PAUL SCHERRER INSTITUT

PSI

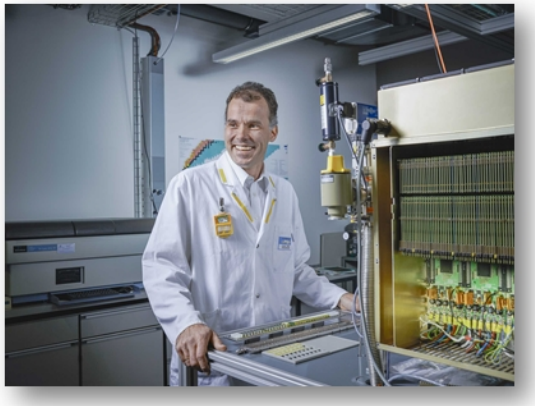
Robert Eichler

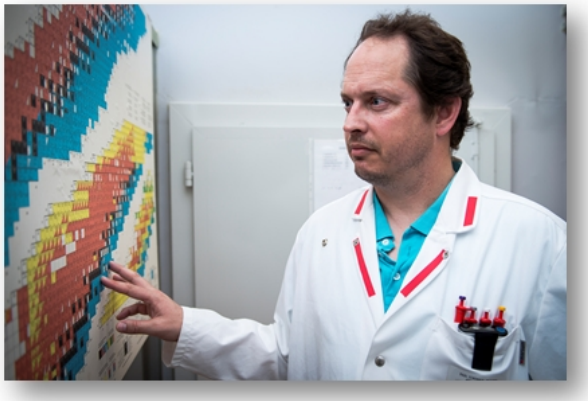
Paul Scherrer Institute

Laboratory for Radiochemistry (LRC)

„NES präsentiert: Kompetenzen und Highlights“, Villigen, 24.10.2017

The People of LRC





HEAVY ELEMENTS	ISOTOPE AND TARGET CHEMISTRY	RADIONUCLIDE DEVELOPMENT
Dr. Robert Eichler	Dr. Dorothea Schumann	Dr. Nicholas van der Meulen
Dr. Rugard Dressler	Dr. Jörg Neuhausen	NN @ CRS
Alexander Vögele	Dr. Emilio Maugeri	
Dominik Hermann	Dr. Ivan Kajan (COFUND/sn)	
Dr. Zeynep Talip (SNF)	Dr. Stephan Heinitz ($EU_{finishing}$)	
Benjamin Kraus (SNF)	Mu Lin (swissnuclear (sn))	Katharina Domnanich
Yves Wittwer (SNF)	Erik Karlson (EU)	Nadezda Gracheva @ CRS
Jiri Ulrich (CROSS/NUM)	Ivan Danilov	Sarah Jordi
Paul Ionescu		

Postdoc

Graduate Students

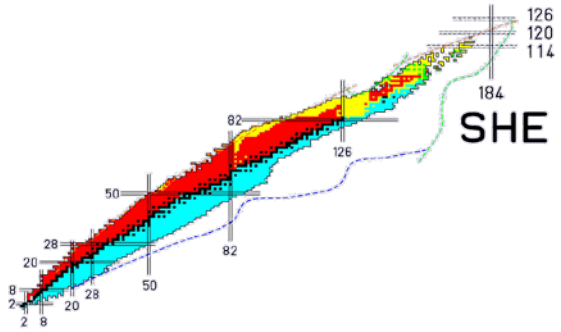
Radioisotopes in Society

1/3 of all elements have only radioactive isotopes

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac**	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
119	120																

*	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
**	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

>90% of all isotopes are radioactive current status



- Industry:
  - industrial tracers chemistry, biology
  - inspection (radiation sources)
  - gauges (e.g. thickness measurements)
  - Nuclear energy:
    - nuclear fuel / waste
- Medicine:
  - radiopharmaceuticals
  - radiation therapy

The LRC @ PSI

Radiochemical science @ PSI

- fundamental aspects: nucleosynthesis, astrophysics, chemistry (kinetics, thermodynamics -> catalysis) of new elements
- isotope production, separation and handling
- nuclear data

The LRC @ PSI

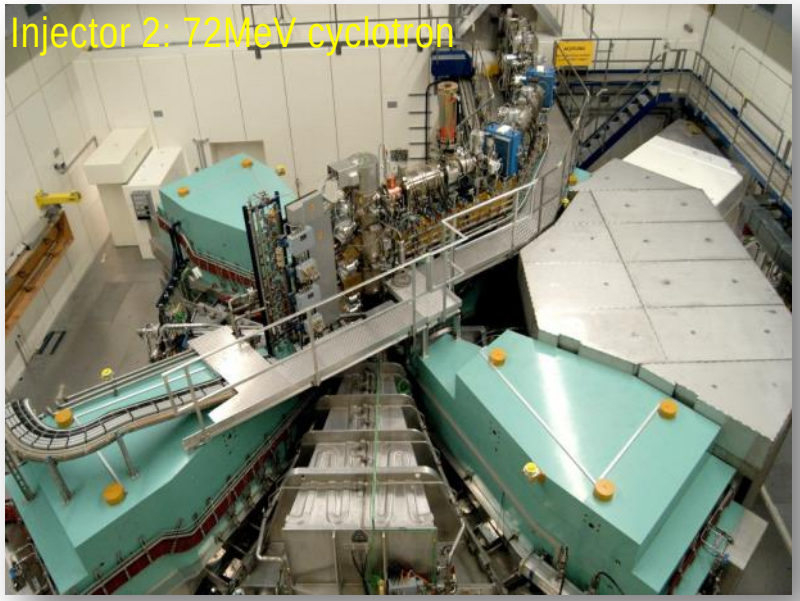
- We maintain theoretical and experimental academic expertise in radiochemistry for Switzerland:
  - We provide exciting and challenging high level international science and research;
  - We educate the next generation scientists;
- We make use of the PSI-Large Scale Facilities and other PSI-Infrastructure:
  - We make use of valuable radioactivity produced at PSI,

