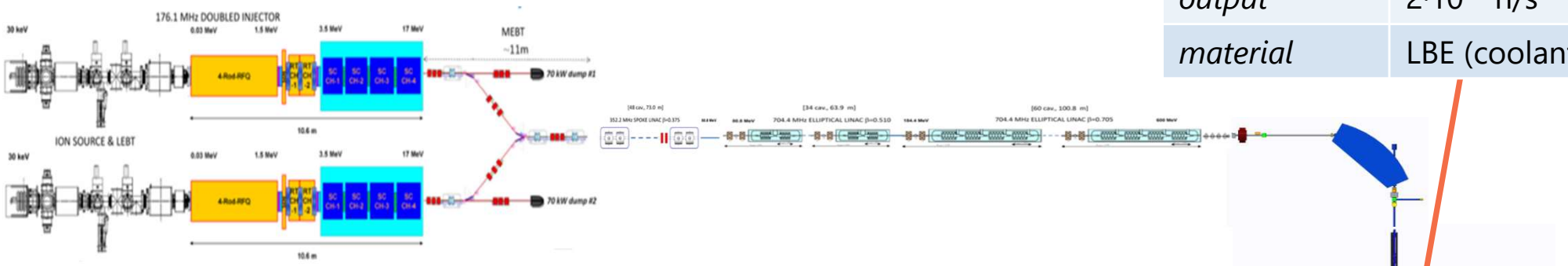
The MINERVA Facility in MYRRHA Phase 1

Carmen Angulo
MINERVA Project Manager, carmen.angulo@sckcen.be
SCK•CEN (Belgian Nuclear Research Centre), Mol, Belgium

EuNPC 2018, Bologna, September 6th, 2018

MYRRHA key objective: an Accelerator Driven System

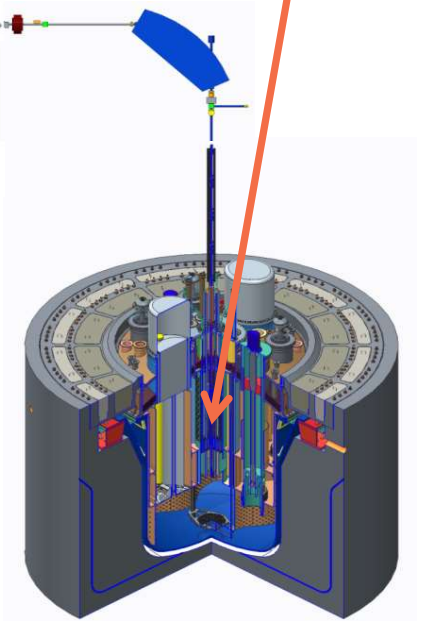
- Demonstrate the **ADS concept** at pre-industrial scale → can work in critical and subcritical mode, accelerator controls criticality
- Demonstrate **Transmutation**
- Fast neutron source → **Multipurpose and flexible irradiation facility**



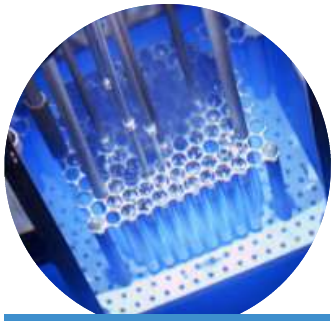
Target	
main reaction	spallation
output	$2 \cdot 10^{17}$ n/s
material	LBE (coolant)

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



MYRRHA broad application portfolio



Fission GEN IV

Multipurpose
h**Y**brid
Research
Reactor for
High-tech
Applications

Fusion

SNF*/ Waste

Fundamental research

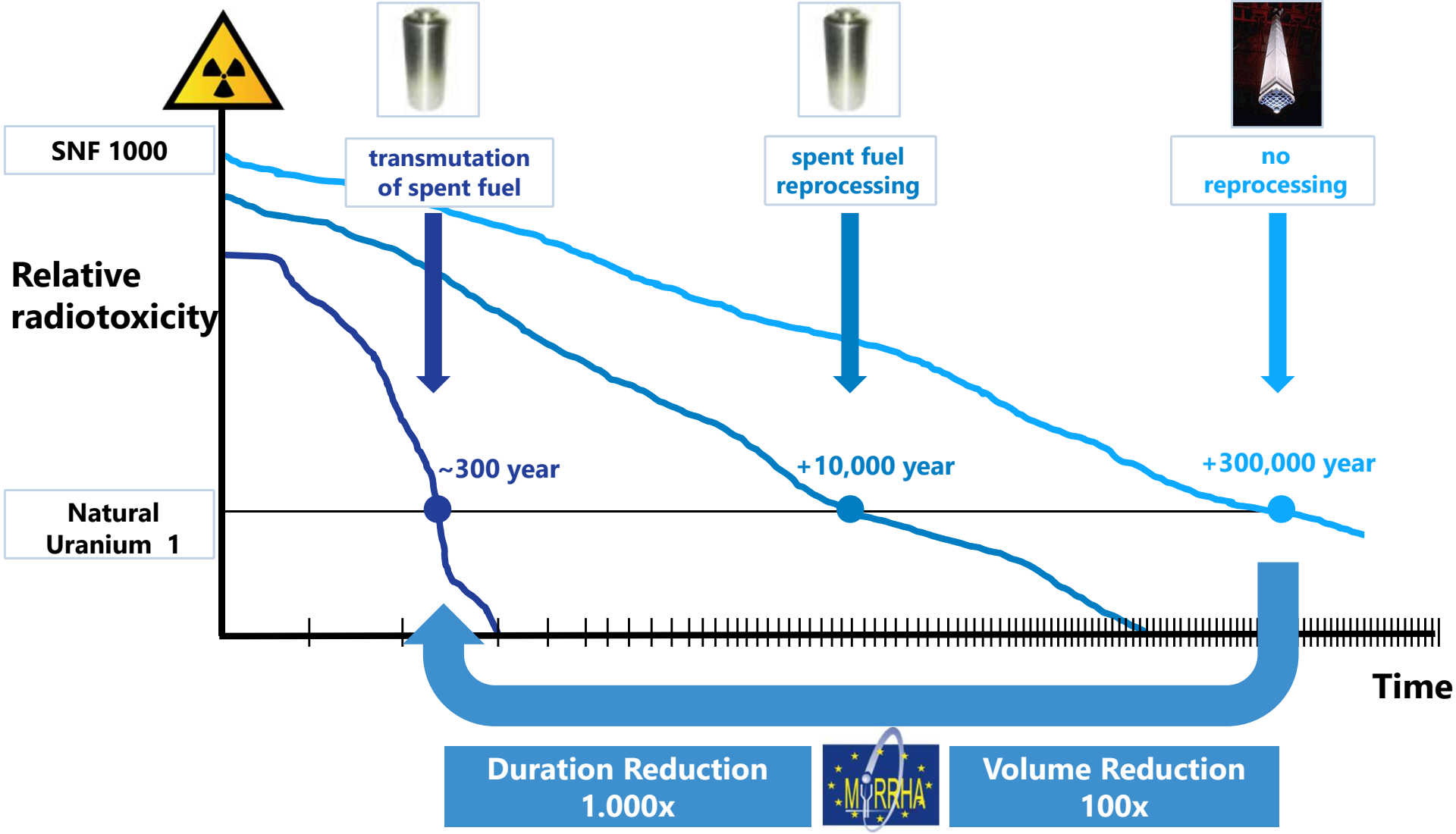
Radio-isotopes

SMR LFR

**SNF = Spent Nuclear Fuel*

Source: SCK•CEN MYRRHA Project Team, MYRRHA Business Plan

Transmutation is the better solution for Spent Nuclear Fuel



*SNF = Spent Nuclear Fuel

Source: European Commission Strategy Paper on Partitioning & Transmutation (2005), SCK•CEN MYRRHA Project Team

Challenge of the MYRRHA accelerator

- The challenge of an ADS driver
  - Not performance itself (energy, beam intensity, beam power)
  - But **reliability** and **availability** under CW operation
- The response to this challenge has 2 aspects
  1. reliability and reparability of individual components: ***engineering & prototyping***
  2. global principle: fault tolerance by efficient implementation of ***redundancy***
- Role of R&D and of prototyping
  - Evaluate engineering design and technological choices
  - Implement fault tolerance related mechanisms

