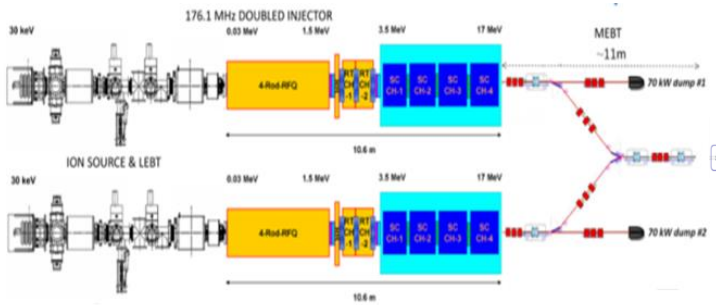
MYRRHA and its impact on fundamental science and medical applications

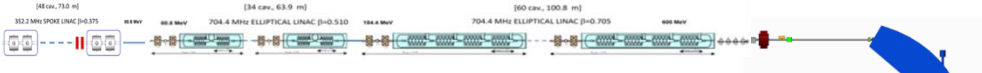
Lucia Popescu (SCK•CEN)

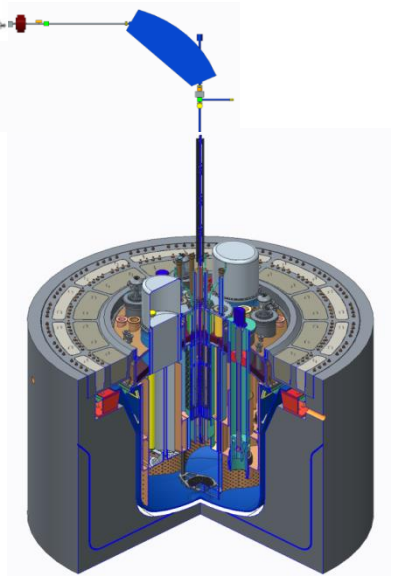
CERN, 21 March 2019

Outline

- Introduction to MYRRHA: an Accelerator Driven System







- Phased-implementation
- ISOL@MYRRHA & the Proton Target Facility
- MYRRHA for physics
- MYRRHA for nuclear medicine

Innovation in Belgium for Europe and beyond
Towards sustainable & innovative nuclear energy and applications

Brief history of recent ADS activity in Europe

- 1993 C. Rubbia, energy amplifier (CERN)
- 1994 H. Aït Abderrahim & Y. Jongen, ADONIS (BE)
- **1995 M. Salvatores, MUSE experiments (FR)**
- **1995 C. Rubbia et al., FEAT/TARC experiments (CERN)**
- 1996 C. Rubbia et al., EA-80 ADS Demo joint programme ENEA, Ansaldo Nucleare, INFN (IT)
- 1998 H. Aït Abderrahim et al., MYRRHA (BE)
- 1999 B. Carluec & M. Salvatores et al., EFIT-Gas AREVA,-CEA (FR)
- 2001 C. Rubbia et al., TRADE ENEA-Casaccia (IT)
- **2001 A. Kievitskaya et al., YALINA experiments (Belarus)**
- 2002 V. Shvetsov et al., SAD facility in DUBNA (JINR/Russia)
- **2007 H. Aït Abderrahim et al., GUINEVERE (BE/FR)**
- **2010 H. Aït Abderrahim et al., MYRRHA in ESFRI & BE Gov. Declaration of support for contruction (BE)**
- 2011 A. Zelinsky et al., Neutron Source based ADS at KIPT (Ukraine)
- 2015 iThEC, iThEC ADS Project at INR in Troitsk (CH/RU)
- **2018 H. Aït Abderrahim et al., BE Gov.:**
  - **Decides MYRRHA phased construction start**
  - **Opens project to international participation**

Slide courtesy of H. Aït Abderrahim (SCK•CEN)

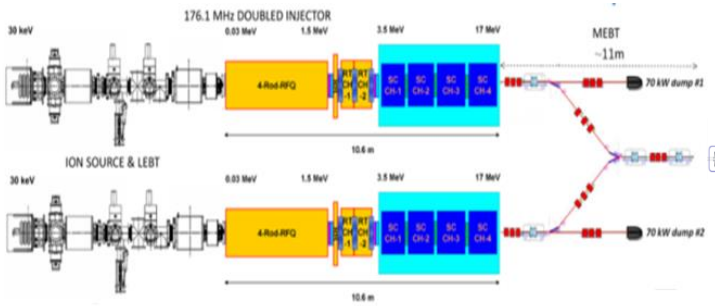
Belgian Government decision on 7 September 2018

- Belgium decided to build a new large research infrastructure at Mol: MYRRHA
- Belgium allocated € 558 M for the period 2019 – 2038:
  - € 287 M investment (CapEx) for building MINERVA (Accelerator up 100 MeV + PTF) for 2019 - 2026
  - € 115 M for further design, R&D and Licensing for phases 2 (accelerator up to 600 MeV) & 3 (reactor) for 2019-2026.
  - € 156 M for OpEx of MINERVA for the period 2027-2038
- Belgium requests to establish an International Non-Profit Organization (AISBL/IVZW) in charge of the MYRRHA facility for welcoming the international partners
- Belgium extends mandate of Secretary of State for Foreign Trade Pieter De Crem* to promote MYRRHA and negotiate international partnerships (*since 01/2019: Deputy Prime Minister Kris Peeters)

Slide courtesy of H. Aït Abderrahim (SCK•CEN)

Key technical objective of the MYRRHA-project: an Accelerator Driven System

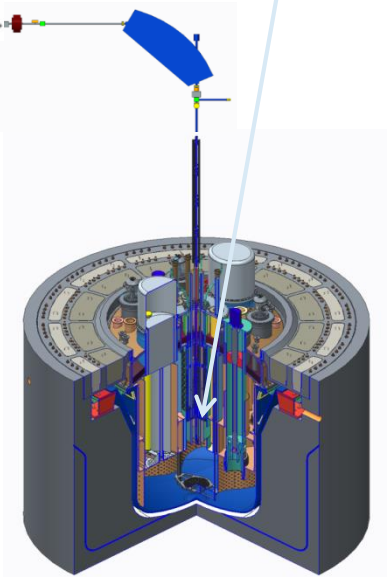
- Demonstrate the ADS concept at pre-industrial scale
  - Can operate in critical and sub-critical modes
- Demonstrate transmutation
- Fast neutron source → multipurpose and flexible irradiation facility



Target	
main reaction	spallation
output	$2 \cdot 10^{17}$ n/s
material	LBE (coolant)

Accelerator	
particles	protons
beam energy	600 MeV
beam current	2.4 to 4 mA

Reactor	
power	65 to 100 MW_{th}
k_{eff}	0,95
spectrum	fast
coolant	LBE



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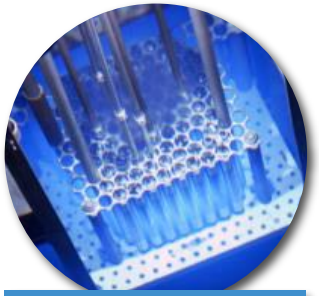
MYRRHA application portfolio



Fission GEN IV

SNF*/ Waste

Multipurpose h**Y**brid **R**esearch **R**eactor for **H**igh-tech **A**pplications

Fusion

Fundamental research

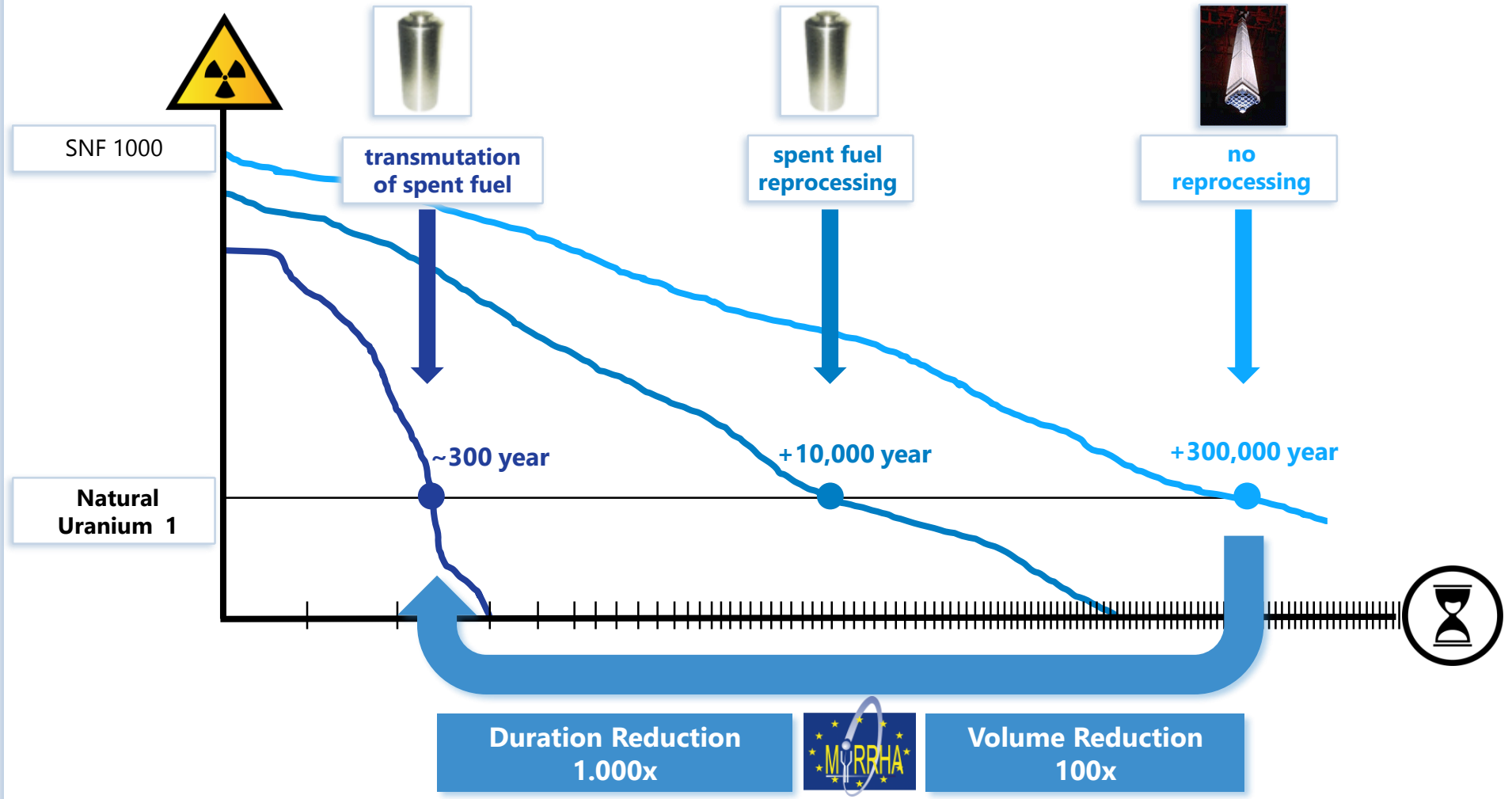
Radio-isotopes

Support to SMR LFR

*SNF = Spent Nuclear Fuel

Slide courtesy of H. Aït Abderrahim (SCK•CEN)