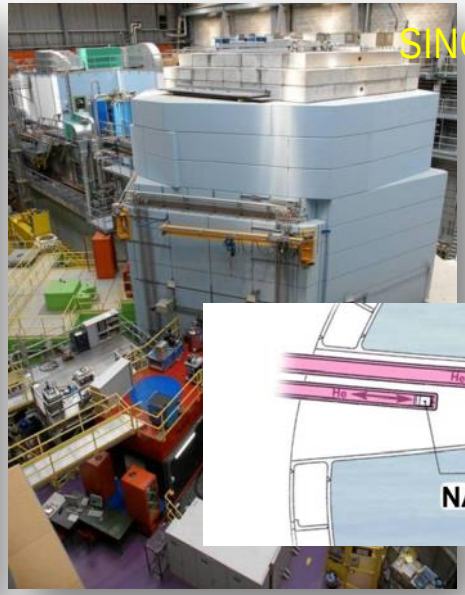
    even if (or despite) it is declared “waste”;
  - We make use of production facilities for producing

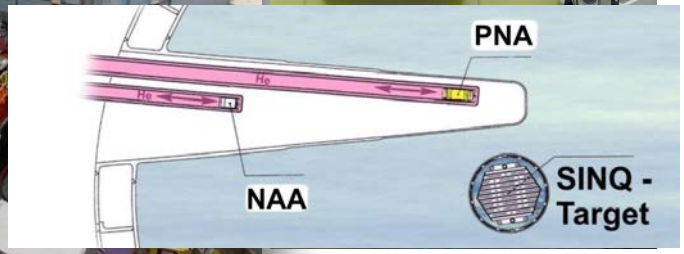
    radionuclides as tracers for fundamental research and radiopharmacy

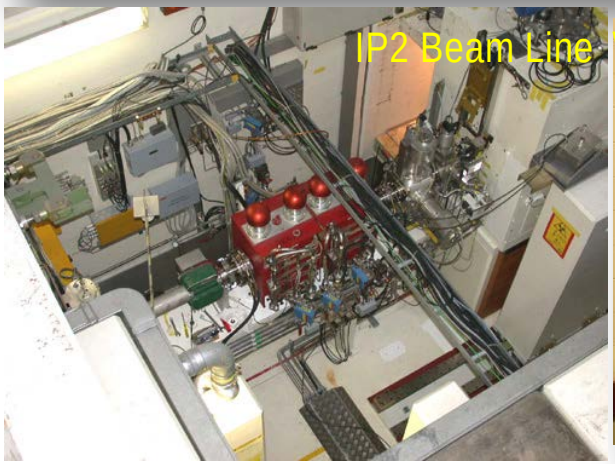
    (SINQ-NIS, SINQ-Stip, IP2, PROTRAC);
  - We make use of radioanalytics and 0-, A-, B-, and C- laboratories at PSI
- We find and use synergies with the other NES Laboratories and other PSI departments;

LRC's Use of Large Scale Facilities at PSI









The Research of LRC within PSI

- Fundamental research for education and maintenance of radiochemical expertise in Switzerland;
  - Chemistry in spallation targets (ADS (Myrrha), ESS, SINQ);
  - (Super-) Heavy elements chemistry (material sciences, fast separations)
    - High temperature materials (PSI-NES-LNM/LRS/LTH: Gen III+IV, ESS),
    - Solid state diffusion and thermal release (PSI-NES-LNM/LRS: Gen IV, ESS);
    - Volatilization and gas phase chemistry (PSI-NES-LRS/LTH: Gen III+IV);

- Disposal strategy for radioactive PSI accelerator-generated waste and Hotlab waste
  - Chemical separation of valuable isotopes and their use in astrophysical experiments (NUM-UCN/NIAG) and radiopharmacy (BIO-CRS),
  - Nuclear Data (Astrophysics, PSI-NES-LRS/LTH);
- Production and separation of radionuclides (PSI-IP, SINQ):
  - New isotopes for radiopharmacy (BIO-CRS) and tracers for radiochemistry (NES);
  - Nuclear Data (NES-LRS, BIO-CRS);