Source:

MYRRHA Accelerator - Roadmap to Reliability

Design

- **Involving major accelerator labs** in Europe and specific **industrial partners**
- **Incorporating fault tolerant** schemes
- **Validation** with reliability model
- **Reviewed by panel of international** accelerator peers

Prototyping

- **Key elements:** Ion source, LEBT, RFQ, CH cavities, Spoke cavities,…
- **Set-up of an experimental test-bench**: 5.9 MeV accelerator @CRC in LLN
- **Hands-on experience** for the team, **return of experience** for manufacturing phase, start of **engineering work** in view of the construction and integration

Scenario 1
100 MeV

- **Representative unit** in view of the 600 MeV accelerator
- **Implementation** of fault tolerant schemes
- **Testing and validation** of technological choices
- **Evaluation of the reliability goal** for the full MYRRHA Linac
- **Applications :** production of (medical) radioisotopes, nuclear applications, and nuclear physics research

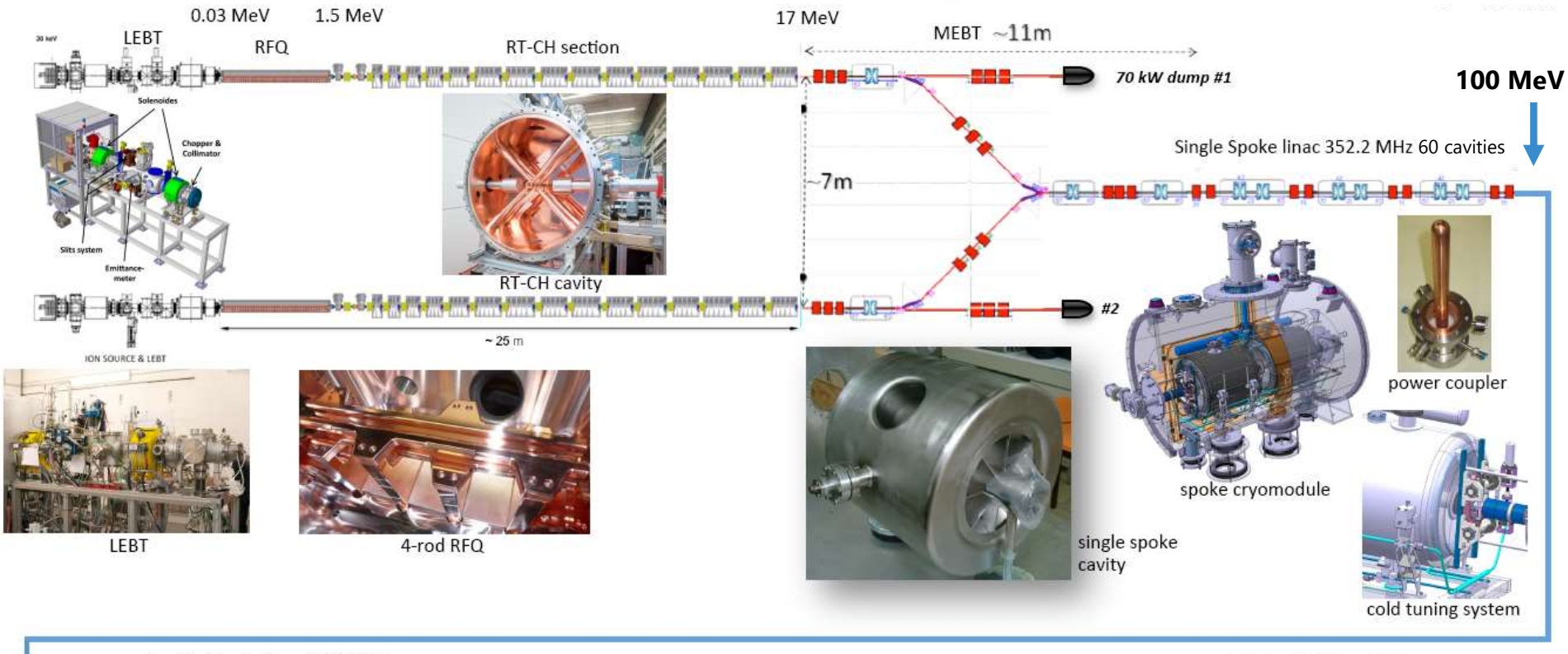
MYRRHA Accelerator - Specific requirements

→ **High power proton beam (up to 2.4 MW)**

Proton energy	600 MeV
Beam current	0.1 to 4.0 mA
Repetition rate	CW, 10 to 250 Hz
Beam duty cycle	10^{-4} to 1
Beam power stability	< ± 2% on a time scale of 100ms
Beam footprint on reactor window	Circular ∅85mm
Beam footprint stability	< ± 10% on a time scale of 1s
# of allowed beam trips on reactor longer than 3 sec	10 maximum per 3-month operation period
# of allowed beam trips on reactor longer than 0.1 sec	100 maximum per day
# of allowed beam trips on reactor shorter than 0.1 sec	unlimited

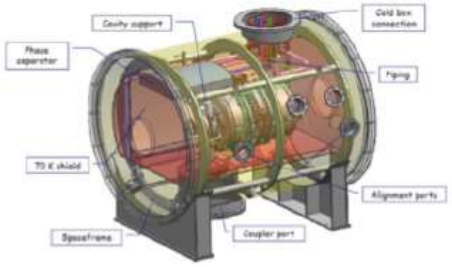
→ **Extreme reliability level: MTBF > 250 hrs**

MYRRHA Accelerator – Overview

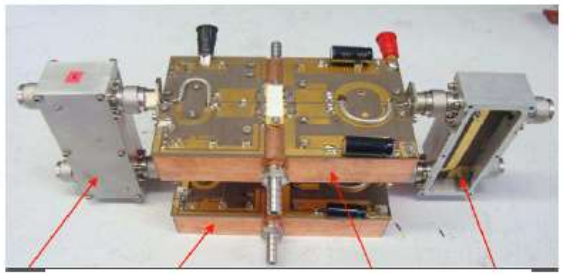


5 element elliptical cavity

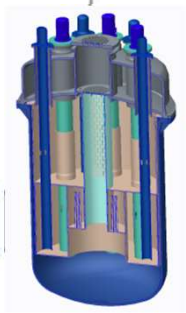
elliptical cavity envelope with cold tuning mechanism