Transmutation: better solution for Spent Nuclear Fuel

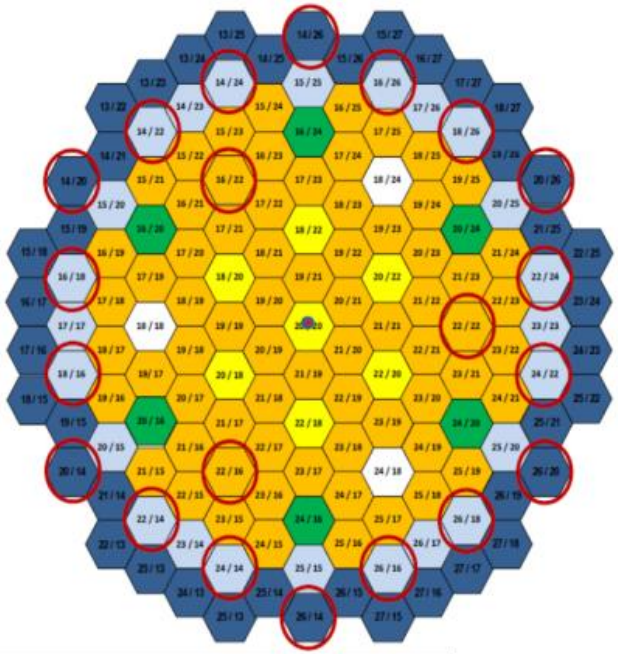


*SNF = Spent Nuclear Fuel

Slide courtesy of H. Aït Abderrahim (SCK•CEN)

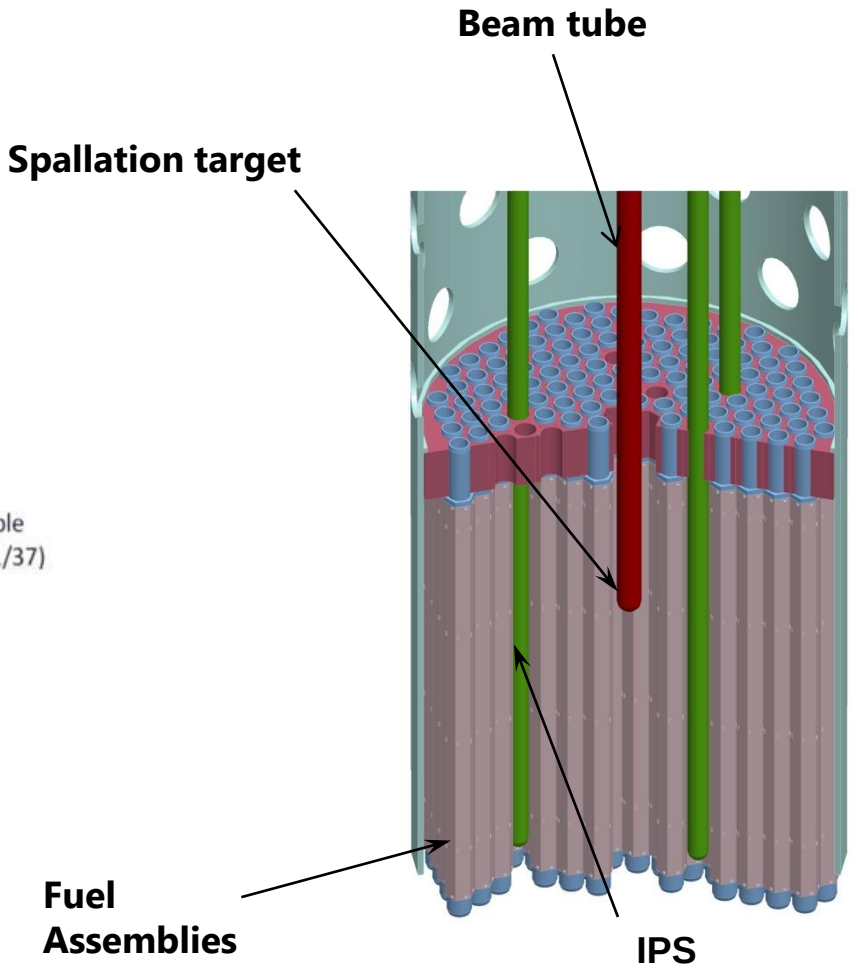
MYRRHA Core and fuel

- 151 positions
- 37 multifunctional plugs



69 FAs
7 (central) IPS
6 CR (buoyancy)
3 SR (gravity)
24 "inner" Dummy (LBE)
42 "outer" Dummy (YZrO)
151 S/As

Additional positions available for inserts from the top (21/37)

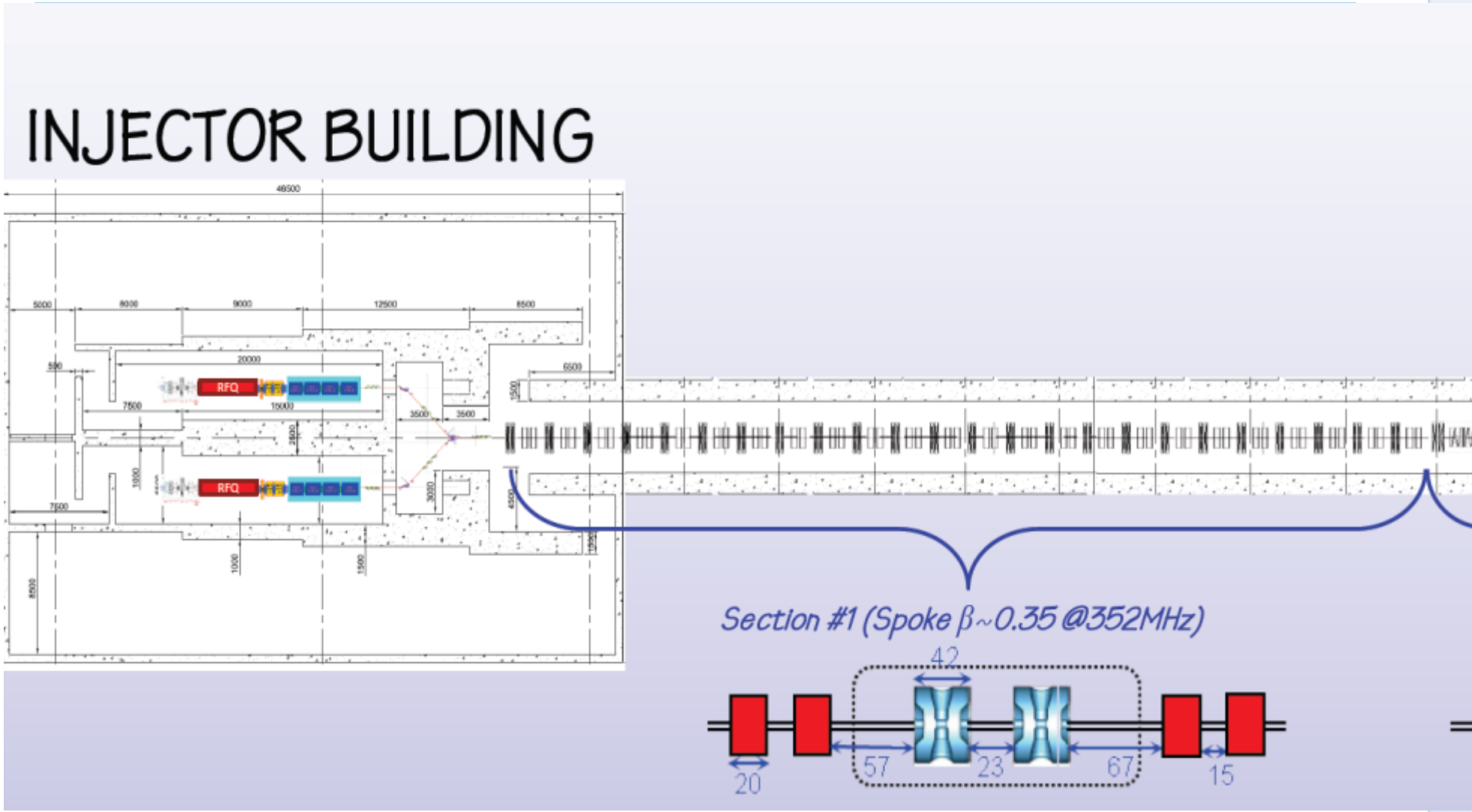


Both critical and subcritical configuration:

- **Critical: 100 MWth**
- **Subcritical 65-75 MWth**
- **MOX driver fuel (~30%)**

Slide courtesy of H. Aït Abderrahim (SCK•CEN)