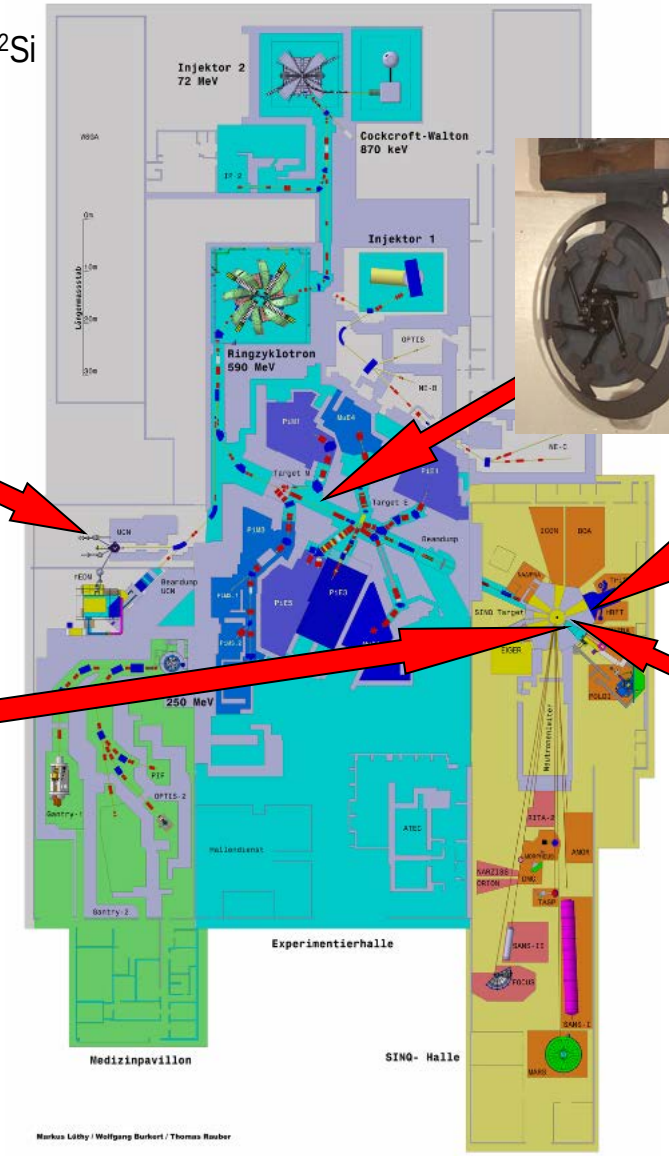
Isotope and Target Chemistry

Copper beam dump

- ^{44}Ti, ^{53}Mn, ^{26}Al, ^{60}Fe, ^{59}Ni, ^{32}Si
- ^{60}Co – 5 GBq

SINQ cooling water

^{7}Be, ^{54}Mn, ^{22}Na, ^{88}Y

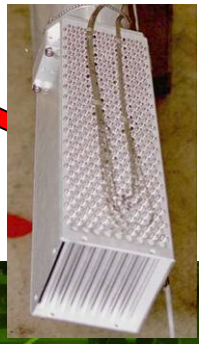


Myon production station

- Operation 1-3 years
- Beam doses 4 – 11 Ah
- Source for ^{10}Be

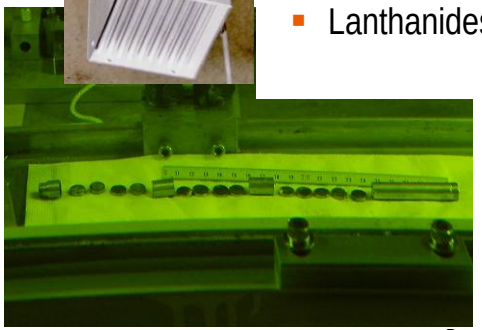
SINQ Target Irradiation Program-STIP

^{44}Ti, ^{53}Mn, ^{26}Al



SINQ target

- ^{207}Bi, ^{172}Hf,
- ^{173}Lu, ^{194}Hg,
- ^{202}Pb, ^{125}Sb,
- ^{106}Ru, ^{44}Ti
- Lanthanides (α)



adopted from D. Schumann

Isotope and Target Chemistry achievements

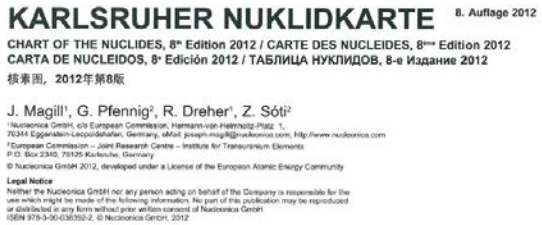
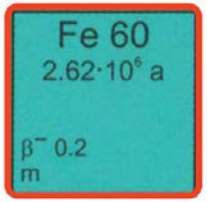
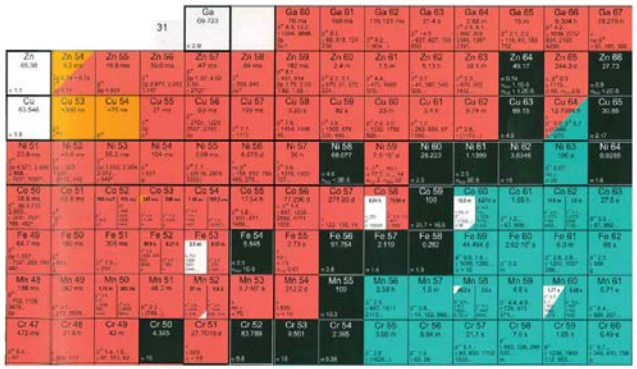

KARLSRUHER NUKLIDKARTE 8. Auflage 2012

CHART OF THE NUCLIDES, 8th Edition 2012 / CARTE DES NUCLEIDES, 8ème Edition 2012
CARTA DE NUCLEIDOS, 8ª Edición 2012 / ТАБЛИЦА НУКЛИДОВ, 8-е Издание 2012
核素图, 2012年第8版

J. Magill[1], G. Pfennig[2], R. Dreher[1], Z. Sóti[2]



G. Rugel, et al.:
Phys. Rev. Lett. **103** (2009) 072502



- ^{60}Fe important waiting point for astrophysical nucleosynthesis

Great collaboration
with Hotlab (M. Martin, Niko Kivel)

Editors' Suggestion

^{7}Be$(n,\alpha)^{4}$He Reaction and the Cosmological Lithium Problem: Measurement of the Cross Section in a Wide Energy Range at n_TOF at CERN

M. Barbagallo *et al.* (n_TOF Collaboration)
Phys. Rev. Lett. **117**, 152701 (2016) – Published 3 October 2016

The neutron-^{7}Be cross section—an important ingredient in Big Bang nucleosynthesis—is measured at a wide range of neutron energies.

