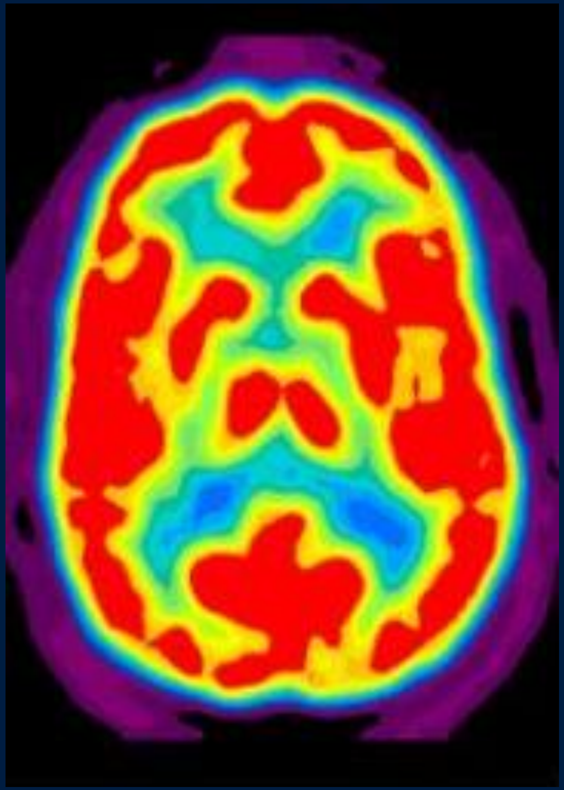


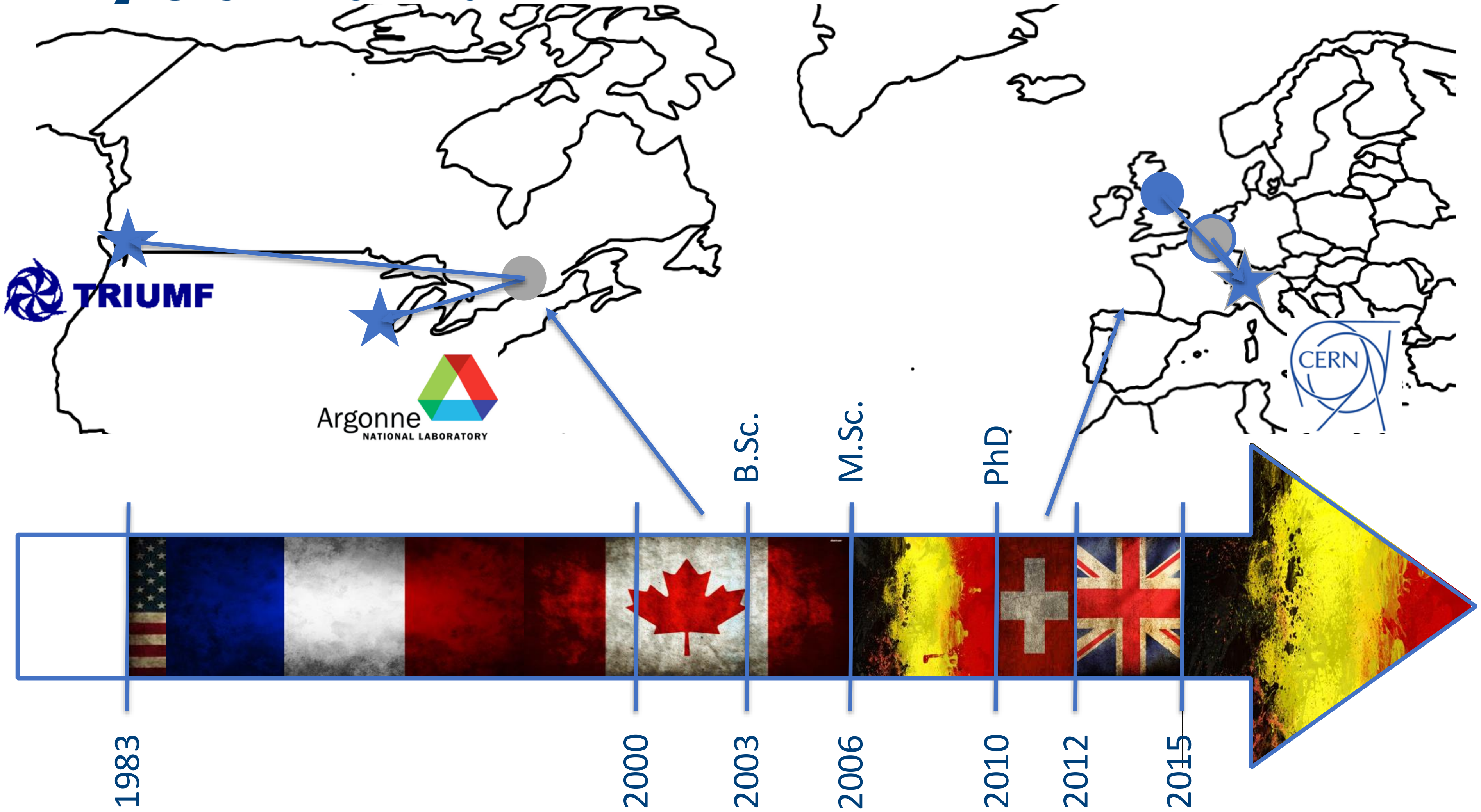
Nuclear medicine

Where nuclear science contributes to society

UK Nuclear Summer School – Monday 27 August 2026

KU LEUVEN

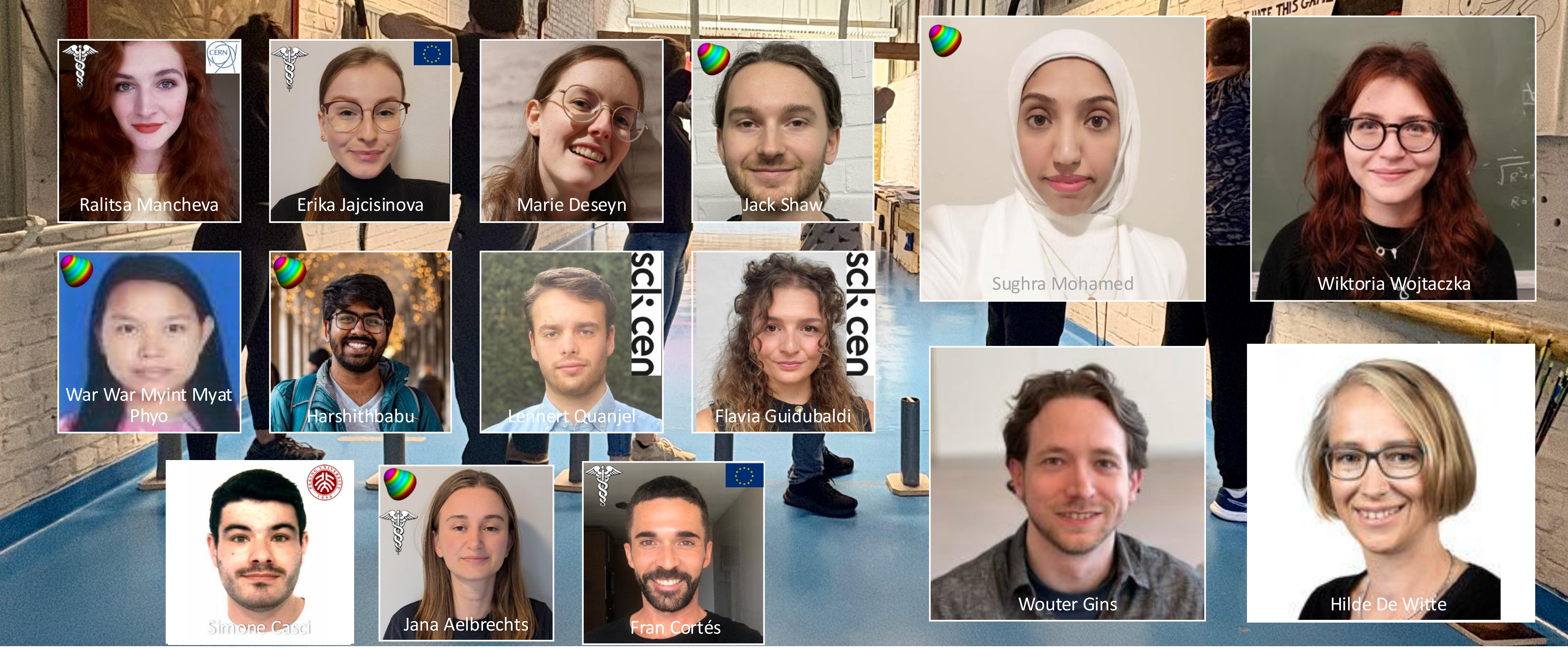
Me, myself and I



My research

	Ion source development	Laser spectroscopy	Decay spectroscopy
Nuclear structure	More beam Better beams Support to other programs	Nuclear shapes Testing ab initio models	Shape coexistence Muonic x-ray spectroscopy
Nuclear astro	More beams Better beams Support to other programs	Nuclear radii Testing EDF	Beta-delayed fission r-process nuclear data
Societal benefits	More radionuclides Better quality	Beam purification New radionuclides	Nuclear data for medical applications

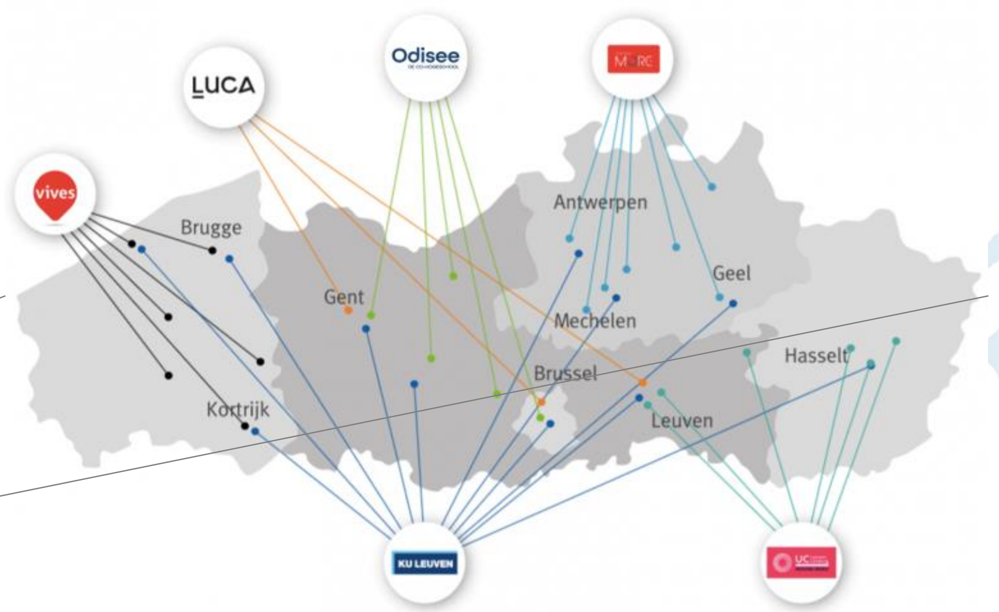
Team work!



https://fys.kuleuven.be/iks/interdisciplinary-research
thomas.cocolios@kuleuven.be

KU Leuven

- Founded in 1425
- 23 campuses across Flanders
- >60,000 students across 15 Faculties
- >20,000 staff
- 3 main Groups:
    - Humanities & Social Sciences
    - Science & Technology
    - Biomedical Sciences
- #1 European university for innovation!