design of the test cryomodule for the elliptical cavity



700 MHz Solid State RF amplifier prototyping

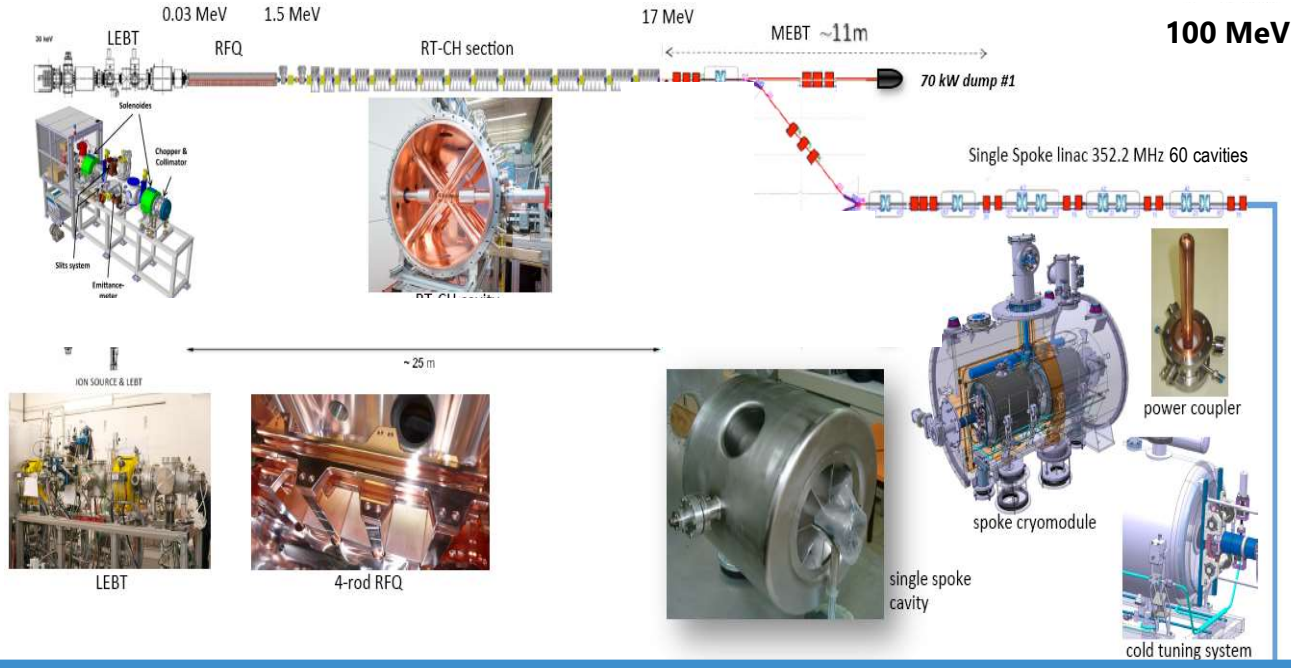


MYRRHA Phased Implementation Strategy

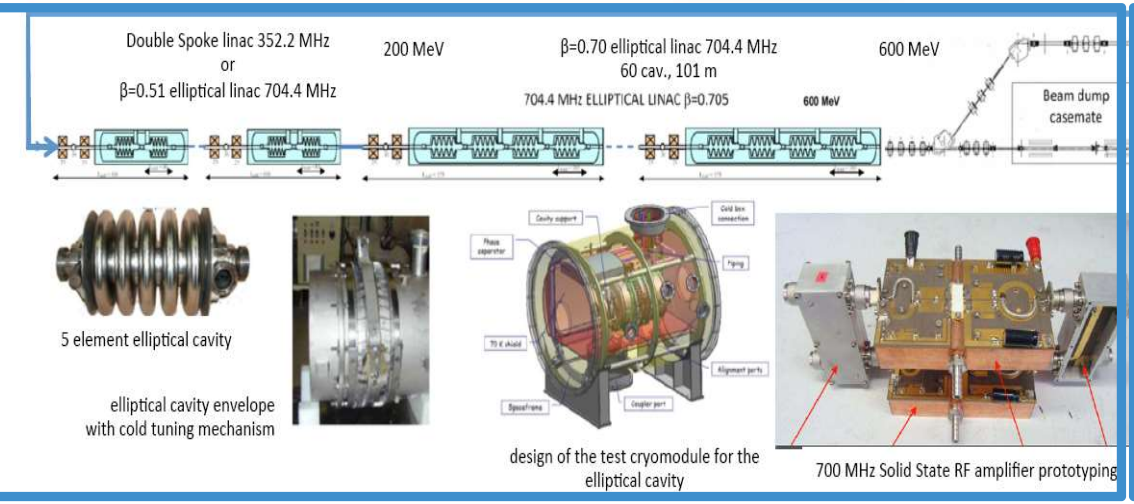
Benefits of phased approach:

- Reducing technical risk
- Spreading investment cost
- First R&D facility available in Mol in 2026

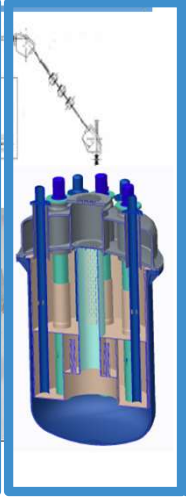
Phase 1 – 100 MeV



Phase 2 – 600 MeV



Phase 3 – Reactor



The MINERVA Facility

MYRRHA Phase 1 (2018-2026)

- **Build & operate a 100 MeV proton linac + ISOL target + Fusion target**
- Conduct R&D in support of the Accelerator (up to 600 MeV) of Phase 2
- Conduct further Design + Licensing + support R&D of the Reactor of Phase 3

MINERVA - 100 MeV linac coupled to a Proton Target Facility (PTF)

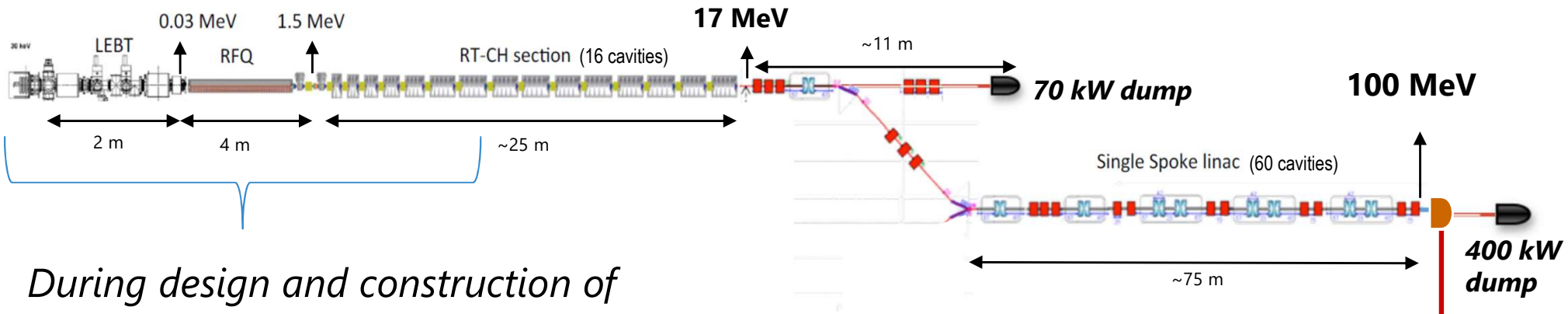
MYRRHA **I**sotopes productio**N** coupling the lin**E**ar accele**R**ator to the **V**ersatile proton target f**A**cility

100 MeV linac

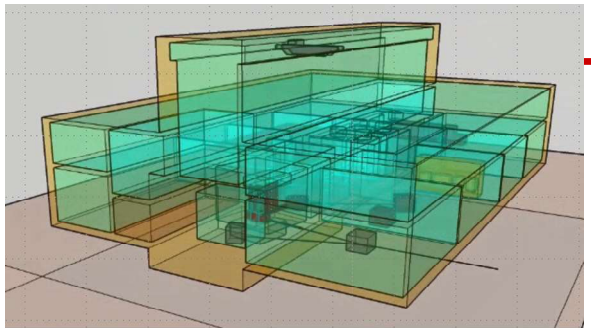
- **Representative unit** of the full MYRRHA linac (600 MeV)
  - Implementation of **fault tolerant schemes**
  - Validation of the **technological choices** (for the injector)
  - Evaluation of the **reliability goal** for the **full MYRRHA linac**
- **Applications**
  - Make use of an extreme accelerator reliability, CW, high intensity proton beam (up to 4 mA)

Schematic view of MINERVA

100 MeV proton linac



During design and construction of MINERVA at SCK•CEN site in Mol, the injector up to 5.9 MeV is built and commissioned (all aspects) in the SCK•CEN bunker at CRC/UCL in Louvain-la-Neuve



A fraction of the beam redirected to the Proton Target Facility (ISOL@MYRRHA)

Unique features of MINERVA

ISOL-target (ISOL@MYRRHA)

1. Versatility: large catalogue of isotopes with highest purity using ISOL technique
2. Novelty: physics separation by mass spectroscopy (instead of chemical separation)

Medical applications

- Use of α/β emitters in radioimmuno therapy and targeted alpha therapy
  → *forthcoming market trend*
- Optimisation of dose as the mean free path corresponds to the size of cells
  → *minimize side effects on healthy tissues*
- Isotopes not commercially available or not easy to produce by other means
  → *isotopes will be available*

Research applications

- Fundamental and applied physics: high-precision, high-statistics experiments
  → *tracking rare events needing long & uninterrupted beam times ("niche")*

Fusion target (*included in scope in January 2018*)

- Material irradiation for fusion research
  → *test and qualification of material that will undergo extreme fusion conditions*