MYRRHA linac: Design frozen since 2014 under prototyping



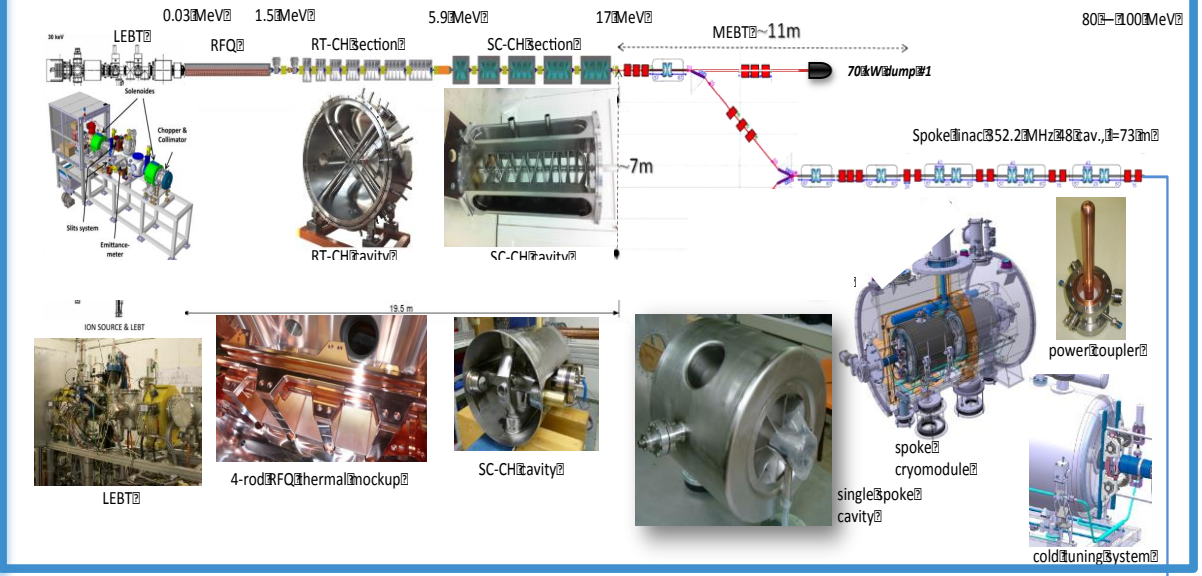
Slide courtesy of H. Aït Abderrahim (SCK•CEN)

MYRRHA's phased implementation strategy

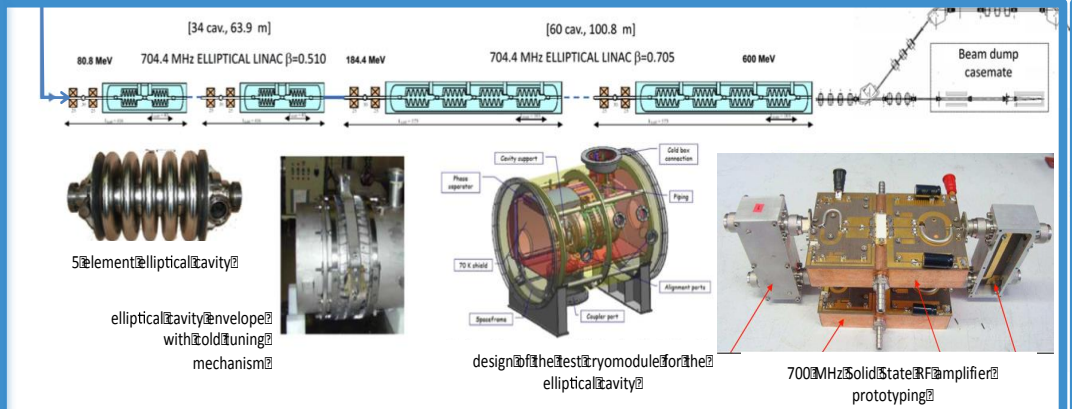
Benefits of phased approach:

- Optimised development management
- Spreading investment cost
- First R&D facility delivered in Mol end of 2026

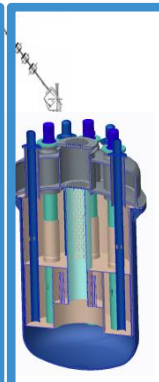
Phase 1 – 100 MeV



Phase 2 – 600 MeV



Phase 3 – Reactor

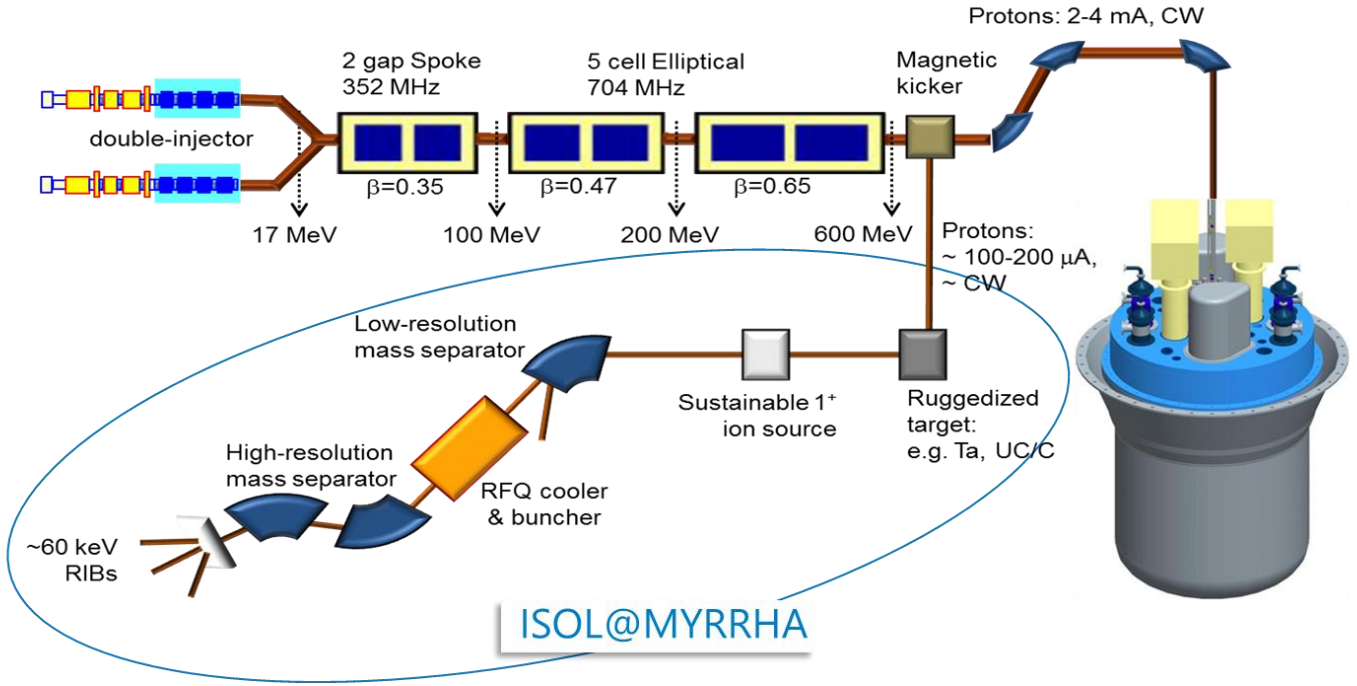


Slide courtesy of H. Aït Abderrahim (SCK•CEN)

ISOL@MYRRHA
ISOL facility for the production of Radioactive Ion Beams

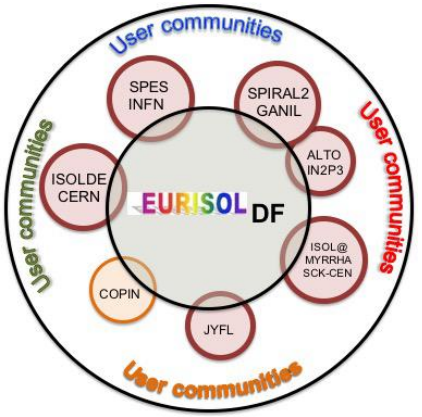
- **Concept** and **Scientific Cases** developed within BriX:

The **B**elgian **r**esearch **i**nitiative on e**X**otic nuclei for atomic, nuclear and astrophysics studies



ISOL@MYRRHA within a European context

EURISOL Collaboration &
The EURISOL-DF project



ISOL@MYRRHA
a **next generation ISOL facility**
(intermediate step towards EURISOL)

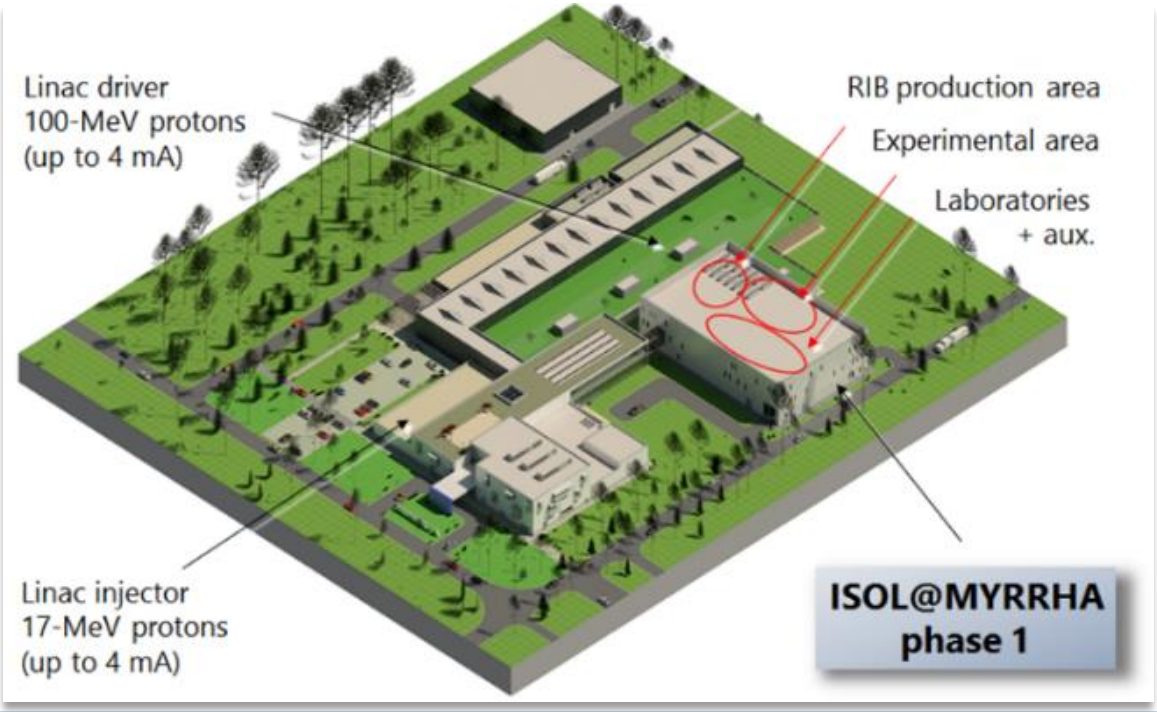
MYRRHA Phase 1

- Accelerator in Phase 1 = a subset of the MYRRHA accelerator
  - RT (until 17 MeV) & SC (single Spoke) linac, modular
  - Chosen energy cut-off = 100 MeV
  - Presently 1 injector (up to 17 MeV)
  - Relevant configuration for reliability check
  - Able to deliver adequate beam for a useful Proton Target Facility
- Layout is compatible with linac extension to 600 MeV
- Accelerator prototyping is ongoing, in parallel with integration activities
  - Broad collaboration : IN2P3 (labs IPNO, LPSC) + IAP + industry (NTG, IBA, Bevatech, Cosylab, JEMA)