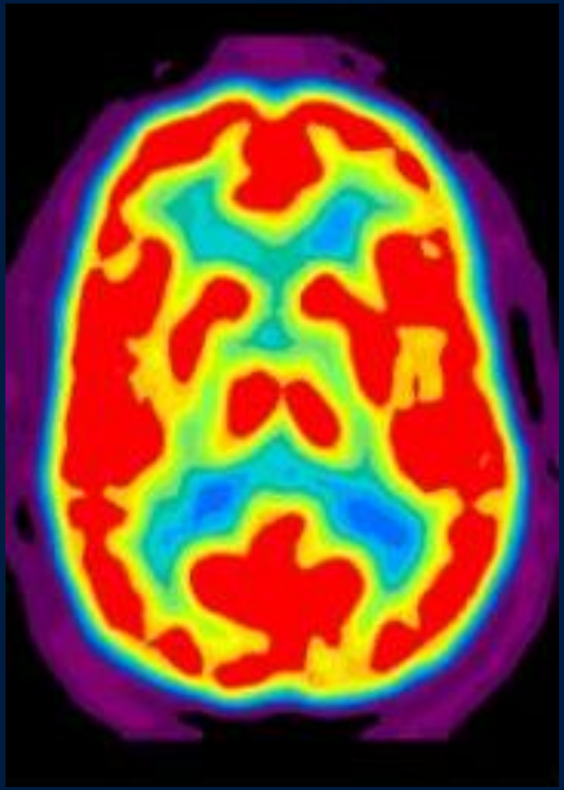
KU Leuven

My engagement

- Funding member of LGBTQ+CERN, back in 2010

- Funding member and current chair of QU Leuven, the KU Leuven employee resource group for LGBTQIA+ staff of the uniersity and their allies.

https://lgbtqcern.com



Nuclear medicine

Where nuclear science contributes to society

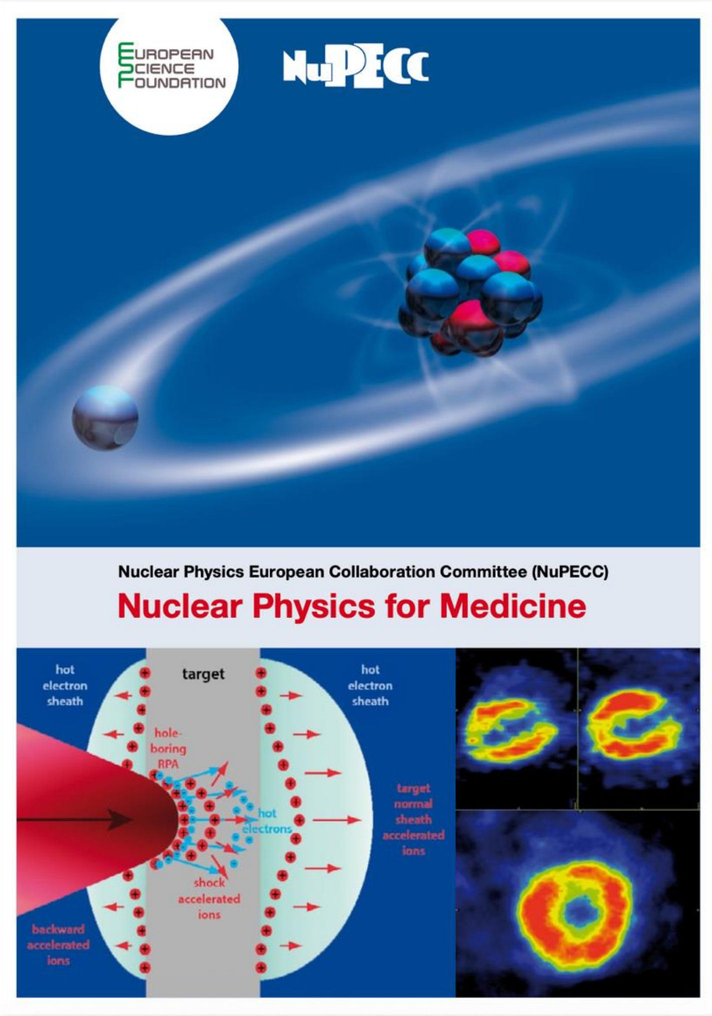
KU LEUVEN

Two key references

NuPECC is the Nuclear Physics European Collaboration Consortium. It is the lobby group for nuclear science in Europe.

https://www.nupecc.org/

- 2014: Nuclear Physics for Medicine
- 2024: NuPECC Long Range Plan 2024



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On the importance of nuclear medicine

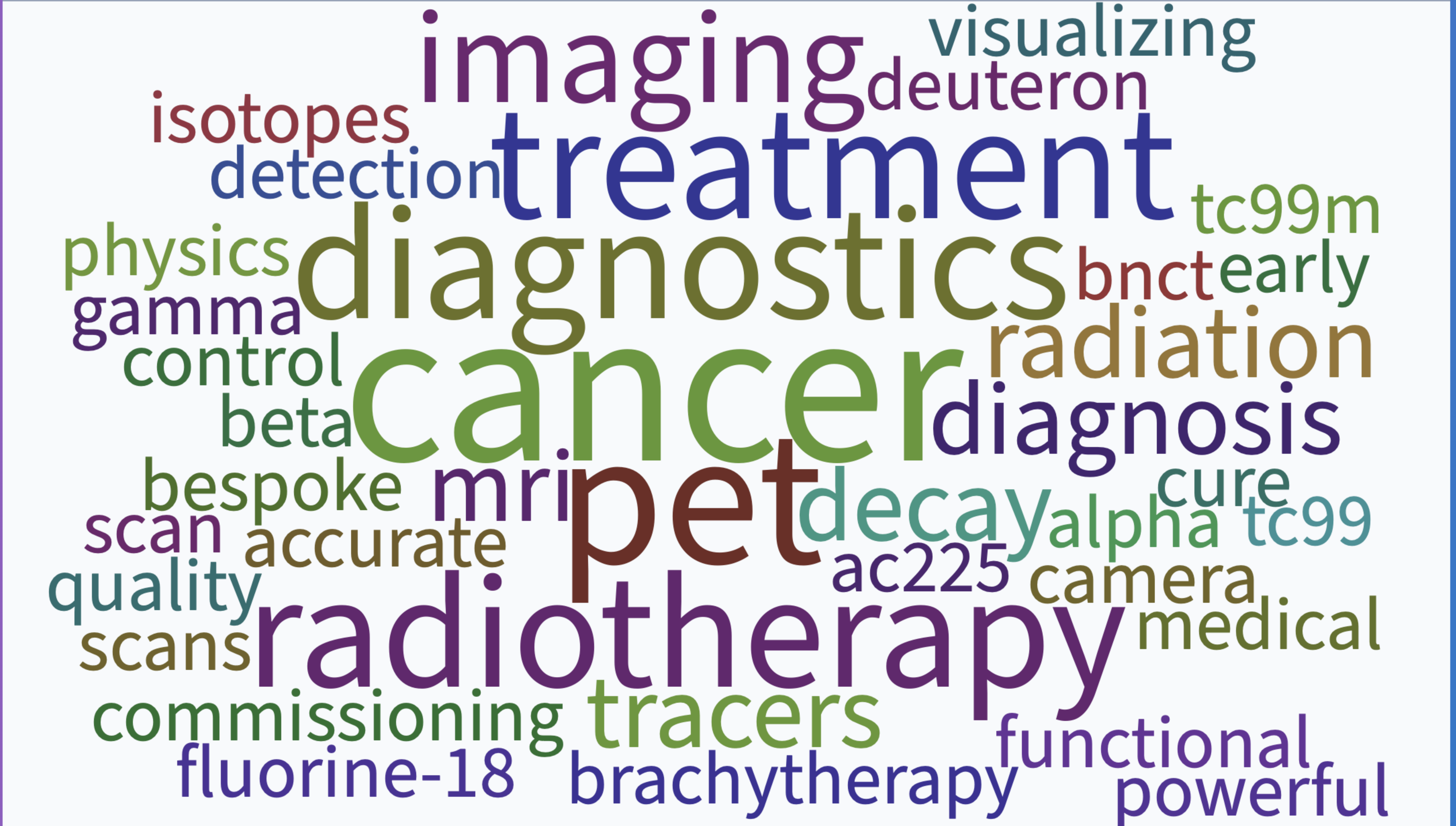
https://sdgs.un.org/goals

Today: Some basics of nuclear medicine

Tomorrow: Nuclear science for nuclear medicine

Today: Some basics of nuclear medicine

Tomorrow: Nuclear science for nuclear medicine


imaging
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isotopes
treatment
detection
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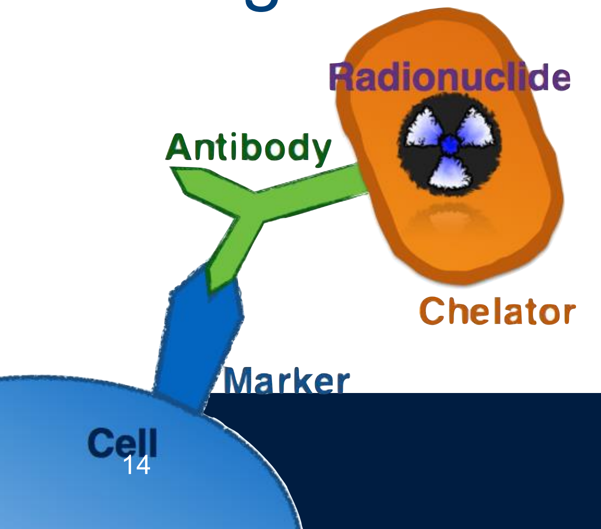
physics
diagnostics
bnct
early
gamma
radiation
control
cancer
beta
diagnosis
bespoke
mri
pet
cure
decay
scan
alpha
tc99
accurate
ac225
quality
camera
radiotherapy
medical
scans
commissioning
tracers
functional
fluorine-18
brachytherapy
powerful

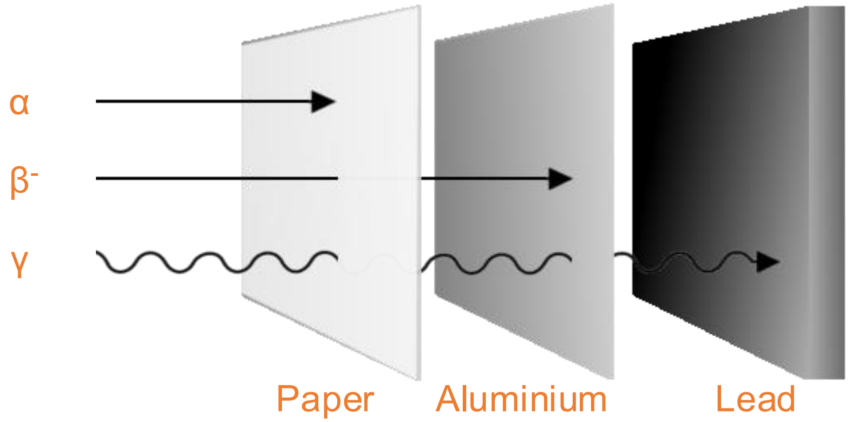
Molecular imaging

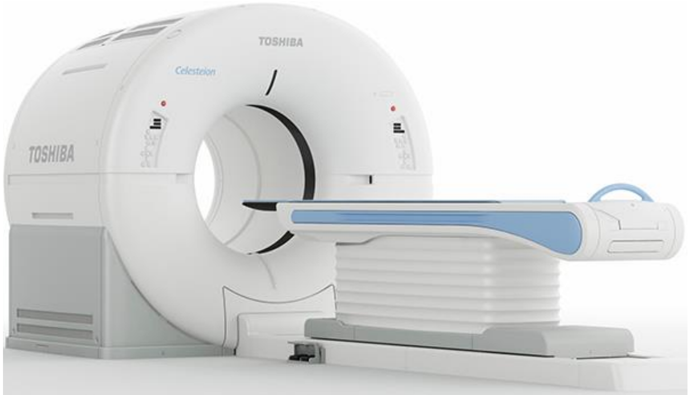
A radionuclide is transported to a specific location in the body where it decays with the emission of a γ ray.