100 MeV accelerator status

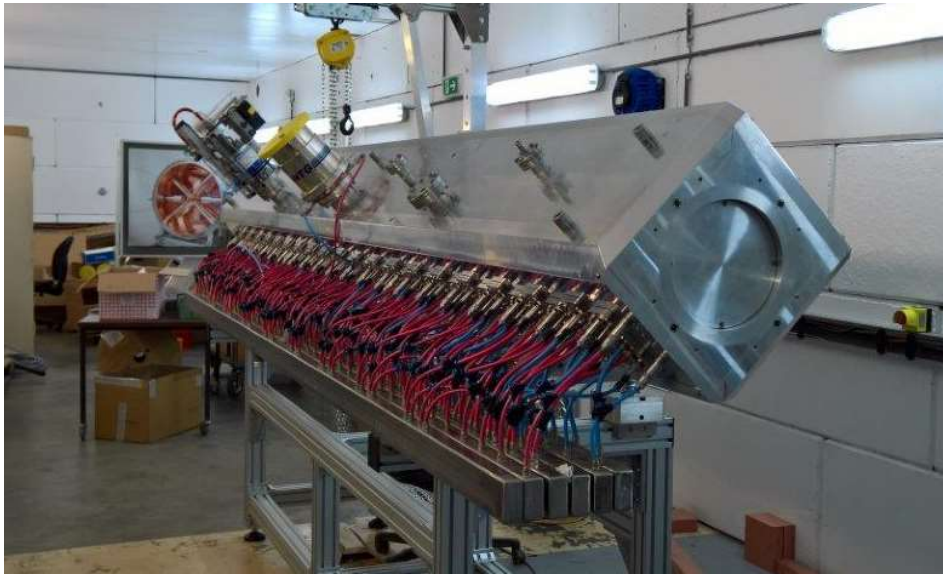
- Today we have a fully coherent 100 MeV linac design
  - Components prototyping considered as terminated
  - Proven technical solution for all critical components
  - Fault tolerant beam dynamics
  - Collaboration framework
  - Confidence

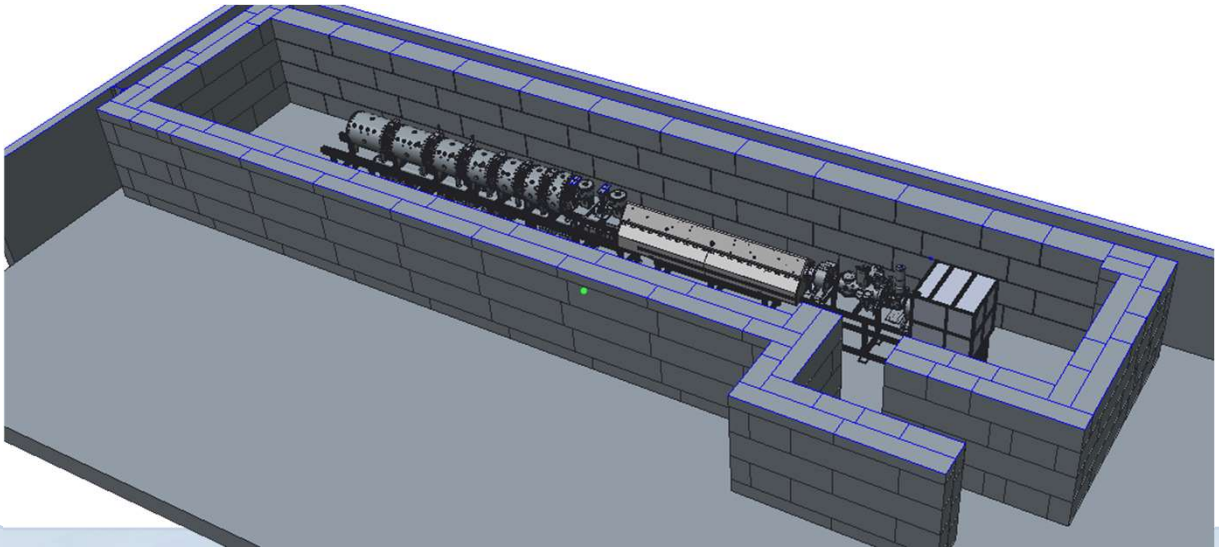
- Integrated prototyping on-going
  - Test platforms: combining components and techniques
  - Make beam (@ low energy)
  - Profit from the modularity

Source:

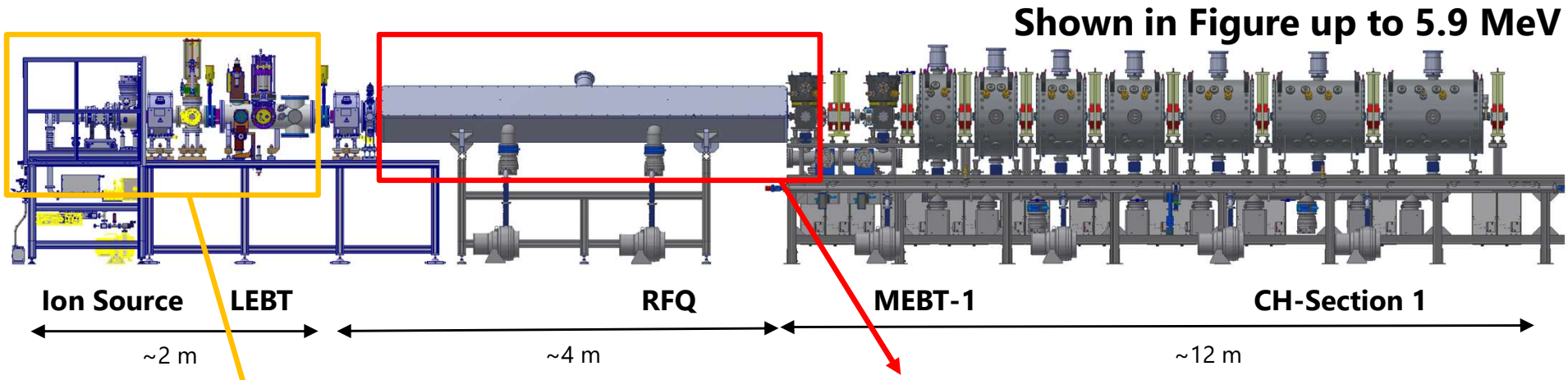
Injector @ *SCK•CEN bunker at CRC/UCL in Louvain-la-Neuve*

Modularity also means that we have already started constructing & commissioning the accelerator





Accelerator injector under commissioning



ECR source: Pantechnik
LEBT: coll. LPSC Grenoble, IPHC Strasbourg (MARISA, MYRTE), installed at SCK•CEN vault at CRC/UCL for commissioning

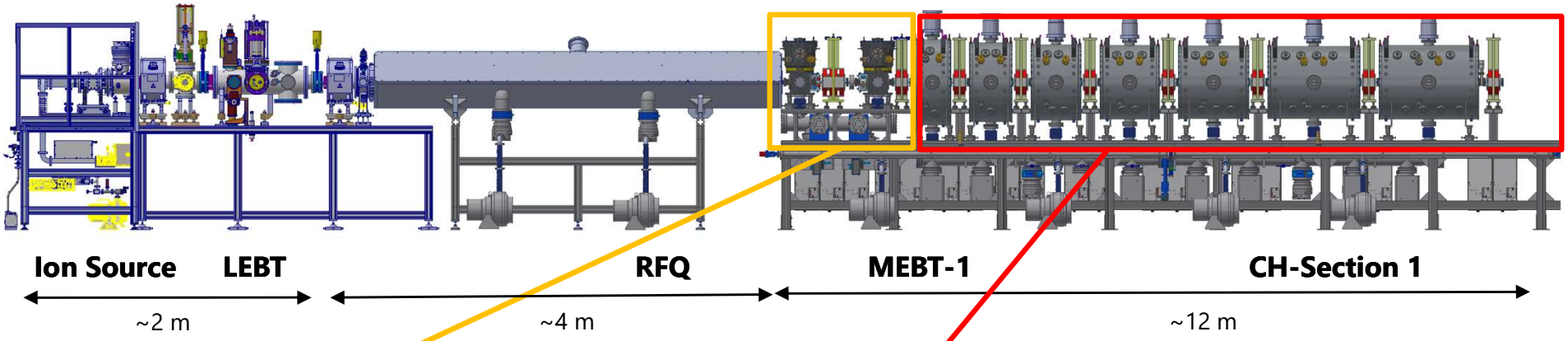
RFQ: Designed by IAP Frankfurt, constructed by NTG (coll. MYRTE project), now at SCK•CEN vault at CRC/UCL for commissioning

