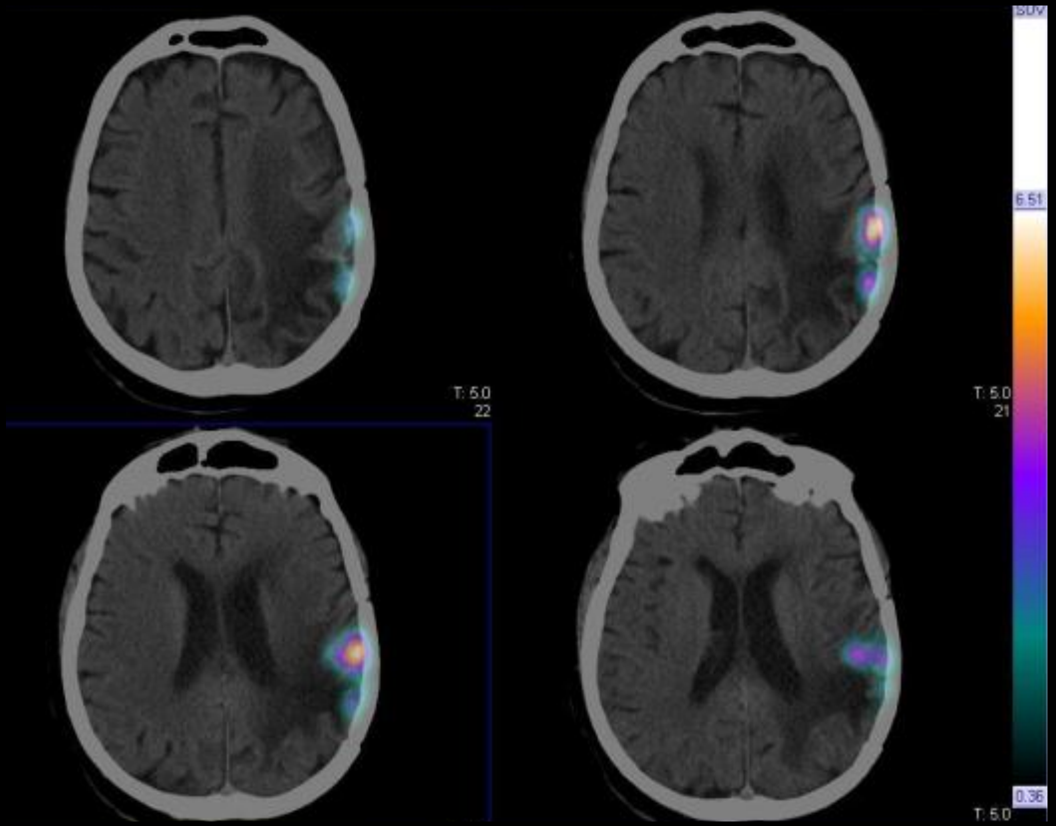

29 Cu 64 (12.7004 h)
1.675
0.579
ε 0.47%
1.346
β⁻ 0.579 MeV
38.48%
γ
1346 keV
0.47%
ε 43.53%
0.0
30 Zn 64
(stable)
β⁺ 0.653 MeV
17.52%
0.0
28 Ni 64 (stable)