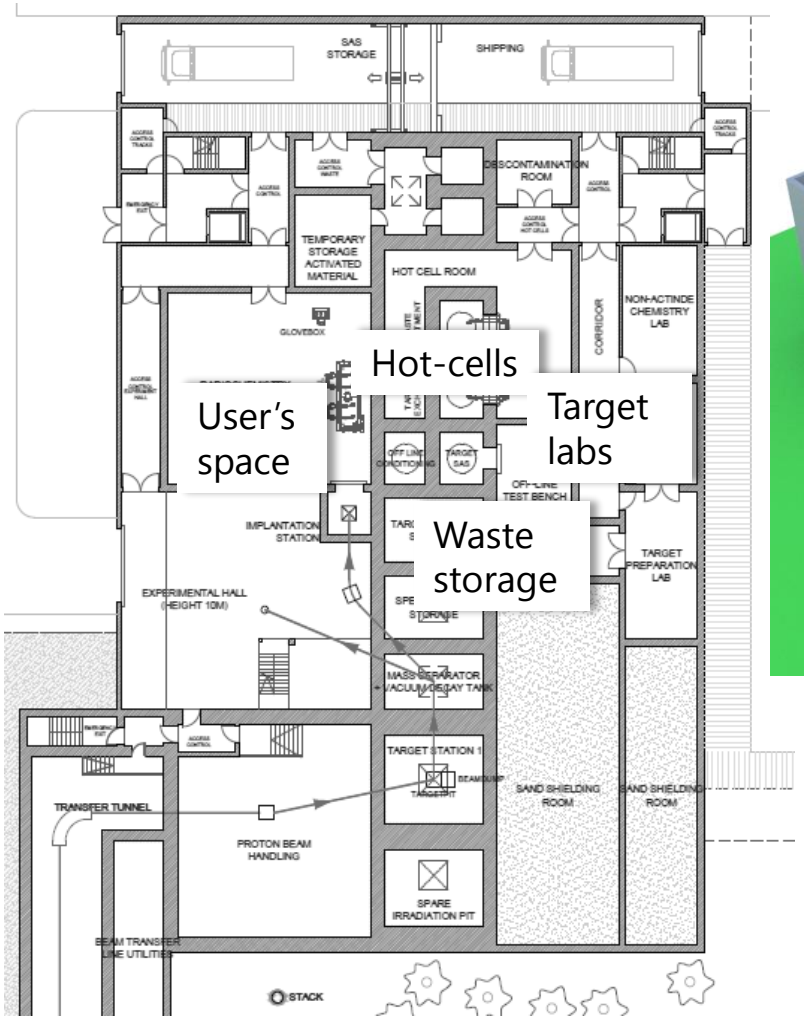
Current status

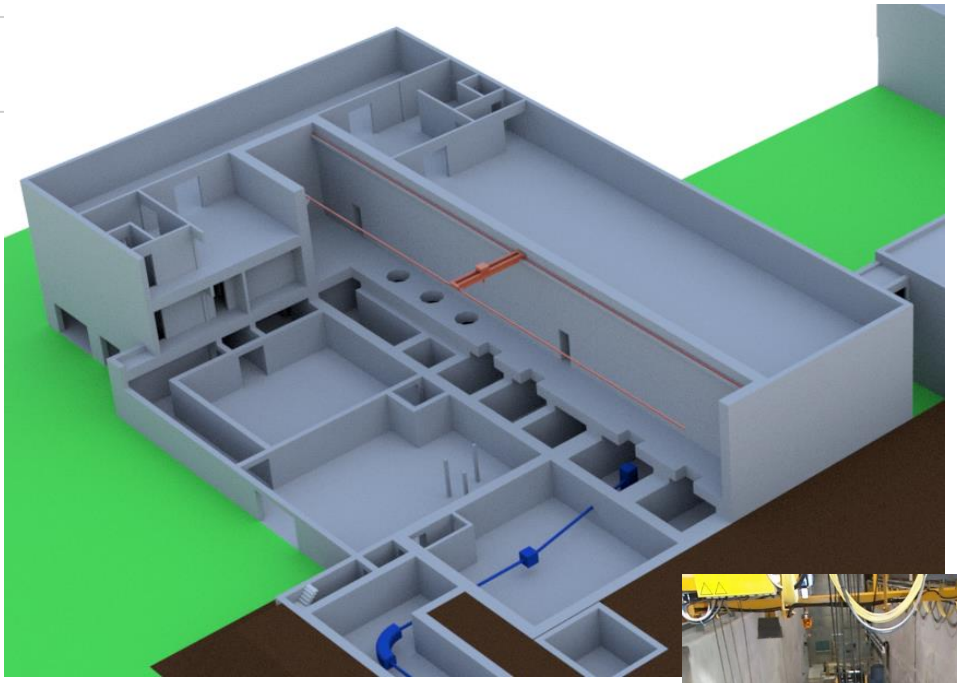
MYRRHA Phase 1

- Beam sharing allows for parallel activities:
  - Feeding the Proton Target Facility hosting **the ISOL** system (ISOL@MYRRHA phase 1)
  - Commissioning the linac for **reliability evaluation**
  - Material-irradiation capabilities for the **fusion** community
- Conceptual Design of the Proton Target Facility – to be finalized in 2019
- First Radioactive Ion Beams anticipated by 2027



Proton Target Facility (PTF) Concept

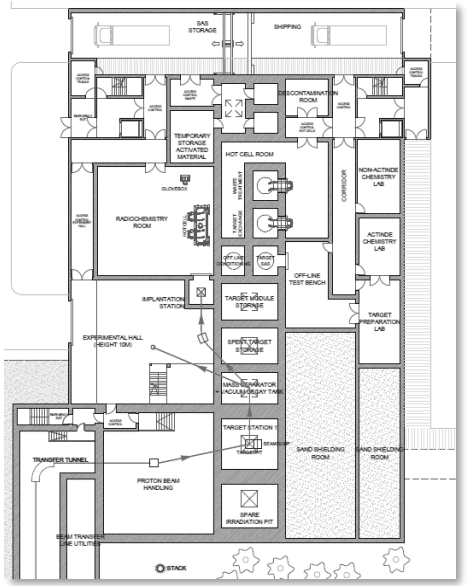


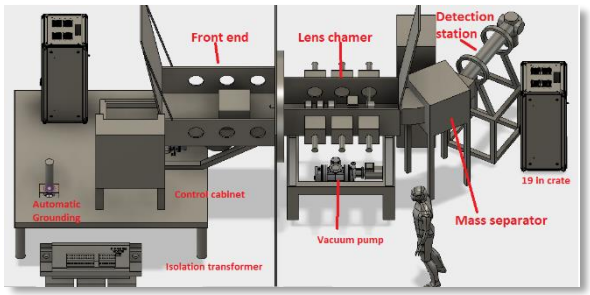


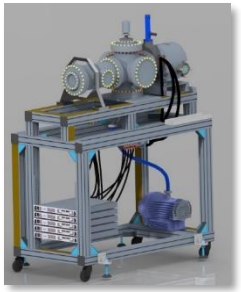
Target module handling similar to ISAC facility @ TRIUMF, but remotely operated

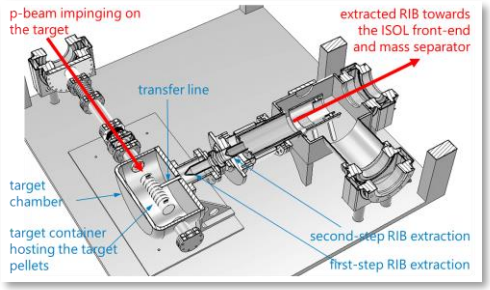
Ongoing PTF-related activities at SCK•CEN

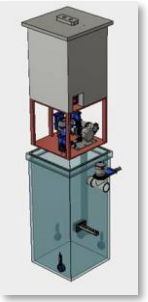
- **RIB production**
  - Target-ion source assembly development
  - ISOL-system development
  - Off-line system construction
- **Facility**
  - Proton Target Facility (PTF) design to service the ISOL system & its auxiliaries (exp. hall, hot-cells, workshops & labs…)
  - Ready to launch design engineer tendering file by mid 2019
- **Licensing**
  - Studies in support of PTF licensing
  - Discussions with licensing authorities
  - Preparing the Preliminary Safety-Assessment Report