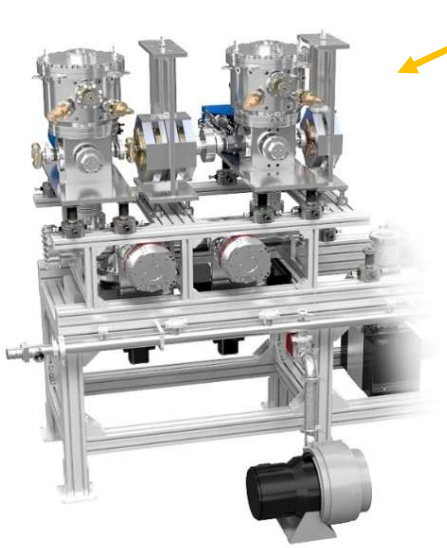
RFQ Solid State amplifier manufactured by IBA (coll. In MYRTE project), installed, under tests

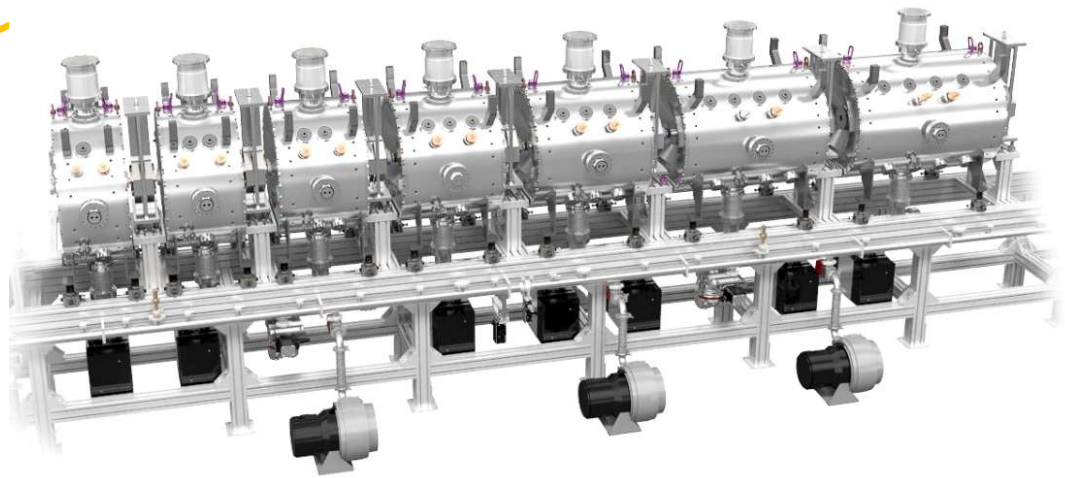
Source:

Accelerator injector under commissioning

Shown in Figure up to 5.9 MeV (7 out of 16 cavities)







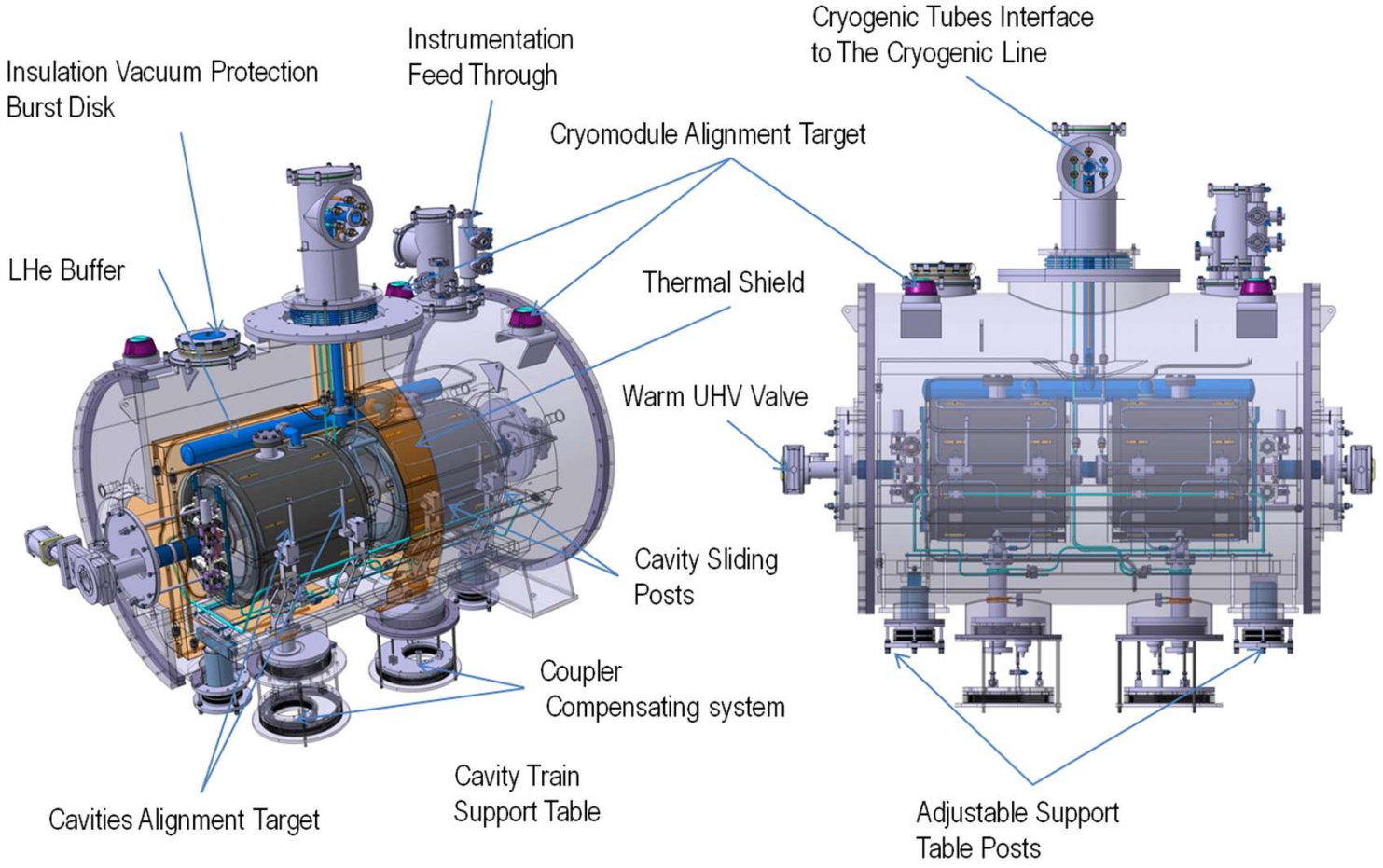
CH-Section

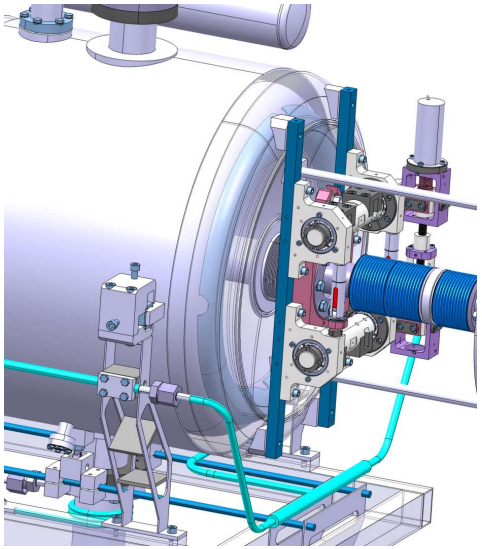
MEBT-1

- *Designed of IAP/Bevatech*
- *Re-bunchers (MEBT1) under construction, CH1 and CH2 manufactured & under test, CH3 to CH7 procurement on-going*
- *RF Solid State amplifiers for all (16) injector cavities*

Source:

100 MeV Accelerator superconducting section





Series of 30 cryomodules (60 Spoke cavities)

- Prototype for SC cavity preparation, cold valve box, RF power coupler, cold tuning mechanisms, instrumentation, assembly and long term operation
- Preparing phase of industrialisation for manufacturing and serial tests