The γ ray penetrates the tissues and exits the body so that it may be recorded externally to visualize where it decayed.

Multiple orientations yield a 3D tomographic reconstruction of the image.







Molecular imaging

SPECT

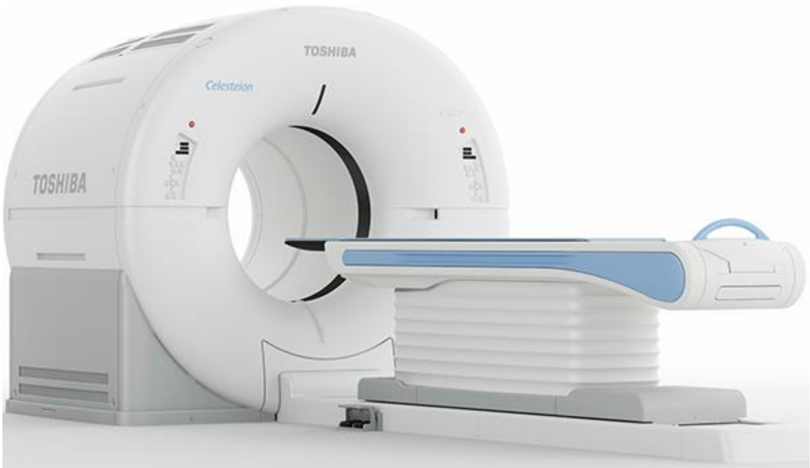
Single Photon Emission Computed Tomography

- Direct picture of the emitted γ ray from the decay process
- A lead screen ensures that only γ rays that come orthogonal to the screen get measured
- 2D image

PET

PositronEmissieTomografie

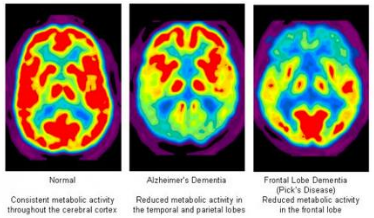
- β^+ decay result in 2 γ rays at 511 keV
- From those 2 points and the time difference, the origin can be determined.
- An array of detectors is placed around the patient



Targeted action

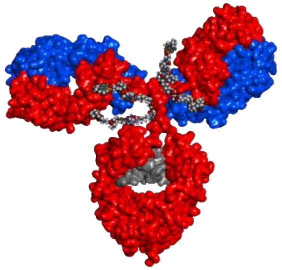
The body uses some trace elements for specific actions:

- iodine for thyroid functions
- calcium in the bones



A radioactive isotope can be included in a molecule involved in metabolic activities:

- sugar-equivalent FDG



Cells may display receptors that are specific and can be linked to by targeting m

- peptides
- hormones
- antibodies

Important to match biodistribution to half-life!

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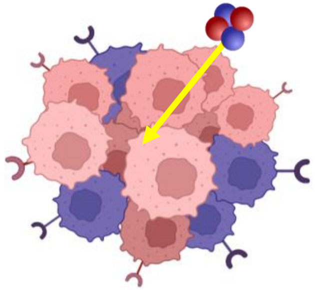
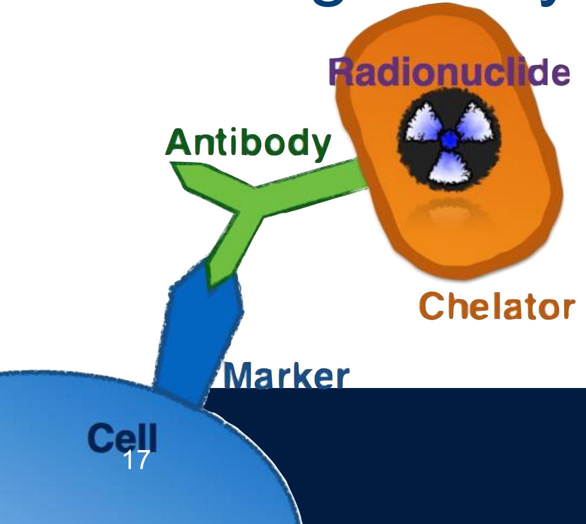
Switching to therapy

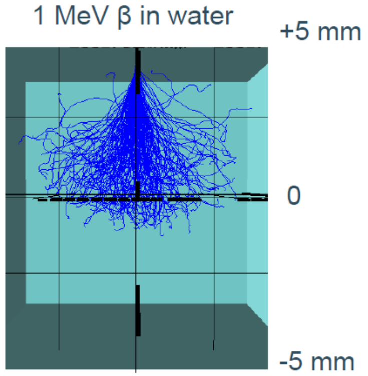


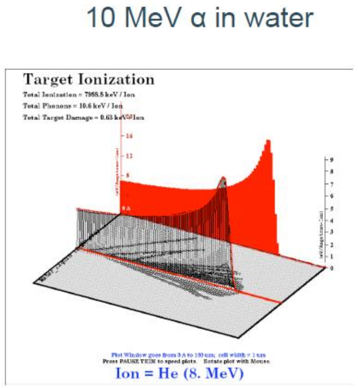
Replacing the γ-ray emission with charged particle emission yields therapeutic effect.

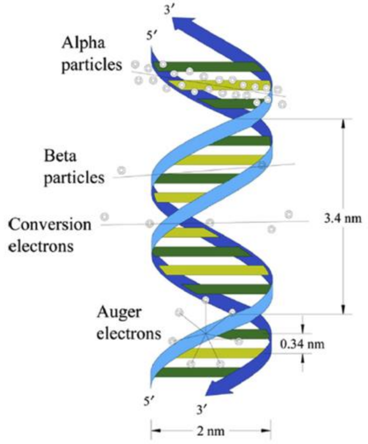
β^- particles may reach up to a few mm, α particles reach but a few cells, Auger electrons act within a cell.

For an efficient treatment, the DNA of the targeted cell must be damaged beyond repair