$^{64}CuCl_2$



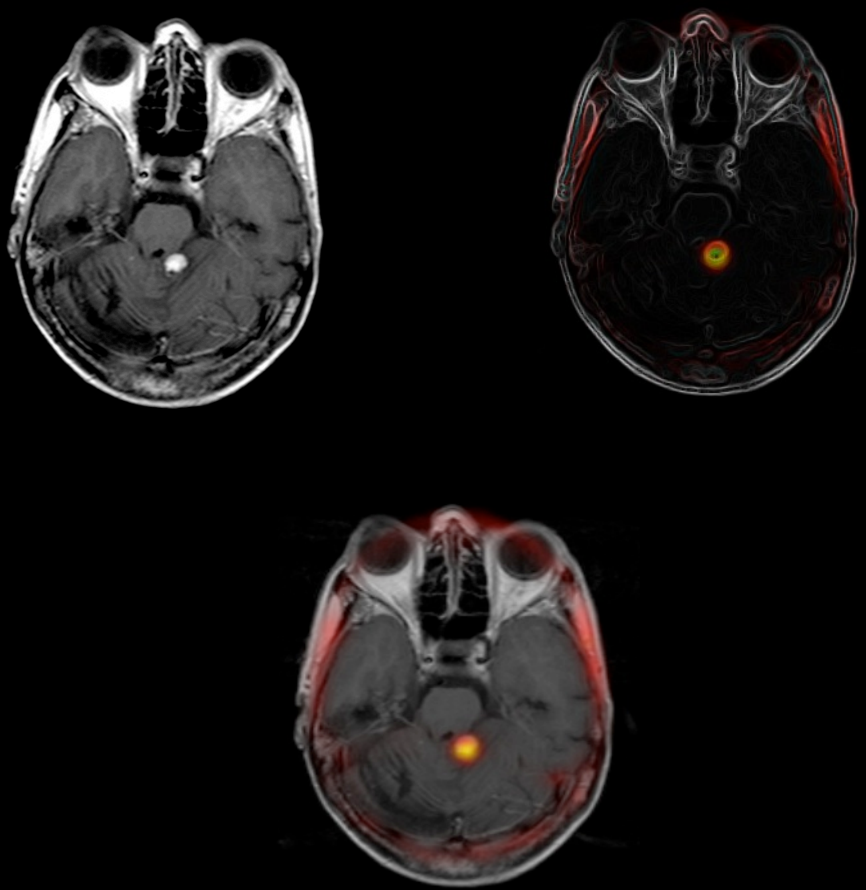
Prostate cancer

$^{64}CuCl_2$



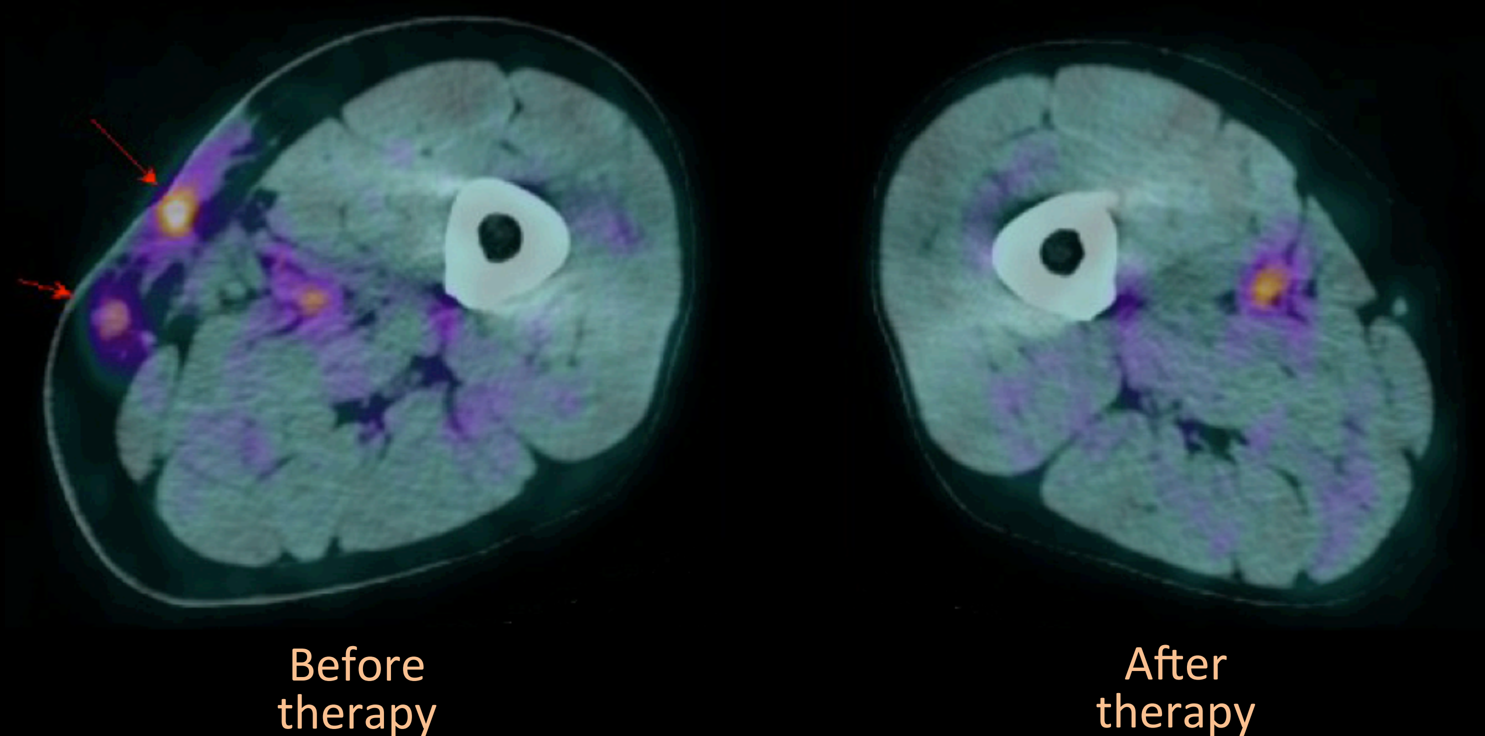
Glioma

Cu-64 PET-MRI



Glioma

$^{64}CuCl_2$

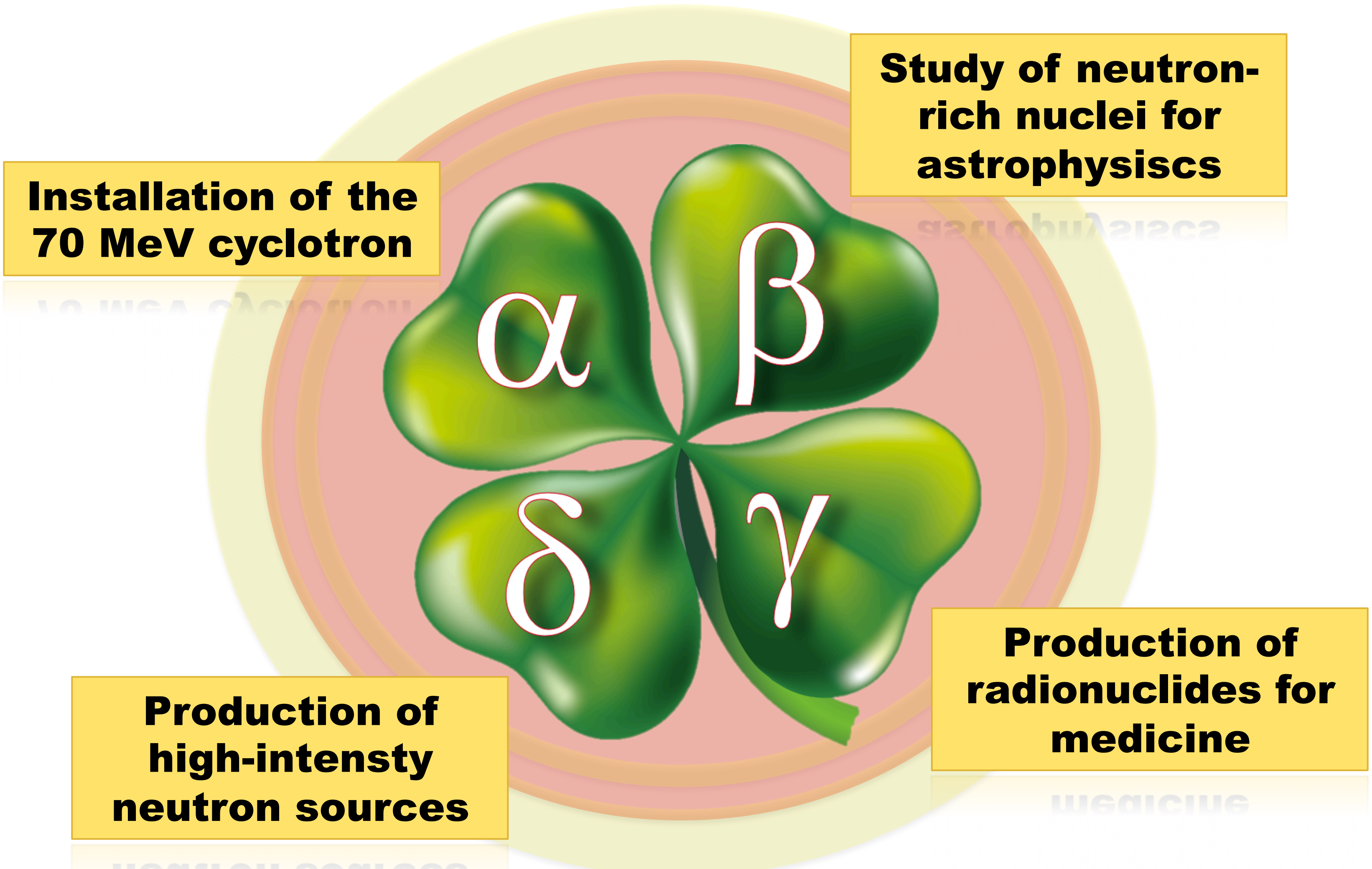


Malignant melanoma on left leg

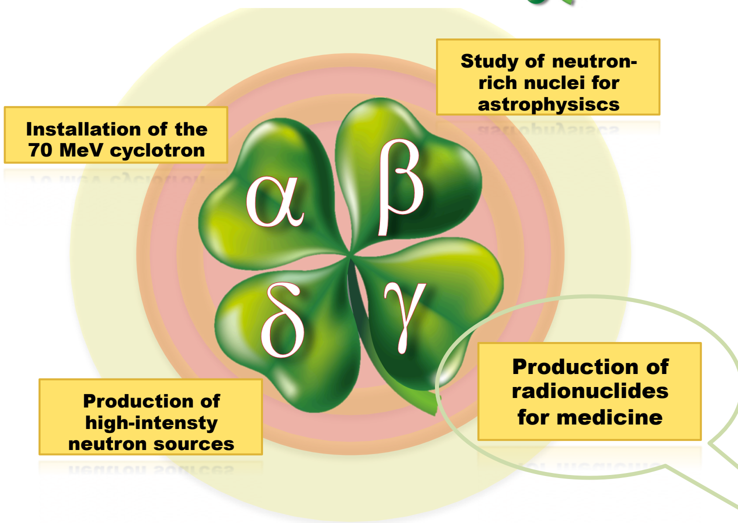
THE SPES-LARAMED PROJECT

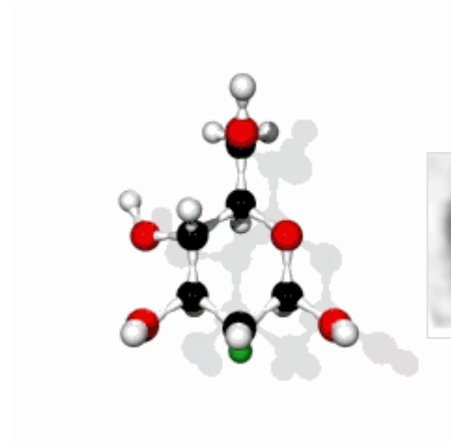
INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