→ Final technical specification for series production

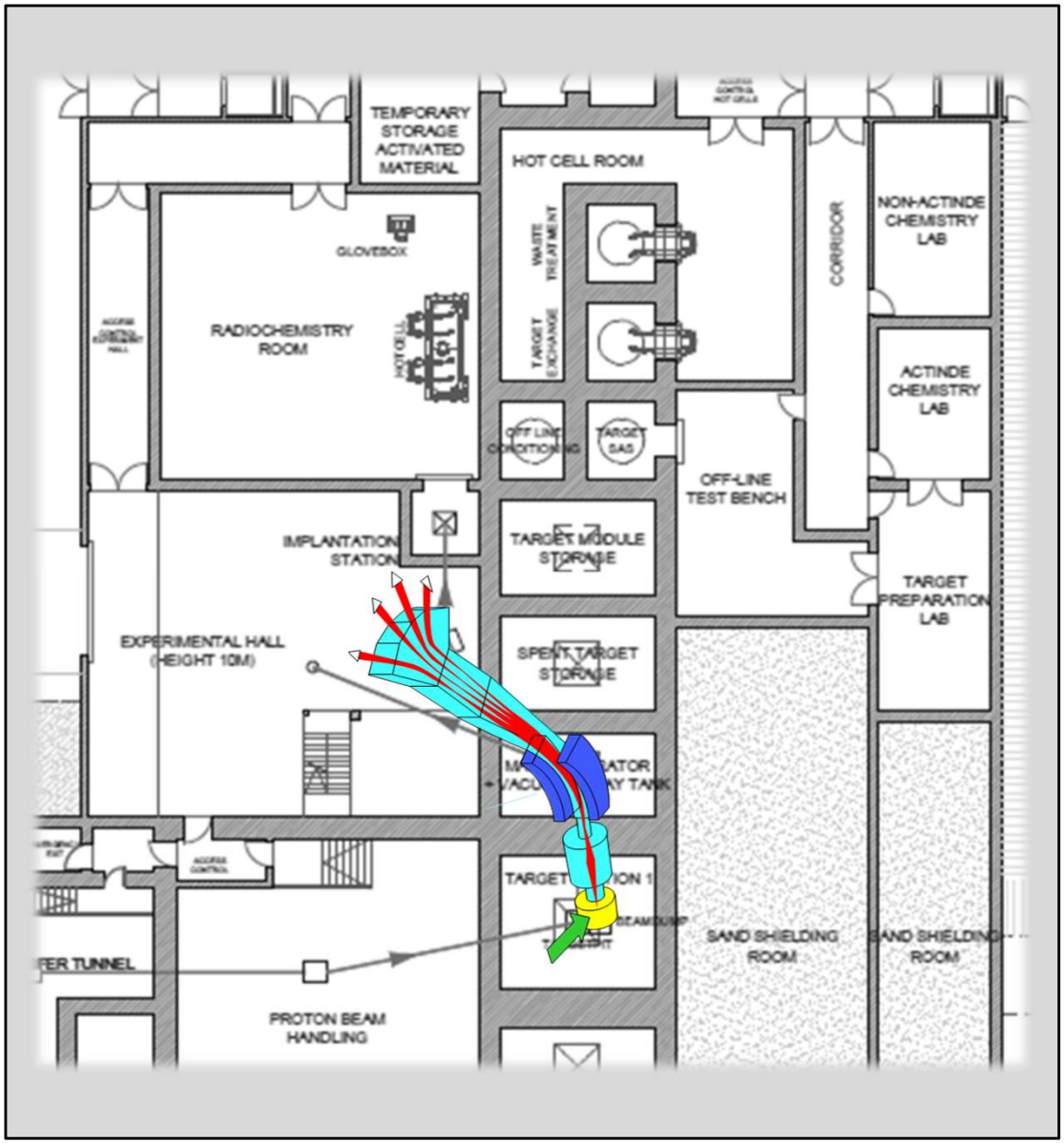
100 MeV Accelerator superconducting section

- Surface preparation process tested at IPN Orsay with these 2 cavities

- Two new final cavities are manufactured and will be fully tested (collaboration agreement with French CNRS/IN2P3).

→ Final technical specification for serial production

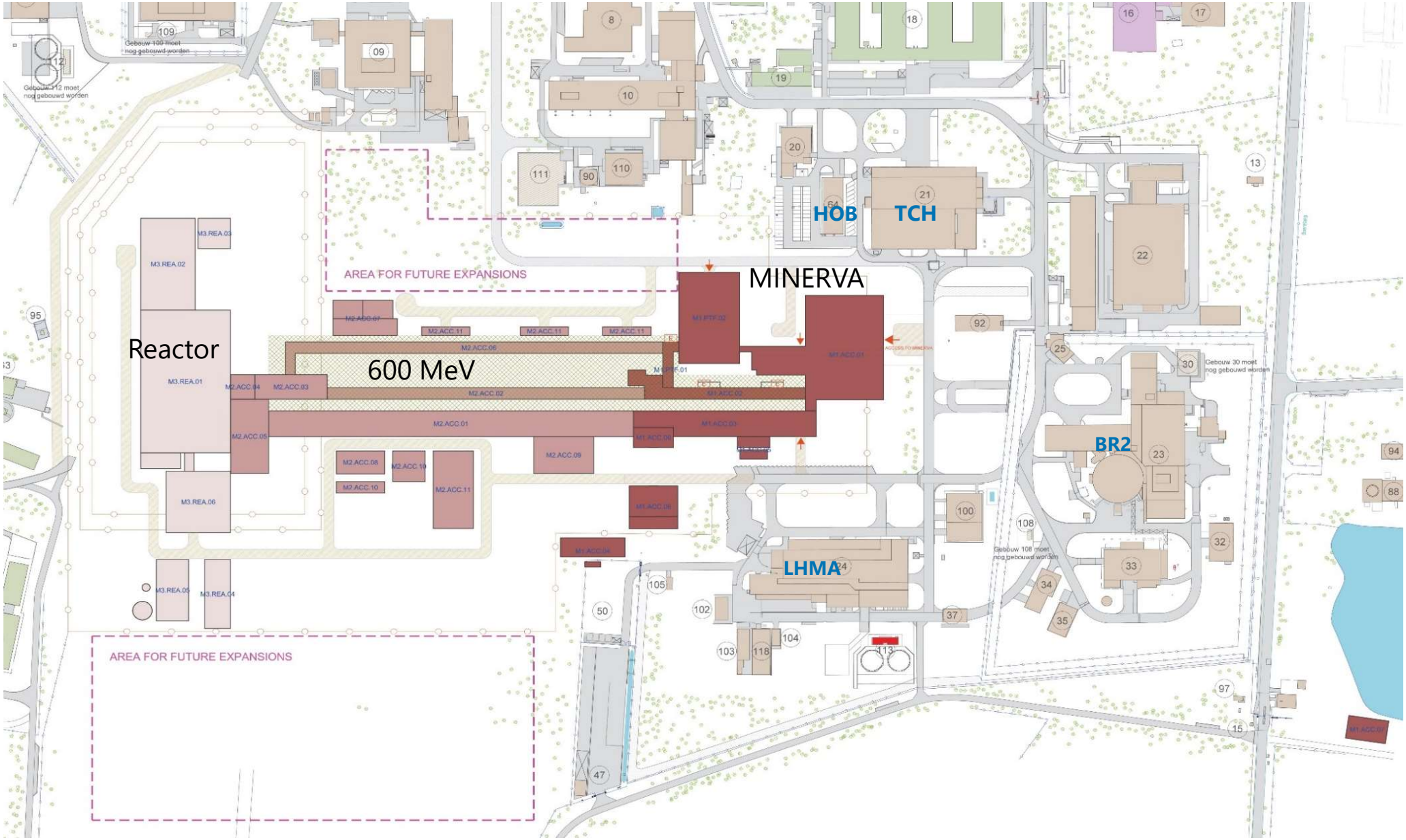
Proton Target facility (ISOL@MYRRHA)



- ISOL System implementation on –going (based on similar existing facilities)
- PTF Conceptual design on-going
- Upgradable experimental infrastructure

