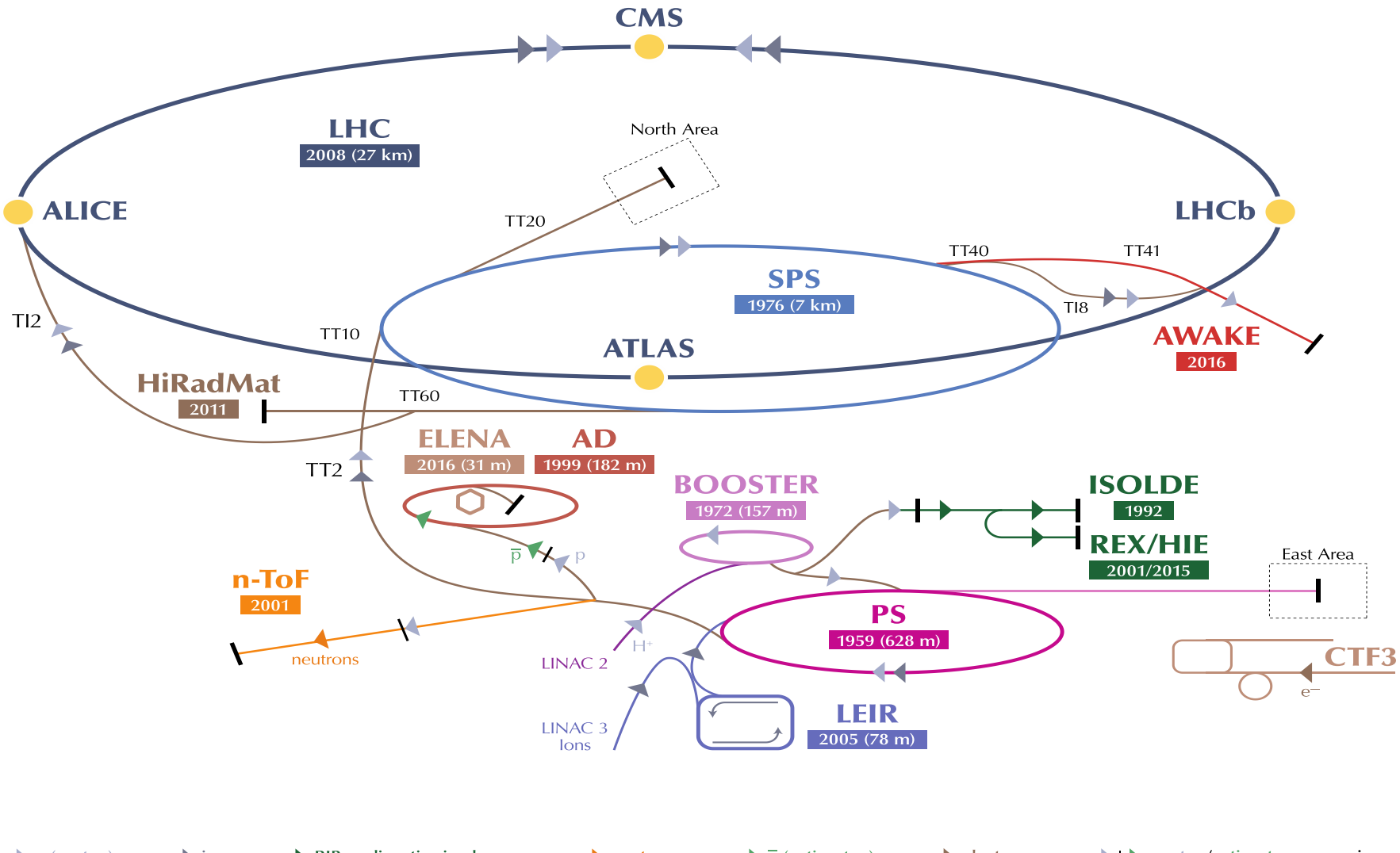
The production of radionuclides for use in biomedical procedures, such as diagnostic imaging and/or therapeutic treatments, is achieved through nuclear reactions in reactors or from charged particle bombardment in accelerators.

In accelerators, the typical charged particle reactions utilize protons, although deuterons and helium nuclei (3He2+ and alpha particles) play a role.

Isotope Production for Medical Applications

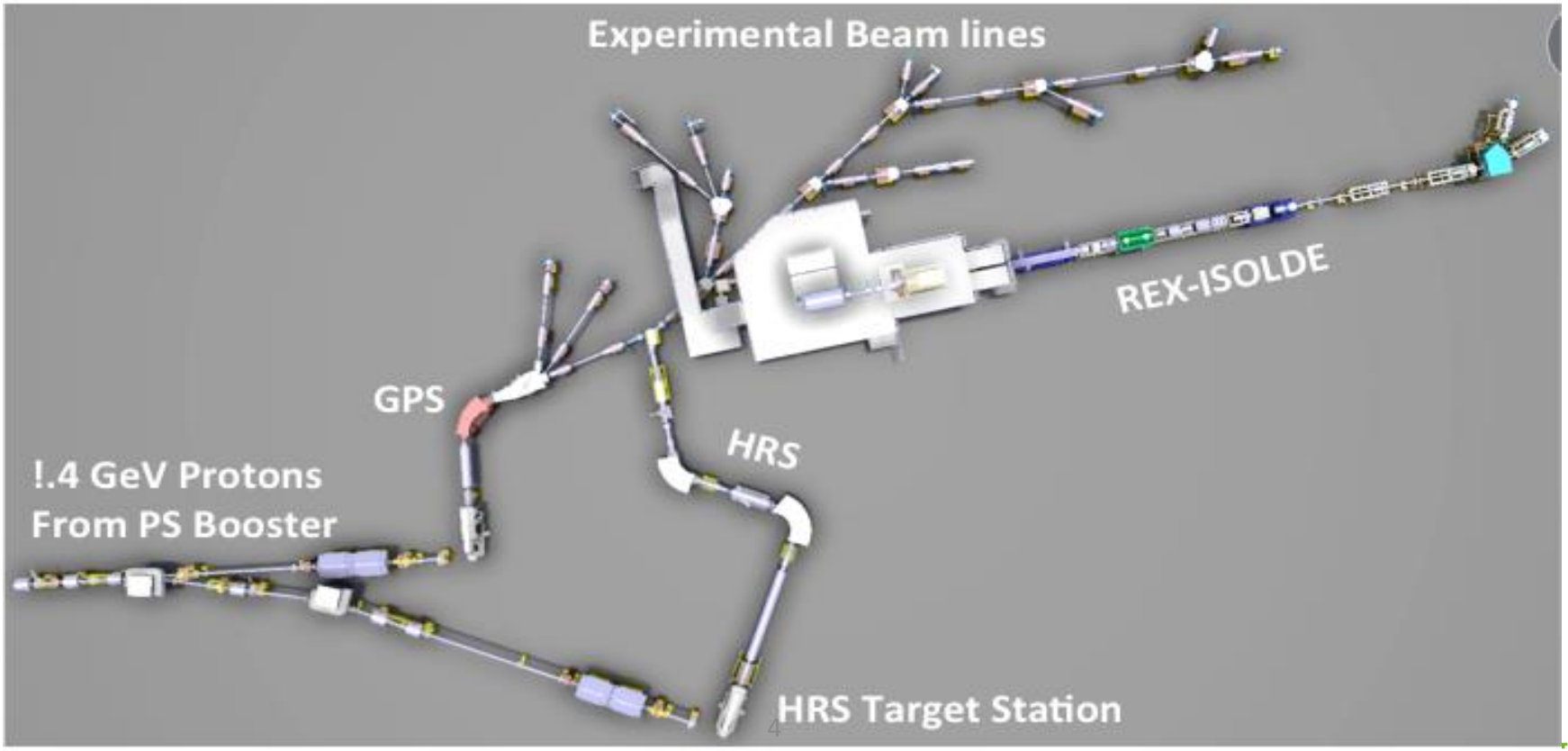
Yacine Kadi, CERN (EN-EA)


CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT20
TT40
TT41
SPS
1976 (7 km)
TI8
TI2
TT10
ATLAS
AWAKE
2016
HiRadMat
2011
TT60
ELENA
2016 (31 m)
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1992
REX/HIE
2001/2015
East Area
n-ToF
2001
p̄
p
PS
1959 (628 m)
CTF3
neutrons
H⁺
LINAC 2
LINAC 3
Ions
LEIR
2005 (78 m)
e⁻
p (proton)
ion
RIBs radioactive ion beams
neutrons
p̄ (antiproton)
electron
proton/antiproton conversion
LHC Large Hadron Collider
SPS Super Proton Synchrotron
PS Proton Synchrotron AD Antiproton Decelerator
CTF3 Clic Test Facility
AWAKE Advanced WAKefield Experiment
ISOLDE Isotope Separator OnLine
REX/HIE Radioacative EXperiment/High Intensity and Energy ISOLDE
LEIR Low Energy Ion Ring
LINAC LINear ACcelerator
n-ToF Neutrons Time Of Flight
HiRadMat High-Radiation to Materials


ISOLD
E
PSB
PS
LINAC2

ISOLDE Facility : a few facts

- ISOLDE is the CERN radioactive beam facility (approved 50 y ago!)
- Provides low energy or post-accelerated beams
- Run by an **international collaboration since 1965. Presently 15 members** (B, CERN, D, DK, F, FI, GR, I, **India**, N, PL, R, **RSA**, S, SW, UK)
- **> 500 Users from 100 Institutions, 50 experiments / year**



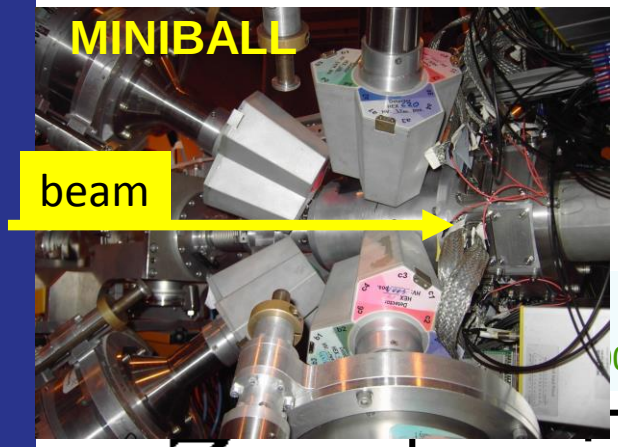
Physics program @ REX

REX-ISOLDE started in 2001

108 different beams already used at REX of 1300 available!

Coulomb excitation with Miniball:

- collectivity versus individual nucleon behaviour



^{184,186,188}Hg
Probing shape coexistence

^{222,224}Ra; ^{220,222}Rn
Probing Pear Shape
Gaffney Nature 2013

^{70}Se, shape coexistence, Hurst PRL 2007

^{96}Sr, ^{88}Kr, ^{92}Kr, PRL 2012

^{122,124,126}Cd
^{138,140,142,144}Xe
^{140,148,150}Ba
Evolution of collectivity around ^{132} Sn

^{74,76,78,80}Zn **Probing large scale shell model,** Van der Walle, PRL2007

^{67,69,71,73}Cu, Stefanescu et al., PRL 2008

^{68,70}Cu, isomeric ^{68}Cu, Stefanescu , PRL 2007

^{30,31,32}Mg, Niedermaier PRL2005, H. Scheit

ISOLDE Physics Topics

- Many beams
- Good beam purity and quality

Best in the World!