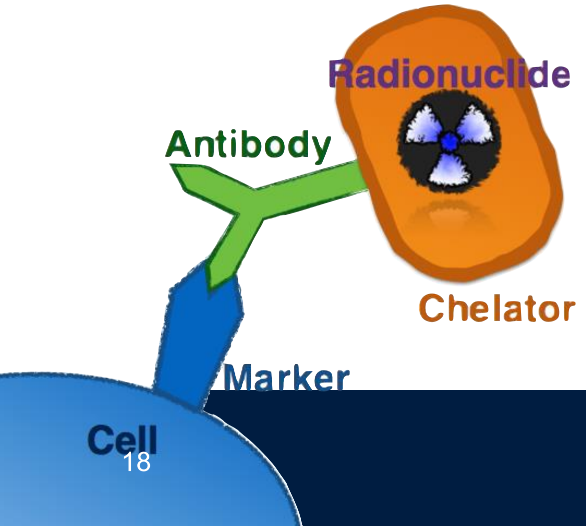


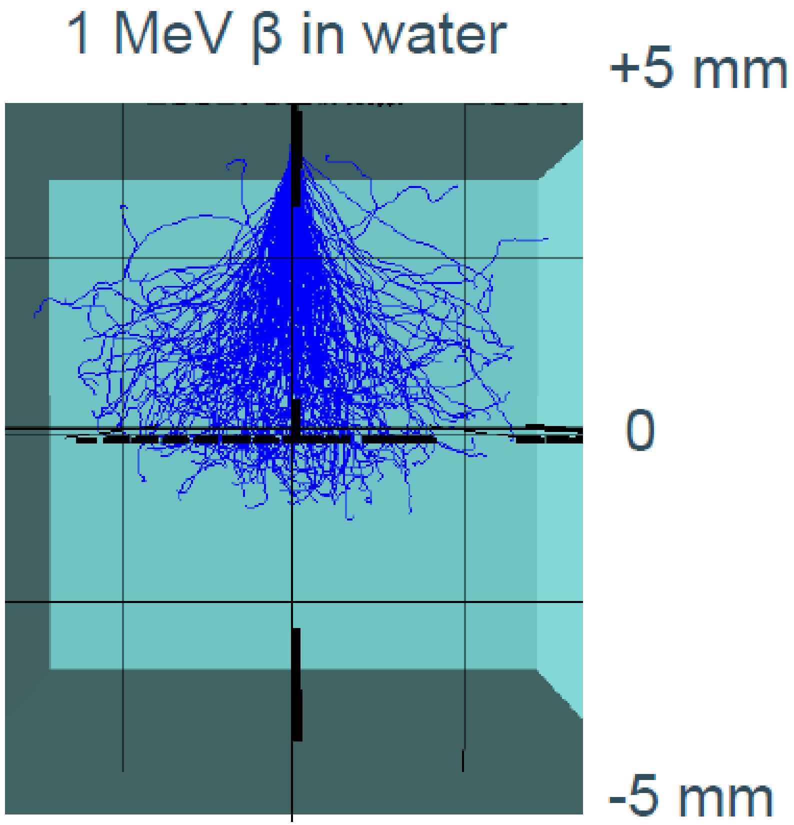


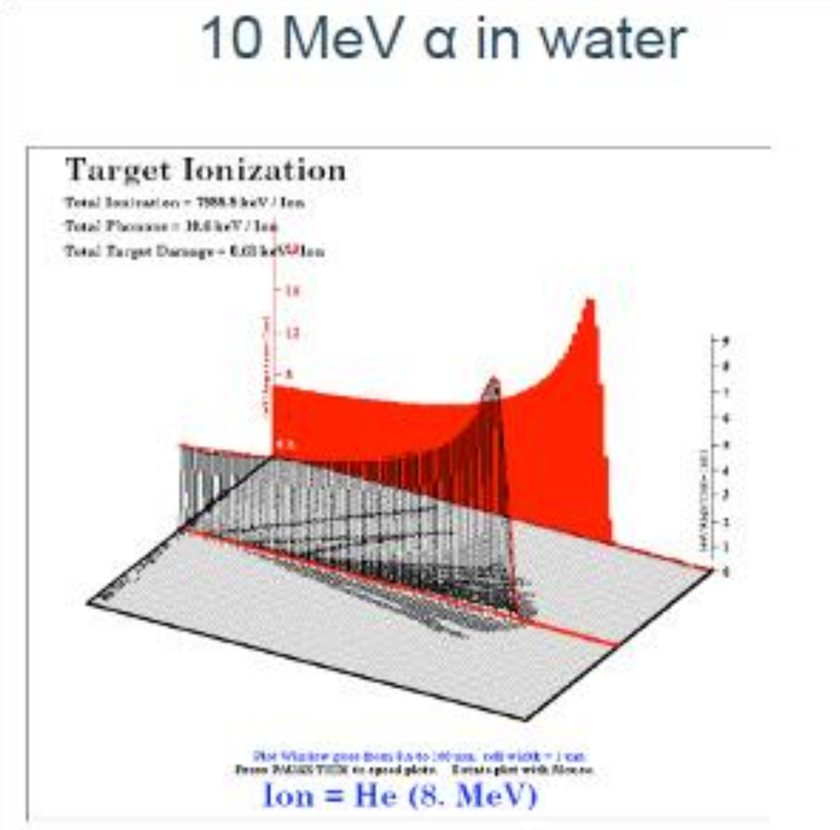




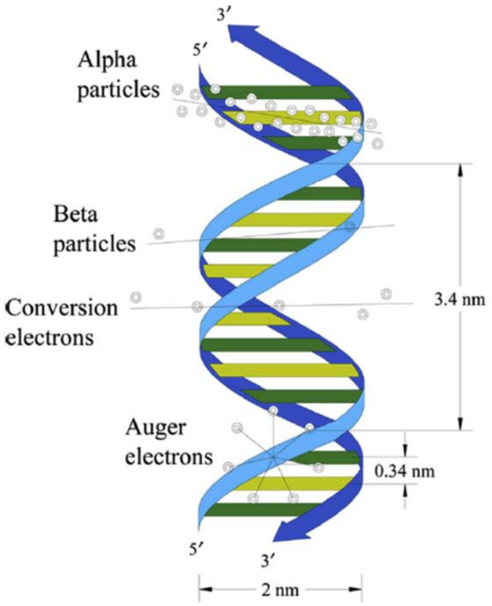
Switching to therapy



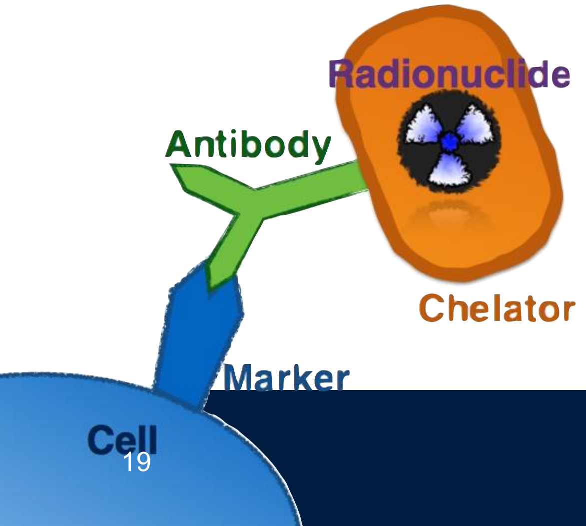




Switching to therapy

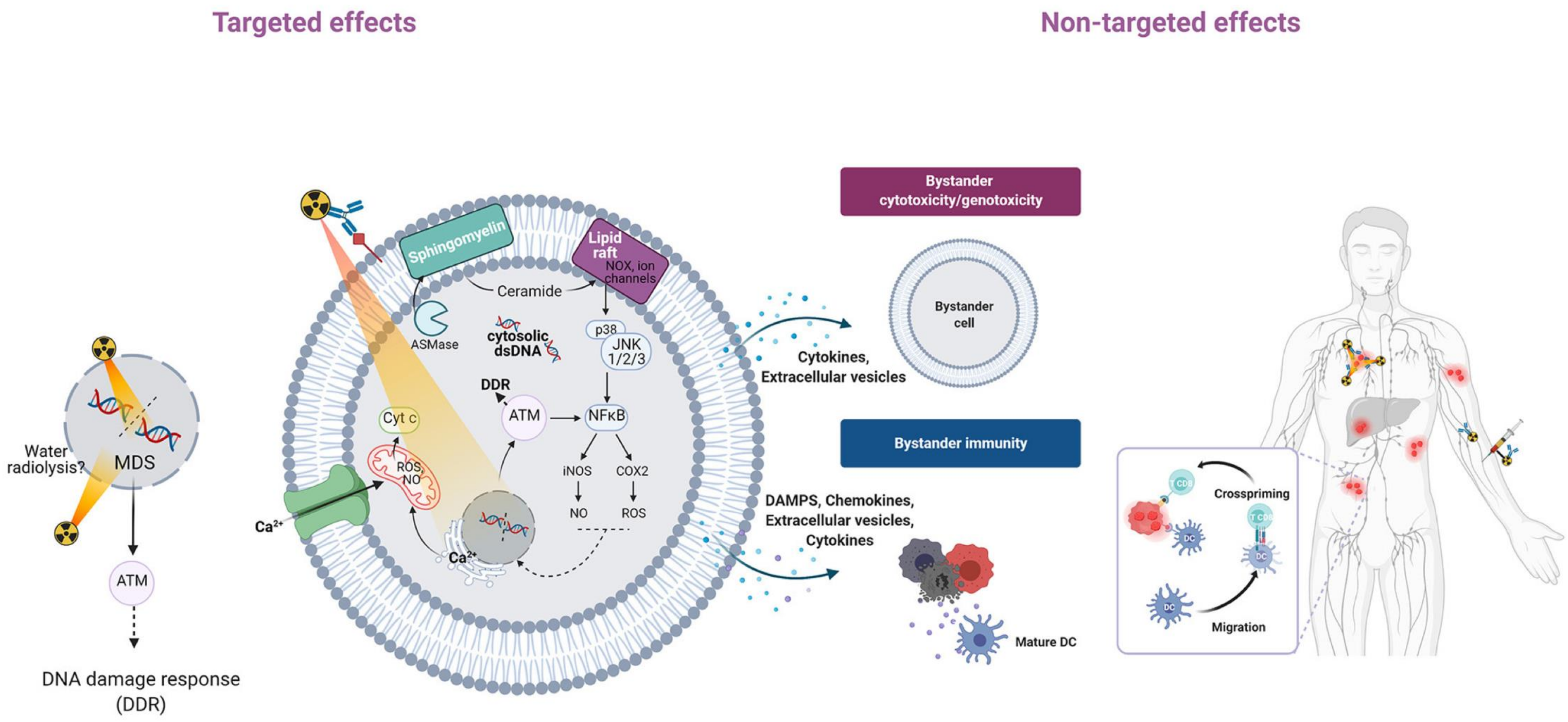


- Alpha decay: ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He^{++}$
- Beta decay: ${}^{A}_{Z}X \rightarrow {}_{Z+1}{}^{A}Y + \beta^{-} + \bar{\upsilon}_{e}$
- Auger electron emission



Why alpha?

More than just DNA hits



J.-P. Pouget & J. Constanzo, Frontiers in Medicine **8** (2021) 692436.

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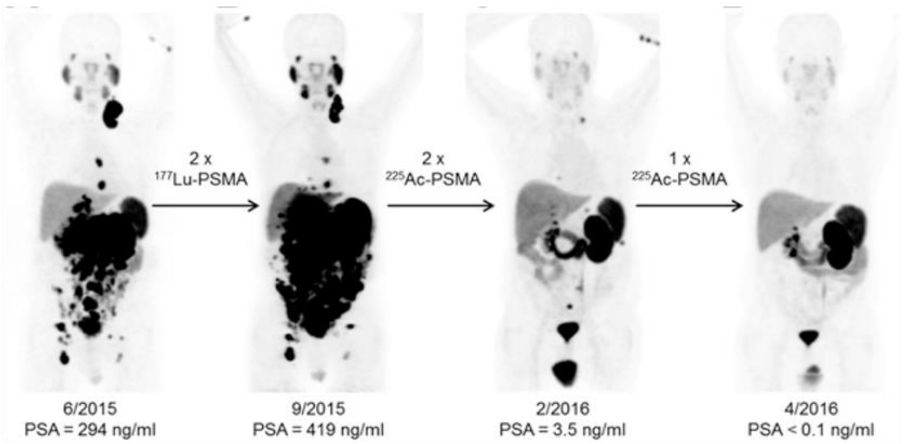
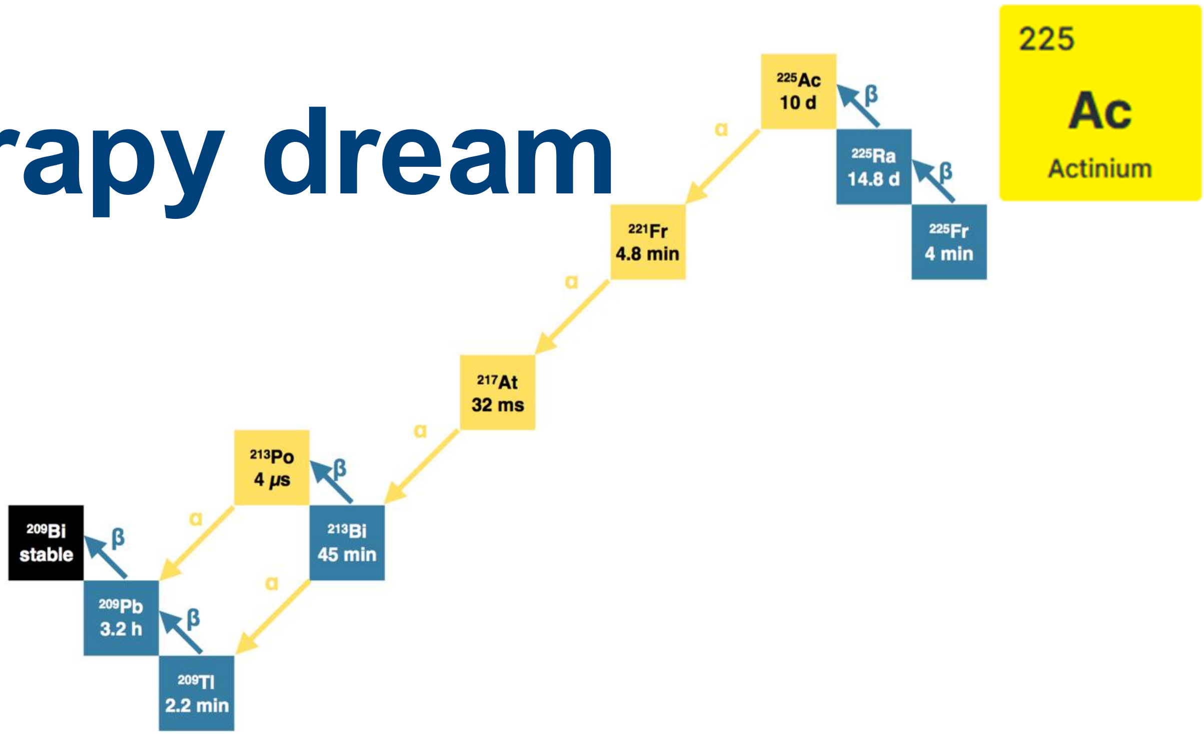
^{225}Ac – the alpha therapy dream