SPES Project



SPES Project

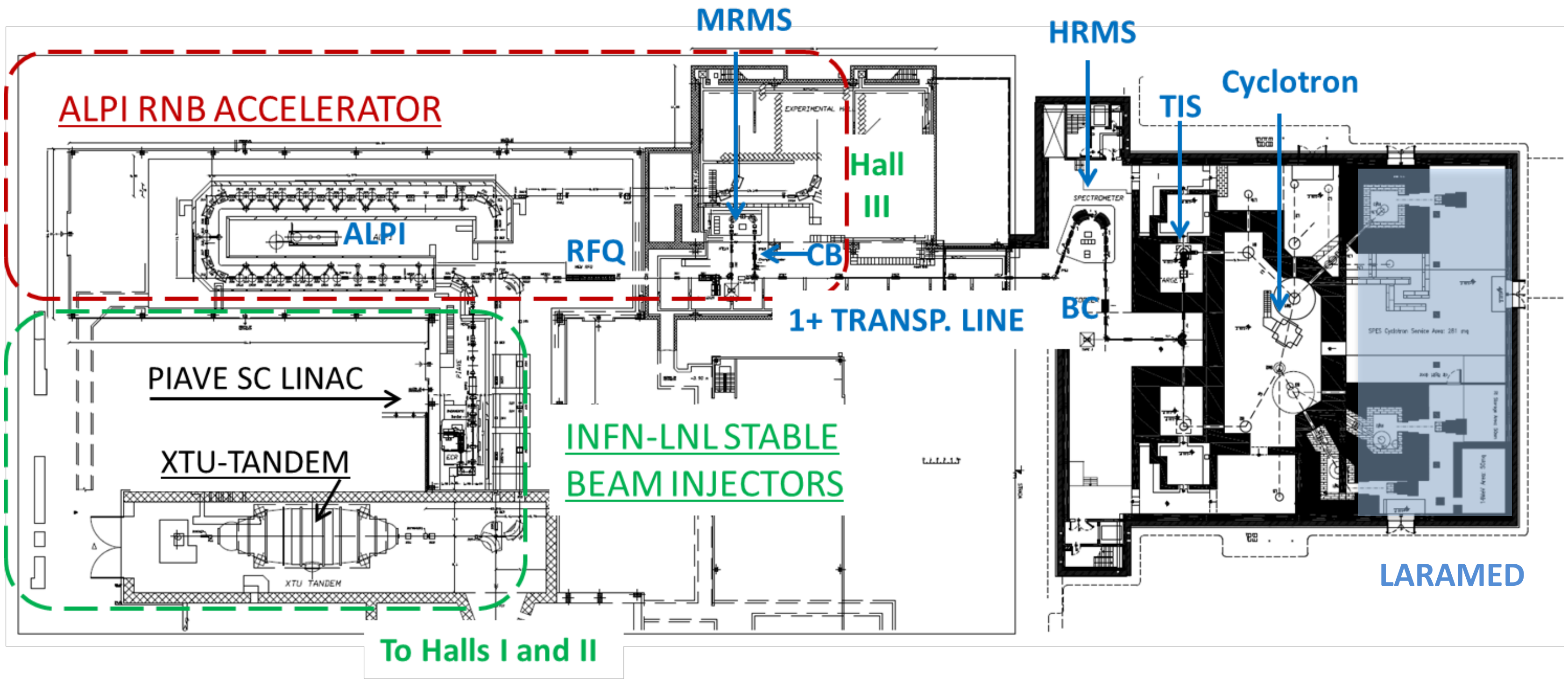




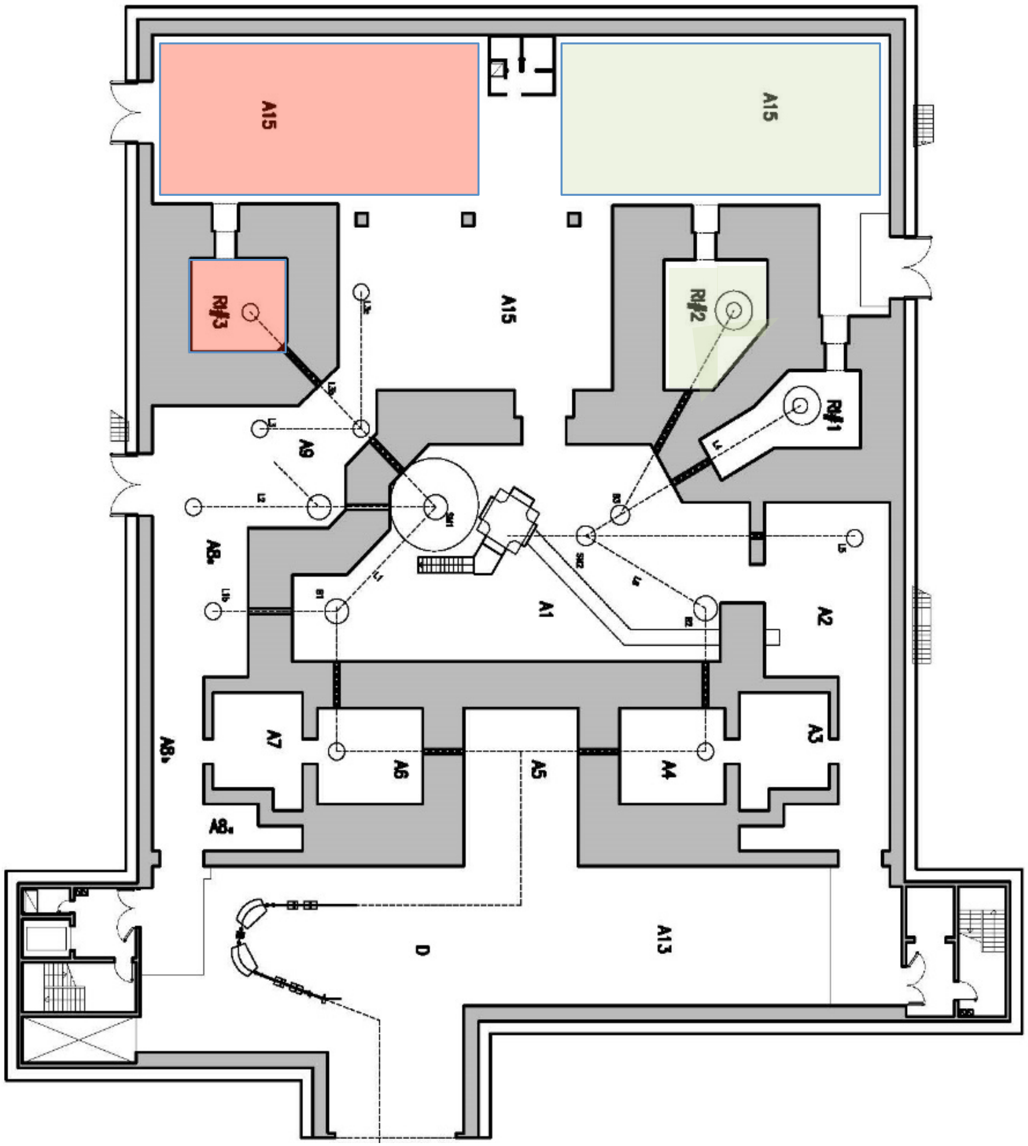
LARAMED

Laboratory for the production of exotic RAdionuclides for MEDicine

The SPES and LARAMED Laboratories



RI-LAB & RI-FAC



THE COME PROJECT

Copper-67

Cu-67 – 29 protons – 38 neutrons

Half Life: 2.58 days

Radiation: Decay Mode: Beta

Gamma Constant: 0.97 mR/hr per 1 mCi at 30 cm

Major Betas:

Max E(MeV)	Avg E (MeV)	# per 100 dis
0.390	0.121	57
0.482	0.154	22
0.575	0.189	20

Max. Beta Range in Air : 200 cm

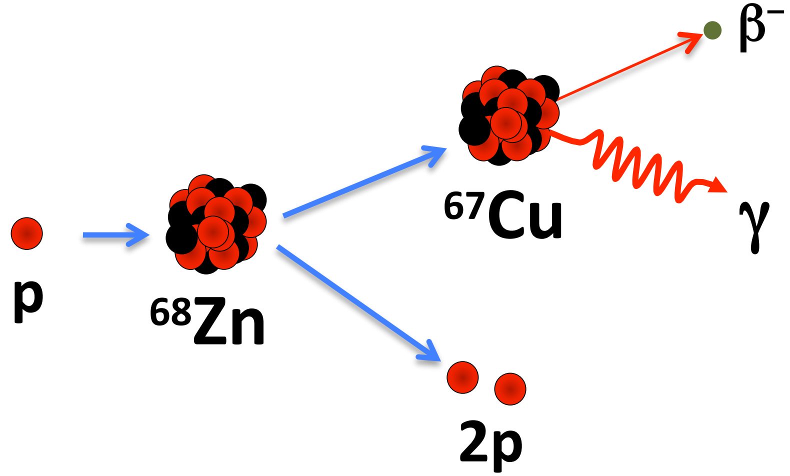
Max. Beta Range in Water : 0.21 cm

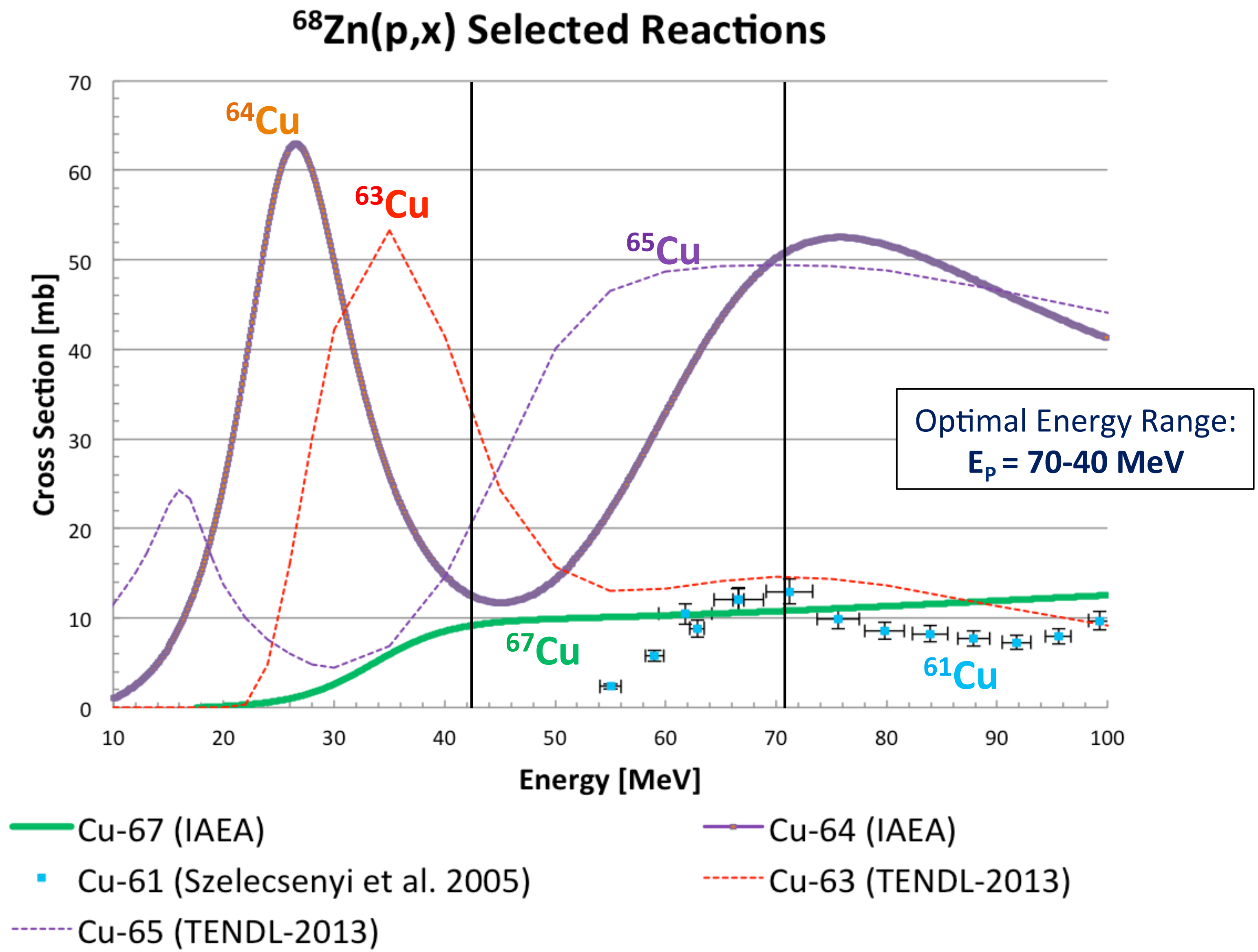
Major Gammas:

E(MeV)	# per 100 Dis
0.091	7
0.093	16
0.185	49

Average gamma E = 0.157 MeV

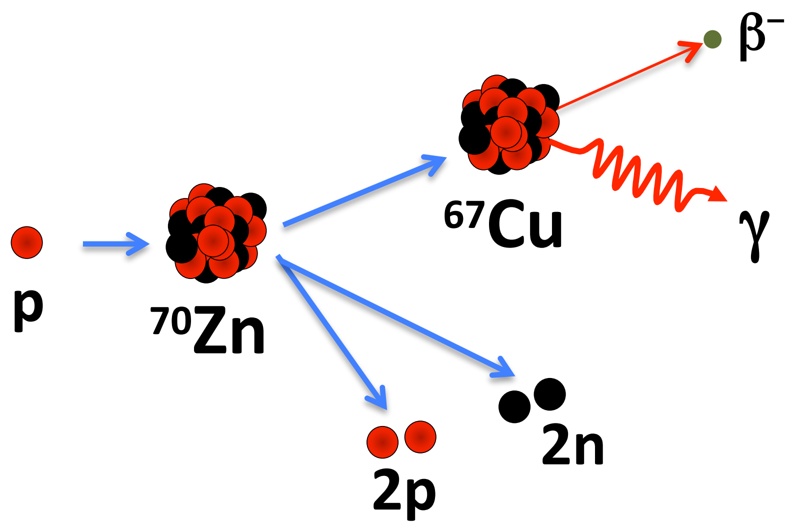
$^{68}Zn(p,2p)^{67}Cu$



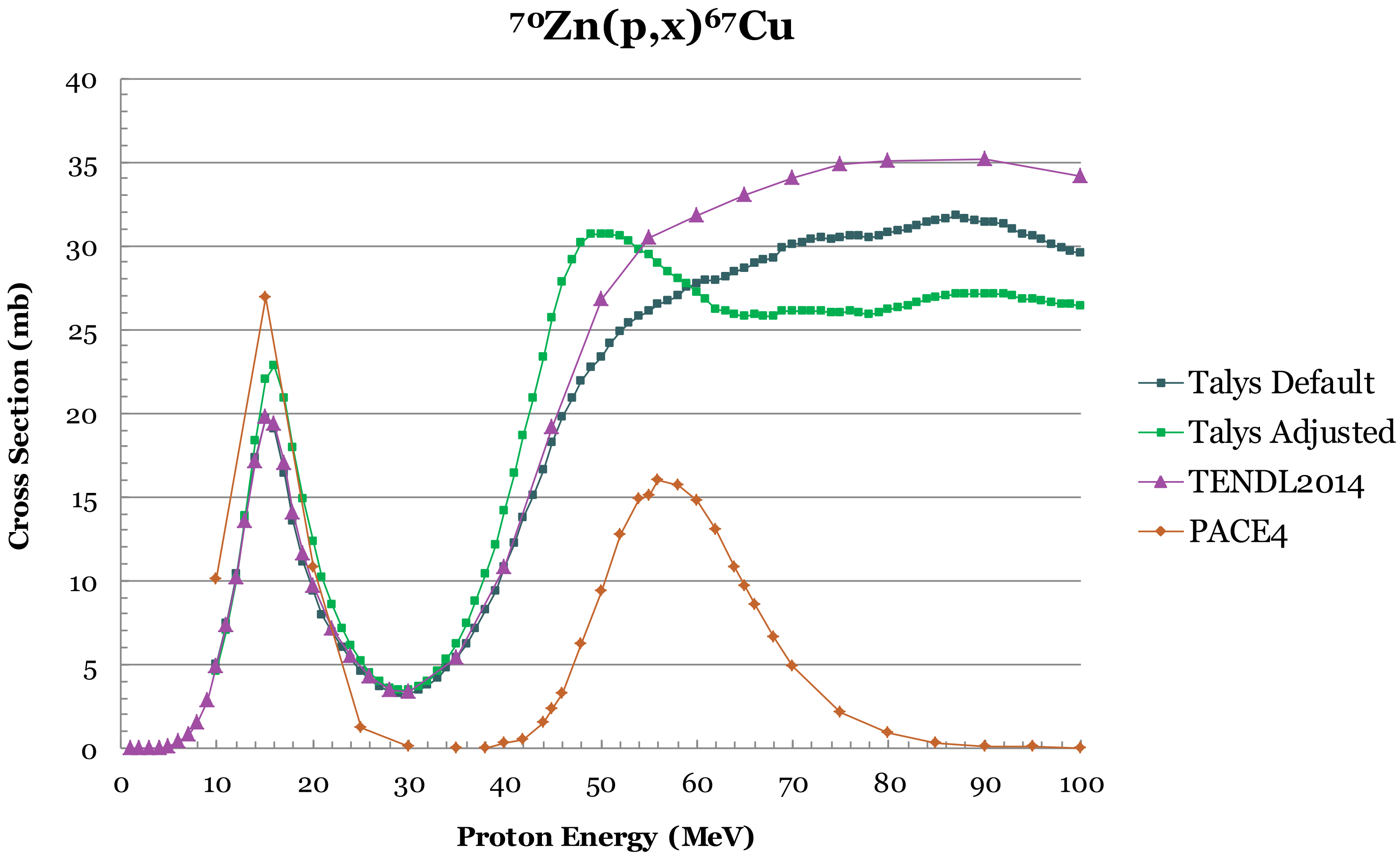


68Zn(p,x) Selected Reactions
Cross Section [mb]
Energy [MeV]
64Cu
63Cu
65Cu
67Cu
61Cu
Optimal Energy Range:
EP = 70-40 MeV
0
10
20
30
40
50
60
70
10
20
30
40
50
60
70
80
90
100
Cu-67 (IAEA)
Cu-61 (Szelecsenyi et al. 2005)
Cu-65 (TENDL-2013)
Cu-64 (IAEA)
Cu-63 (TENDL-2013)

$^{70}Zn(p,2n2p)^{67}Cu$

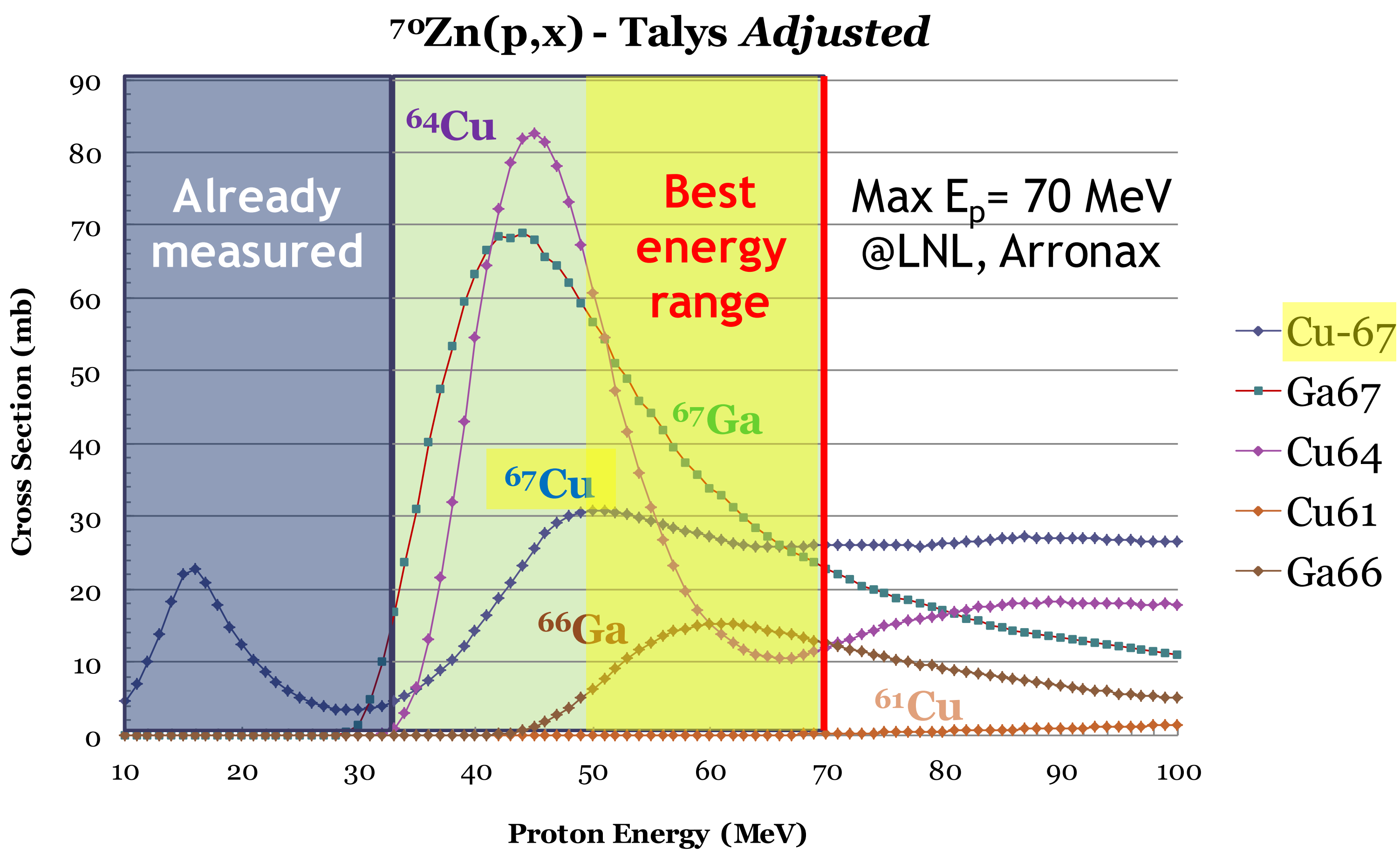


$^{70}Zn(p,x)^{67}Cu$



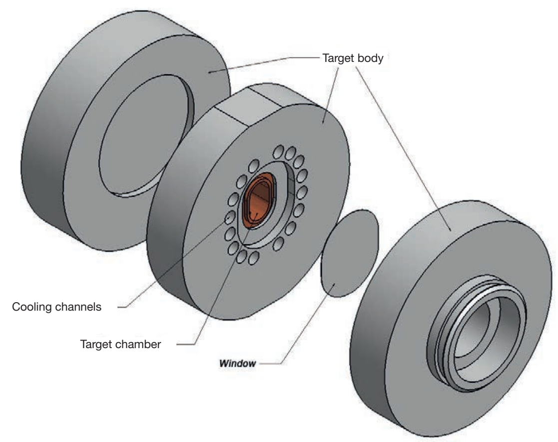
70Zn(p,x)67Cu
Cross Section (mb)
Proton Energy (MeV)
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
100
Talys Default
Talys Adjusted
TENDL2014
PACE4