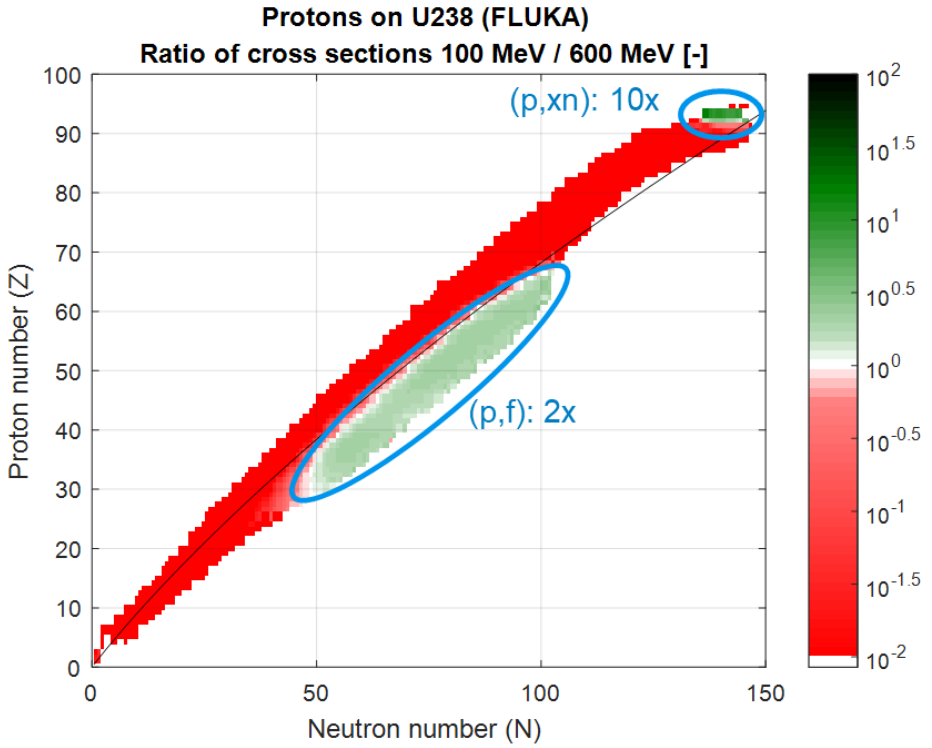




Regions accessible by ISOL@MYRRHA Phase 1

Nuclei produced by 100-MeV protons

- Actinide targets [e.g. UC_x, ThC_x]:
  - Neutron-rich <u>fission fragments</u>
  - <u>Spallation</u> region around target material
- Lighter targets [e.g. TiC_x, CaO_x]:
  - Light <u>Neutron-deficient</u> spallation products

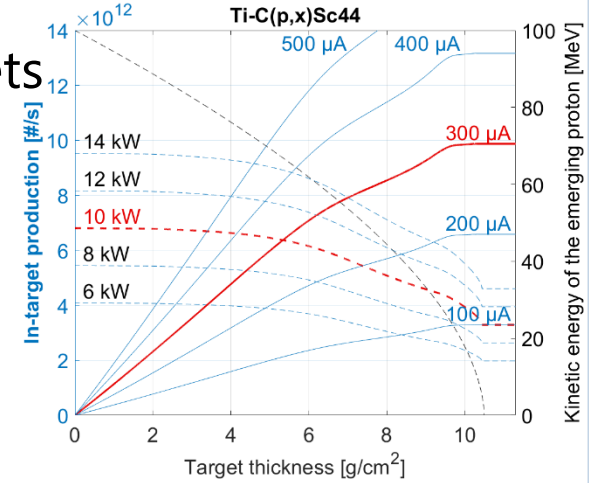


FLUKA simulation - Ratio of cross sections for 100 / 600 MeV protons on U-238

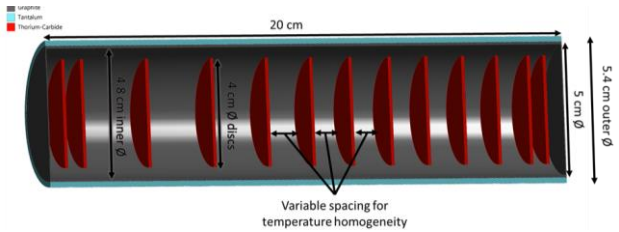
Low-energy high-power direct targets: ISOL@MYRRHA Phase 1

Non-actinide targets for day-1 operation

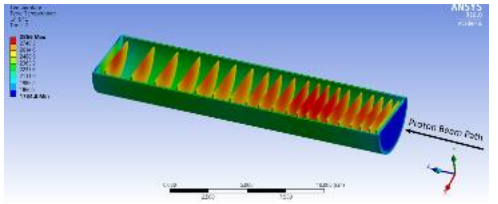
- Startup of the ISOL system with non-actinide targets
- Initial study: titanium-based targets for Sc production
  (PhD M. Ashford (SCK•CEN & UCL))
  - Ti-carbide as target material (T_{melt} = 3140°C)
- Target optimized for in-target isotopes production
  - By variation of target material density (g/cm^2)
- Detailed FLUKA and ANSYS calculations
  - Optimal distribution of the discs to get uniform target temperature



1D model for quick assessment of optimal target density (g/cm^2) favoring high in-target yields

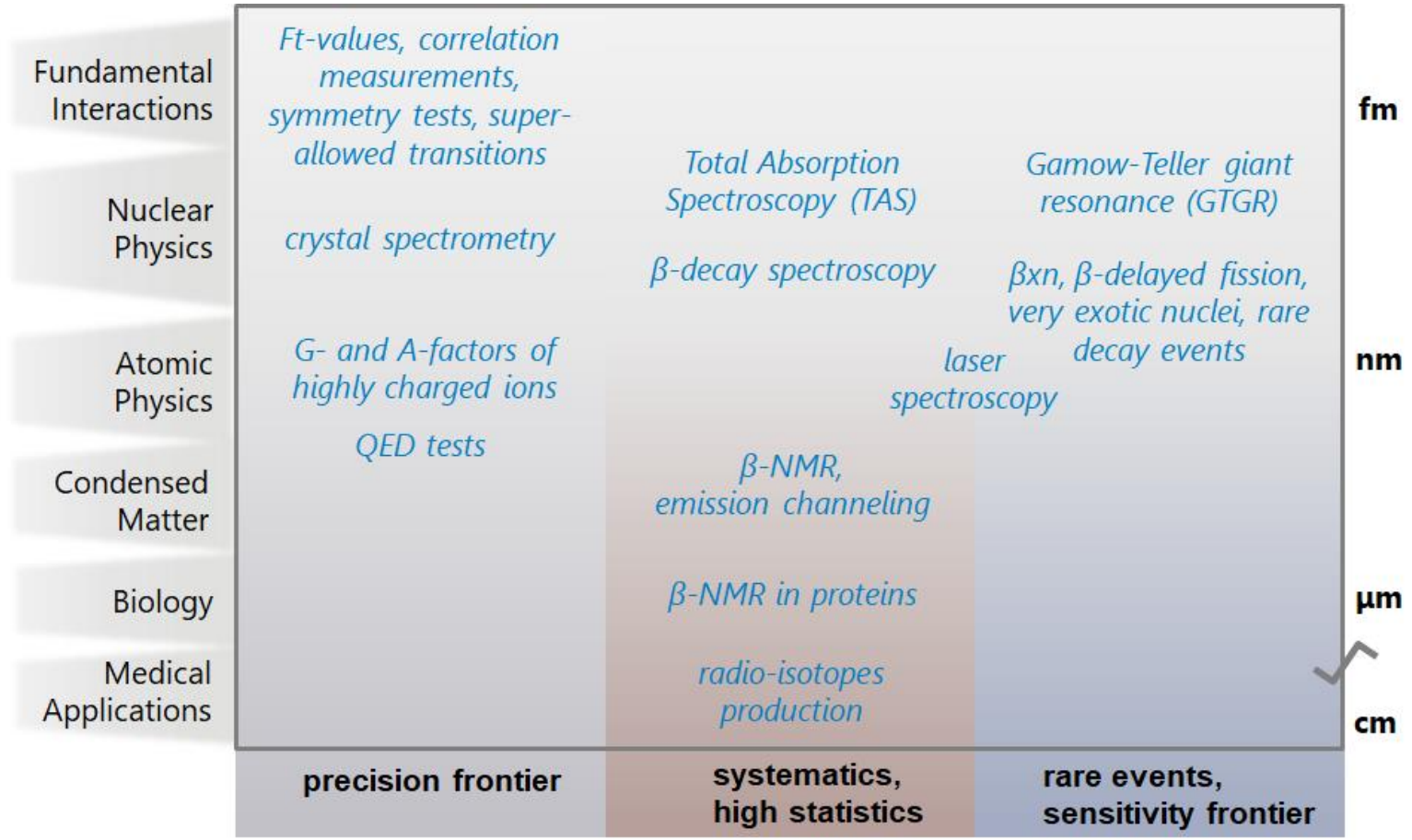


Temperature profile in 20 TiC discs, total thickness 10 mm:



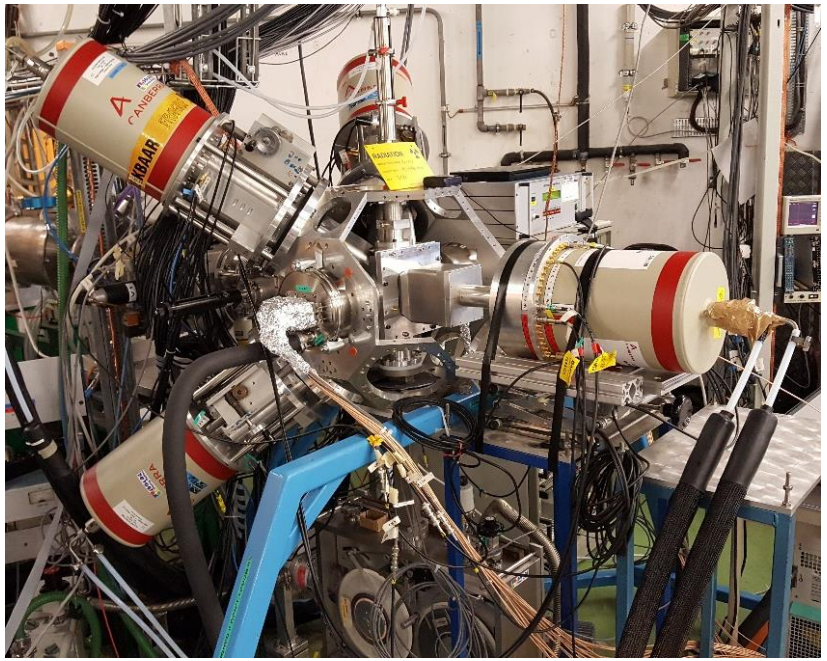
ISOL facility applications

- Physics cases identified through a series of topical workshops within BriX
- Updated for the ISOL facility at 100 MeV (SCK•CEN, IKS/KU Leuven)



"Day one" experiment at ISOL@MYRRHA

- Inspired on ISOLDE Decay Station (IDS)



- Flexible decay set-up
  - Implantation chamber
  - High-purity Ge detectors (clover + Miniball)
  - Ancillary detectors ($LaBr_3$, Si, plastic scintillator, neutron detectors,…)
  - Silicon detectors
- Focus on β- (delayed) decay studies
- 25+ institutes involved, led by IKS-KU Leuven
- Upgrades planned in near future