- High intensity

Nuclear Physics

Nuclear Decay Spectroscopy and Reactions
Structure of Nuclei
Exotic Decay Modes

Applied Physics

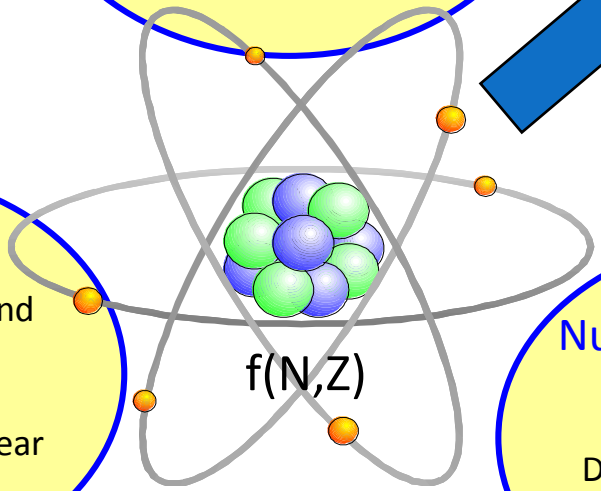
Implanted Radioactive Probes, Tailored Isotopes for Diagnosis and Therapy
MEDICIS Project
Condensed matter physics and Life sciences

Fundamental Physics

Direct Mass Measurements, Dedicated Decay Studies - WI CKM unitarity tests, search for b-n correlations, right-handed currents

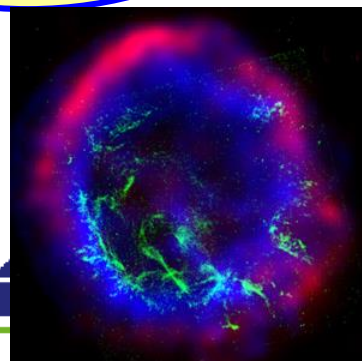
Atomic Physics

Laser Spectroscopy and Direct Mass Measurements
Radii, Moments, Nuclear Binding Energies



Nuclear Astrophysics

Dedicated Nuclear Decay/Reaction Studies
Element Synthesis,
Solar Processes



"*in vivo*" use of Radioisotopes in nuclear medicine today

In Europe: **10 million patient procedures per year**

World wide: **35 million patient procedures per year**

90% are diagnostic & 10% therapeutic (mainly cancer, incl. pain palliation)

85-90 % of diagnostic ones use Tc-99m (nuclear reactor produced)

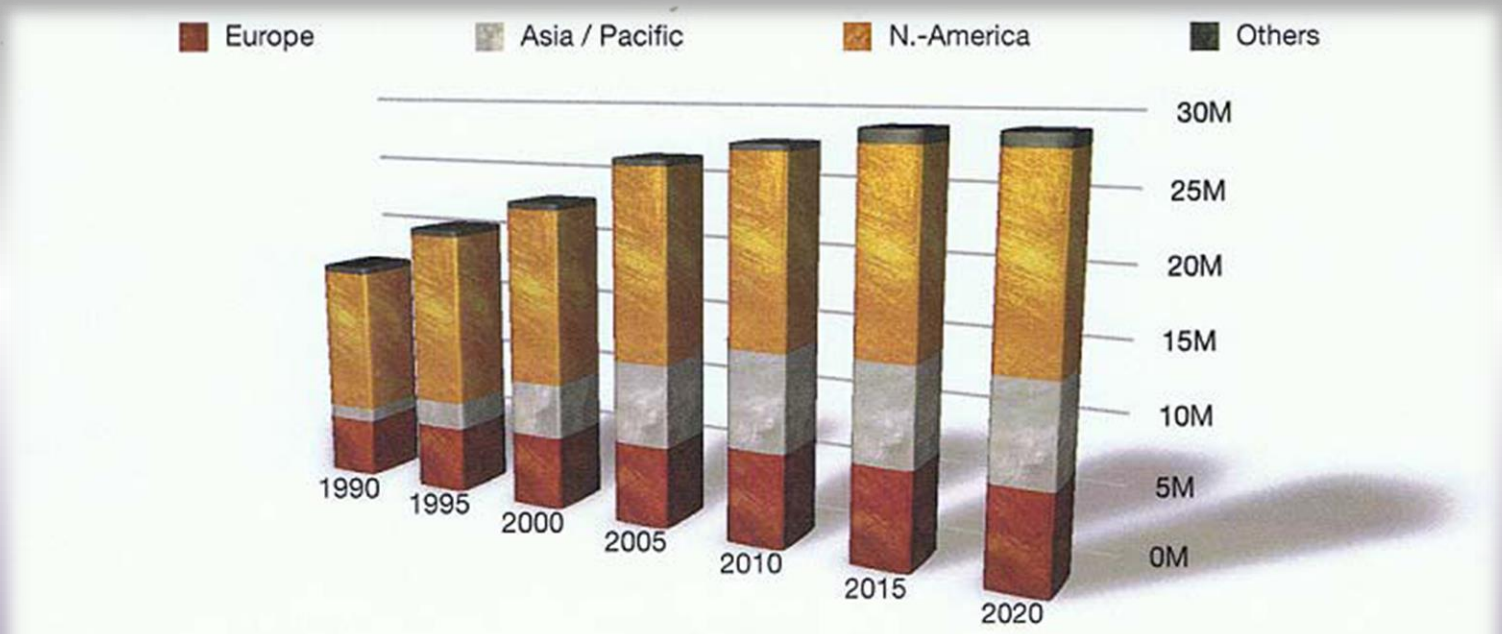


Fig 1. - Estimated in vivo *nuclear medicine procedures with $^{99m}Tc/^{99}Mo$, lab tests excluded, for major world regions 1990-2020 (million procedures per year).*

RADIOISOTOPES IN MEDICINE

DIAGNOSIS
90% of the cases

γ emitters for **SPECT**

^{99}Mo-^{99m}Tc

^{201}Tl, ^{123}I, ^{111}In,
^{81}Rb-^{81m}Kr,
^{67}Ga, …. others

ß$^{+}$ emitters for **PET**

^{18}F, ^{11}C, ^{13}N, ^{15}O
^{86}Y, ^{124}I
^{68}Ge-^{68}Ga
^{82}Sr-^{82}Rb
Others

85-90 % of diagnostic ones use **^{99m}Tc**
(nuclear reactor produced)

THERAPY
10% of the cases

internal

systemic:
^{131}I, ^{90}Y, ^{153}Sm, ^{186}Re, ^{188}W-^{188}Re, ^{166}Ho, ^{177}Lu, …
α-emitters: ^{225}Ac-^{213}Bi, ^{211}At, ^{223}Ra ^{149}Tb, …
e-emitters: ^{125}I, …

Sources:
sealed sources & applicators: ^{192}Ir, ^{182}Ta, ^{137}Cs, …
brachytherapy: ^{103}Pd, ^{125}I
Microspheres: ^{90}Sr or ^{90}Y, …

external

tele radio:
Gamma knife: ^{60}Co
Microspheres: ^{137}Cs

Radioisotopes may be transported to distances according to their half-life *(parameter that indicates its duration in time)*. With a few exceptions, **PET** radioisotopes can be transported to maximum 3-5 hours distance only (Business in: **regional market**) while **SPECT** radioisotopes can be transported to longer distances (Business in: **International market**)

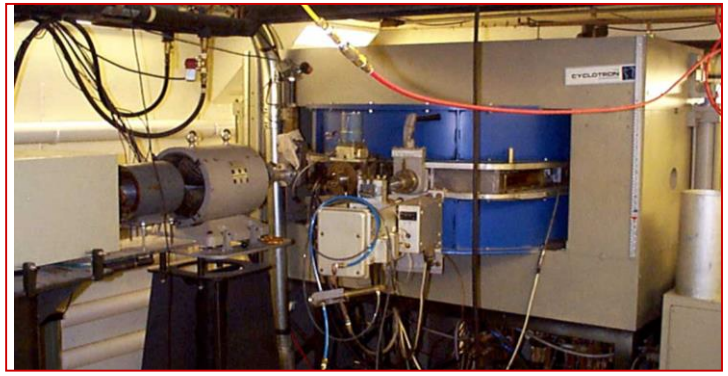
Production of Radionuclide

Nuclear Reactor (neutrons)

- Neutron rich radioisotopes
- Alpha, Beta, gamma decay
- (n, γ) reaction, …

Cyclotron (charged particles)

- Proton rich
- Positron, electron capture
- (p,n), (d,n) reactions, … most common



Comparison of Radioisotopes from Nuclear Reactors & Accelerators

Nuclear Reactors	Accelerators
➢ Neutron rich isotopes are produced. ➢ Specific activity is low due to (n,γ) reactions with thermal neutrons. ➢ ^{99m}Tc is the work horse, but for some application no optimal ^{99m}Tc product is available	➢ Neutron deficient isotopes are produced. ➢ Obtained in no-carrier added form, having high specific activity. ➢ Advantageous in certain applications.

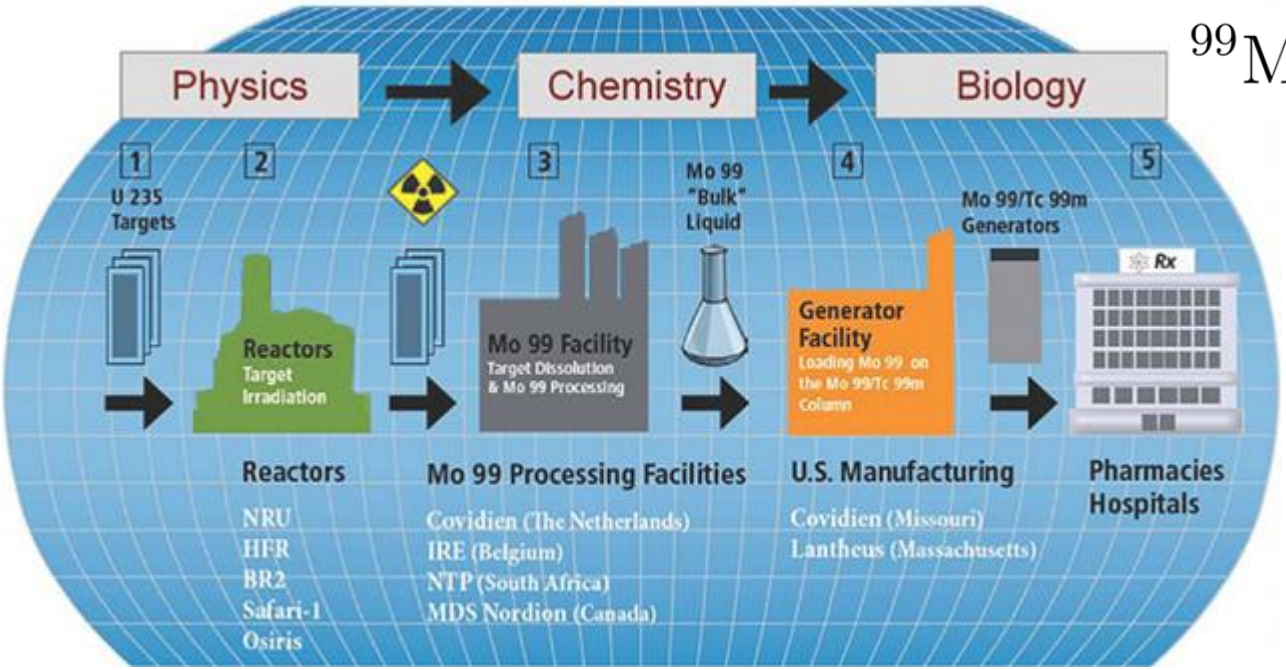
List of main nuclides with large scale (medical) use during 2010-2020, and possibly later

Imaging: conventional, single photon emission tomography SPECT, SPECT/CT	Imaging: positron emission tomography (PET, PET/CT, PET/MRI)	Therapy, pain palliation, radioimmunotherapeutics	
^{67}Ga (a)	^{18}F (a)	^{67}Cu (a)	**^{131}I (r)**
^{99m}Tc/^{99}Mo (r)(g)	^{61}Cu (a)	**^{89}Sr (r)**	**^{153}Sm (r)**
^{111}In (a)	^{64}Cu (a)	^{89}Zr (a)	^{169}Er (r)
^{123}I (a)	^{68}Ga/^{68}Ge (a)(g)	**^{90}Y/^{90}Sr (r)(g)**	**^{177}Lu (r)**
^{131}I (r)	^{82m}Rb/^{82}Sr (a)(g)	**^{90}Y (r)**	**^{186}Re (r)**
^{133}Xe (r)	^{89}Zr (a)	^{117m}Sn (r)	**^{188}Re/^{188}W (r)(g)**
^{201}Tl (a)	^{124}I (a)	^{123}I (a)	alpha emitters, e.g. ^{213}Bi/ ^{225}Ac (g)(a)

Methods of production *: (r) = nuclear reactor, (g) = generator, (a) = accelerator*

Reactor Produced Radioisotopes

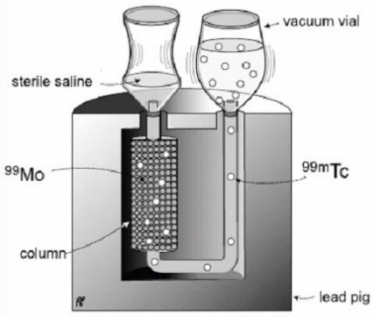
(the process)



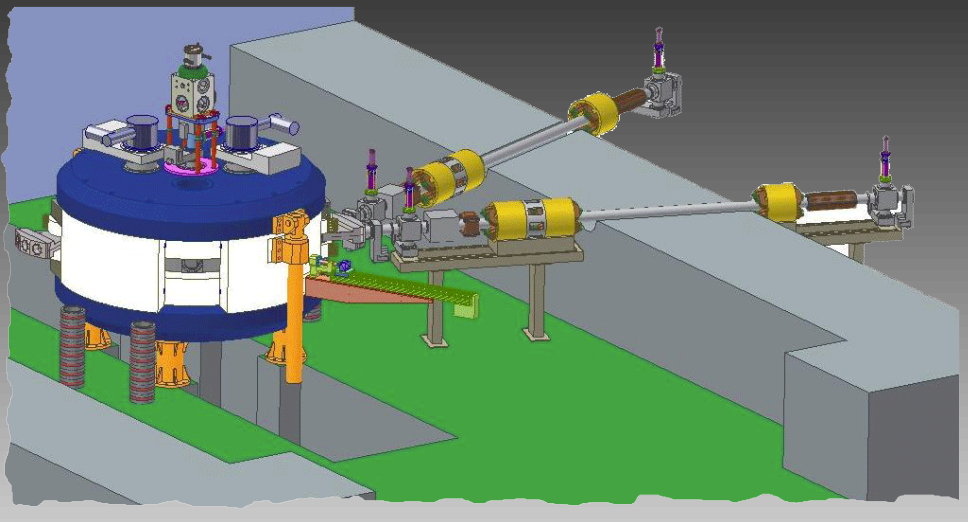
$$^{99}\mathrm{Mo} \xrightarrow{\beta^-} {}^{99\mathrm{m}}\mathrm{Tc} \xrightarrow{\gamma} {}^{99}\mathrm{Tc}$$

Once Mo-99 has been produced it is placed into a technetium generator which are transported to hospitals. The technetium generators make use of the fact that molybdenum likes to bond with aluminium oxide (alumina) but technetium does not. The generators are “milked” by drawing a saline solution across an inner molybdenum/alumina capsule; during this elution process any technetium that has formed will be drawn away with the saline and can then be used in tests.