Show Abstract +

Isotope and Target Chemistry achievements

Metal chemistry (J. Neuhausen)

- The thermal release of mercury, iodine, cesium, polonium from LBE is investigated by transpiration methods;
- The indirect identification of released species is tried using various reactive gas phases via thermochromatography;
- The use of various stationary gas chromatographic phases allows for investigation of deposition properties relevant for filtering and safety absorbers;
- The possibility of the tracer production at PSI is absolutely crucial for this work (e.g. ^{210}Po, I, ^{134}Cs, ^{131}I);
- This work is supported by the EU
  - the projects SEARCH and MYRTE under EURATOM HORIZON2020
  - >10 publications already published

MYRRHA: an innovative research installation

SCK•CEN is actively working on designing and building a new multifunctional research installation: MYRRHA as in *Multi-purpose hYbrid Research Reactor for High-tech Applications.*

The Chemistry of Transactinide Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac**	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
119	*120*																

*	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
**	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

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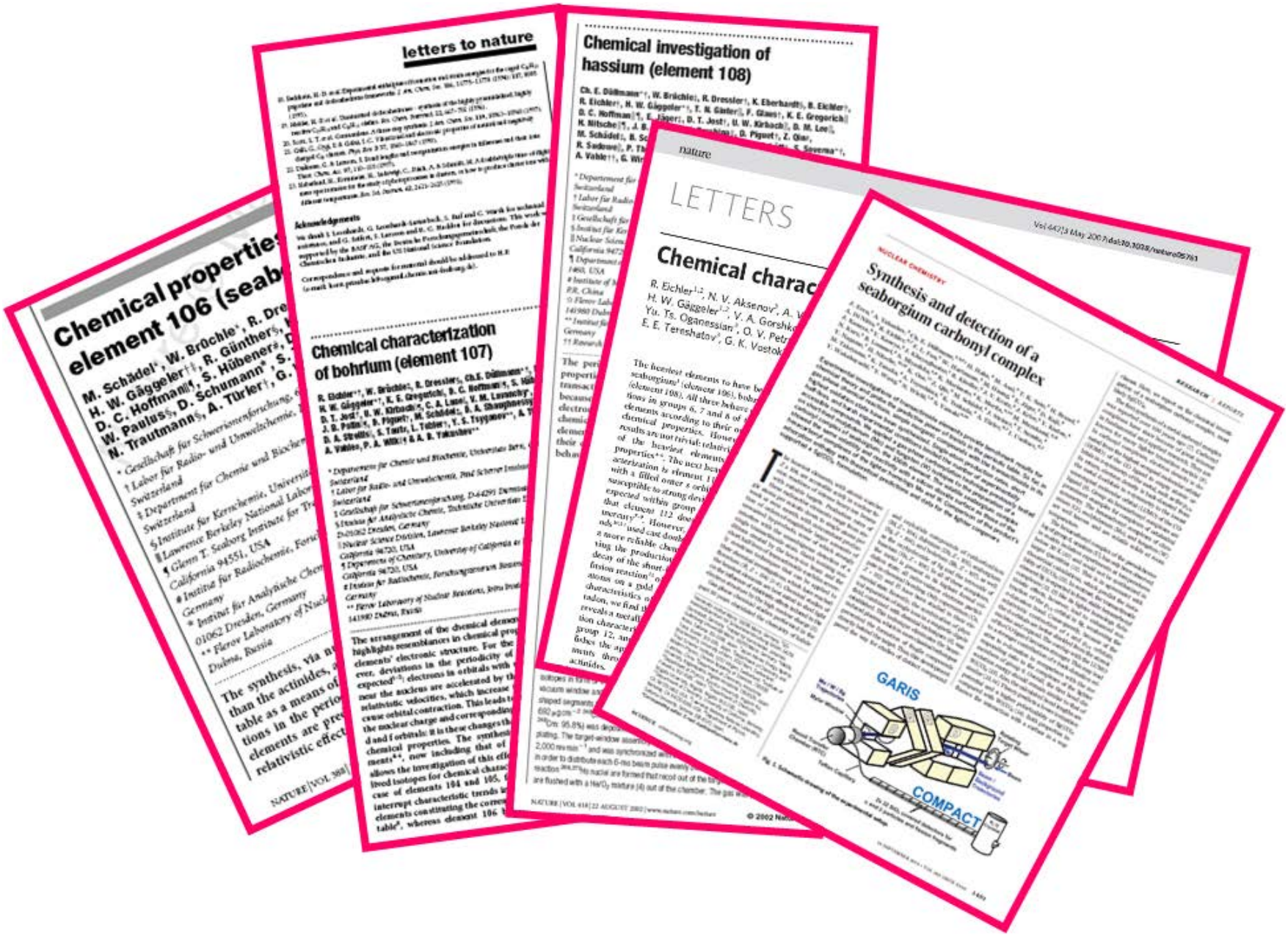
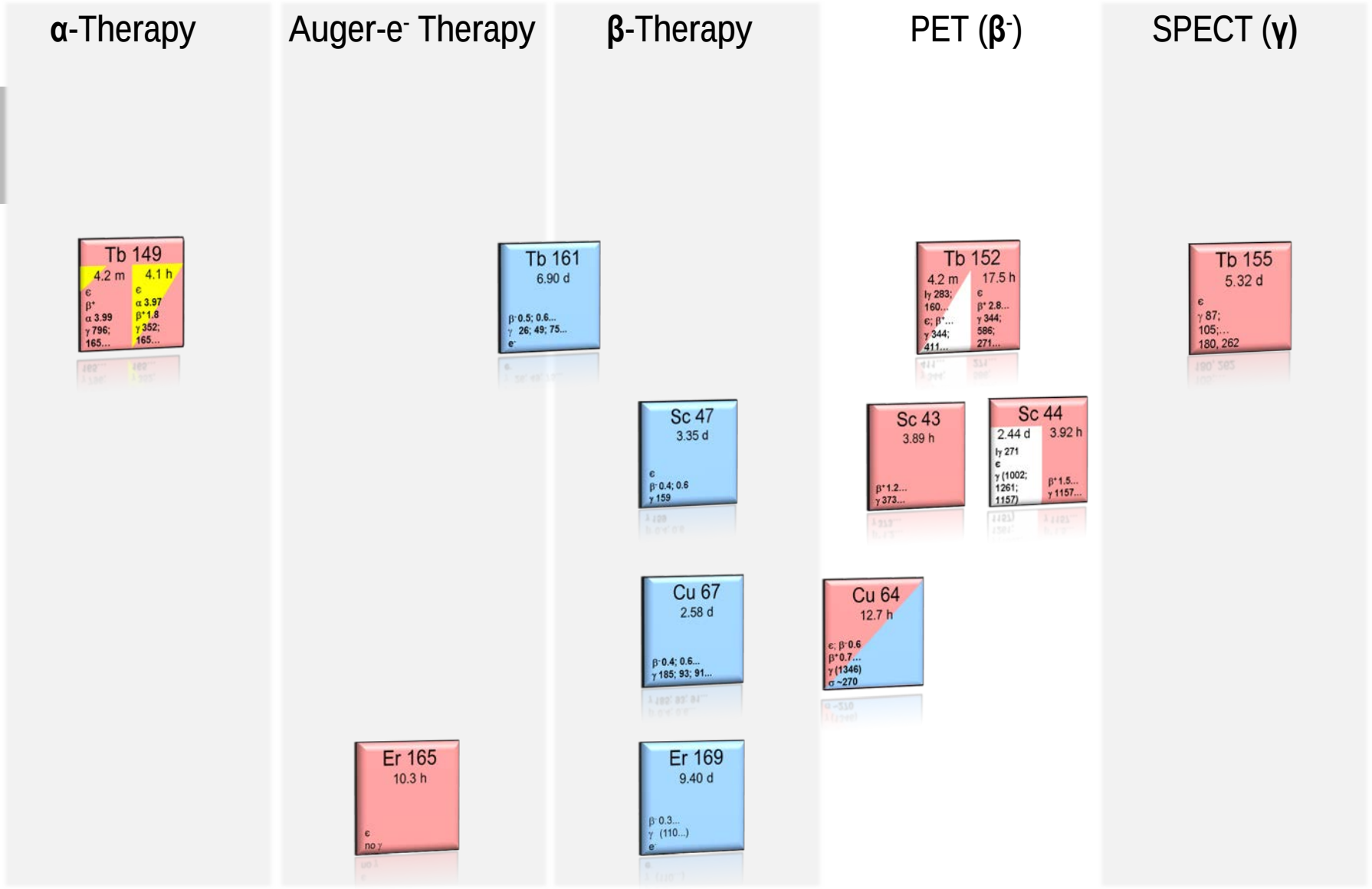
The Chemistry of Transactinide Elements



Radionuclide Development

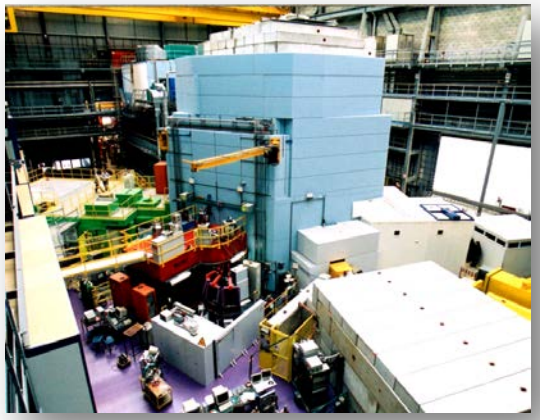


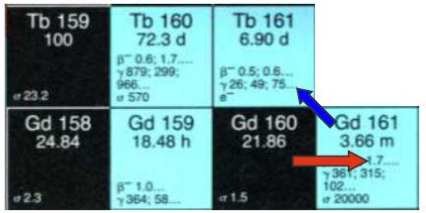
- Theranostic principle of *matched pairs*