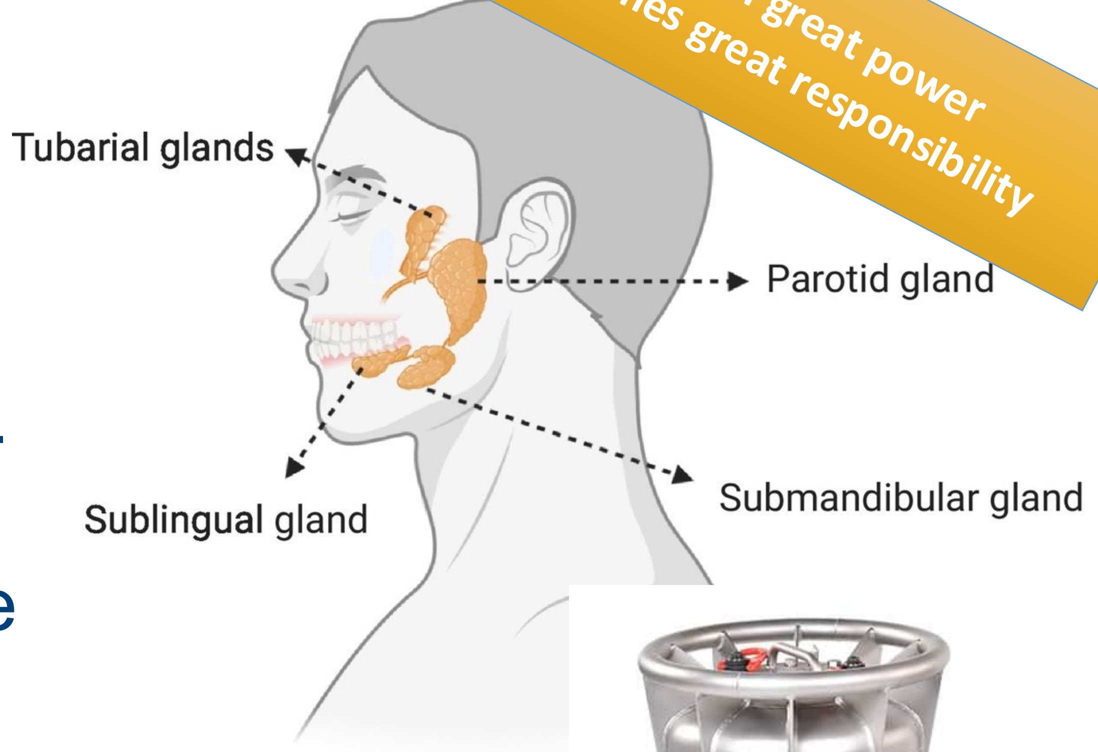
- From a single ^{225}Ac isotope, 4 α particles are emitted in a short time, resulting in the highest possible dose to short distance.
- ^{225}Ac may also be used as a long-lived generator for ^{213}Bi, which yields 1 α for each decay but with a half-life of 45 min only, perfectly fit to fast-acting medicine.
- Coordination chemistry appropriate for all sorts of vector molecules, and can be paired with PET-imaging using ^{68}Ga or ^{135}La.

*C. Kratochwil et al, The Journal of Nuclear Medicine **57** (2016) 1941-1944*

And why not?

With great power
comes great responsibility

- The high destructive power of alpha therapy induces more pronounced secondary effects – such as the destruction of salvary glands from Ac-225-PSMA.
- Alpha-emitting radionuclides are more challenging to handle and fewer institutions are licenced for it.
- The transport guidelines are evolving and the shipping limits will soon be lowered, possibly hindering the broad applicability of targeted alpha therapy.

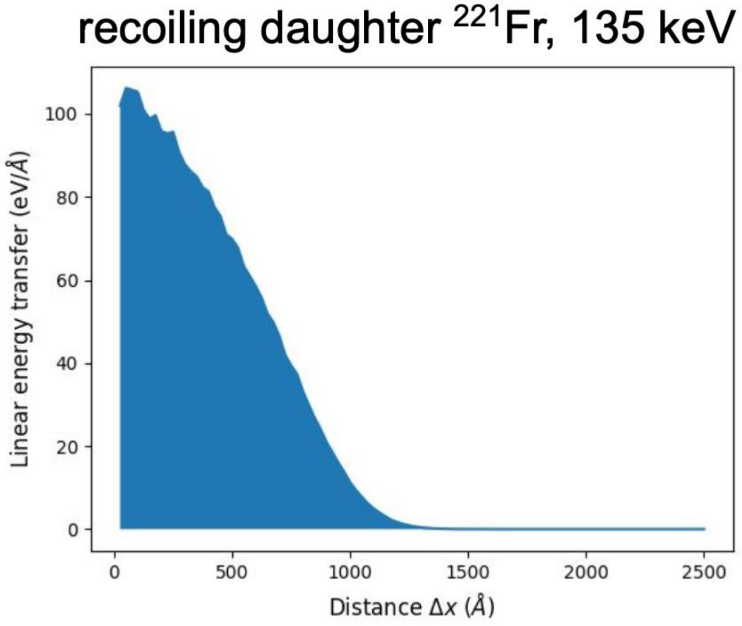


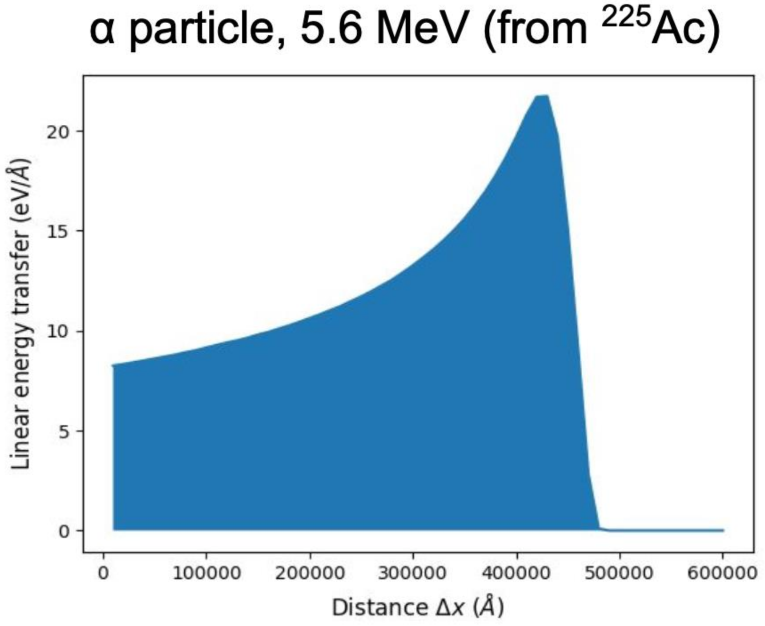
N. Heyninkcx et al., Nuclear Medicine and Biology ***98-99*** *(2025) 30-39.*
https://snmmi.org/Web/News/Articles/SNMMI-Concerned-with-IAEA-Proposed-Revisions-to-Specific-Safety-Requirements-for-the-Transport-of-Ra.Mobile.aspx

Beyond the alpha, the recoil

Conservation of energy & momentum…

➢ For every action, there is an equal and opposite reaction… So if the alpha particle flies one way, the daughter nucleus will fly in the opposite direction!





D. Kaczér & Z. Op de Beeck, BSc Thesis, 2021 (KU Leuven).

Bad recoils!

- The high energy of those recoils (>100 keV) far surpasses the binding of the chelator that hosts the mother radionuclide (few eV). As a consequence, the recoiling daughter is free to roam the body.
- This leads to a potential redistribution of the daughter and, in the case of a long decay chain such as in ^{225}Ac, radioactive recoils may accumulate in other organs – such as the kidneys, bones, …
- This limits the applicability of such radionuclide and requires a dedicated targeting strategy that ensures minimal redistribution of the daughter radionuclides.

*J. Schzartz et al., Physics in Medicine and Biology **56** (2011) 721.*
V. Di Iorio et al., SECURE project publication in review, https://doi.org/10.20944/preprints202508.0853.v1

Good recoils!

- While the recoils only carry 2% of the energy, they have an even higher LET and even shorter range than the alpha particles and deposite the entirety of their energy within their cell, leading to 10% of the total energy deposited in that single cell.
- The high concentration of that energy deposition is similar to that of Auger electrons. Could recoils actually have a **therapeutic value**? In particular, one may wonder what the impact of a recoiling nucleus from an antagonist vector could be on a cell membrane.

It is necessary to break down the processes to identify this impact

Theranostics

Theranostics

If a single vector molecule can be identified with interchangeable radioisotopes, then its efficacy and properties can be **tested with molecular imaging** and then **applied with therapy**.

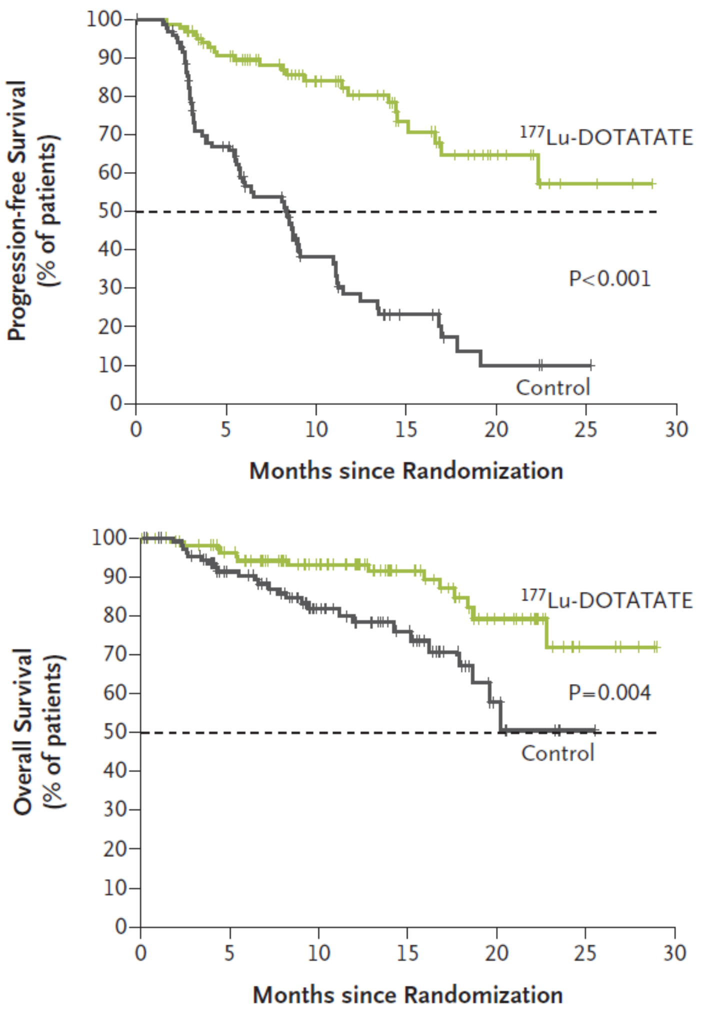
If a single radioisotope decays by both γ-ray or β^+ emission and α or β^- emission, then that single radioisotope can be used to **treat** and at the same time **monitor the patient dose** and the treatment's efficacy.

Important to match biodistribution to half-life!

Final aim: personalized medicine where the treatment is tailored to the needs of the patient

NETTER-1: a success story

- Midgut endocrine cancer with over-expressed somatostatin receptors
- Linking somatostatin-equivalent to ^{177}Lu: DOTATATE under the brand name Luthatera® (AAA).
- Theranostic partner with ^{68}Ga-DOTATATE
- A worldwide phase-3 clinical trial was performed (including Leuven)
- AAA's value tripled on the stock market when it came out and has since been purchased by Novartis for a few billion €.