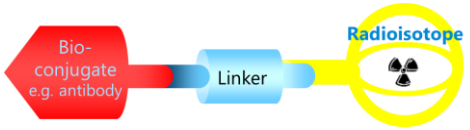
- Decay station @ MYRRHA: to be developed by SCK•CEN in collaboration with partners (IKS, IDS collaboration,…)

MYRRHA for nuclear medicine

Essential successful treatment development steps

Access to radionuclide

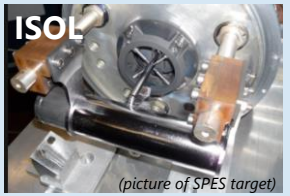
Radiopharmaceutical development

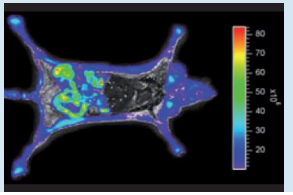


Pharma industry

Top-qualified doctors and hospital facilities

- New SCK•CEN Strategic Plan: the "Medical Campus" for a complete radiopharmaceutical development
  - Radioisotopes **production**
  - Chemical **purification**
  - **Radiolabeling**
  - **Pre-clinical studies**



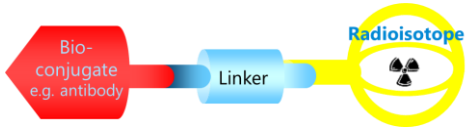


MYRRHA for nuclear medicine

Essential successful treatment development steps

Access to radionuclide

Radiopharmaceutical development

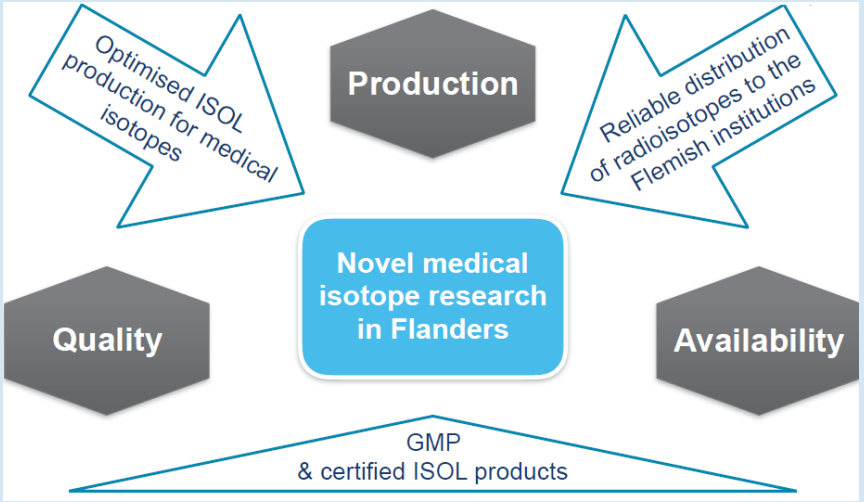


Pharma industry

Top-qualified doctors and hospital facilities

- Tb-IRMA-V: **Tb** ISOL **R**adioisotopes for **M**edical **A**pplications in **V**laanderen
- Project funded with € 2.2 M by the Flemish Fund for Scientific Research (FWO)

Project Partners



Advisory Board (future users)

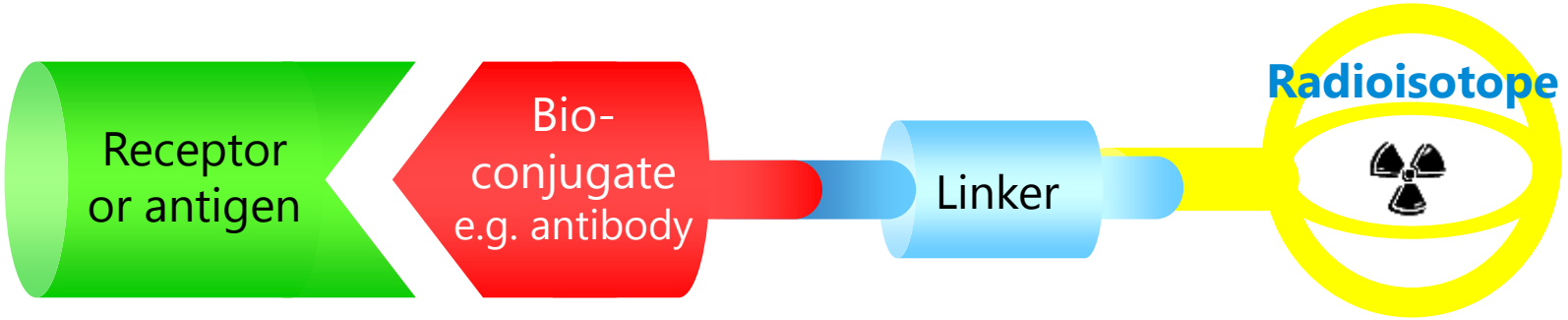
Therapy isotopes in modern health care

From
radiation therapy

To
molecularly targeted therapy

Therapy isotopes in modern health care

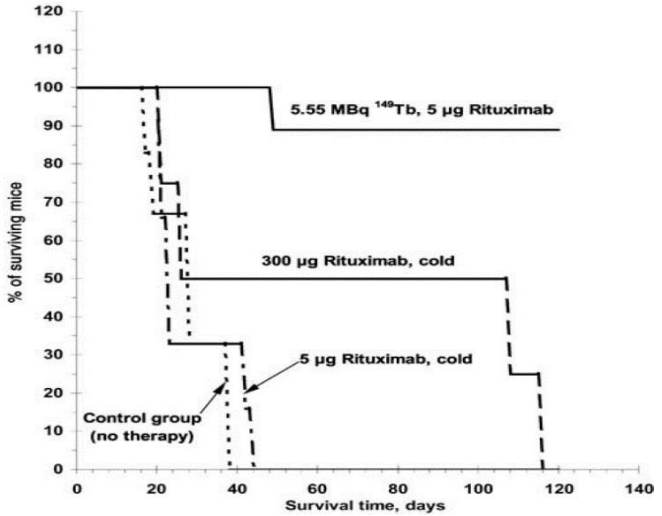
- Radio-pharmaceuticals for a selective dose delivery
  - Targeted radiotherapy for circulating single cancer cells, small cancer-cell clusters & secondary tumors
  - Tumor-seeking tracer labeled with α/β emitter
  - Range of α emitters: 30-80 μm (cell surgery)



Structural biology | Coordination Chemistry | Nuclear physics and Radiochemistry

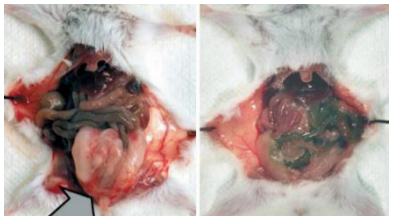
- Requires successful combination of various disciplines

Targeted alpha therapy: the Tb-149 case



300 µg Rituximab

Tb-149: 120 days p.i.



- Pre-clinical studies only
- Supply limitation
- ISOL is mandatory!

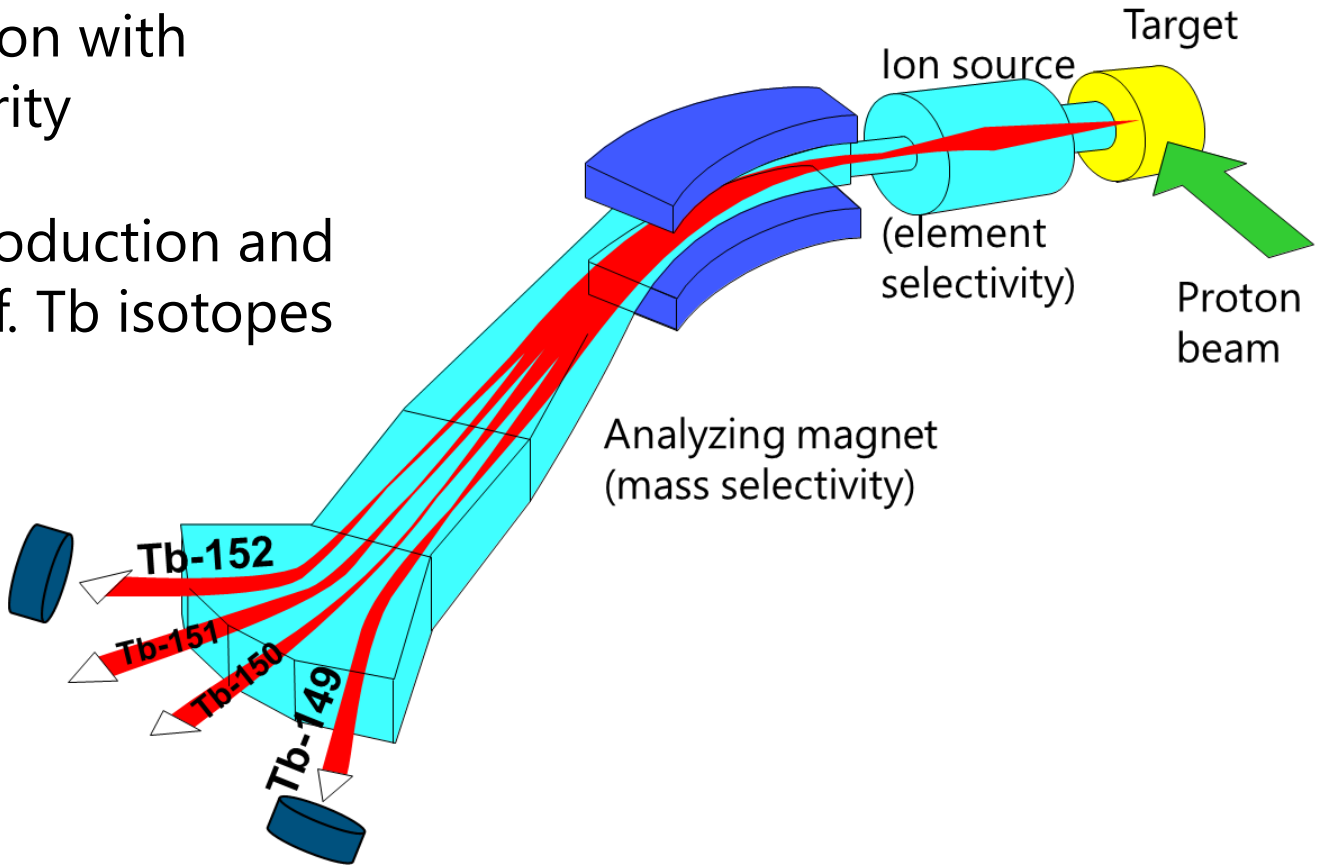
G.J. Beyer et al., Eur. J. Nucl. Med. Molec. Imaging 31 (2004) 547