Ch. Müller et al. J Nucl Med (2014) vol. 55 no. 10 1658-1664

^{161}Tb: A β$^-$-Emitter for Therapy

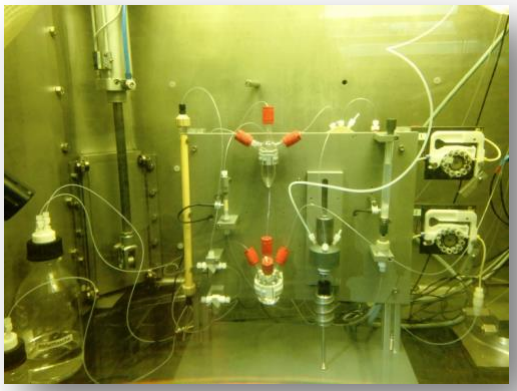
Neutron Irradiation of Target Material



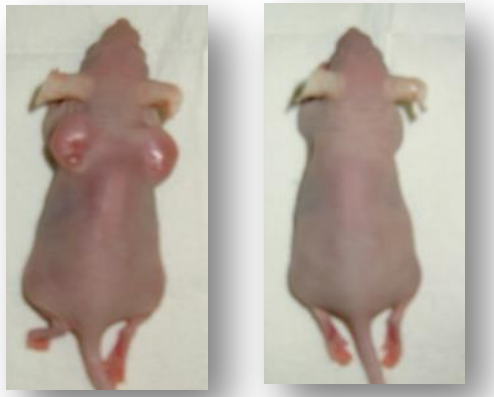


^{160}Gd(n,γ)^{161}Gd ⟶ ^{161}Tb

Chemical Separation and Processing

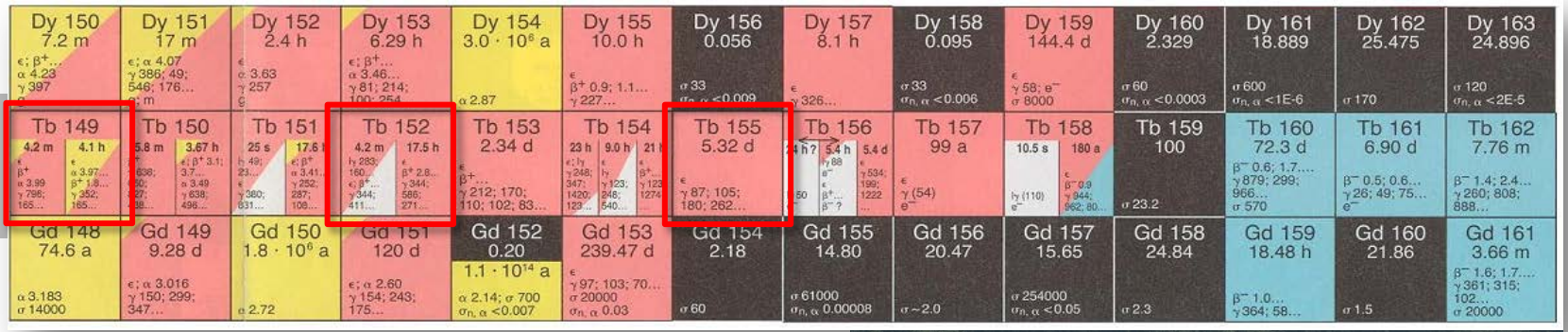


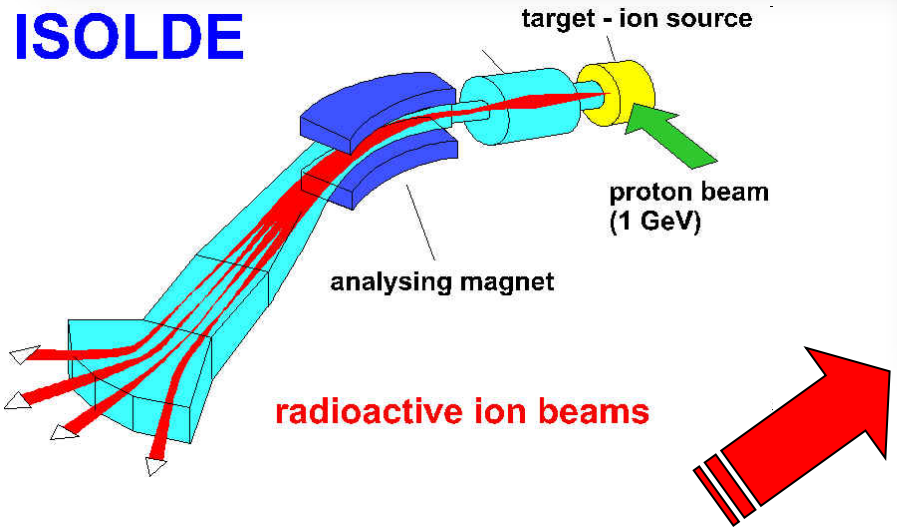
^{161}Tb therapy with low-energy β-particles



Müller et al., J. Nucl. Med. 53:1951 (2012)

Collaboration: ISOLDE (CERN) & PSI





Spallation of Ta with high-energy protons, followed by online mass separation

Müller *et al.*, J. Nucl. Med. 54: 124 (2013)