 J. Strosberg et al., *The New England Journal of Medicine* **376** (2017) 125-135.

VISION: repeating success

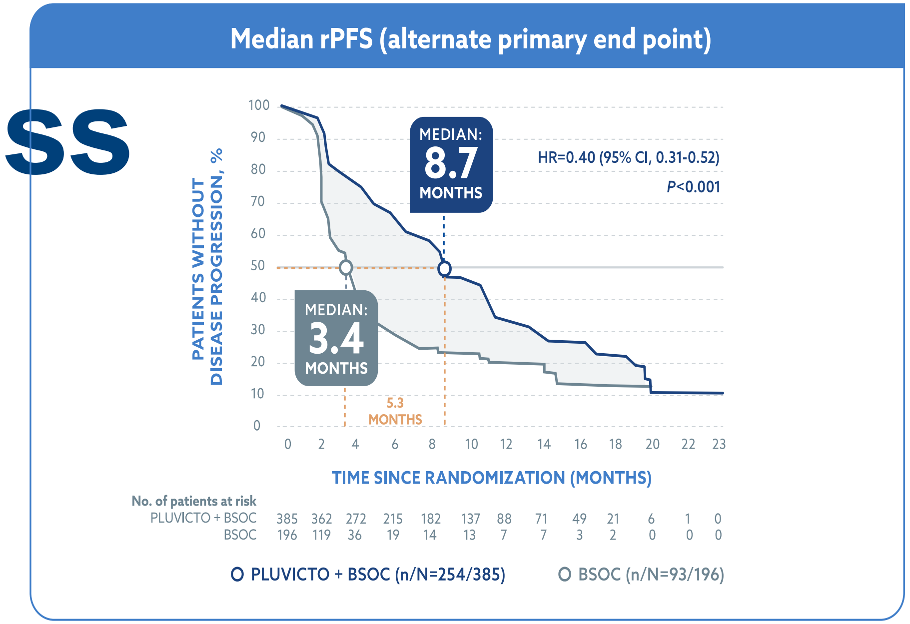
Targeting castration-resistant metastatic prostate cancers.

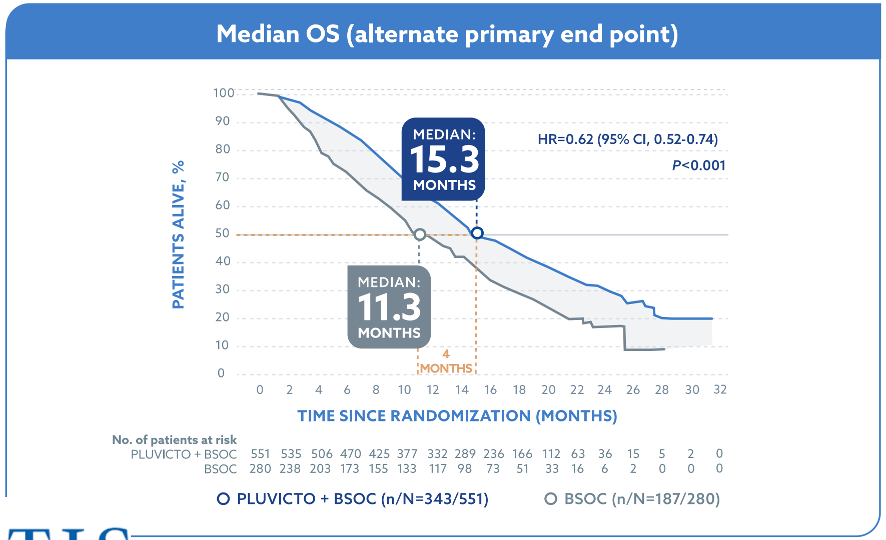
Linking ^{177}Lu to prostate-specific membrane antigen: PSMA-617 under the brand name Pluvicto®.

Theranostic partner with ^{68}Ga-PSMA-617

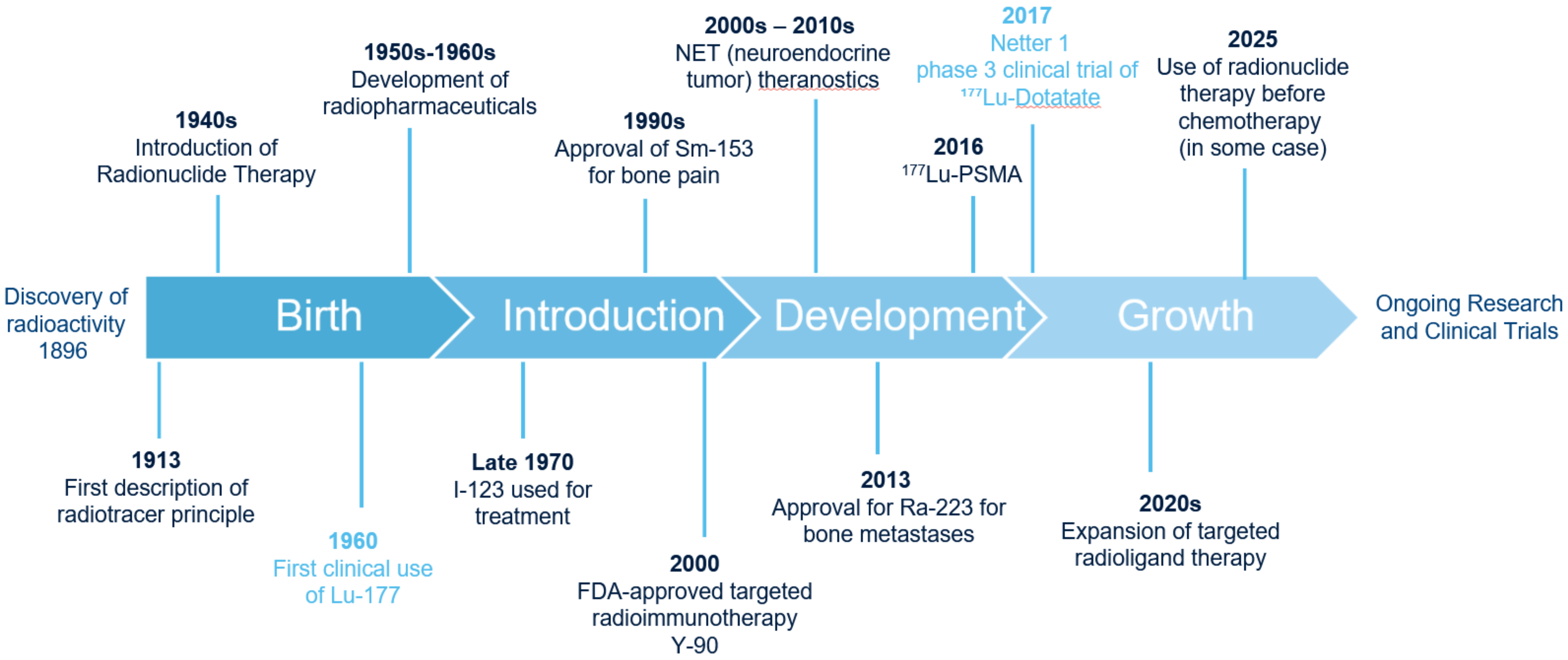
A worldwide phase-3 clinical trial was performed

The outcome was also very successful and Pluvicto® is now a standard of care across Europe.



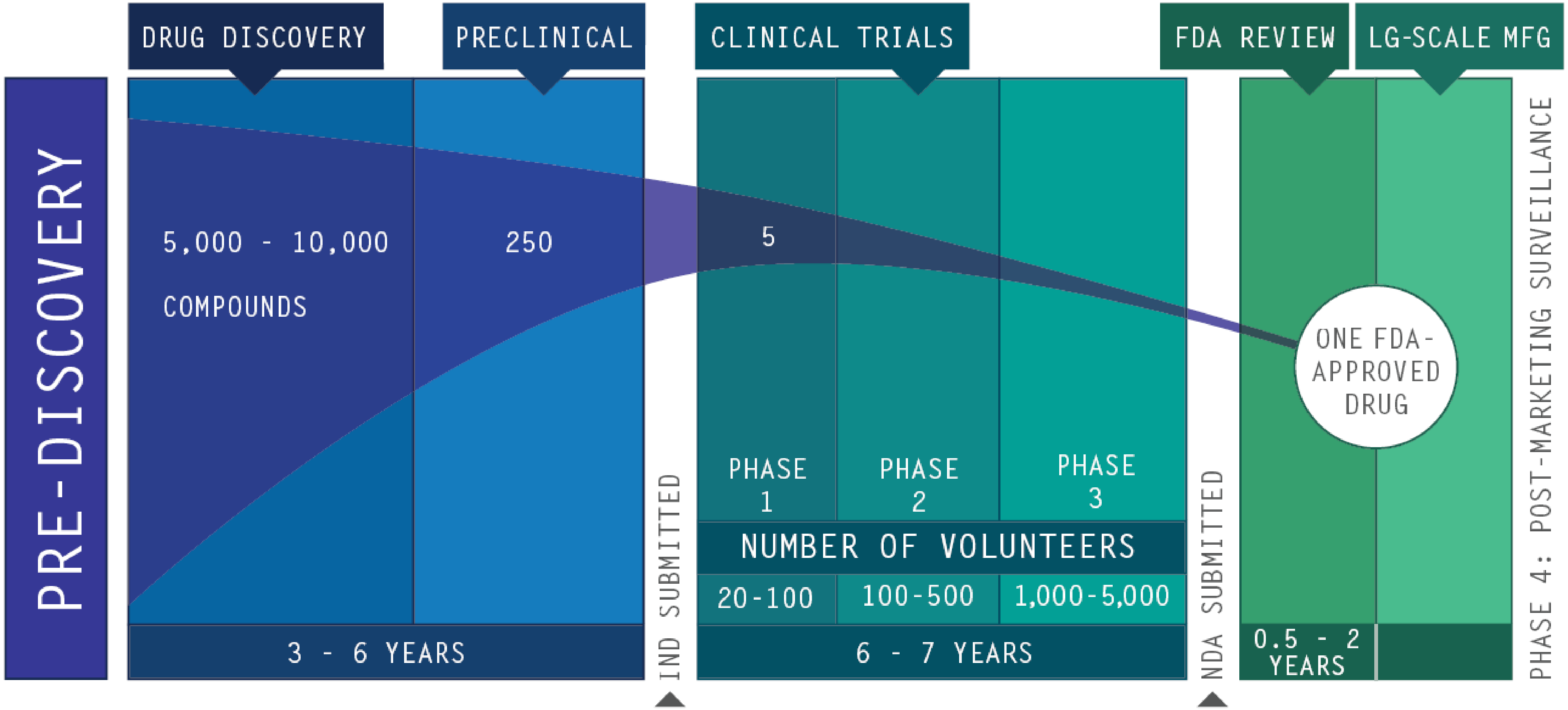


The ^{177}Lu storyline



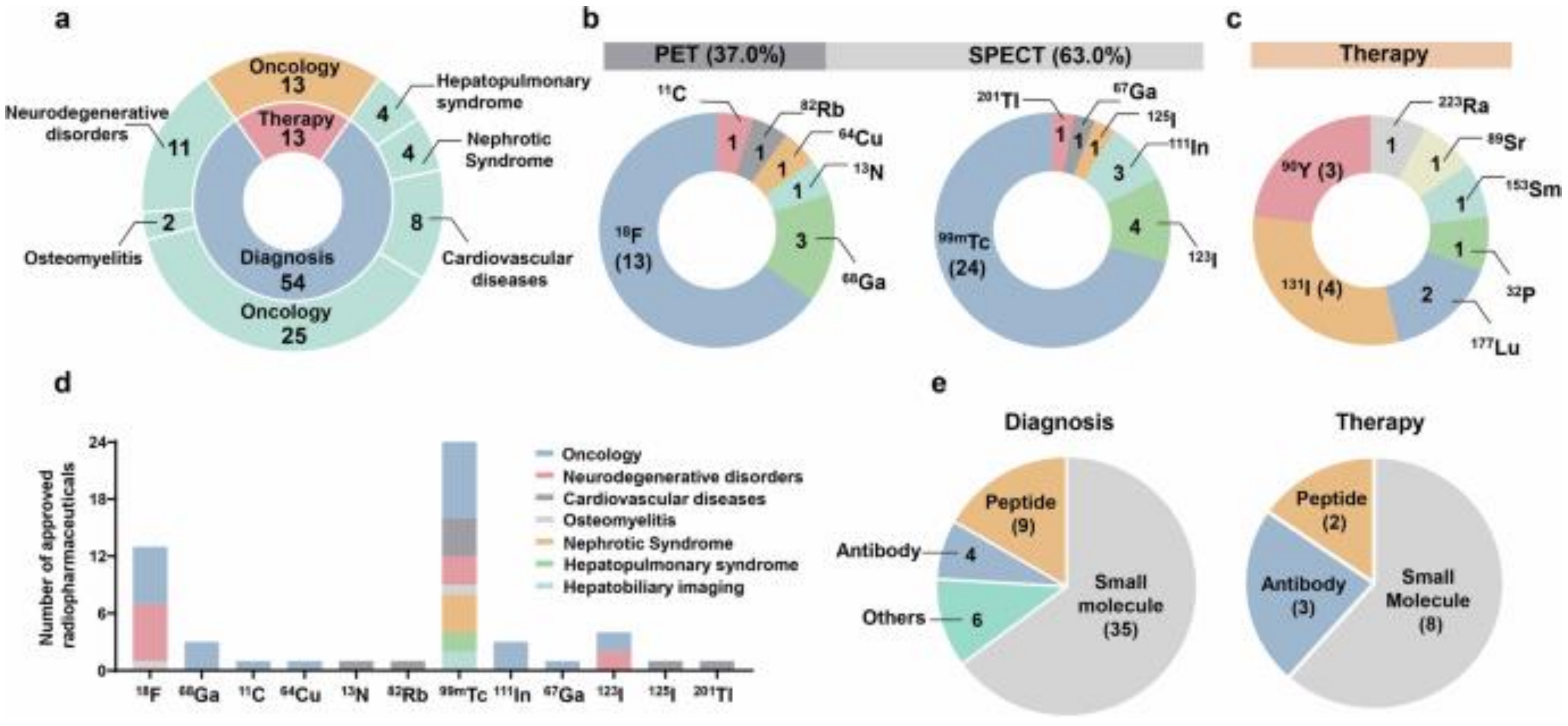
 Slide courtesy of Wiktoria Wojtaczka

Drug development pipeline



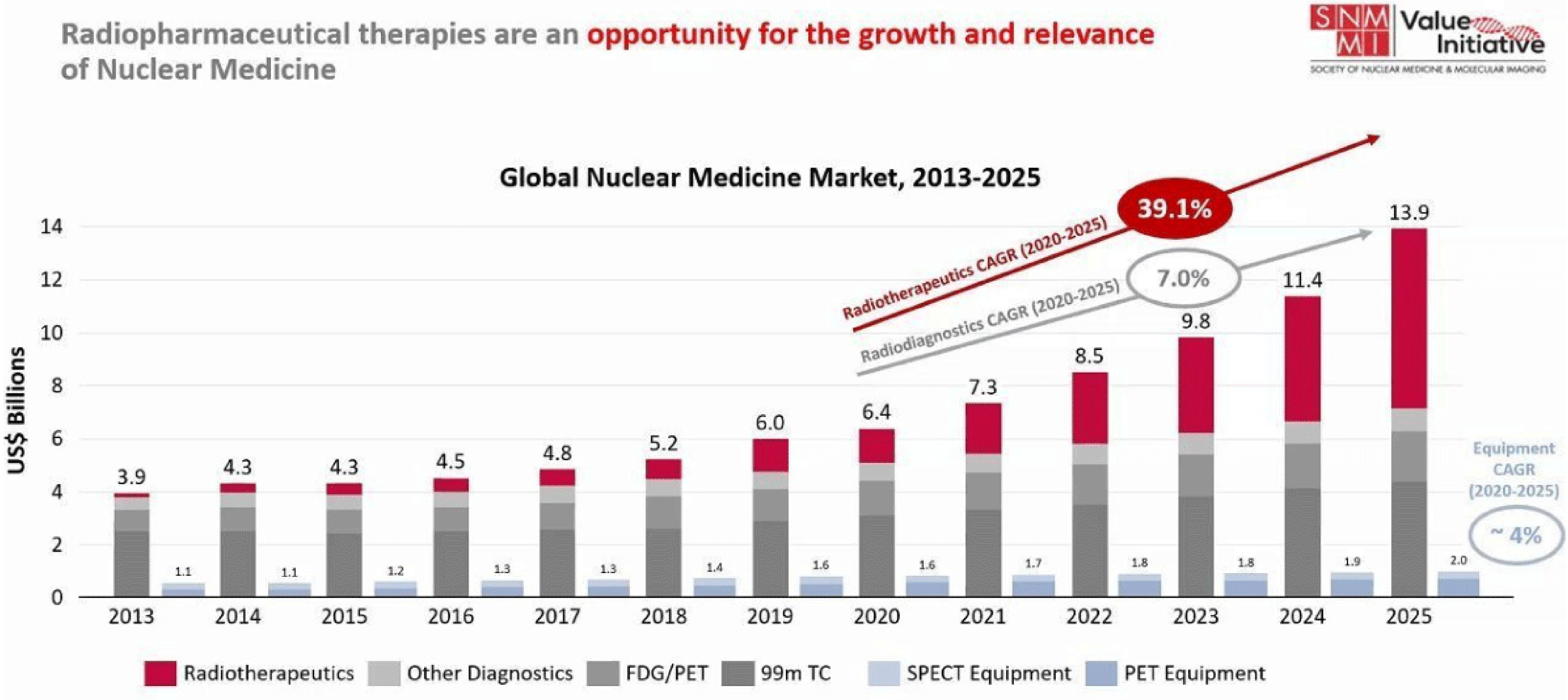
Interdisciplinary Research Group
Instituut voor Kern- en Stralingsfysica
Department of Physics & Astronomy

Medical radionuclide landscape



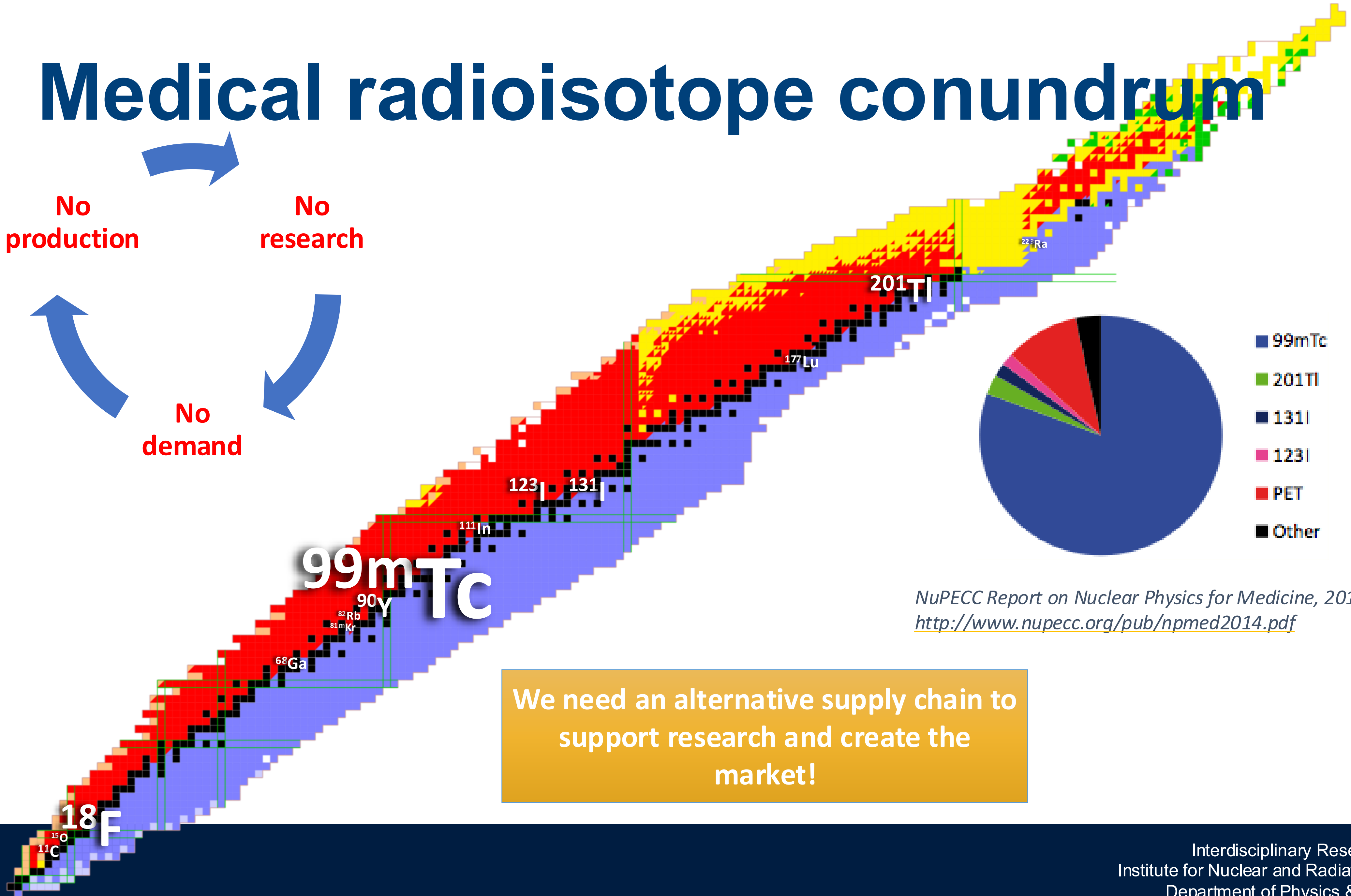
S. Zhang et al., Radiopharmaceuticals and their applications in medicine, Signal Transduction and Targeted Therapy ***10*** *(2025) 1.*

Medical radionuclide market



MEDraysintell, as presented at the SNMMI ivrtual meeting 2021 and retrieved from https://www.oncidiumfoundation.org/2021/06/17/global-nuclear-medicine-market-2013-2025/#

Medical radioisotope conundrum



NuPECC Report on Nuclear Physics for Medicine, 2014
http://www.nupecc.org/pub/npmed2014.pdf

We need an alternative supply chain to support research and create the market!