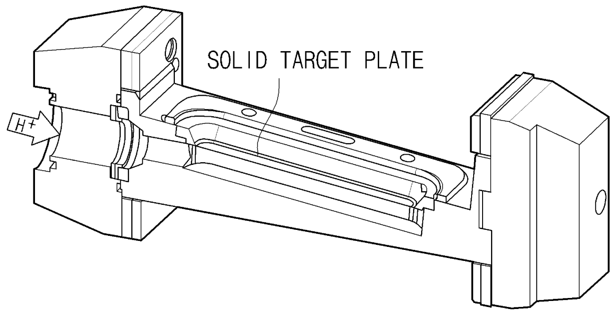
$^{70}Zn(p,x)$

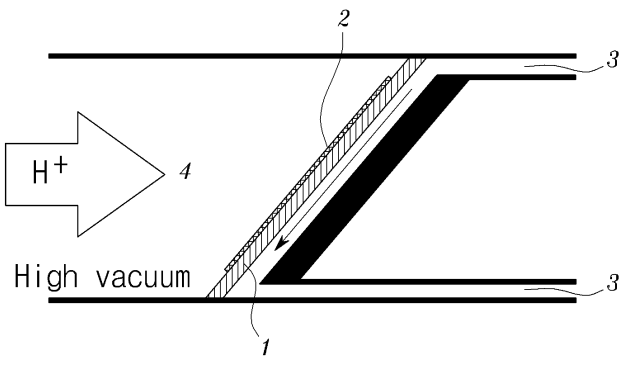


70Zn(p,x) - Talys Adjusted
Cross Section (mb)
Proton Energy (MeV)
Already measured
Best energy range
Max Ep= 70 MeV
@LNL, Arronax
64Cu
67Ga
67Cu
66Ga
61Cu
Cu-67
Ga67
Cu64
Cu61
Ga66

High-Power Targets

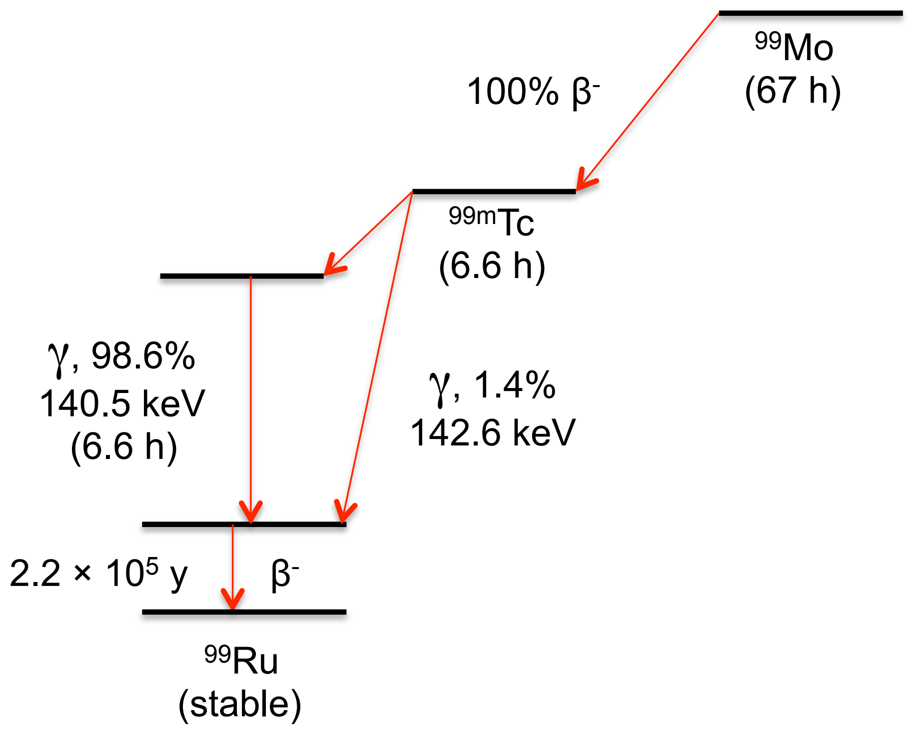




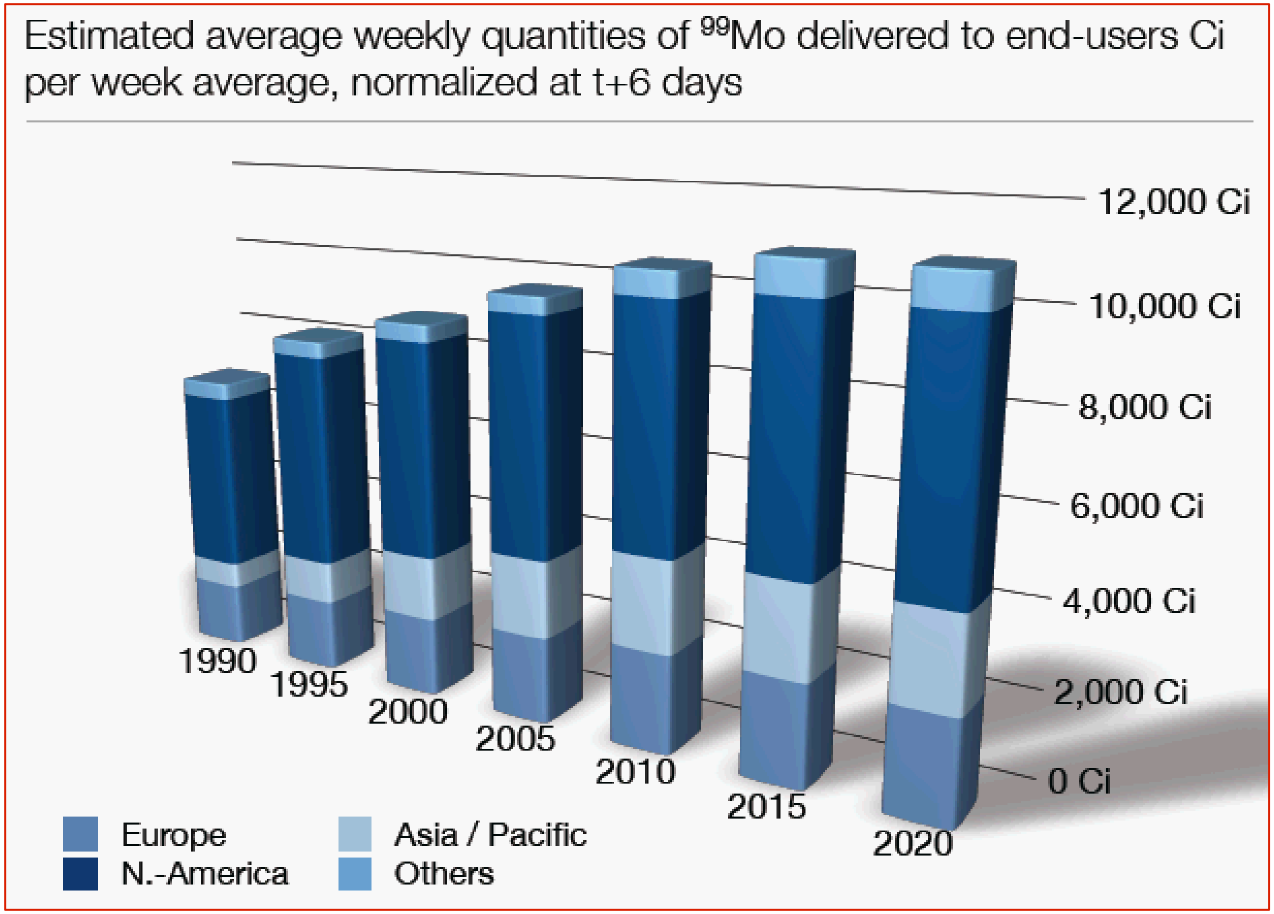


THE APOTEMA AND TECHNOSP PROJECTS

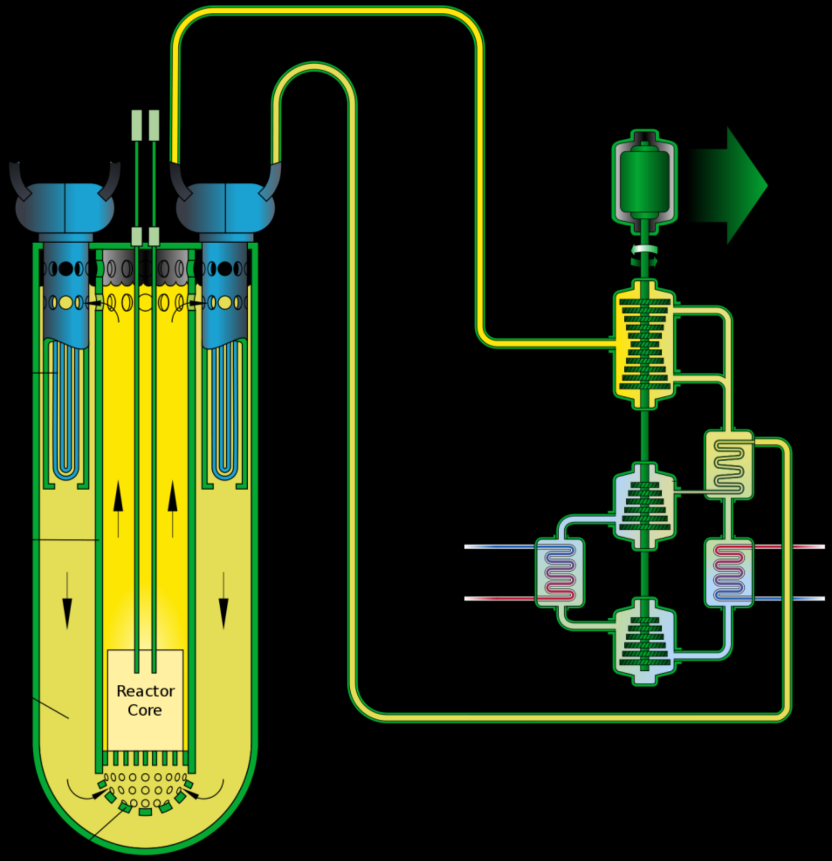
Technetium-99m



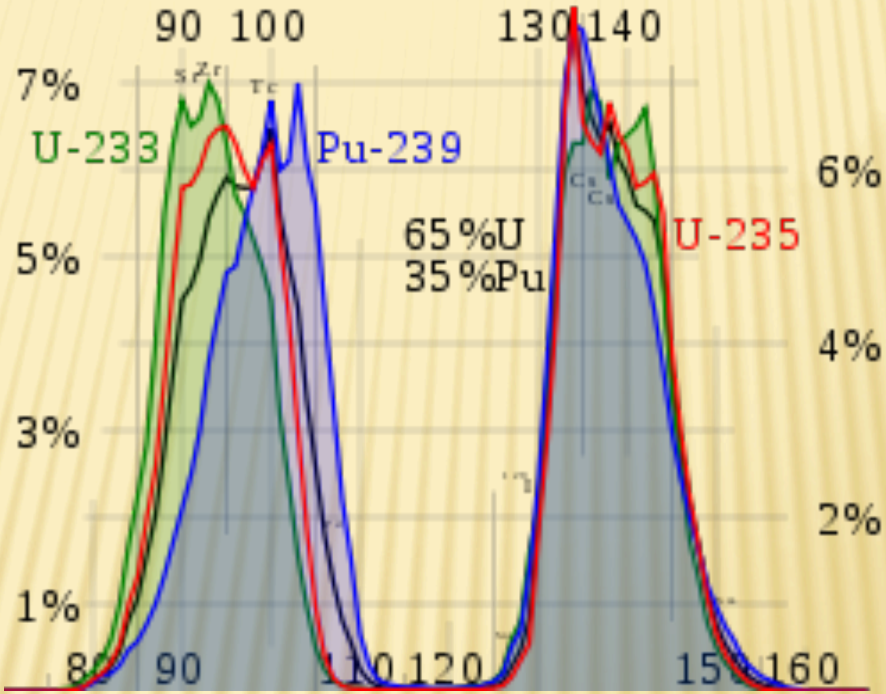
Technetium-99m

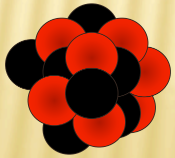


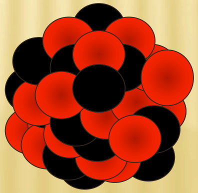
Nuclear Reactor



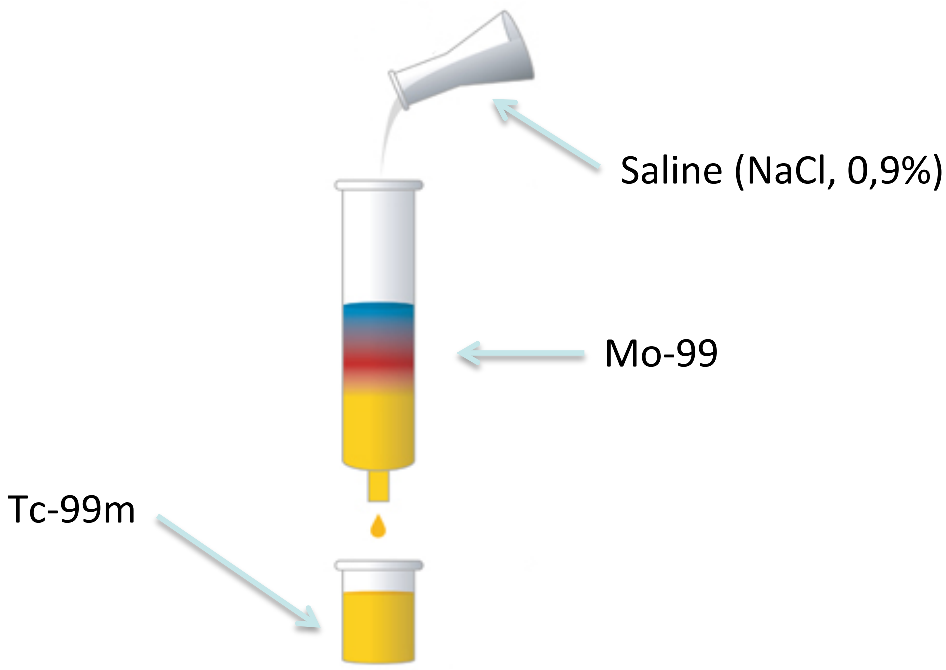
Fission Products

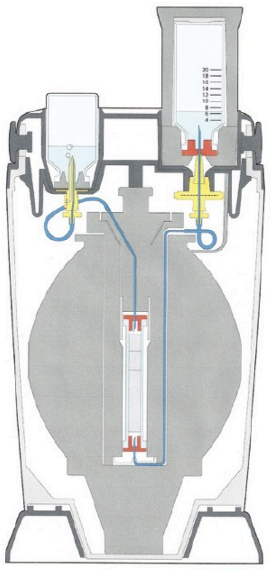




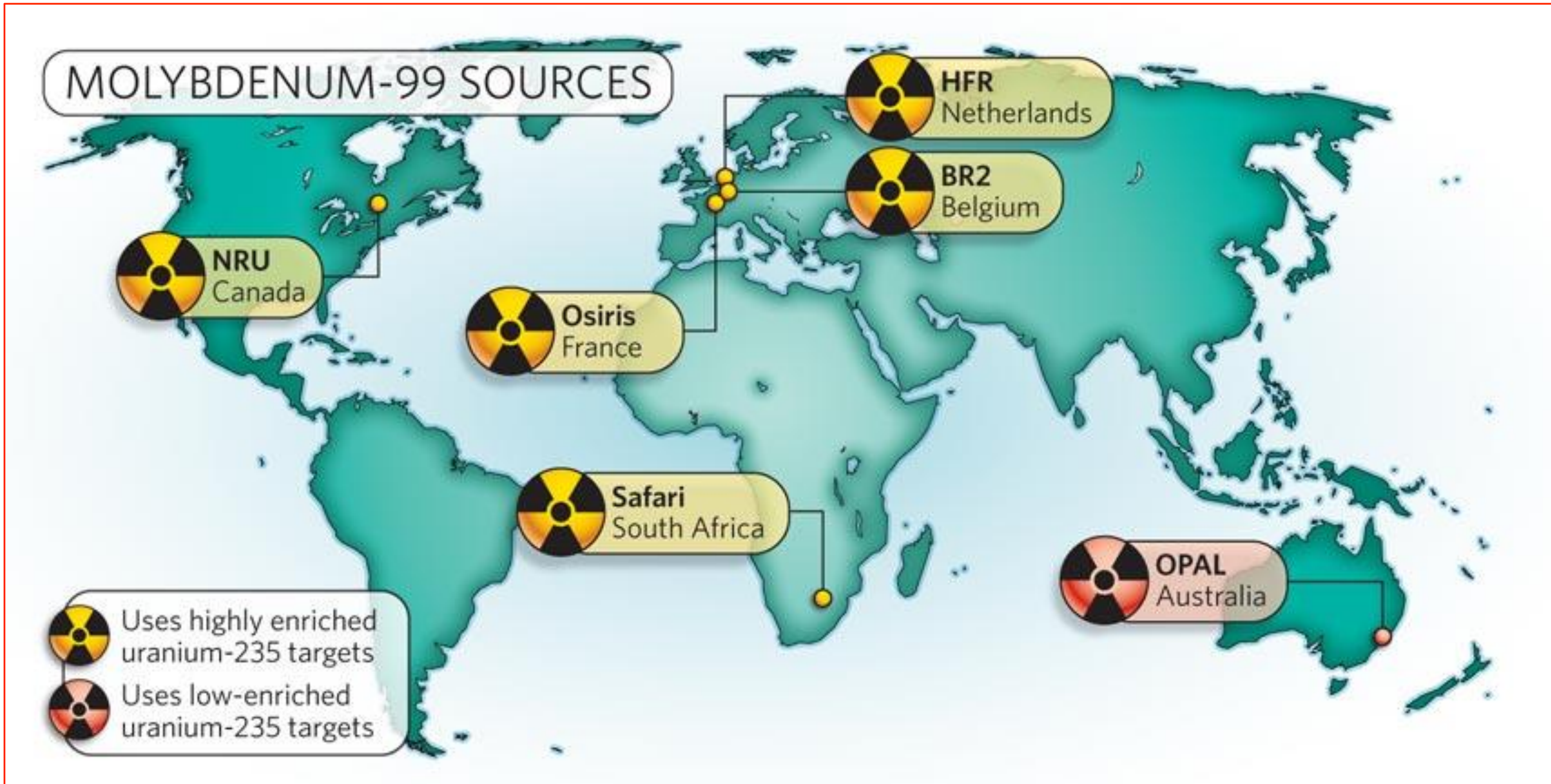


Mo-99/Tc-99m Generator