Chemestry



A cutaway model of a technetium generator



- Charged particles are accelerated using accelerators (Linac or Cyclotron).
- The accelerated particles are driven to a specific target which, after irradiation, contains the desired radioisotope.
- The parameters like particle energy, beam intensity, target material and time will determine the kind and the quantity of produced radioisotopes.
- Following the irradiation, the radioisotopes must be separated using specific laboratories (HOT-LAB)
- **The cost of an accelerator centre for the production of radioisotopes may vary between 5 and 30 Million Euro, depending (mostly) on the energy of the accelerator.**

Methods of producing Radioisotopes

Accelerator Produced Radioisotopes

Steps Involved in Radioisotope Production in Cyclotrons

1- Nuclear data relevant to production

- Nuclear Cross-section data, excitation function.

2- High current targetry

- Target design for high-power beams => Proper cooling of the target during irradiation.

3- Chemical separation of desired radioisotopes

- By different chemical separation techniques dry distillation, ion exchange, solvent extraction.

4- Recovery of the enriched target material

5- Automation

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Indirect production routes

$^{138}Ce(^{16}O,5n)^{149}Dy$

$^{143}Nd(^{12}C,6n)^{149}Dy$

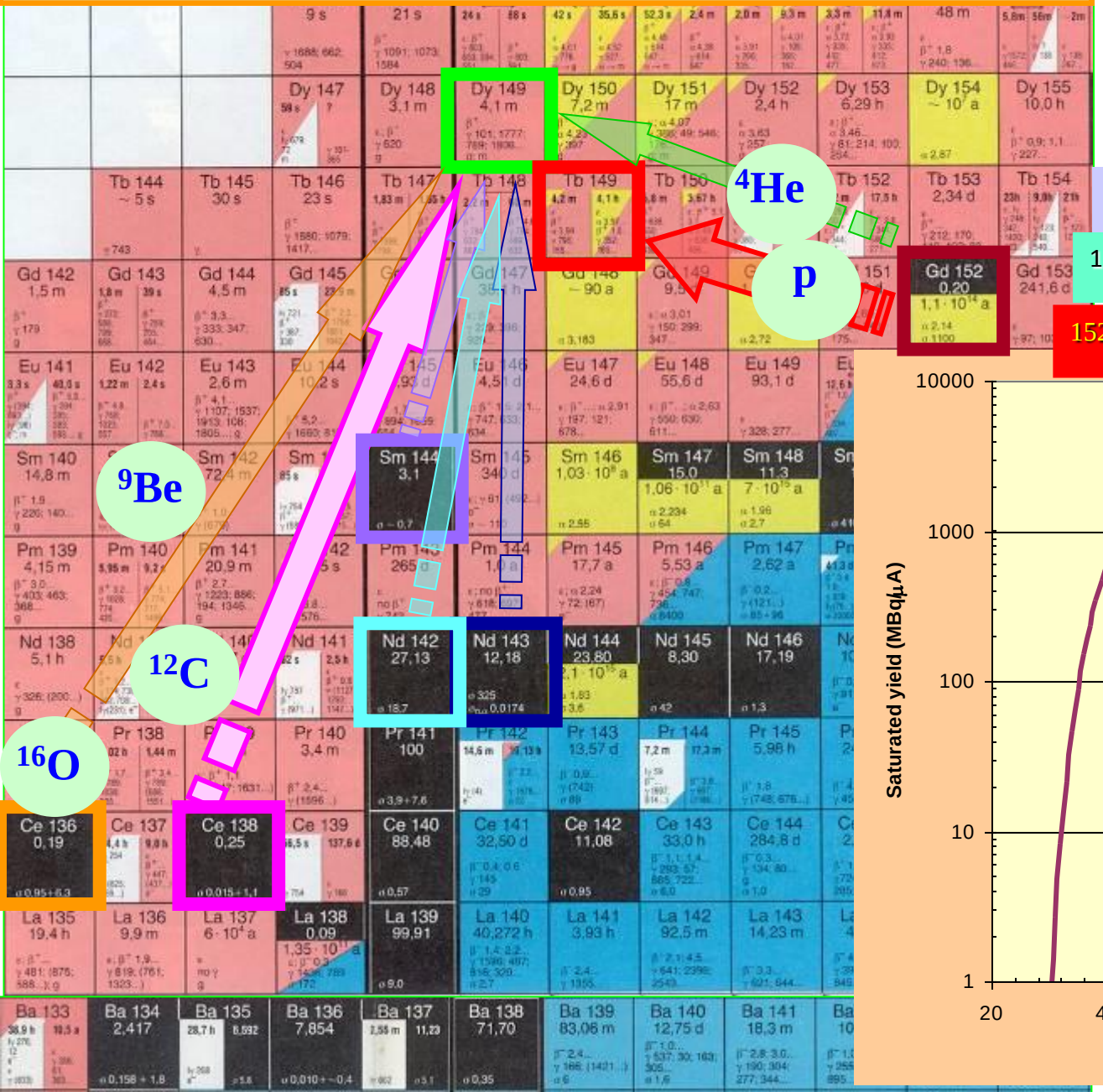
$^{136}Ce(^{16}O,3n)^{149}Dy$

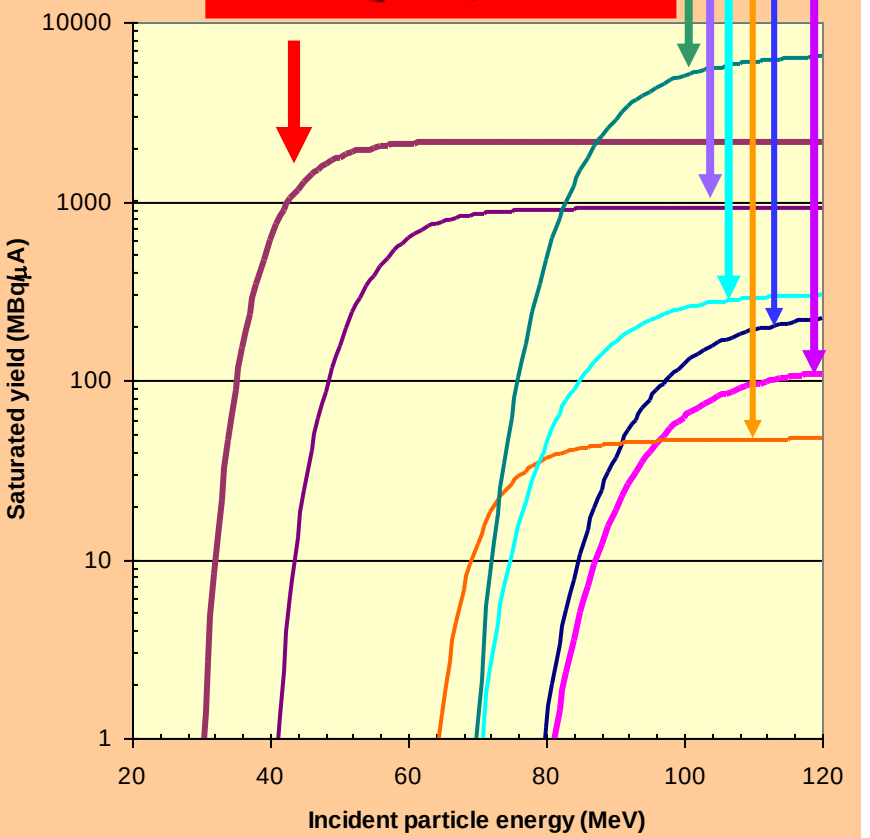
$^{142}Nd(^{12}C,5n)^{149}Dy$

$^{144}Sm(^{9}Be,4n)^{149}Dy$

$^{152}Gd\ (\alpha,7n)\ ^{149}Dy$

$^{152}Gd\ (p,4n)\ ^{149}Tb$





Cyclotron production of Pd-103 by irradiation of palladium with high-energy (50 MeV) protons

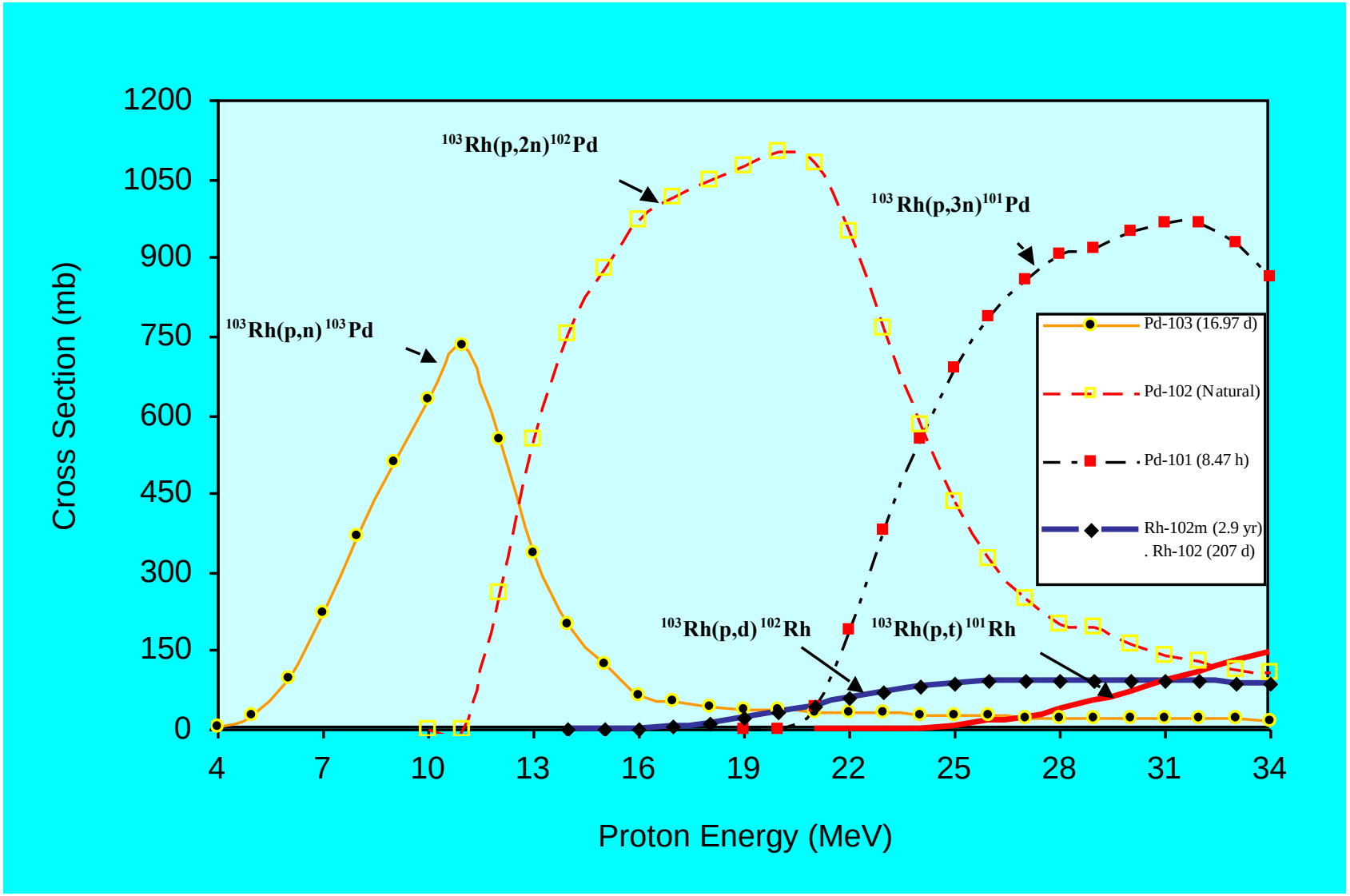
$^{104}Pd(p,pn)^{103}Ag \rightarrow ^{103}Pd$

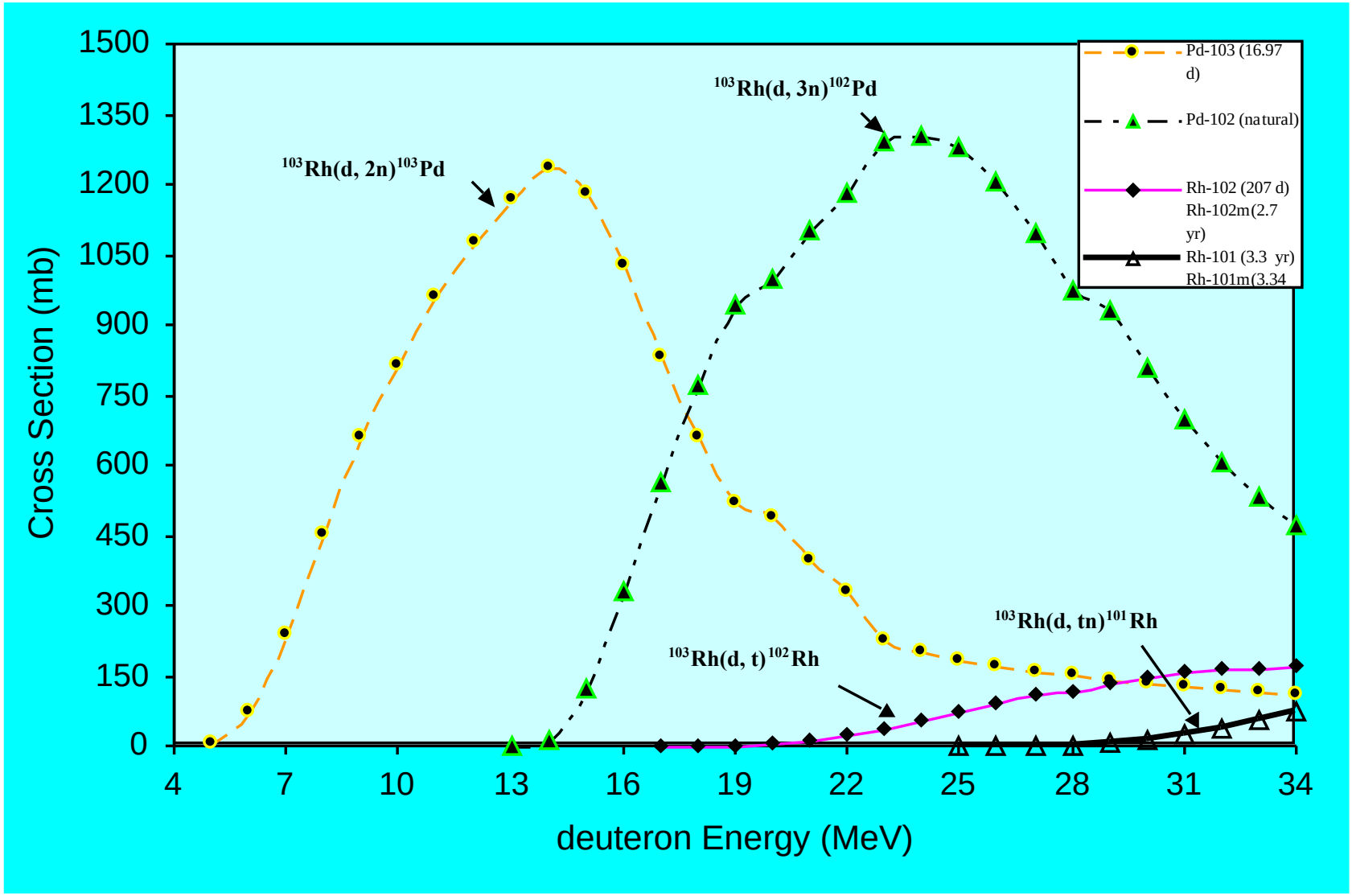
$^{105}Pd(p,p2n)^{103}Ag \rightarrow ^{103}Pd$

$^{106}Pd(p,p3n)^{103}Ag \rightarrow ^{103}Pd$

Y-86 production

$^{86}Sr(p,n)^{86}Y$	15 MeV
^{86} Sr $(d,2n)^{86}Y$	15 MeV
$^{85}Rb(^{3}He,2n)^{86}Y$	30 MeV
$^{85}Rb(\alpha,3n)^{86}Y$	30MeV
$^{nat}Zr(d,\alpha 2n)^{86}Y$	45 MeV
$^{Nat}Ge(O^{+6},x)^{86}Y$	115 MeV


Cross Section (mb)
1200
1050
900
750
600
450
300
150
0
4
7
10
13
16
19
22
25
28
31
34
Proton Energy (MeV)
103Rh(p,2n)102Pd
103Rh(p,3n)101Pd
103Rh(p,n)103Pd
103Rh(p,d)102Rh
103Rh(p,t)101Rh
Pd-103 (16.97 d)
Pd-102 (Natural)
Pd-101 (8.47 h)
Rh-102m (2.9 yr)
. Rh-102 (207 d)


Cross Section (mb)
deuteron Energy (MeV)
0
150
300
450
600
750
900
1050
1200
1350
1500
4
7
10
13
16
19
22
25
28
31
34
103Rh(d, 2n)103Pd
103Rh(d, 3n)102Pd
103Rh(d, t)102Rh
103Rh(d, tn)101Rh
Pd-103 (16.97 d)
Pd-102 (natural)
Rh-102 (207 d)
Rh-102m(2.7 yr)
Rh-101 (3.3 yr)
Rh-101m(3.34

Steps Involved in Radioisotope Production in Cyclotrons

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- **Target design for high-power beams => Proper cooling of the target during irradiation.**

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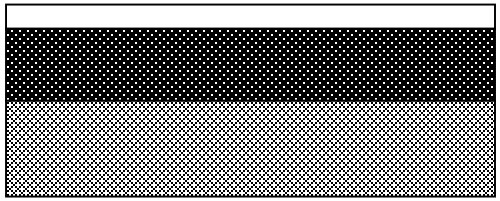
4- Recovery of the enriched target material

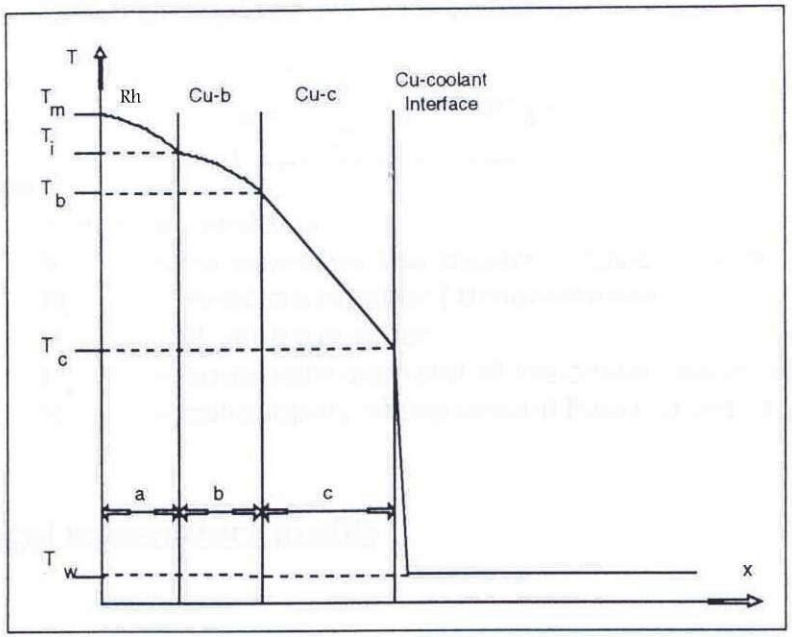
5- Automation

Target Heat Transfer During Bombardment



Rh layer
Cu-Backing
Coolant flow

$$T_m - T_w = \left(\frac{13.I}{2.k_{Rh}}.\frac{a}{s}\right) + \left(\frac{13.I}{k_{Cu}}.\frac{b}{s} + \frac{5.I}{2.k_{Cu}}.\frac{b}{s}\right) + \left(\frac{18.I}{k_{Cu}}.\frac{c}{s}\right) + \left(\frac{18.I}{h.s}\right)$$

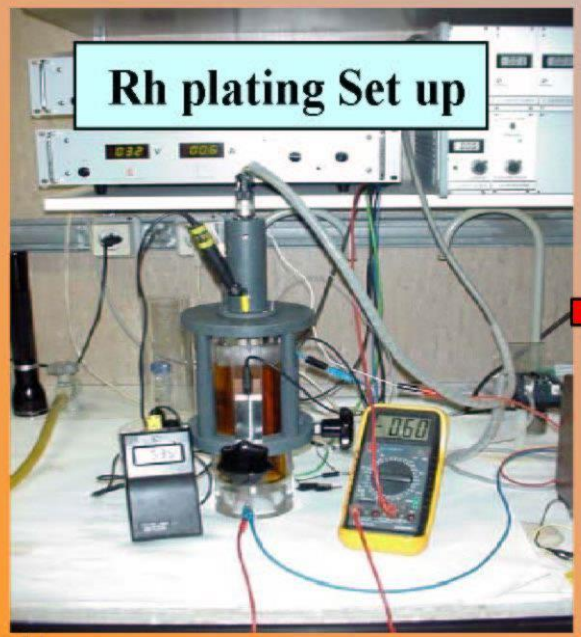


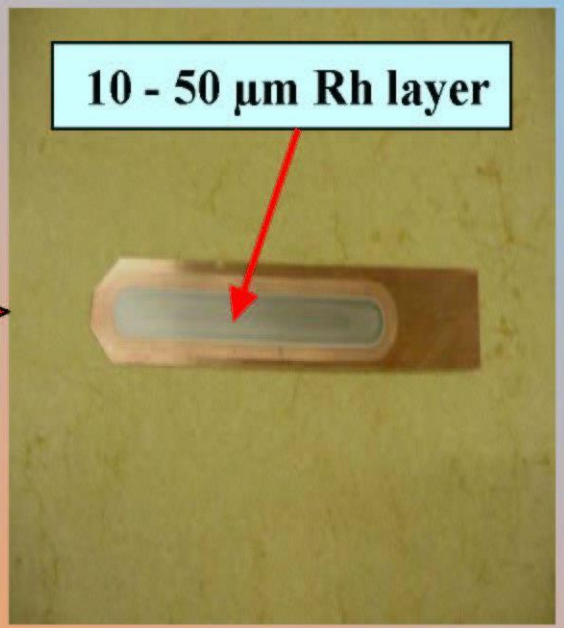
I(μA)	T_m-T_i	T_i-T_b	T_b-T_c	T_c-T_w	T_m-T_w
100	0.18	0.026	3.849	18.12	22
200	0.36	0.052	7.698	36.24	44
300	0.54	0.078	11.547	54.36	66
400	0.72	0.104	15.396	72.48	88
500	0.9	0.13	19.245	90.6	110
600	1.08	0.156	23.094	108.72	132
700	1.26	0.182	26.943	126.84	154
800	1.44	0.208	30.792	144.96	176
900	1.62	0.234	34.641	163.08	198
1000	1.8	0.26	38.49	181.2	220
1050	1.89	0.273	40.415	190.26	231

Atomic Energy Organization of Iran

2. Rhodium plating : plating 10 - 50 μm Rh layer

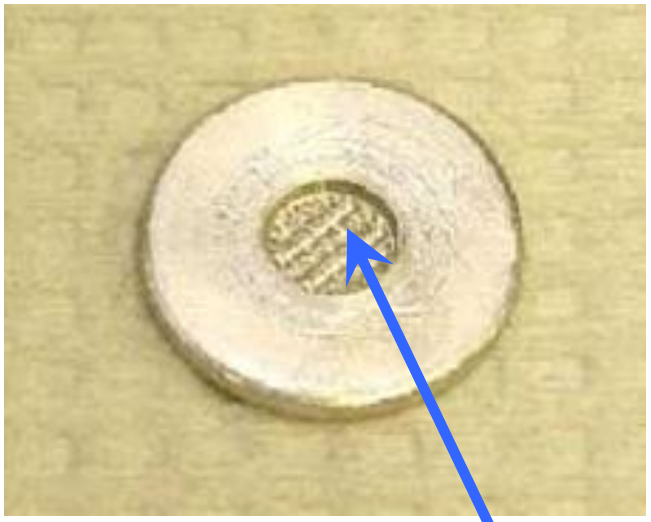
1. Mount the pre-treated Cu carriers in Rh-plating vessel (11.69 cm^2 windows)
2. Introduce plating solution containing an appropriate weight of rhodium
3. Apply dc current (25 - 200 mA/target), stir (1000 rpm, 8/8 cycle) and heat (40 - 60 °C)
4. Continue for 12 - 48 hrs (Rh depletion > 98 %)
5. Empty plating vessel, remove targets, rinse with water/acetone and paper-dry
6. Remove superficial Rh-black layer with scouring suspension, rinse and dry





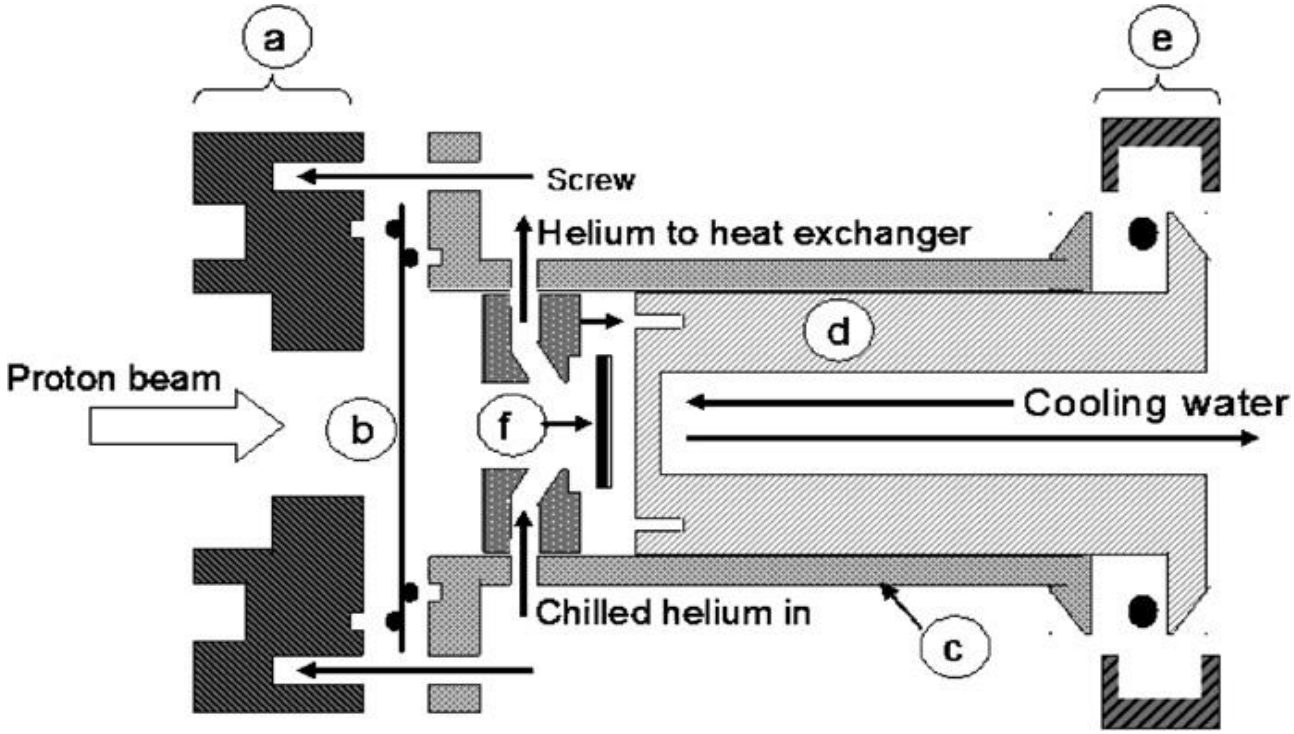
Powder Target

$SrCO_3$



SrO

Powder System

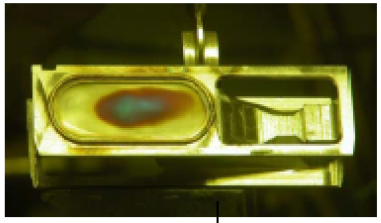


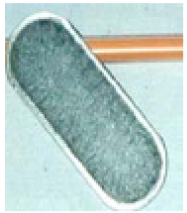
Water-cooled target mounting with circulating chilled helium: (a) standard vacuum flange, (b) 24.5 mm aluminum entrance foil, (c) aluminum cooling jacket, (d) aluminum cooling stage, (e) quick clamp and flange, and (f) target material.

Sr-82 Pd-103 Sn-117m Ge-68 Na-22 Cd-109

T a r g e t s

Rb Ag Sb Ga Al In



-Los Alamos, USA
-IPPE, Obninsk

-Karpov,Obninsk
-Mayak, Ozersk

IPPE, Obninsk
Brookhaven, USA

-Cyclotron Co., Obninsk
-IPPE, Obninsk

-Los Alamos, USA

-Applied Chemistry,
St-Petersburg

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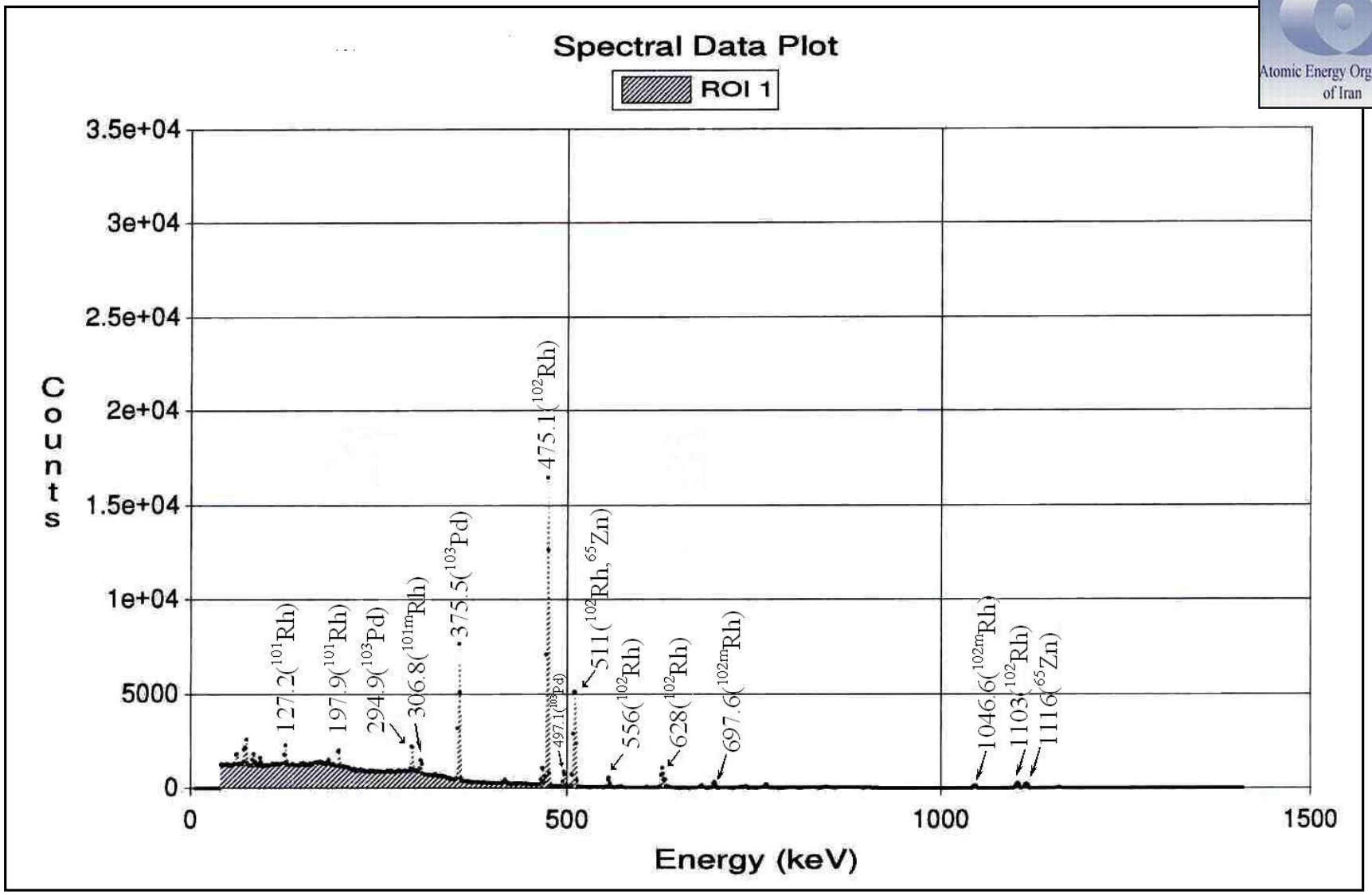
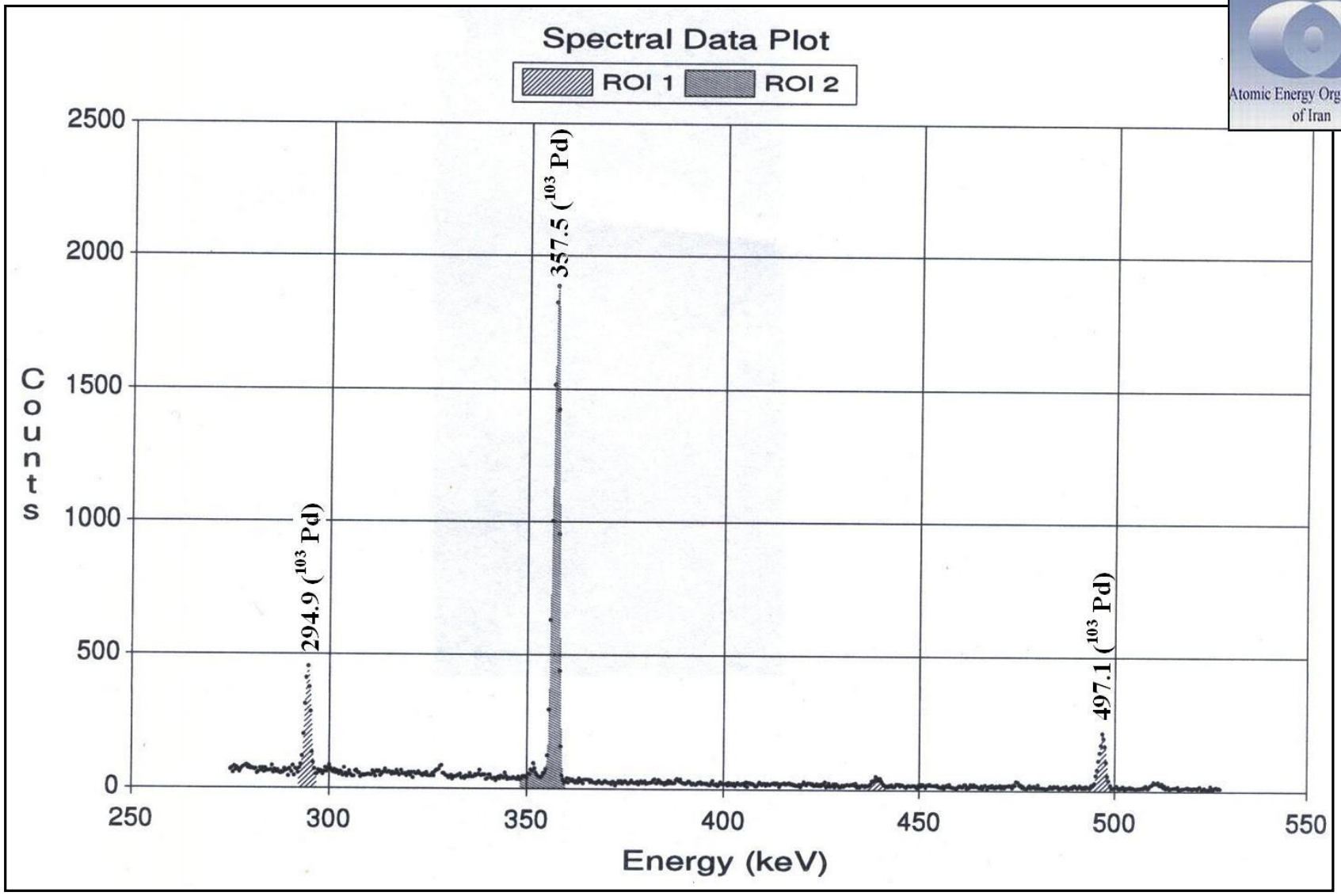


Gamma-ray spectrum of an irradiated ^{103}Rh target after electrodissolution.



Atomic Energy Organization of Iran

HPGe spectrum of radiochemically separated ^{103}Pd. No other peaks have been detected in the γ-spectrum.

Separation Set-up

Radiolabelling

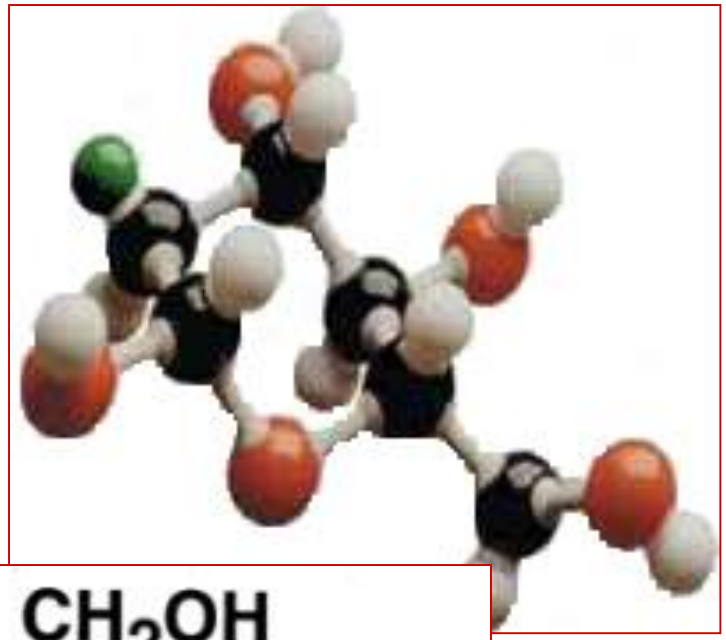
Initially ^{15}O ion labeled to O_2, CO, and CO_2

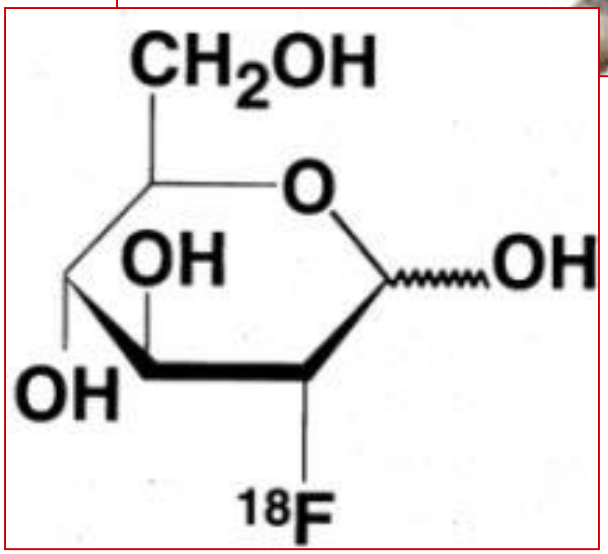
- Main applications in brain oxygen

In mid 70s, cyclotrons were brought in.

- FDG, a glucose based tracer introduced.

FDG is now the dominant PET tracer





PET Radiotracers

- ^{18}FDG is probably the most widely used PET tracer.
  - Fluorodeoxyglucose
  - Glucose based, hence high metabolic relevance
- Can also be used to measure rate of metabolism in brain.

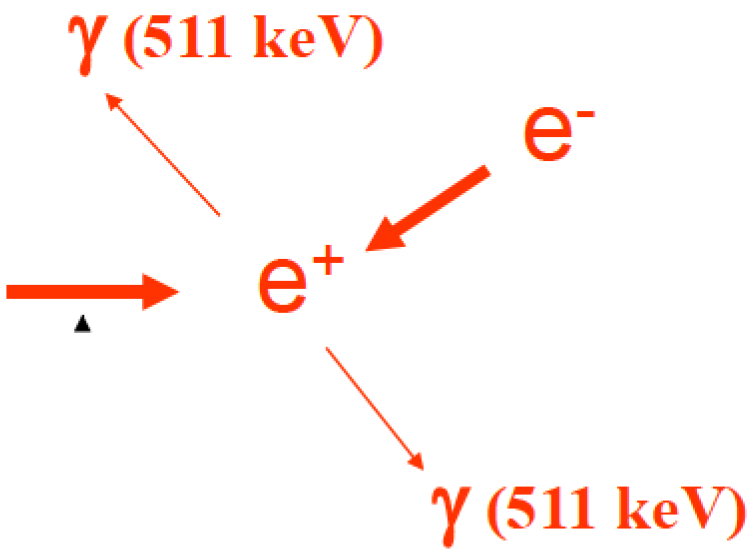
Existing Accelerator Facilities for Radioisotope Production at High Intensity Proton Beam of Middle Energy

- **Brookhaven National Laboratory (NY, USA)**
  200 MeV, 100 μA
- **Los Alamos National Laboratory (NM, USA)**
  100 MeV, 200 μA
- **TRIUMF (Vancouver, Canada)**
  110 MeV, 70 μA
- **iThemba Laboratory (Cape Town, South Africa)**
  66 MeV, 150 μA
- **Institute for Nuclear Research (Troitsk, Russia)**
  160 MeV, 120 μA

(Regular beam currents on typical targets)

Short-lived radionuclides used in PET

- ^{18}F (110 min)
- ^{15}O (2 min)
- ^{13}N (10 min)
- ^{11}C (20 min)
- ^{82}Rb (1.3 min)
  - ^{82}Sr (25.5 d)
- ^{68}Ga (68 min)
  - ^{68}Ge (271 d)



Hospital-Based Radiopharmaceutical Production

Proton	12.5 MeV
Extracted protons	120 μA
Fluorine-18 (60')	3000mCi
Nitrogen-13 (10')	480mCi
Carbon-11 (CO_2) (30')	2000mCi
Carbon-11 (CH_4) (30')	2000mCi
Oxygen-15 (H2O) (10')	1600 mCi

Isotope Production with Cyclotrons

(p,n) process with ~15 MeV protons

^{18}F: ^{18}O (p, n) ^{18}F — most important

PET isotope, commercialized by many centers using dedicated small cyclotrons, however also done at 30 MeV or even at 65 MeV cyclotrons as well (Nice)

^{124}I: ^{124}Te (p,n) ^{124}I

very important PET isotope with commercial interest (in-vivo dosimetry), large scale production technology not yet available, same technology could be used for medium scale ^{123}I production based on ^{123}Te target material

^{86}Y: ^{86}Sr (p,n) ^{86}Y

very important PET isotope with commercial interest (in-vivo dosimetry)

^{64}Cu: ^{64}Ni (p,n) ^{64}Gu

therapeutic isotope for RIT, PET allows the measurement of the biodistribution during therapy.

^{186}Re: ^{186}W(p,n) ^{186}Re

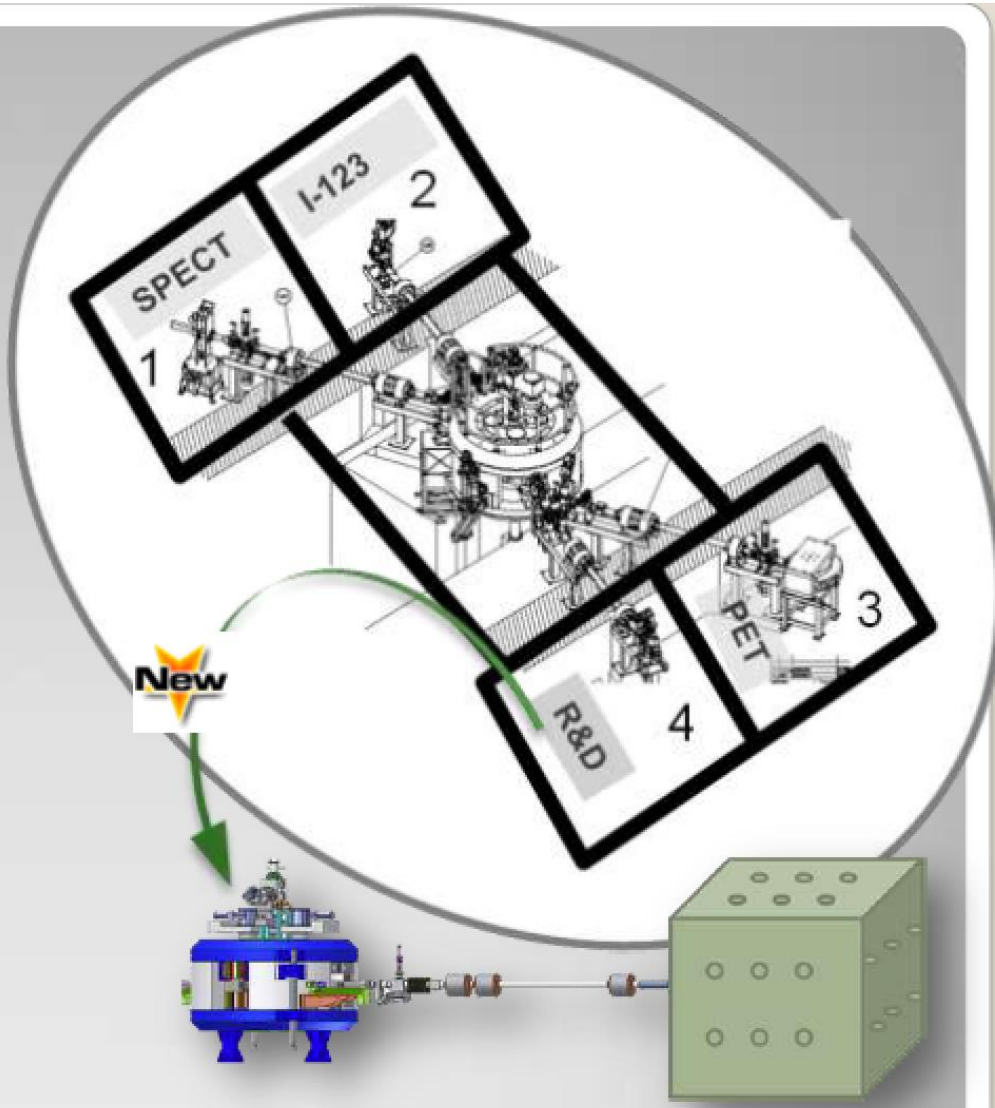
^{186}Re (3.7 d) is one of the two important therapeutic isotopes of Re. The advantage over ^{188}Re (16 h) is the longer half-life, the advantage over the reactor based ^{185}Re(n,γ)^{186}Re process is the carrier free quality.

Production of other useful isotopes

with < 20 MeV proton induced reactions

Isotope	$T_{1/2}$	Reaction	Batch size	Application
^{45}Ti	3.08 h	$^{nat.}$Sc (p,n) ^{45}Ti	100 GBq	PET: bioconjugates
^{55}Co	17.54 h	^{nat}Fe (p,2n) ^{55}Co	50 GBq	PET, encymes, vitamines
^{64}Cu	12.7 h	^{64}Ni (p,n) ^{64}Cu	100 GBq	PET & therapy,
^{67}Cu	61.9 h	^{70}Zn (p,α) ^{67}Cu	50 GBq	therapy, bioconjugates
^{66}Ga	9.4 h	^{66}Zn (p,n) ^{66}Ga	50GBq	PET
^{76}Br	16 h	^{76}Se (p,n) ^{76}Br	10 GBq	PET
^{81}Rb/^{81m}Kr	4.58 h	^{82}Kr (p,2n) ^{81}Rb	20 GBq	Generator, SPECT
^{86}Y	14.7 h	^{86}Sr (p,n) ^{86}Y	50 GBq	PET, bioconjugates
^{89}Zr	78.4 h	^{89}Y (p,n) ^{89}Zr	20 GBq	PET, bioconjugates
^{90}Nb	14.6 h	^{90}Zr (p,n) ^{90}Nb	20 GBq	PET, bioconjugates
^{94}Tc	4.9 h	^{94}Mo (p,n) ^{94}Tc	20 GBq	PET
^{110}In	69.1 m	^{110}Cd (p,n) ^{110}In	20 GBq	PET
^{120}I	1.35 h	^{120}Te (p,n) ^{120}I	10 GBq	PET
^{123}I	13.2 h	^{123}Te (p,n) ^{123}I	20 GBq	SPECT
^{124}I	4.15 d	^{124}Te (p,n) ^{124}I	2 GBq	PET
^{165}Er	10.3 h	^{nat}Ho (p,n) ^{165}Er	40 GBq	Auger Therapy
^{186}Re	90.6 h	^{186}W (p,n) ^{186}Re	20 GBq	Therapy

The irradiation of solid materials requires much better beam quality parameters than gas targets. Consequently, beam homogenisation and beam manipulation is needed, ussually not possible at the PET cyclotrons.
External beam lines, known from classical isotope production at cyclotrons, will take this function over.
The new generation of multi-purpose cyclotrons will be equipped with high-tech diagnostic tools and provide higher beam current than in the past.



Reactor based radioisotopes
Tc99m ….

MCYC-30

30 MeV PET, SPECT, R&D

Commercial Isotope Production with cyclotrons ~30 MeV proton beam

^{201}Tl: ^{203}Tl (p,3n) ^{201}Pb → ^{201}Tl

most important SPECT isotope, commercialized by all radiopharmaceutical Co. The worldwide installed production capacity exceeds the demand

^{123}I: ^{124}Xe (p,2n) ^{123}Cs → ^{123}I very important SPECT isotope, corresponding target design from Karlsruhe is installed worldwide. Batch size up to 10 Ci possible.

^{111}In: ^{112}Cd (p,2n) ^{111}In

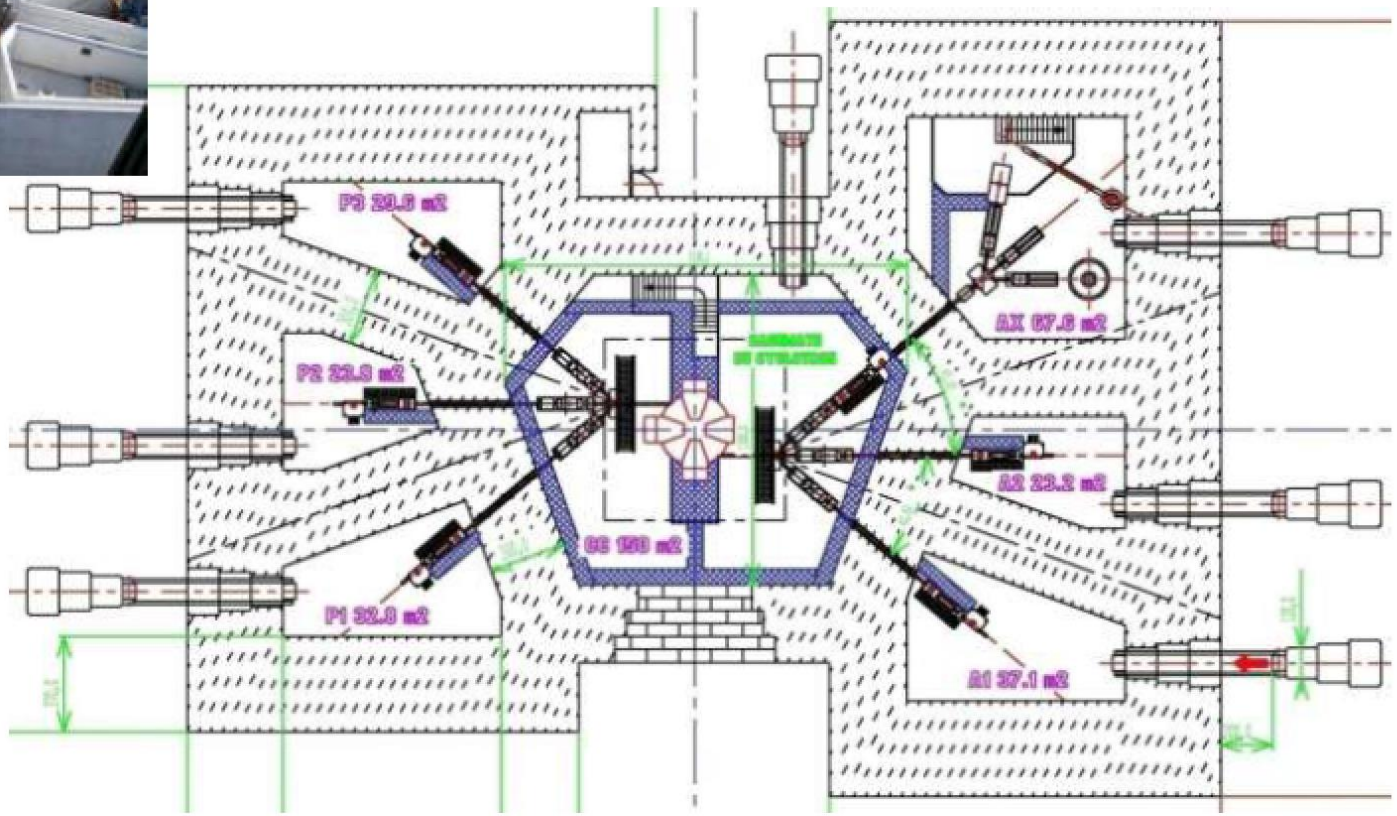
important for certain SPECT techniques, expensive because of low demand

^{67}Ga: ^{68}Zn (p,2n) ^{67}Ga

easy to make, low and decreasing demand

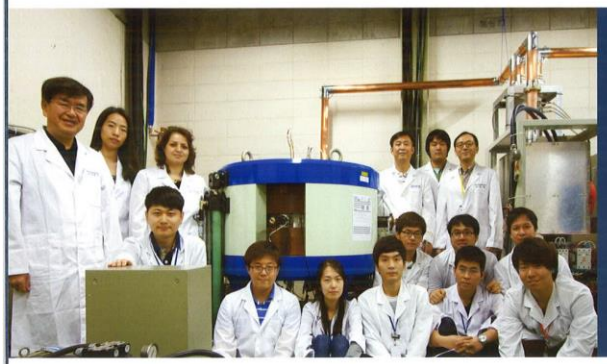
MEDICYC
65 MeV ++Protontherapy (eye)

Casemates et lignes de faisceau



Proposed Accelerator Facilities for Radioisotope Production at High Intensity Proton Beam of Middle Energy

- **ARRONAX/IBA (Nantes, France)**
  H^- Cyclotron - 70 MeV, 2x375 μA
- **Institute for Nuclear Research (Troitsk, Russia)**
  H^- Cyclotron - 120 MeV, 1000 μA: production of ^{82}Sr, ^{117m}Sn, ^{225}Ac, ^{223}Ra
- **Petersburg Nuclear Physics Institute**
  H^- Cyclotron - 80 MeV, 100-200 μA, Isotope separator facility: ^{82}Sr from Y-target
- **Institute for Nuclear Research of National Academy of Sciences of Ukraine (Kiev)**
  H+ Cyclotron, 70 MeV, 100 μA (^{82}Sr production from RbCl-target)
- **Legnaro National Laboratory, INFN (Padova, Italy)**
  Cyclotron - 70 MeV, 2x400 μA
- **Positron Corporation (Illinois, USA)**
  H^- Cyclotron - 70 MeV, 2x375 μA: ^{82}Sr production
- **Proton Engineering Frontier Project (Gyoungju, South Korea)**
  LINAC - 100 MeV, >300 μA
- **National Institute for Radioelements, IRE and IBA (Belgium)**
  Cyclotron - 350 MeV, 1000 μA (Ta-target to produce neutrons for ^{99}Mo)
- **TRIUMF (Vancouver, Canada)**
  Existing H^- cyclotron - 500 MeV. Isotope separator facility: ^{99}Mo from ^{98}Mo-targets



"A Low – cost compact 9 MeV cyclotoron and FDG synthesizer for Radiopharmaceuticals Production system"

Compact circular accelerator for production of medical radioactive isotopes, SKKUCY-9

- Compact cyclotron for production of radioactive isotope used for PET (Positron Emission Tomography) diagnosis
- World smallest cyclotron (for 9 MeV) and realization of low power consumption by highly effective main systems
- Lower spatial and financial requirement to install cyclotron

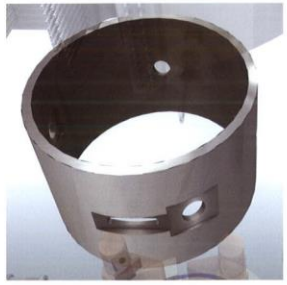
SKKUCY-9	DxH(mm)1250x1257	
Weight	8 tons	
Beams	Ions	Protons
	energy / current	9 MeV / 50 μA
Magnet	type	Compact cylindrical-type
	# of sectors	4
	pole diameter	0.7 m
	hill/valley gap	2~3 cm / 35 cm
	extraction radius	0.31 m
	B max (hill) / B max (valley)	1.89 T / 0.24 T
	center magnetic field	1.366 T
	power	10 kW
RF	frequency	83.2 MHz
	harmonic number	4
	number of dees	2
	Q-factor	4500
	dee voltege	40 kV
Extraction	Charge Exchange Carbon Foil	
Ion Source	Internal Cold Cathode PIG	

SKKUCY-9 Specification

Main Systems

Magnet System

Generates magnetic field to make charged particle moves along the circular path



Vacuum System

Maintains high vacuum state inside the cyclotron to prevent the collision between air and charged particle

RF System

Generates high electric field to supply energy to the charged particle be accelerated successively

Ion Source

Is inserted into the center of cyclotron and produces charged particles by high voltage and discharge process

Features of SKKUCY-9

Automatic Resonance Tuning System

Remote control and detection system using smart device

●

Automatic resonance control by Fine Tuner

●

Real-time control system

Low Power Consumption

Optimization of electromagnet system

●

Prevention of the magnetic flux loss by bigger return yoke structures

●

Effective operating system for low power consumption

High Quality Beam

Increasing the quality of beam through minimization of vertical divergence inside the cyclotron

●

Faster particle acceleration until 9 MeV using higher resonance frequency

Optimized as an Effective Radioactive Isotope Production System

High probability of production of F-18 radioactive isotope at 9 MeV proton energy

●

Development of multiple radioactive isotope production system using fixed target system

ACCSYS TECHNOLOGY, INC.

PULSAR™

PULSAR™ 7 PET Isotope Production System

TECHNOLOGY BRIEF

CERN technology

Find out more; www.cern.ch/KT, david.mazur@cern.ch

High Frequency Compact Linear Proton Accelerator

As part of the Medical Applications Programme at CERN, a novel very compact radio-frequency quadrupole (RFQ) linear accelerator has been designed. Operating at a frequency of 750 MHz and having adapted beam optics, this RFQ can reach an energy of 5 MeV over a distance of 2 m. It is a suitable alternative to cyclotrons for use in medical applications, for example as an injector for higher energy linacs or as a standalone accelerator for radioisotope production.

Applications

- **Linac-based proton therapy facilities**
- **PET isotope production**
- **Technetium production for SPECT tomography**
- **Brachytherapy**
- **Material analysis**

Features

- **Modular, permitting cascading of several RFQ modules and integration into larger accelerating structure**
- **Very compact**
- **No shielding required**

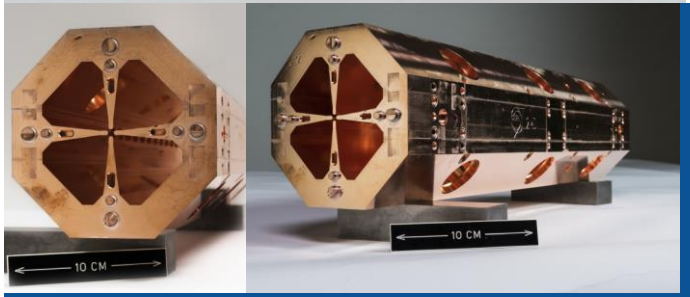
Benefits of Working with CERN

Outputs of the world's leading scientific research institute

Research developed and experimentally validated technologies

World class infrastructures and facilities

Possibility of using CERN labels for your branding and marketing



High-Frequency Compact Linear Proton Accelerator — Design

IP Status:

Patented; available for licensing

Technology Readiness Level:

First prototype is being manufactured. Beam tests scheduled for 2016.

Technology Domain: Accelerators

Artwork Credit: Xavier Cortada (with the participation of physicist Pete Markowitz), "In search of the Higgs boson: H - > tau tau", digital art, 2013

Short-lived radionuclides used in PET

- ^{18}F (110 min)
- ^{15}O (2 min)
- ^{13}N (10 min)
- ^{11}C (20 min)
- ^{82}Rb (1.3 min)
  - ^{82}Sr (25.5 d)
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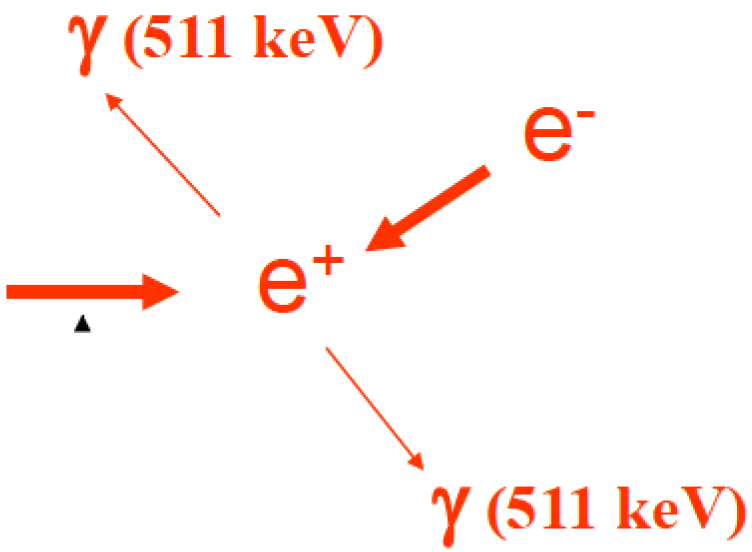


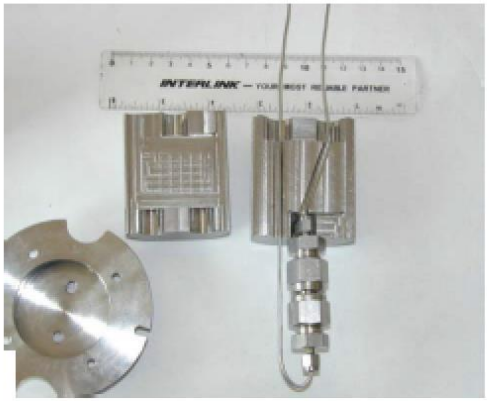
CardioGen-82® US Sr/Rb-82 Generator

(10/30 kG, 100-120 mCi, 28-day operation)