- Tb: a unique nuclear medicine

Production of ^{149}Tb, ^{152}Tb and ^{155}Tb via ISOL

- High-energy proton-irradiation of Ta-metal targets + **I**sotope **S**eparation **O**n-**L**ine (ISOL)

- Sample production with high isotopic purity
- Simultaneous production and separation of diff. Tb isotopes



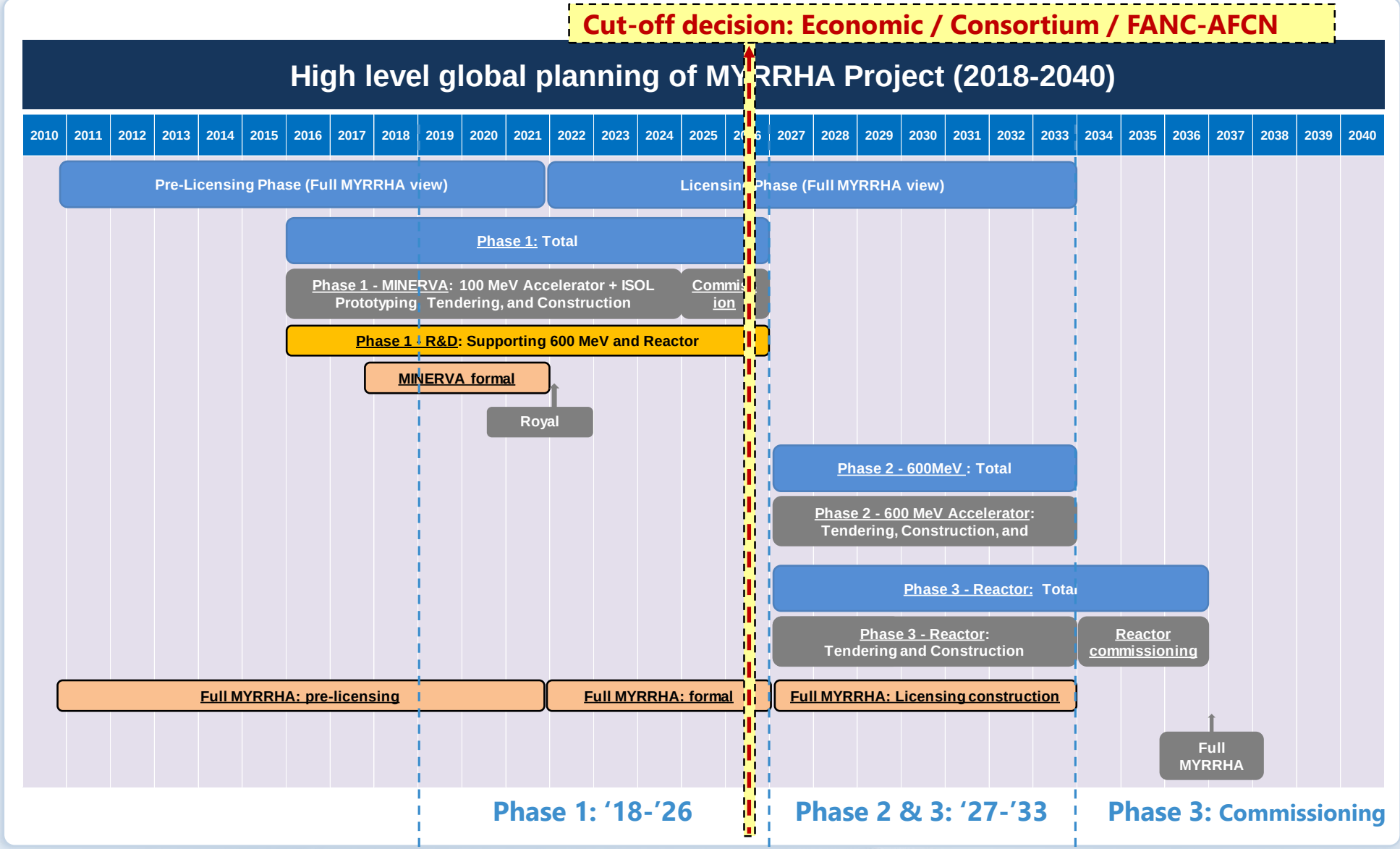
Unique MYRRHA accelerator features

- Meets medical needs:
  - Highest Accelerator Productivity (primary beams up to 4 mA available)
    - Availability of isotopes = Number 1 limiting factor for clinical application of Radio-Immuno Therapy and Targeted Alpha Therapy
  - Highest Isotope Purity (through ISOL)
    - Radio-isotope purity crucial to optimize dose to the patient and minimize side effects
  - R&D isotopes sample production that are not commercially available or easy to produce with other means
  - Isotopes with ultimate specific activity for R&D

    e.g. studies of efficacy versus specific activity.

MYRRHA Project Status

MYRRHA Phased implementation (2018-2065…) High-level Schedule



Slide courtesy of H. Aït Abderrahim (SCK•CEN)

MYRRHA is recognized in Europe to contribute to strategic objectives of both Energy and Knowledge economy

ESFRI
European Strategic Forum for Research Infrastructure

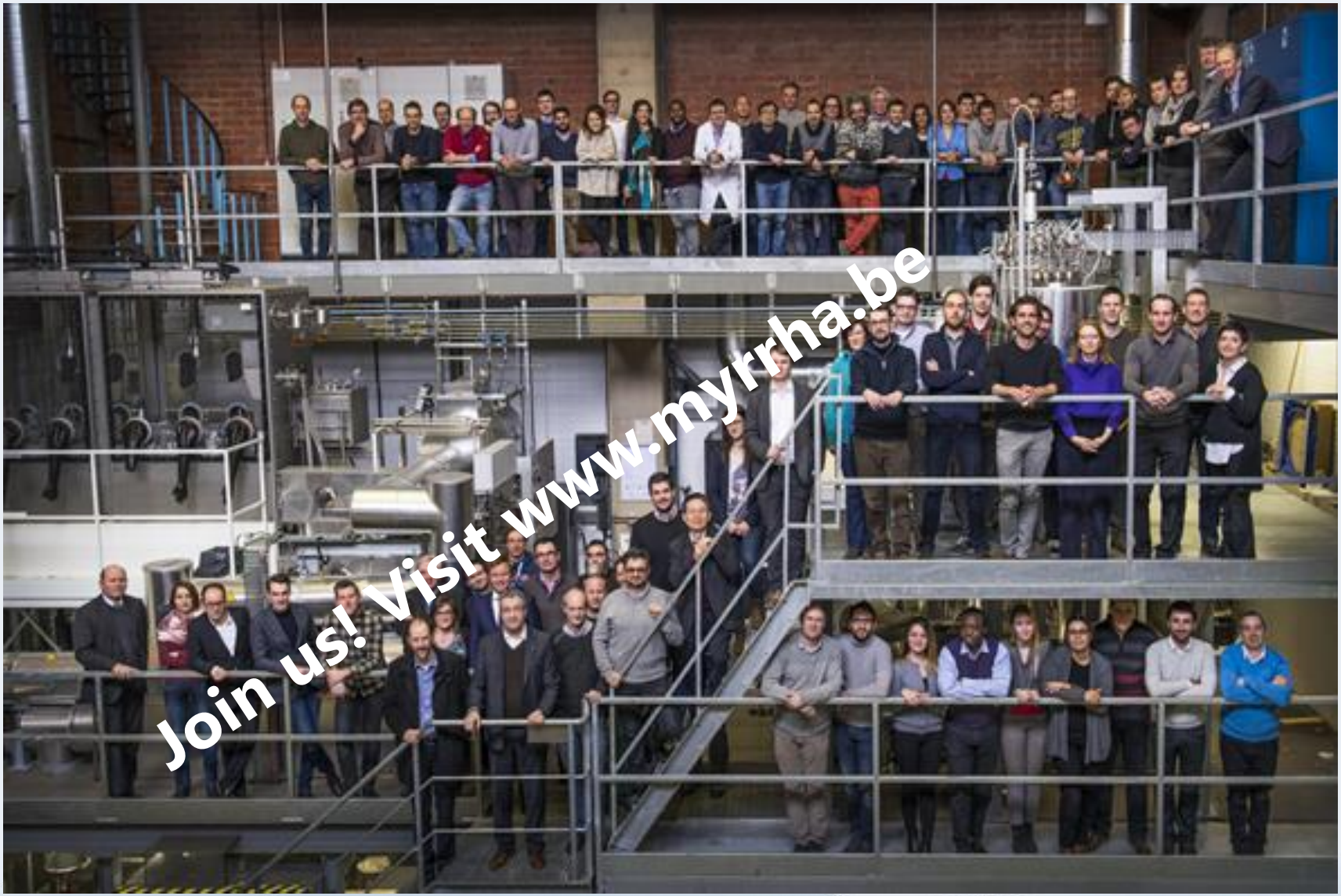
SET Plan
European Strategic Energy Technologies Plan

EIB InnovFin	MYRRHA is selected by the **European Investment Bank (EIB)** as a potential project for financing and benefits from advisory services from EIB InnovFin
Juncker Plan	MYRRHA is on the list of projects candidate to be financed by the **European Fund for Strategic Investments** (**EFSI**, also called **"Juncker plan"**)

Slide courtesy of H. Aït Abderrahim (SCK•CEN)

MYRRHA is embedded in an international R&D network

Enabled by highly qualified people at SCK•CEN and in our international MYRRHA network



Slide courtesy of H. Aït Abderrahim (SCK•CEN)

Belgium
Sends strong message on its determination to maintain high level of nuclear knowledge and expertise
Offers MYRRHA for international collaboration