First Preclinical PET/CT Scan: ^{149}Tb-DOTANOC

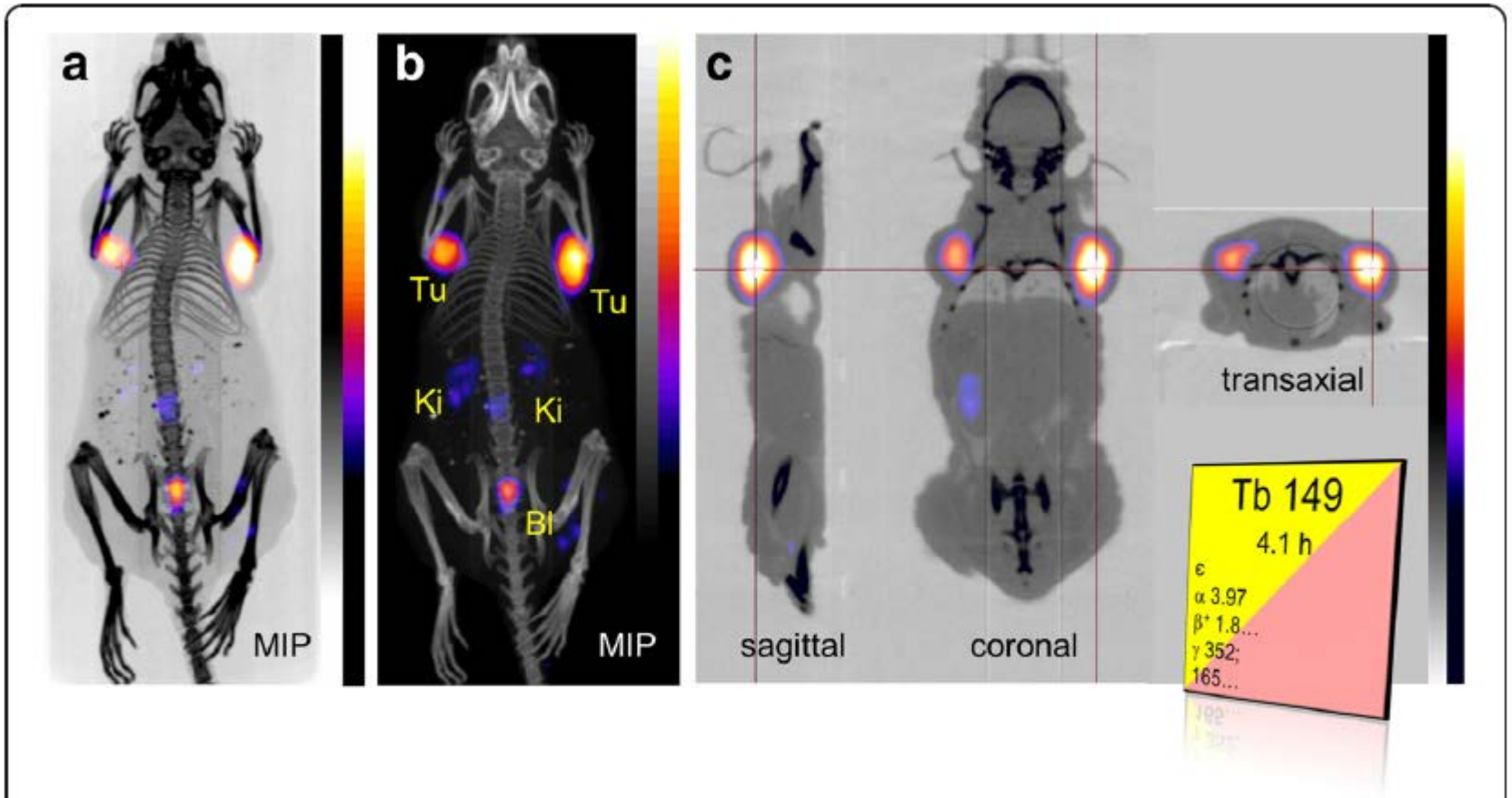


Fig. 1 PET/CT images of an AR42J tumor-bearing mouse 2 h after injection of ^{149}Tb-DOTANOC (7 MBq). (**a**, **b**) Maximal intensity projections (MIP) and (**c**) sections showed distinct accumulation of radioactivity in tumor xenografts (Tu) and residual radioactivity in kidneys (Ki) and urinary bladder (Bl). The decay scheme of ^{149}Tb is shown as in the Karlsruhe Nuclide Chart (www.nucleonica.com)

PET/CT Scanner at CRS: G8 (Perkin Elmer)

Alpha-PET: a New Concept in Nuclear Medicine

Collaboration between PSI (CRS-BIO and LRC-NES) and ISOLDE/CERN Geneva

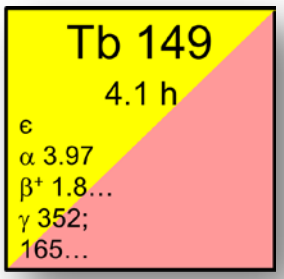
Müller *et al. EJNMMI Radiopharmacy and Chemistry* (2016) 1:5
DOI 10.1186/s41181-016-0008-2

EJNMMI Radiopharmacy and Chemistry
a SpringerOpen Journal

LETTER TO THE EDITOR Open Access

Alpha-PET with terbium-149: evidence and perspectives for radiotheragnostics

Cristina Müller[1*], Christiaan Vermeulen[1], Ulli Köster[2], Karl Johnston[3], Andreas Türler[4,5], Roger Schibli[1,6] and Nicholas P. van der Meulen[1,4*]



- Radiolanthanide for α-therapy (easy chelation using DOTA)
- Ideal half-life of 4.1 h
- Low α-energy of 3.9 MeV
- No α-emitting daughters
- Is it also suitable for PET imaging?

Where do we want to go @ LRC ?