Medical radionuclides and where to find them

Medical radionuclide supply

In nuclear reactors

Medical radionuclides are produced in nuclear reactors either from neutron capture or from fission of ^{235}U.

The irradiated material always requires heavy radiochemical post-processing in hot cells.

Well established pipeline but limited (and ageing) infrastructure.

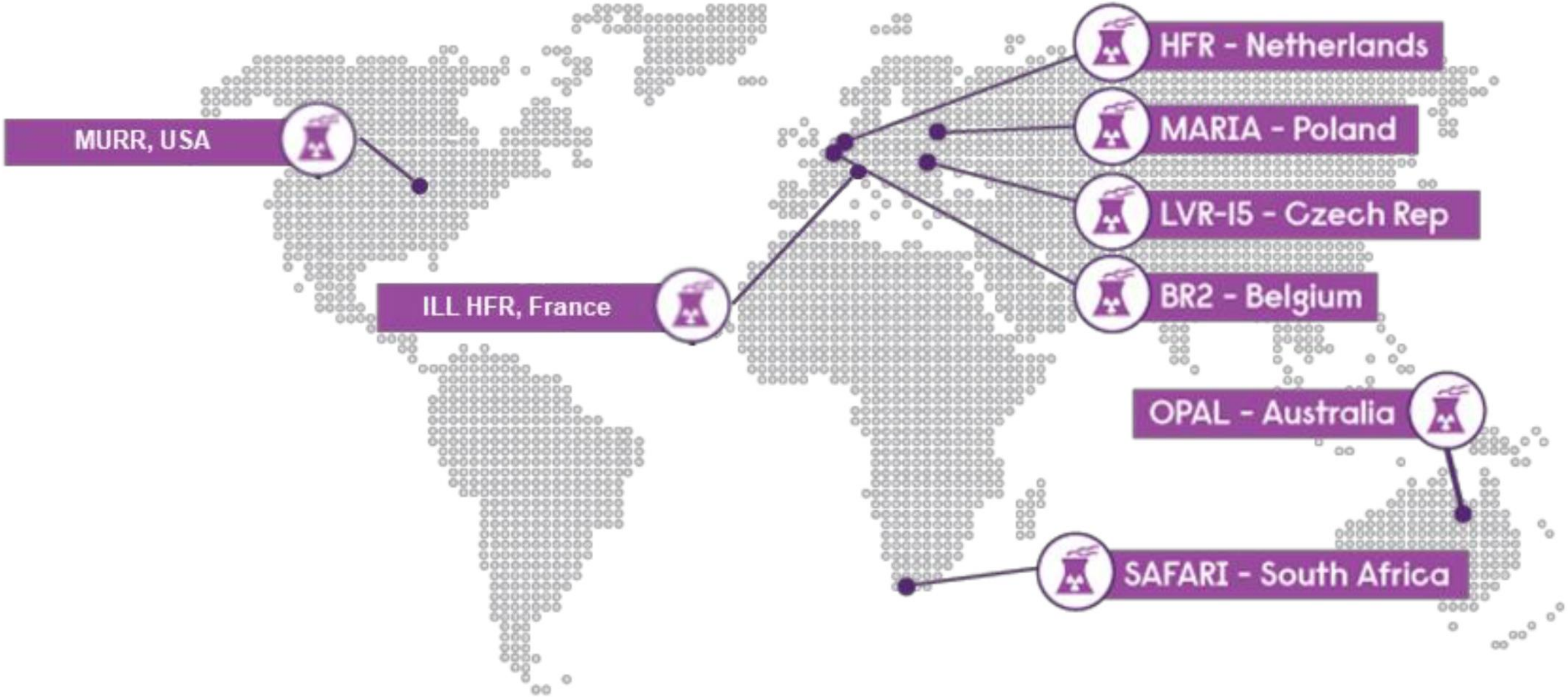
At particle accelerators

Accelerators are very modular and depending on their energy and particles accelerated, different reactions are possible.

Many hospitals have their own accelerator and are thus independent.

Innovative radionuclides require exotic accelerators.

Research reactors worldwide



https://nucleus.iaea.org/rrdb/#/home
https://nuclearmedicineeurope.eu/security-of-supply/

Hot cells

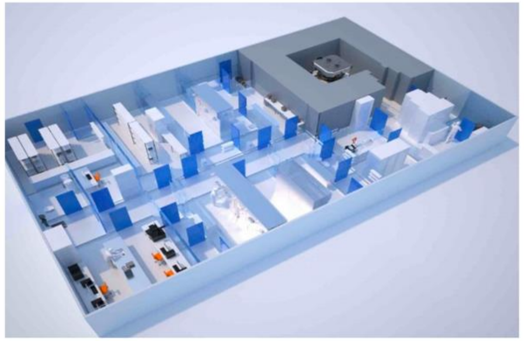
Manipulations with hot cells has been standardised through the years, but remain a rare skill.

Very few institutes are licenced worldwide to producing the ^{99}Mo generators for ^{99m}Tc – the most distributed radionuclides in the world.

LEMERPAX

KU LEUVEN 600

Medical cyclotrons

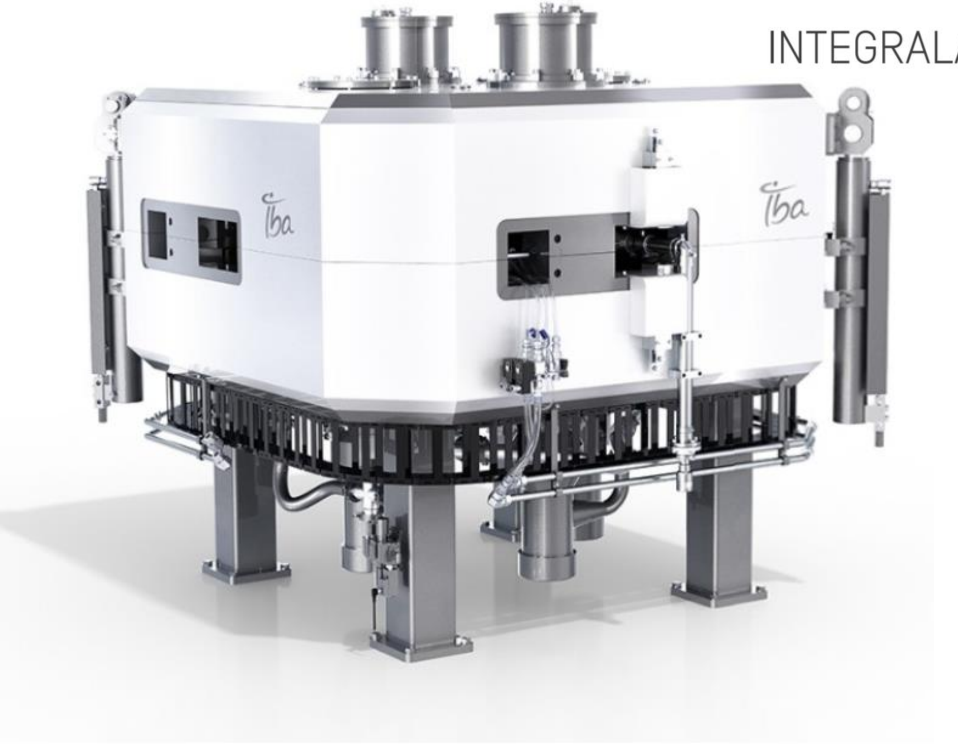


INTEGRALAB®

Those can be found in many hospitals around the world, coupled with the local radiopharmacy.

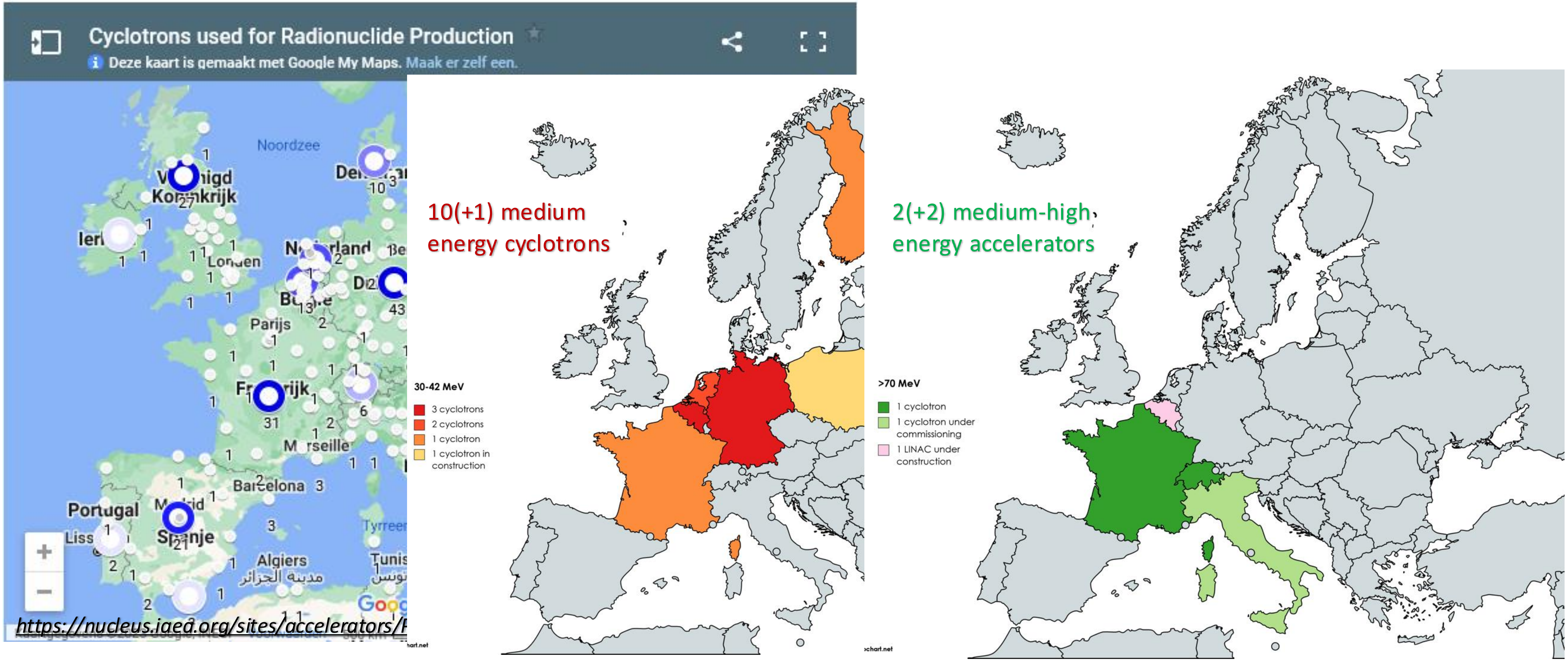
They consist of typically low-energy machines, up to 11 or 18 MeV, with built-in target systems that may even already process the radiochemistry part of the preparation and can be integrated with automated synthesis of the radiopharmaceuticals.

Ideal for PET isotopes ^{11}C and ^{18}F.



CYCLONE®KIUBE

From standard to advanced cyclotrons



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Thinking points for the tutorials

- Alpha, beta, Auger electrons: what is the next big thing and why?

- Try to identify yourself a radionuclide that has potential for medical application but is currently missing from the landscape (slide 34).

- Where do the challenges lie in turning a promising radionuclide into a success story?

Today: Some basics of nuclear medicine

Tomorrow: Nuclear science for nuclear medicine