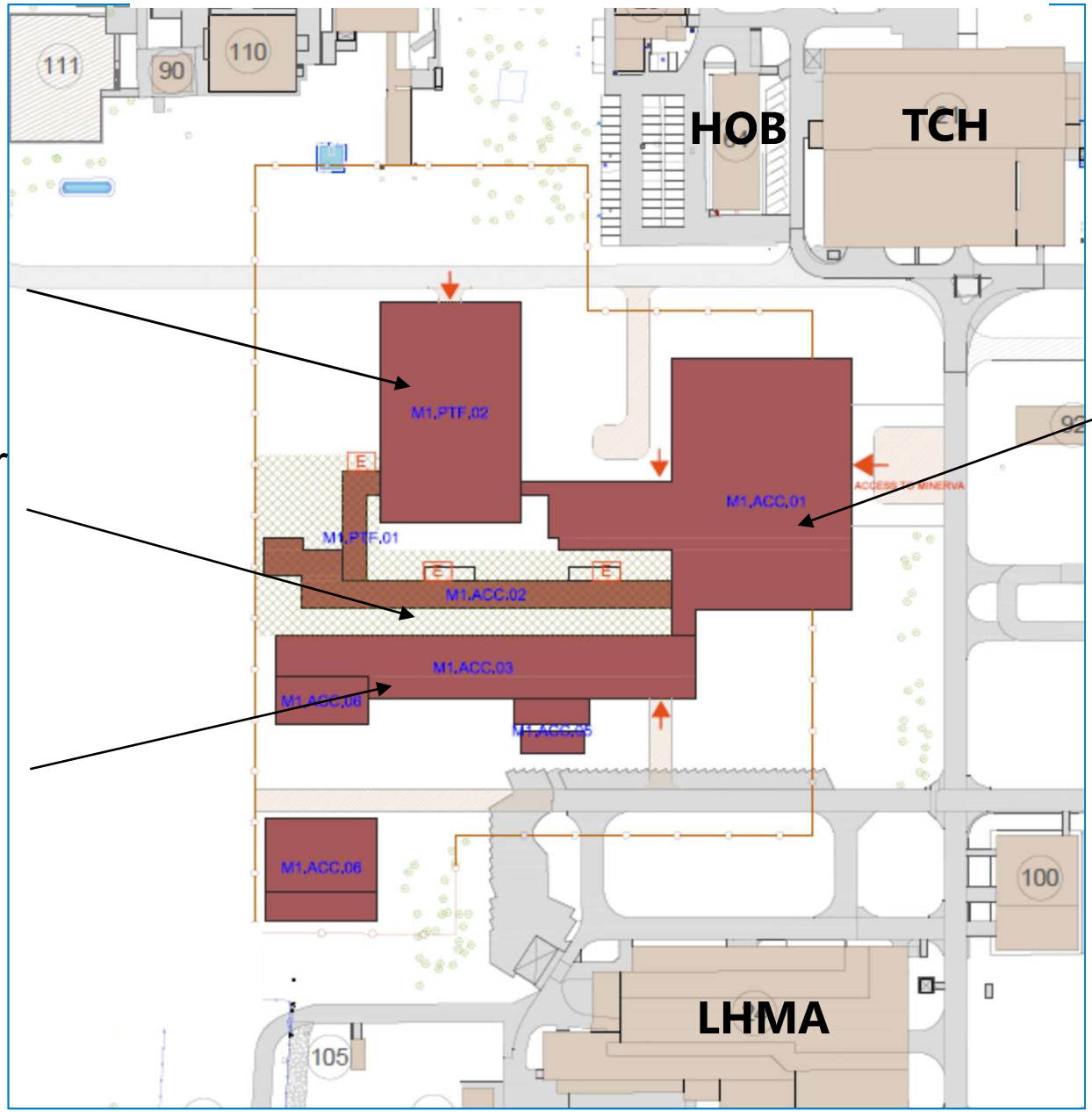
  100 MeV → 600 MeV

Project Masterplan at SCK•CEN site



MINERVA Masterplan

Footprint of ~ 125 m x 125 m



Proton target facility

Accelerator tunnel

Cryogenics installation

Front end building

100 MeV accelerator buildings & auxiliary systems

- Conceptual design ✓
  - Masterplan
  - Process systems
  - HVAC & dynamic confinement
  - Building architecture
  - Civil & Structural engineering
  - Electrical systems and I&C
  - Integration, 3D model
  - Safety and security in design

MINERVA team SCK•CEN

- Basic design
- Detailed design, incl. lots descriptions
- Follow-up of construction

Design Engineer call launched, companies selected, Granting phase on-going

Source:

Major scientific collaborations supporting the Project

- **Accelerator**
  - Design has benefited from results of more than 15 years of R&D collaboration through the successive European FP and in particular 6 dedicated to MYRRHA design and associated prototyping and technologies.

  - Current collaborations (either via H2020 MYRTE project and/or *direct agreements and outsourcing contracts* ***or both****)*

Research, scientific partners	Industrial partners
CRC/UCL (BE)	ACS (F)
CNRS/IN2P3	ADEX (E)
CNRS/IPN Orsay (F)	*Bevatech (D)*
CNRS/LPC Grenoble (F)	Cosylab (SI)
CEA (F)	Empresarios Agrupados (E)
GANIL (F)	***IBA (B)***
IAP (D)	NTG (D)
U Darmstadt (D)	Thales (F)
CERN (CH)	

Major scientific collaborations supporting the Project

- **Proton Target Facility**

- **BriX Collaboration**: The **B**elgian **r**esearch **i**nitiative on e**X**otic nuclei for atomic, nuclear and astrophysics studies (Inter-University Attraction Pole)

- **Belgian Eurisol Consortium** (BEC): in Support of Science with RIB

Created in 2013 for Belgian participation in EURISOL, coordinated R&D programme for ISOL developments

- **Collaboration with CERN: high-power targets**
- **Collaboration with TRIUMF** : **design of the PTF and ISOL systems**
  - MoU signed in March 2018
  - Technical content agreed

MYRRHA embedded in an international R&D network

→ *MINERVA profits from the MYRRHA well-established R&D network*

MINERVA Selected Project Management related aspects

- This is a large infrastructure involving both R&D and engineering practices

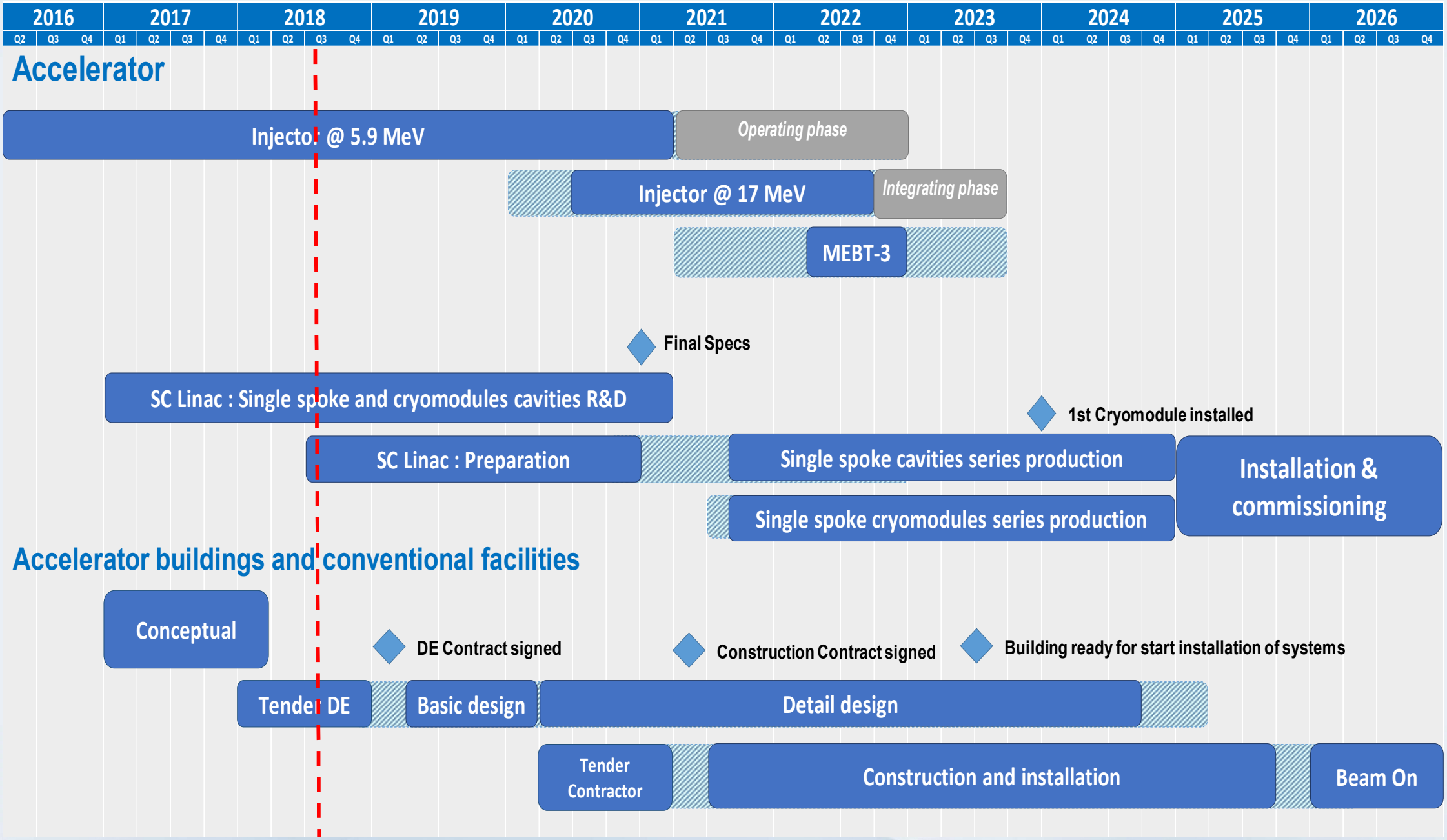
  → ***emphasis in integration and optimisation***