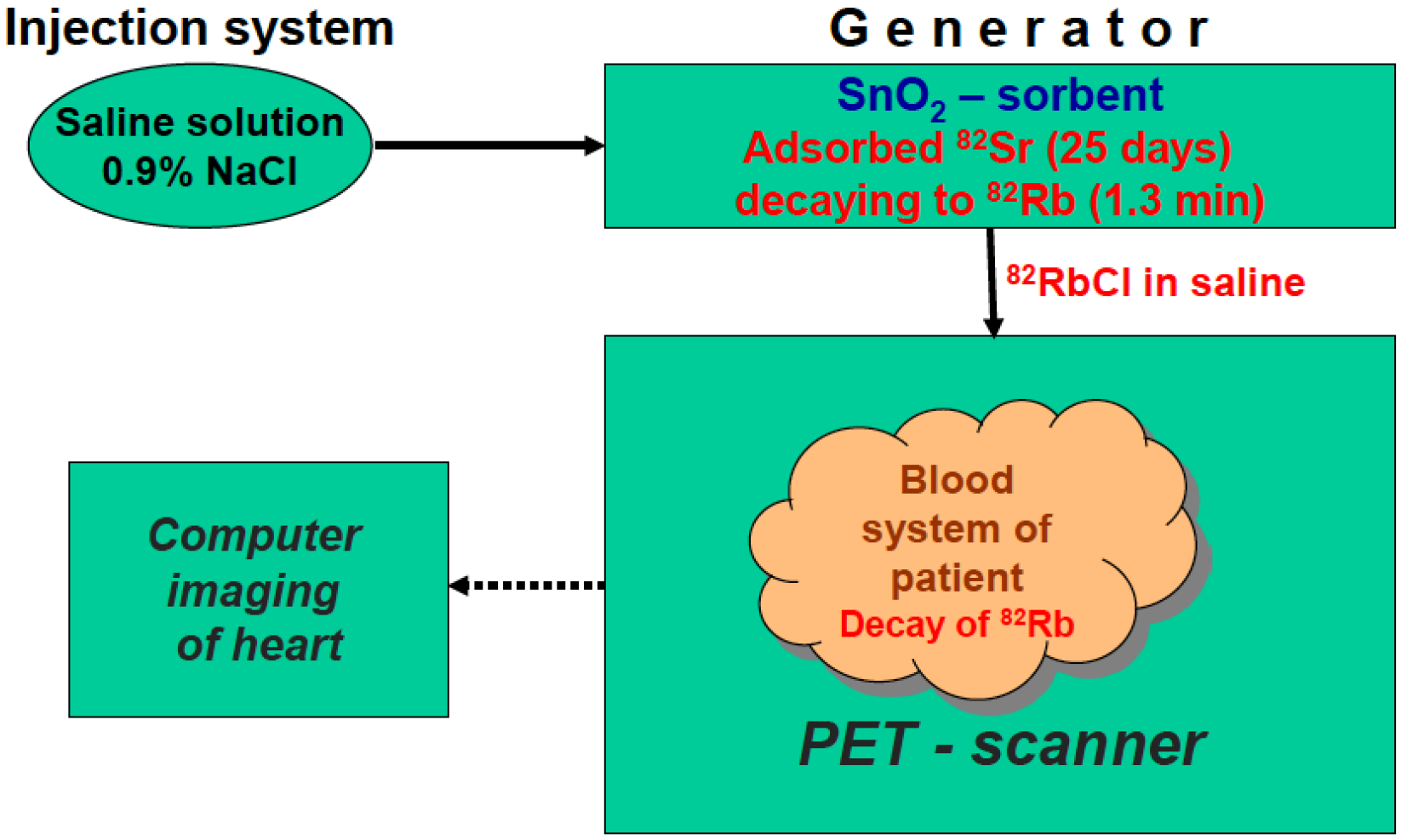
RECALL in July 2011

GR-01 Russian Sr/Rb-82 Generator in tungsten container

(21/38 kG, 50-160 mCi, 60-day operation)



Principle of Operation with $^{82}Sr/^{82}Rb$- Generator: an alternative of ^{13}N and ^{99m}Tc in some cases



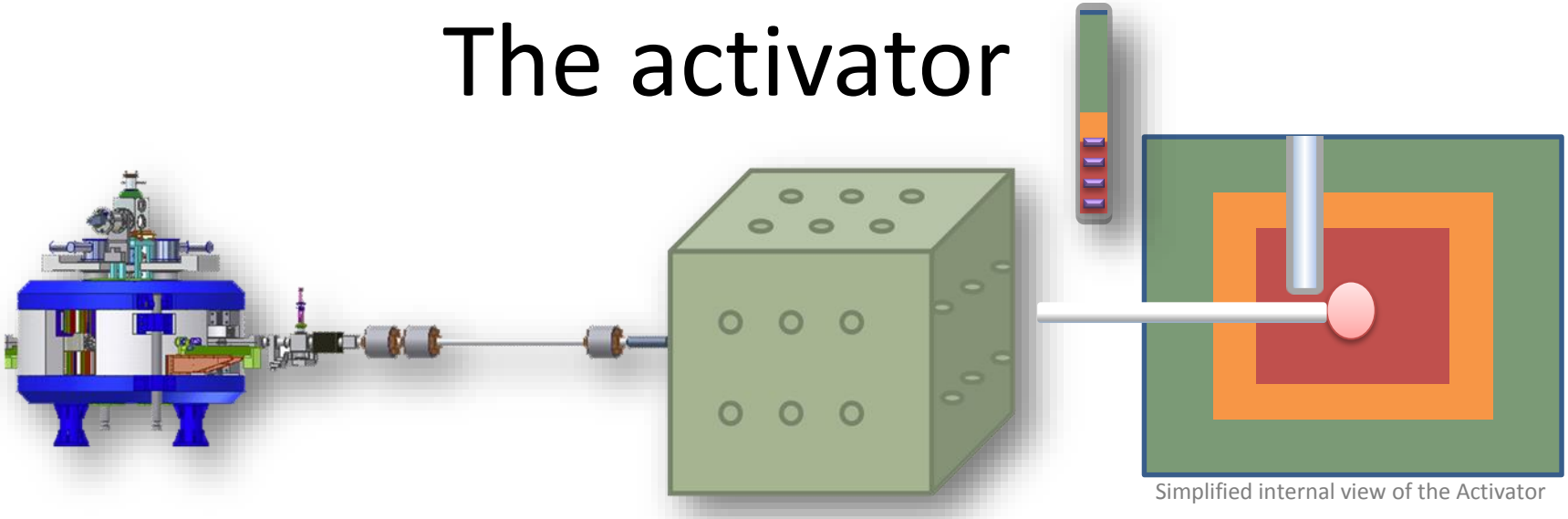
The technology has been originally invented at CERN and the concept has been proven through experiments

In addition to its use for the production of radiopharmaceuticals, the same concept is used for the transmutation of long leaved radioactive elements and for the destruction of nuclear waste.

The initial concept has been optimized and its performance, according to our calculations, has been increased, at least, by a factor of 100.

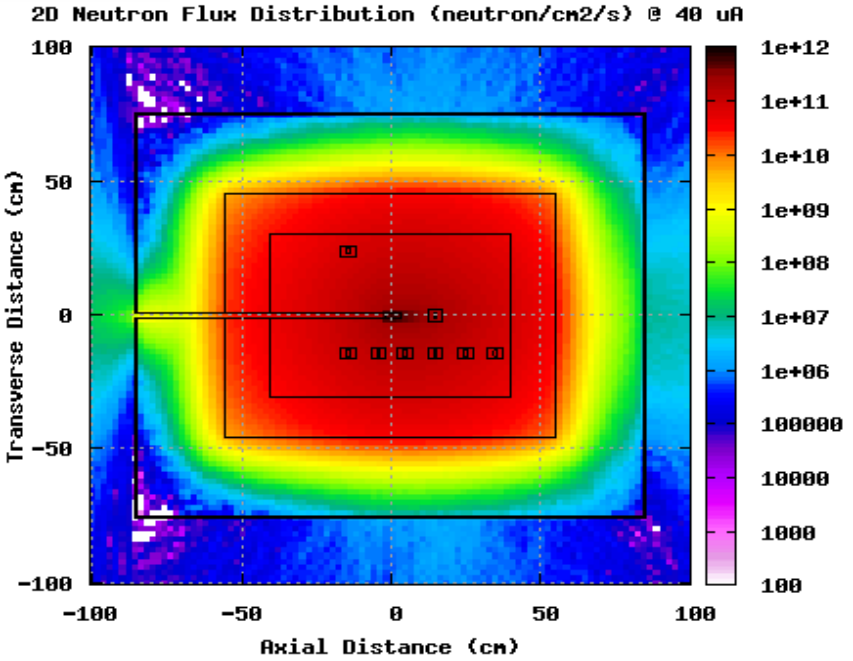
The Activator

The activator



Simplified internal view of the Activator

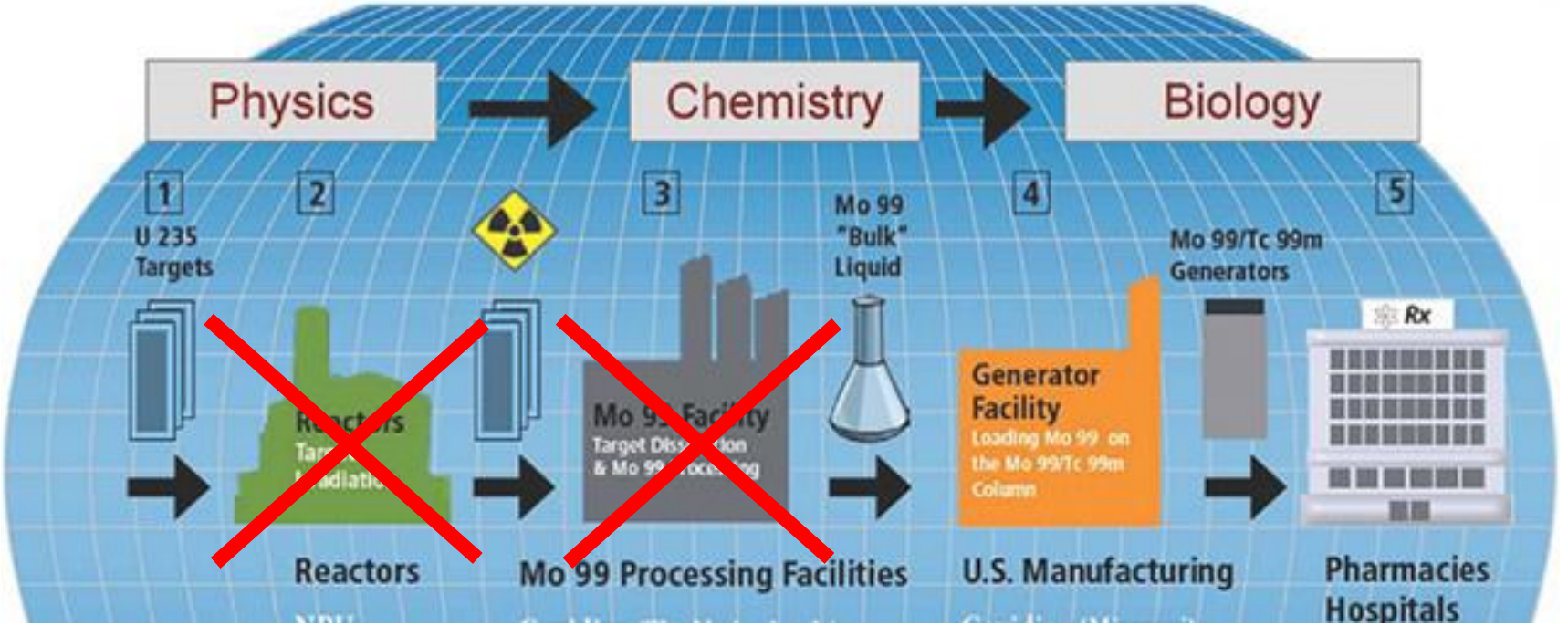
- The activator is an innovative device that can be used to produce most of the reactor based radioisotopes.
- The activator is coupled to a “dedicated” accelerator
- The charged particles are interacting with target material (usually beryllium) at the centre of the device and produce neutrons.
- Neutrons are interacting with the target isotope materials (in the tube halls) in order to produce the desired radioisotopes.



Main advantages

Compact design	• The design of the Activator is compact. It can be installed in places where there is no availability of space (eg in regional hospitals)
Low cost	• The cost of the Activator is low and affordable by any institution even those with limited budget
Modular	• The system is modular and allows production of any kind of reactor produced radioisotopes (simultaneously)
Facilitates R&D	• R&D radioisotopes are difficult to find and when they become available they are very costly. The activator allows production of R&D radioisotopes at low cost.
Safe	• The device is self shielded and so Radiation is contained within the Activator.

In comparison with current solutions



THANK YOU
FOR YOUR ATTENTION