- *Isotope and Target Chemistry + Radioanalytics:*

  Chemical Separation (tracers), Mass separation;

  Targets for astrophysical experiments (^{53}Mn, ^{10}Be, ^{26}Al,^{59}Ni, ^{93}Mo, ^{163}Ho);

  Nuclear data;

- *Heavy Elements + Metal chemistry:*

  Fast separation (tracers, diffusion and release) ;

  Reaction chromatography (Hg, Pb & Cn, Fl);

  Inorganic radiochemistry (Tl, Po, Bi, At & Nh, Lv, Mc, Ts);

  Organometallics (Mo/W, Tc/Re, Ru/Os & Sg, Bh, Hs;

  Stern-Gerlach for SHE (diffusion and release, single atomic beam, Lr);

  High power target development;

  Single molecular speciation, mass measurement;

- *Radionuclide development + Isotope production:*

  >350 Isotopes with scientific potential can be produced at SINQ & IP

  Relevant for radiopharmacy e.g.: ^{43,44,47}Sc, ^{64,67}Cu & ^{165,169}Er

  Chemical Separation / Mass separation (targets and tracers)

  Nuclear data

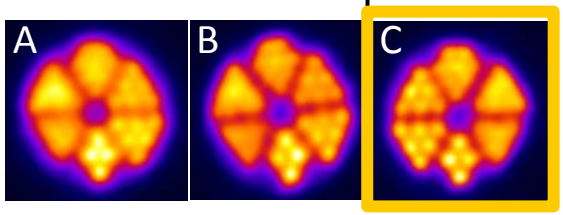
Mass separation @ LRC Examples

- Measurement of the $^{53}Mn(n,y)^{54}Mn$ cross section

Relevance:

- ^{53}Mn used for dating (e.g. meteorites);
- neutron capture → additional loss;
- PSI accelerator waste → world's largest ^{53}Mn source

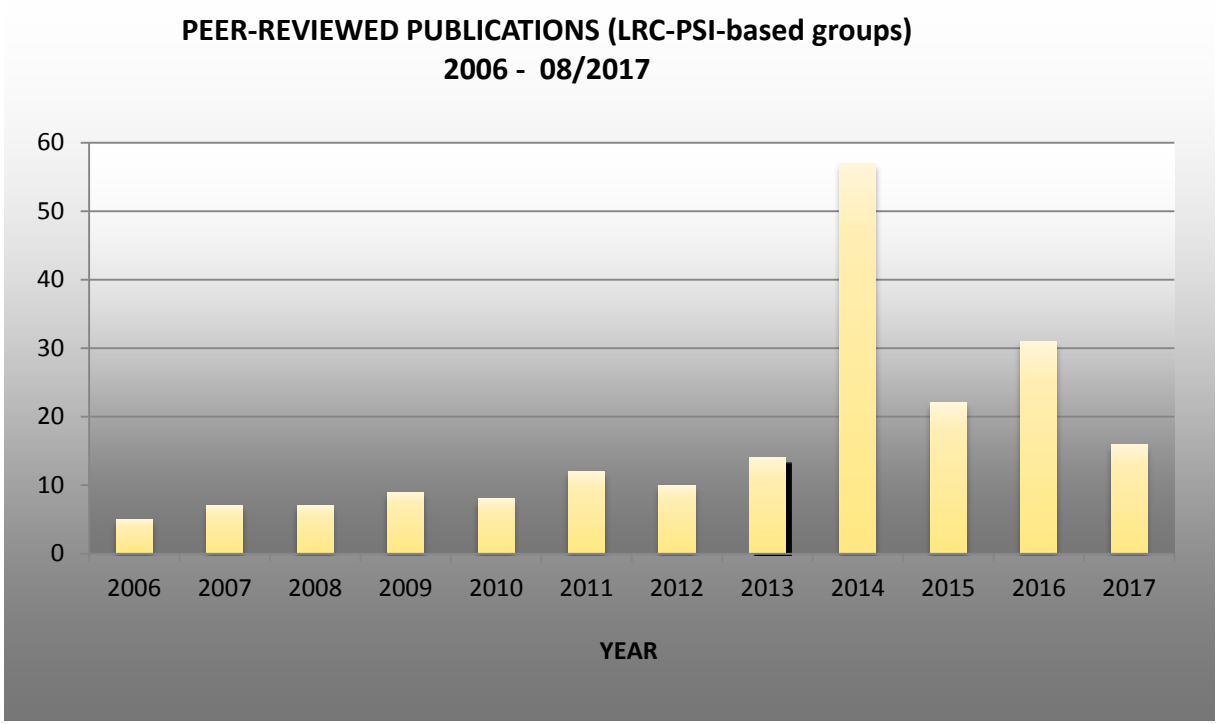
- Scandium isotopes for radiopharmacy



PET phantom images of
^{44}Sc (A),
^{43}Sc produced from ^{43}Ca (B) 25% ^{44}Sc
^{43}Sc produced from ^{46}Ti (C) 1.5% ^{44}Sc

Nuclear- and Radiochemistry Research World with LRC-collaborations

PSI-based LRC is a Driver for Radiochemistry in Switzerland



Take Home Message LRC

…LRC
→belongs to a modern division in an institute with visions and tasks for radiochemistry in the future Switzerland from nuclear energy and beyond;

…LRC
→is at the frontiers of fundamental chemical and physical research and stays involved in isotope production for life science and research;

… LRC
→does exciting research and solves important tasks for PSI in multidisciplinary approaches and solid international collaborations;

…LRC
→ Offers unique expertise and exciting educational environment and possibilities