- Project organisation & planning and key milestones (2018 – 2026) defined
- Resources defined, hiring of key roles strengthened (hiring plan)
- A coordinated procurement of components and Design Engineer contracts
- Industrialisation phase: serial production and tests platforms
- This is a facility to be built in a nuclear research centre

  → *Dialogue with Belgian Safety Authorities on-going: PSAR and EIA*

- *Last but not least*, continous integration of national and international collaborations

MINERVA 100 MeV Accelerator high-level schedule



Source: SCK•CEN/30185813

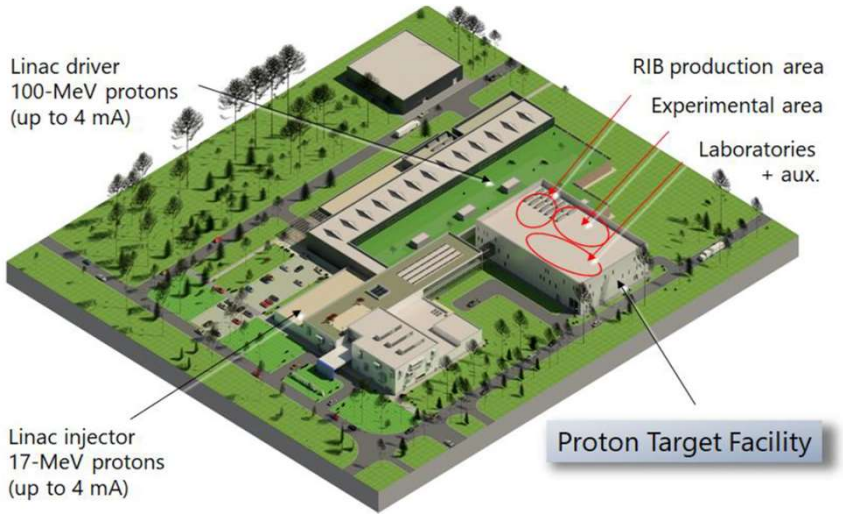
Conclusion

- MYRRHA main objective is the **demonstration of transmutation** as a viable solution to reduce the radiotoxicity of long-life nuclear waste → one of the 4 building blocks of **EU strategy for P&T**.
- MYRRHA is benefiting from **SCK•CEN continuous support** since 1998, has been **endorsed by Belgian Government** since 2010 and is supported by a dedicated financial endowment.
- MYRRHA profits since 2001 from the **results of many projects** co-funded by the European FP
- MYRRHA R&D programme involves **more than 100 engineers and researchers** at SCK•CEN and collaborations with national and international industry, research centres and academia.
- MYRRHA **phased implementation strategy** allows reducing technical risk, spread of investment cost

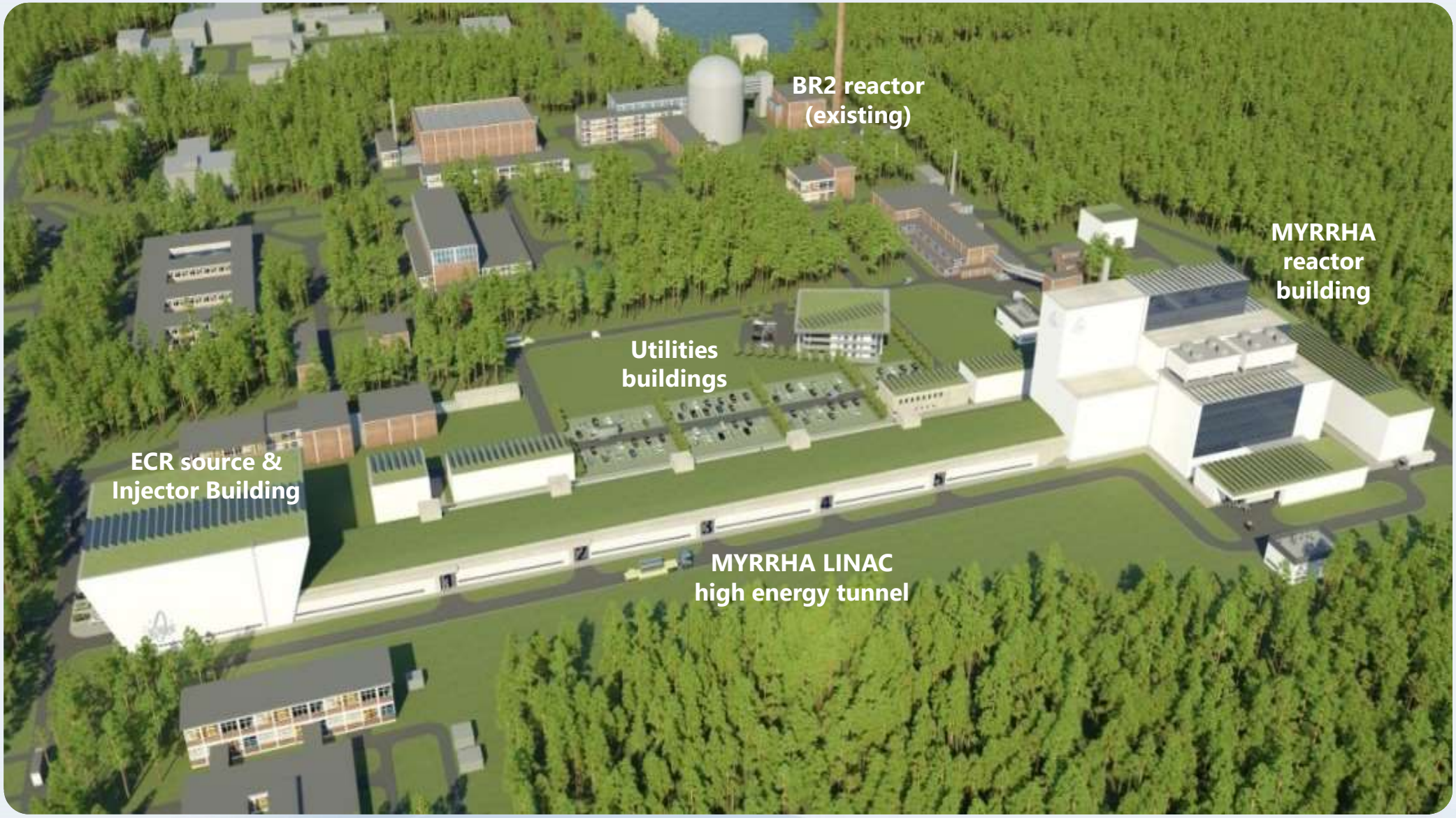
MINERVA

R&D infrastructure in Mol by 2026

- Demonstrate accelerator reliability for MYRRHA ADS
- Deliver intense proton beams to target facilities for 1) production of isotopes for innovative research and medicine and 2) fusion research



A jump in the future for pioneering innovation in Belgium
For sustainable nuclear energy in Europe



http://myrrha.sckcen.be


MYRRHA

...?

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