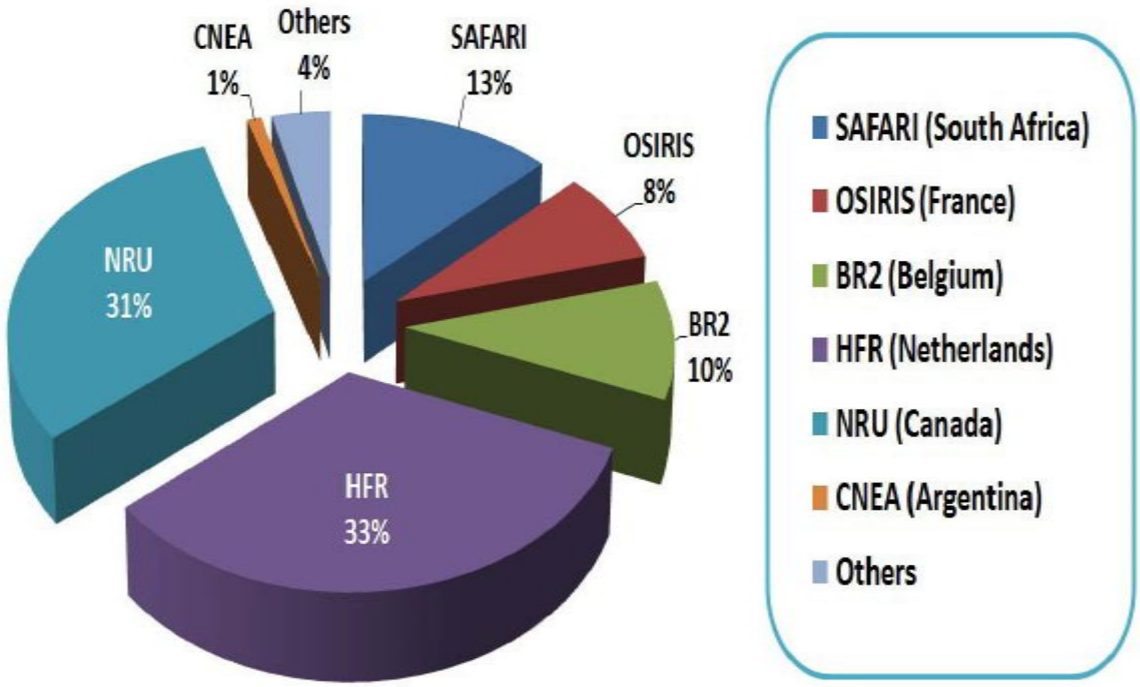




Global Production of Mo-99

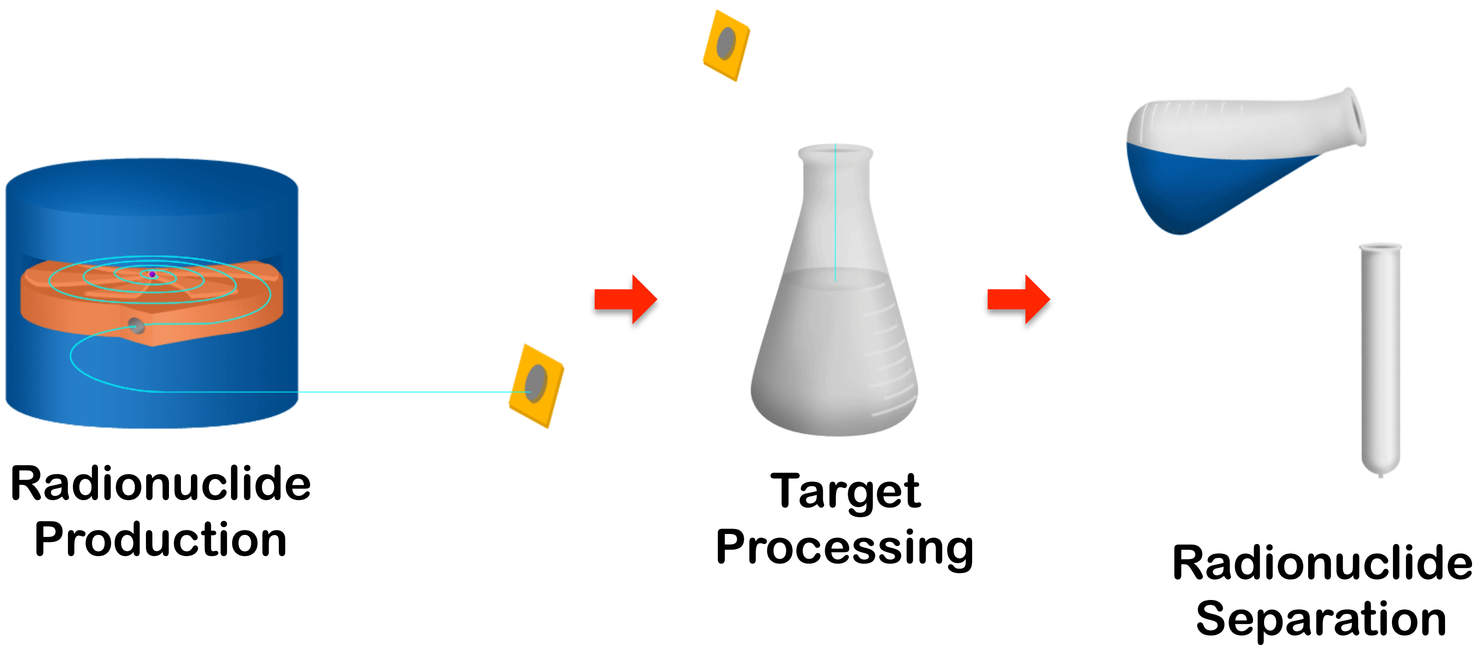


Global Producers of Mo-99

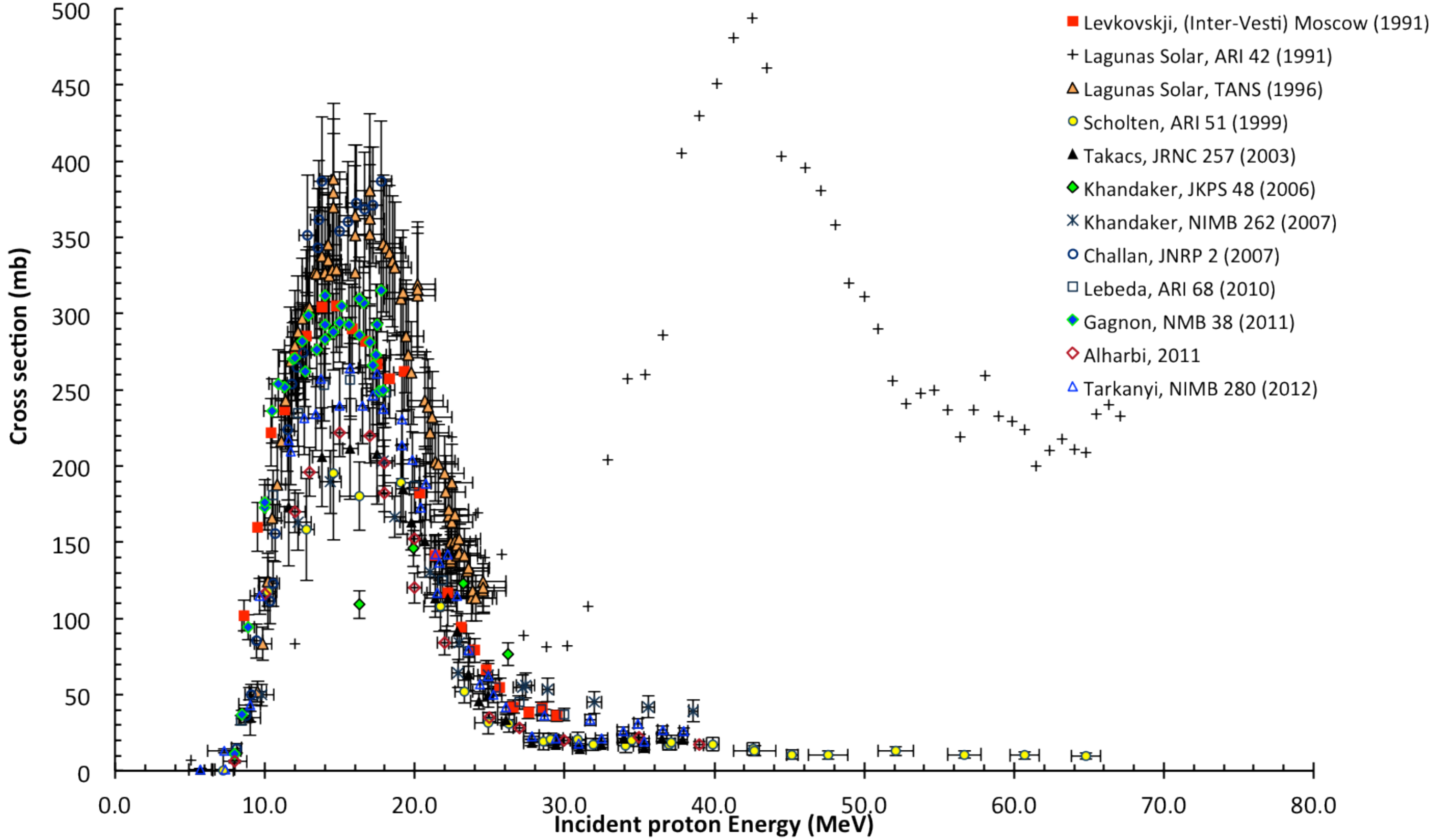


Cyclotron Production of Tc-99m

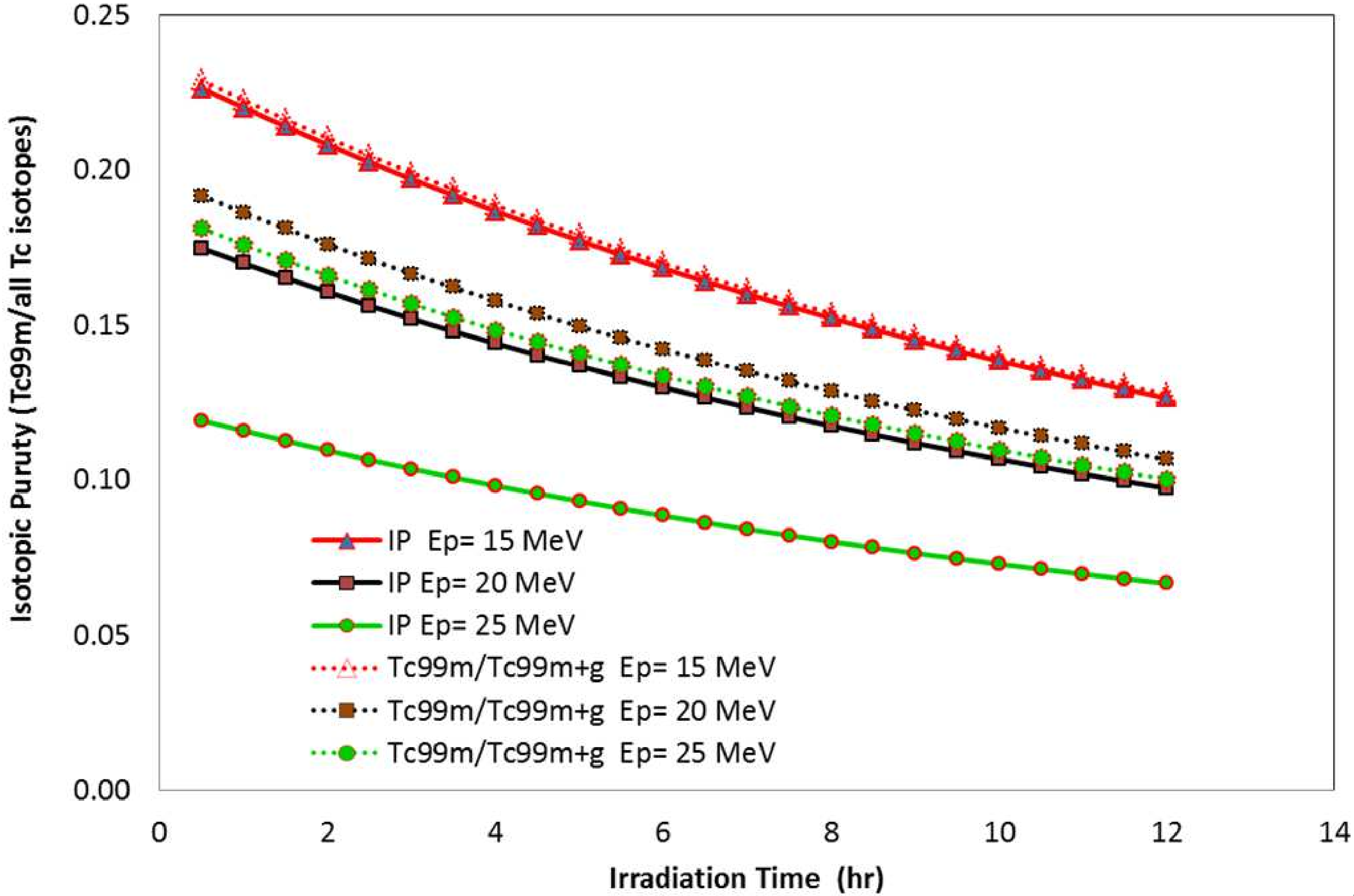
$$^{100}\mathrm{Mo}(p,2n)^{99m}\mathrm{Tc}$$



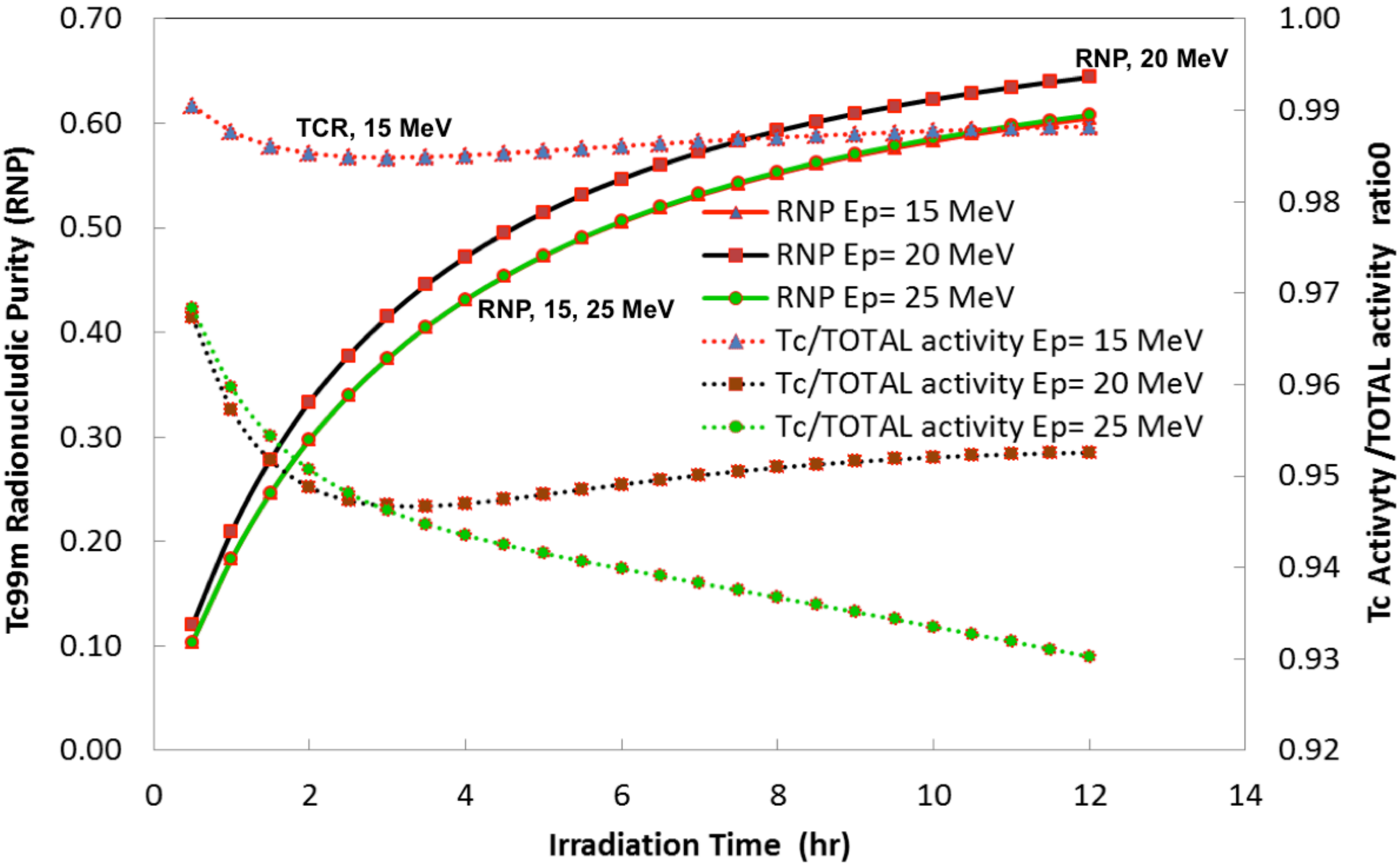
Experimentally Measured Excitation Function for $^{100}Mo(p,2n)^{99m}Tc$ Reaction



^{99m}Tc Isotopic Purity at EOB of 99.05%-Enriched ^{100}Mo Optimized Target



^{99m}Tc Radionuclidic Purity (RNP) and Isotopic Purity at EOB of 99.05%-Enriched ^{100}Mo Optimized Target



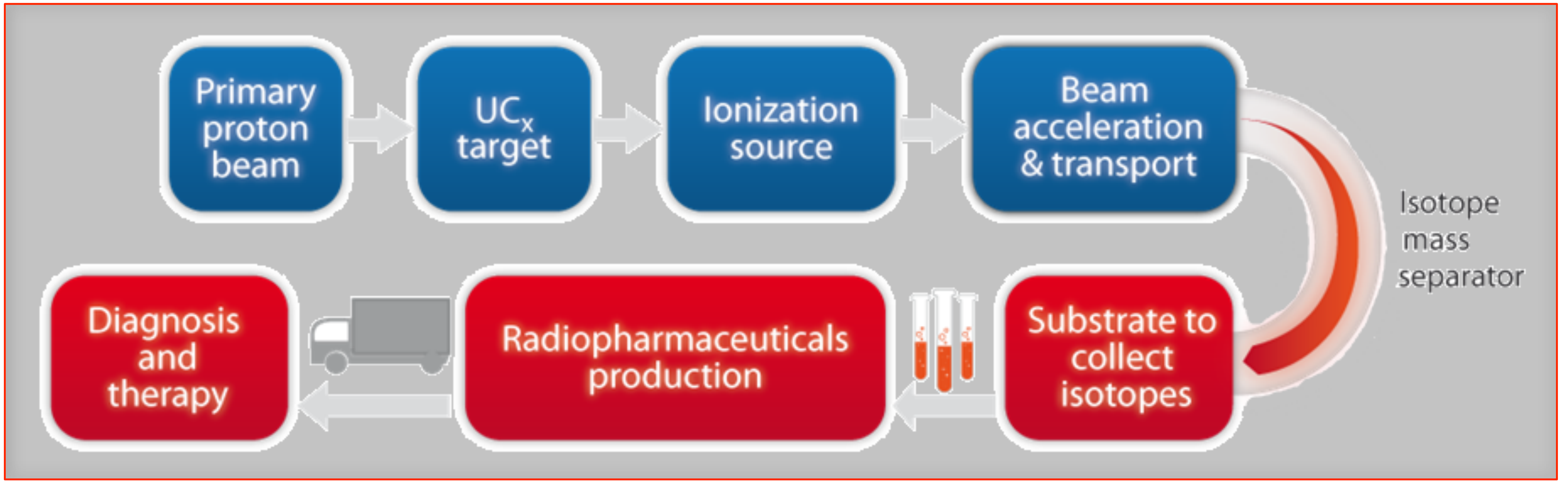
Main Conclusions

- ✓ **Irradiation at proton energies above 25 MeV is not useful, even using higly ^{100}Mo-enriched material.**
- ✓ **Time window 1-10 h post EOB (RNP > 99%; IP > 10%).**
- ✓ **Optimal conditions: energy window, 15 MeV < Ep < 20 MeV, irradiations time ≤ 3 hrs.**

THE ISOLPHARM PROJECT

ISOLPHARM

High specific activity radioPHARMaceuticals production with ISOL technique



HIGH SPECIFIC ACTIVITY

THANK YOU!