Following the positive
full phase 1 decision
on 7 September 2018

MYRRHA will break ground in 2021

Slide courtesy of H. Aït Abderrahim (SCK•CEN)

www.myrrha.be

Needs its European partners as co-developers and future users

Needs talented young people today & tomorrow

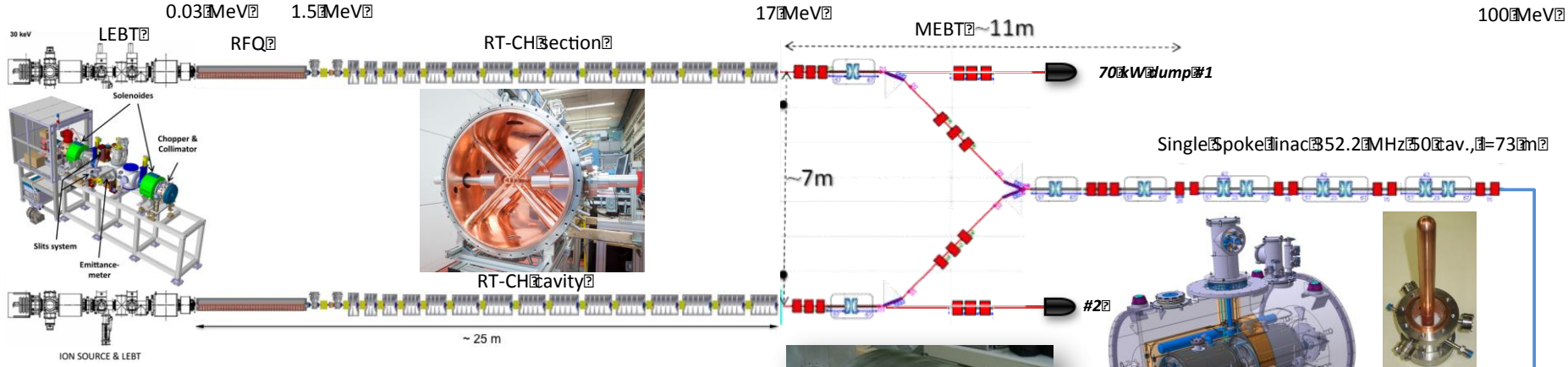
Offers you making your Master or PhD thesis

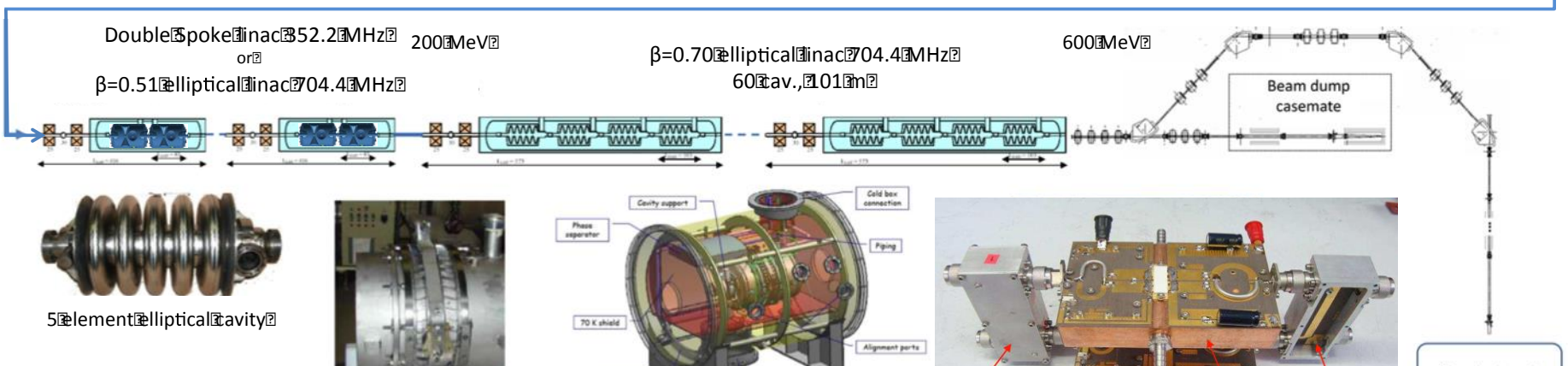
Offers you job opportunities (hiring 80 persons in 2019)

SCK•CEN
Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire
Belgian Nuclear Research Centre

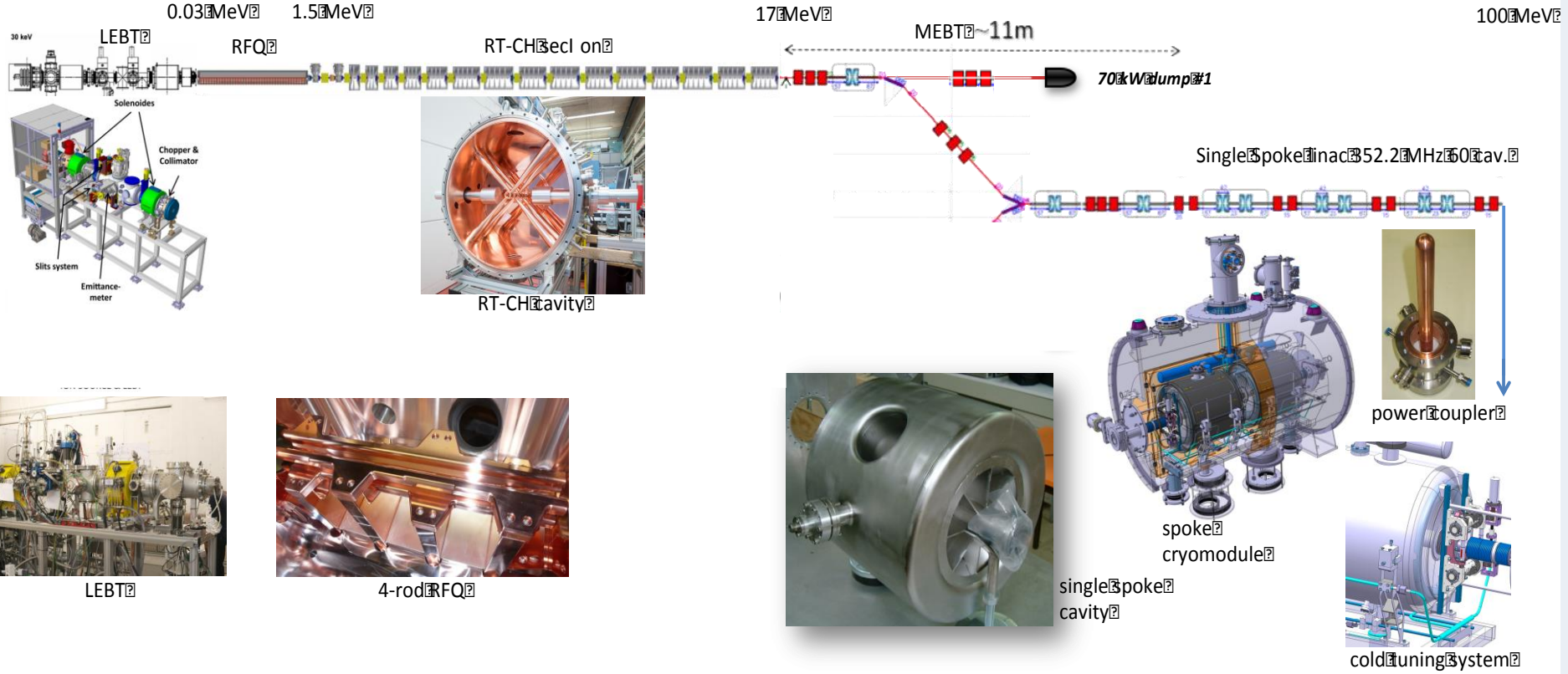
Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSELS
Operational Office: Boeretang 200 – BE-2400 MOL

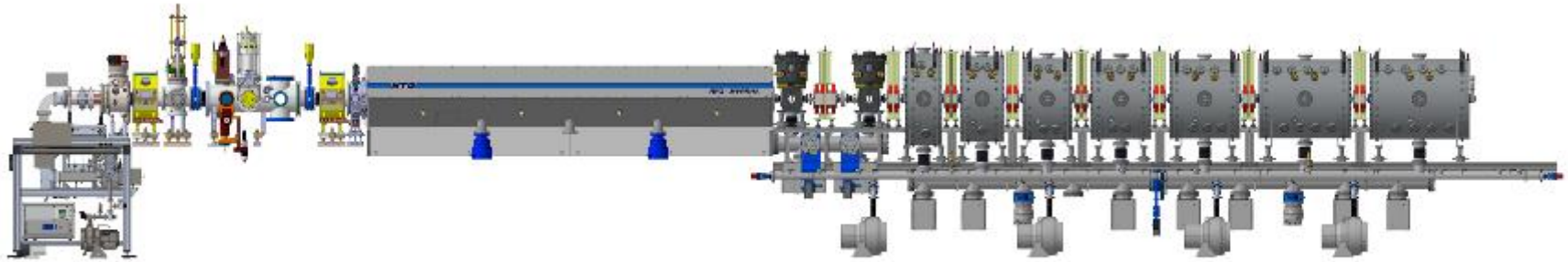

0.03 MeV
1.5 MeV
17 MeV
MEBT ~11m
100 MeV
LEBT
RFQ
RT-CH section
30 keV
Solenoides
Chopper & Collimator
Slits system
Emittance-meter
ION SOURCE & LEBT
~ 25 m
~7m
#1
#2
Single Spoke linac 352.2 MHz 50 cav., L=73m
RT-CH cavity
power coupler
spoke cryomodule
single spoke cavity
cold tuning system
LEBT
4-rod RFQ


Double Spoke linac 352.2 MHz
or
β=0.51 elliptical linac 704.4 MHz
200 MeV
β=0.70 elliptical linac 704.4 MHz
60 cav., 101m
600 MeV
Beam dump casemate
Reactor target
5 element elliptical cavity
elliptical cavity envelope with cold tuning mechanism
design of the test cryomodule for the elliptical cavity
700 MHz Solid State RF amplifier prototyping

100 MeV linac overview



Injector R&D in LLN



Injector 5.9 MeV in LLN

Collaboration:

ECR: Pantechnik
LEBT: LPSC
RFQ: IAP / NTG / IBA
CH-string: IAP / Bevatech / IBA

Source: