Status and challenges of the MYRRHA SRF linear accelerator

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SRF2019

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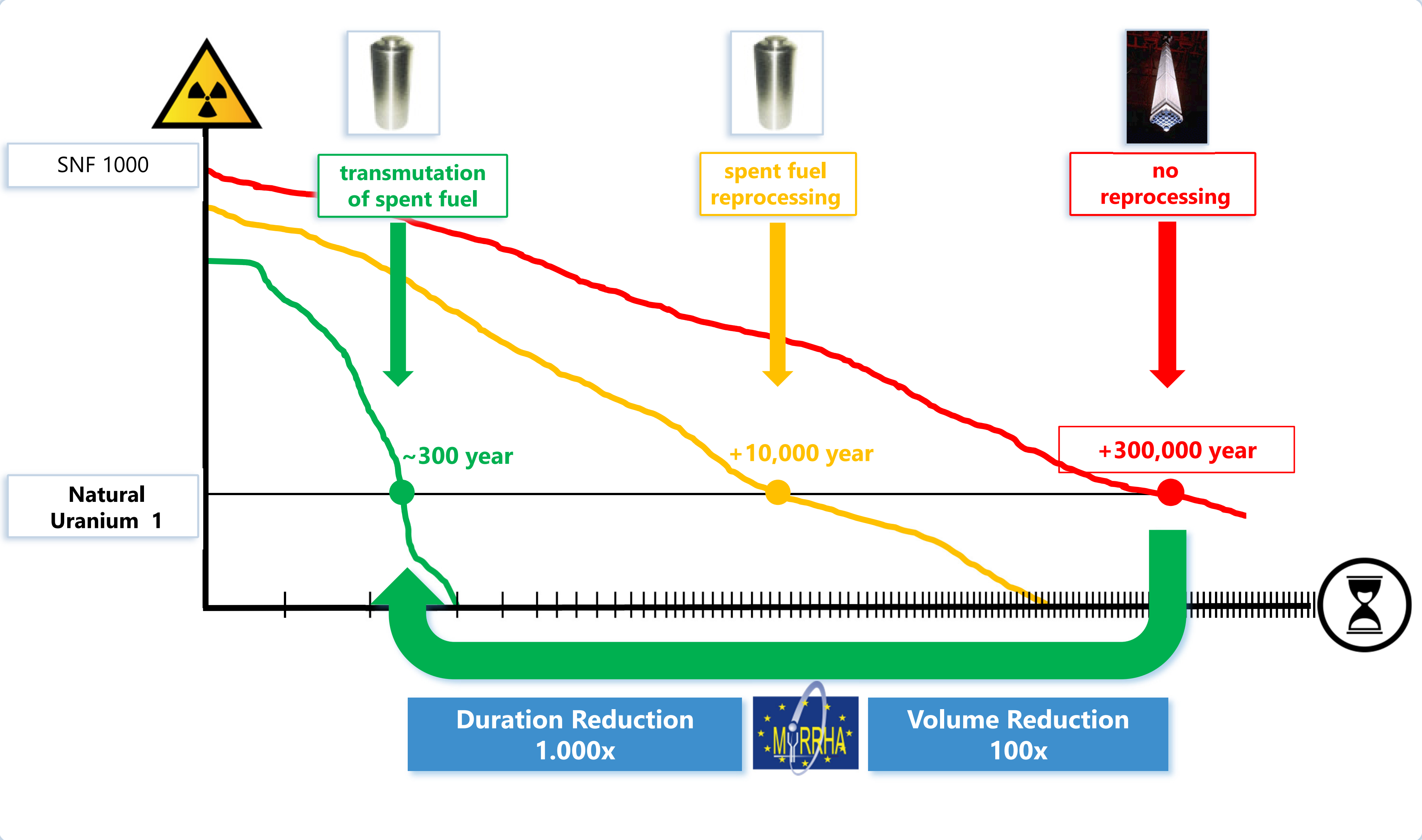
Transmutation: better solution for Spent Nuclear Fuel

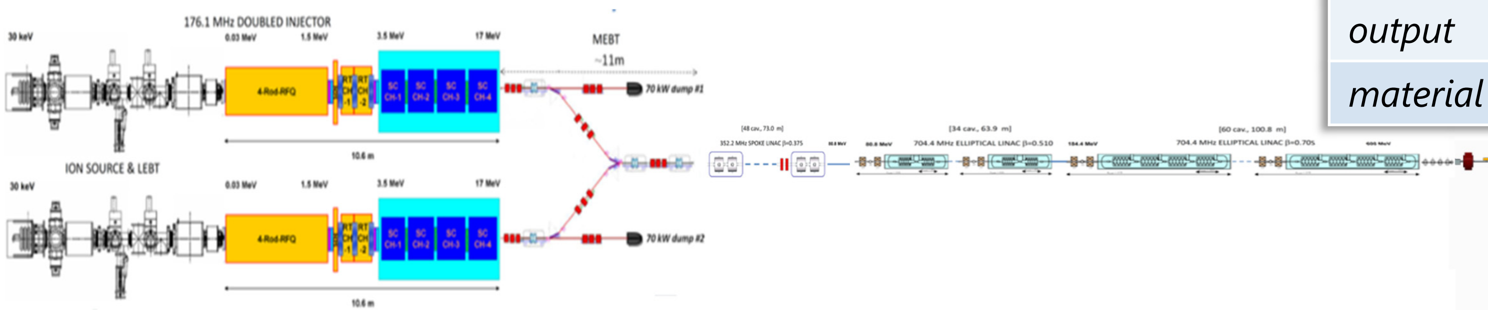


Source: European Commission Strategy Paper on Partitioning & Transmutation (2005), SCK•CEN MYRRHA Project Team

MYRRHA = Accelerator Driven System
Key Objectives

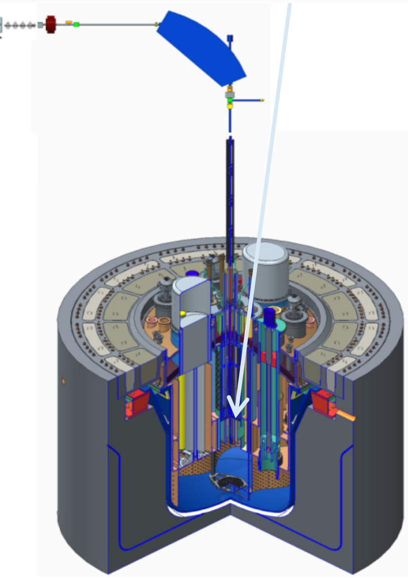
1. **Demonstrate the ADS concept at pre-industrial scale**
2. **Demonstrate transmutation**
3. **Multipurpose and flexible irradiation facility** (with fast neutron source)

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

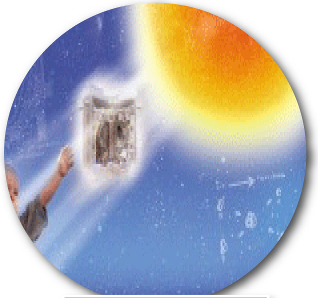


Belgian Government decision on September 7, 2018

- **Decision to build** in Mol a new large research infrastructure MYRRHA
- Belgium **allocated budget** of 558 M€ for the period 2019 - 2038:
  - 287 MEUR investment (CapEx) for building MINERVA (Accelerator up 100 MeV + PTF) for 2019 - 2026
  - 115 MEUR for further design, R&D and Licensing for phases 2 (accelerator up to 600 MeV) & 3 (reactor) for 2019-2026.
  - 156 MEUR for OpEx of MINERVA for the period 2027-2038
- Establishment of an **International Non-Profit Organization**
  - in charge of the MYRRHA facility for welcoming international partners
- **Political support** for establishing MYRRHA international partnerships
  - Belgium mandates Vice Prime Minister Kris Peeters for promoting and negotiating international partnerships

MYRRHA application portfolio

SNF*/ Waste

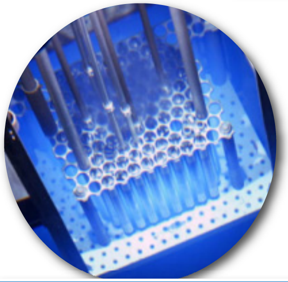


Fusion

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

Medical Radioisotopes

Fundamental research

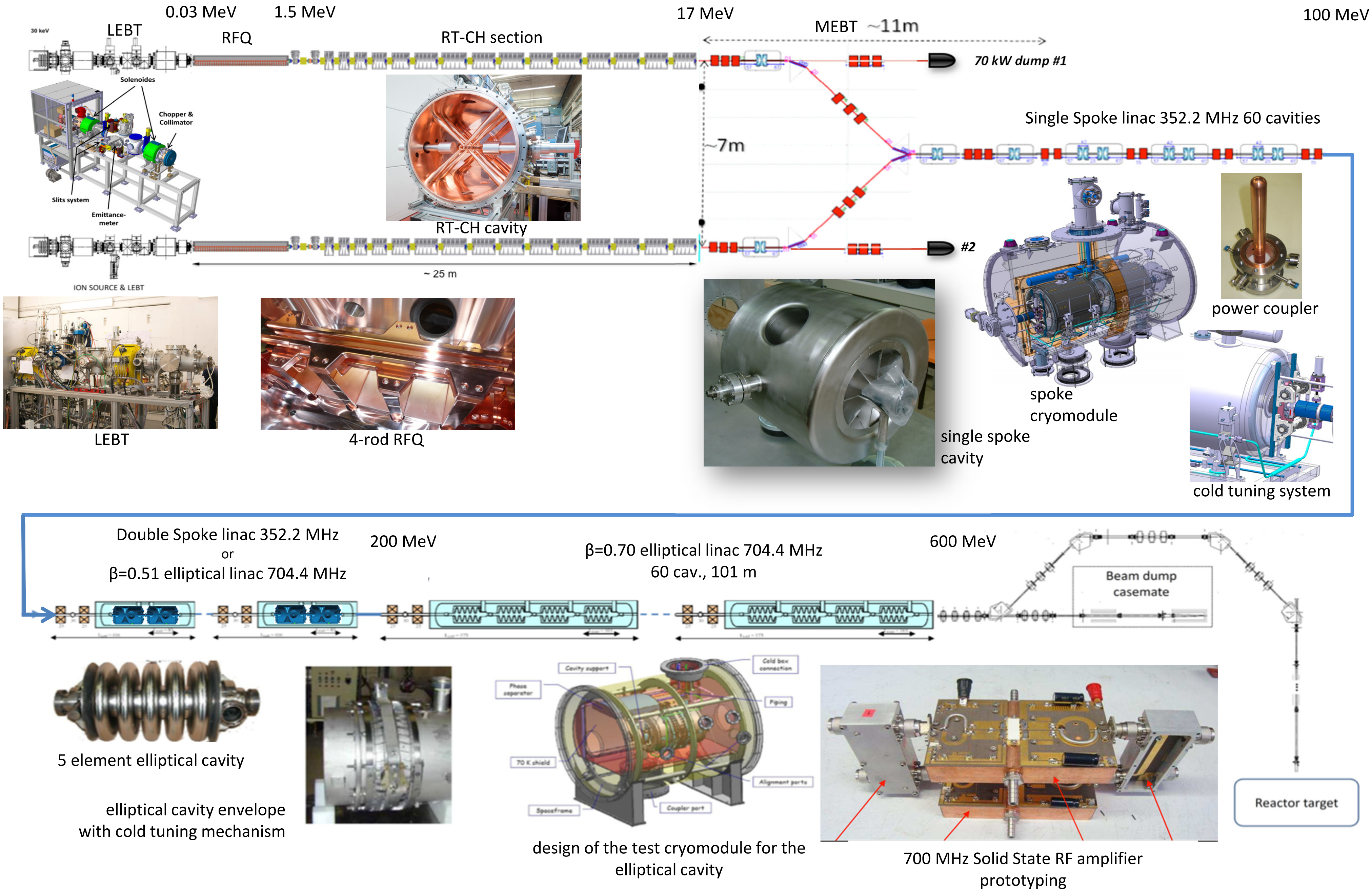


Support Fission GEN IV

Support to SMR LFR

*SNF = Spent Nuclear Fuel

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



0.03 MeV
1.5 MeV
17 MeV
100 MeV
30 keV
LEBT
RFQ
RT-CH section
MEBT ~11m
70 kW dump #1
Solenoides
Chopper & Collimator
Slits system
Emittance-meter
RT-CH cavity
~7m
Single Spoke linac 352.2 MHz 60 cavities
#2
~ 25 m
ION SOURCE & LEBT
power coupler
LEBT
4-rod RFQ
spoke cryomodule
single spoke cavity
cold tuning system
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., 101 m
600 MeV
Beam dump casemate
5 element elliptical cavity
elliptical cavity envelope
with cold tuning mechanism
Cavity support
Cold box connection
Phase separator
Piping
70 K shield
Alignment ports
Spaceframe
Coupler port
design of the test cryomodule for the
elliptical cavity
700 MHz Solid State RF amplifier
prototyping
Reactor target

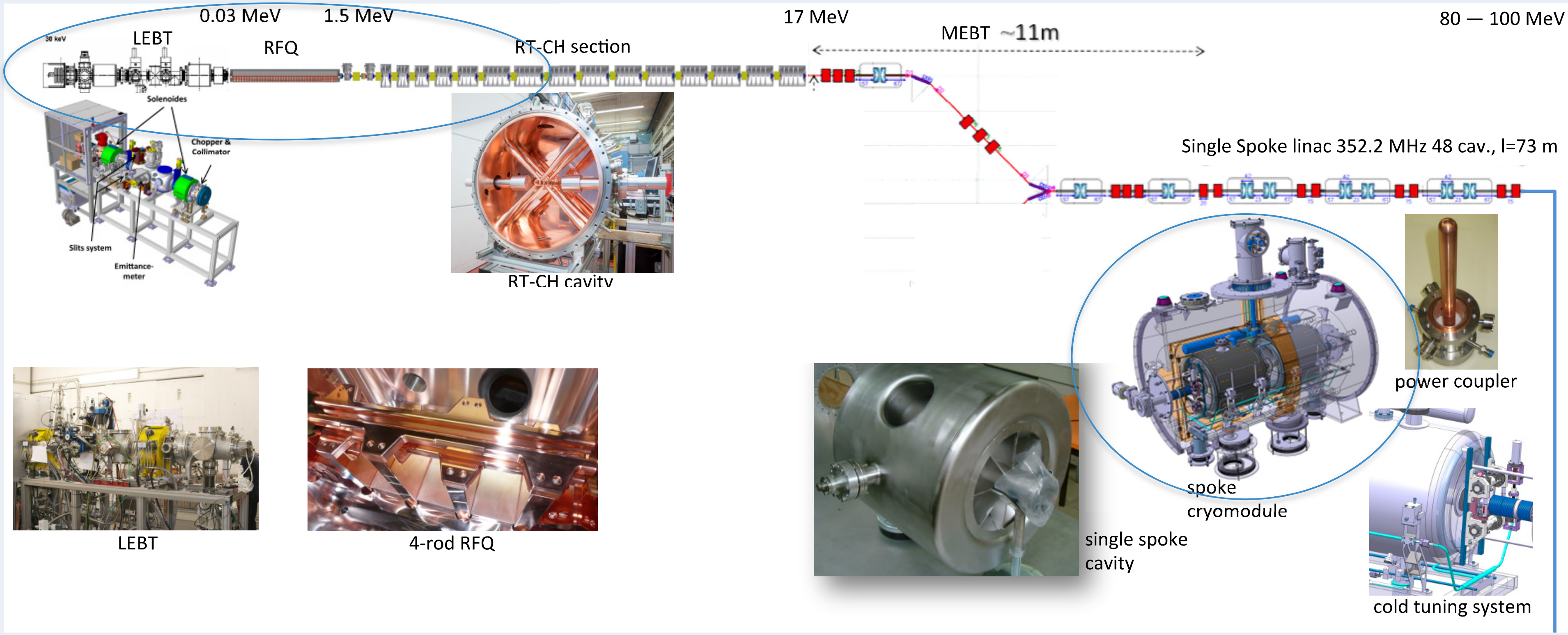
MYRRHA's phased implementation strategy

- Phase 1 : construction linac 100 MeV, linac R&D, reactor R&D
- Phase 2 : construction linac 600 MeV
- Phase 3 : MYRRHA reactor

- decisional hold point after phase 1
- Benefits of phased approach :
  - reduction of technical risk
  - spreading investment cost
  - first operational research tool available at Mol end of 2026

Source: [TBD]

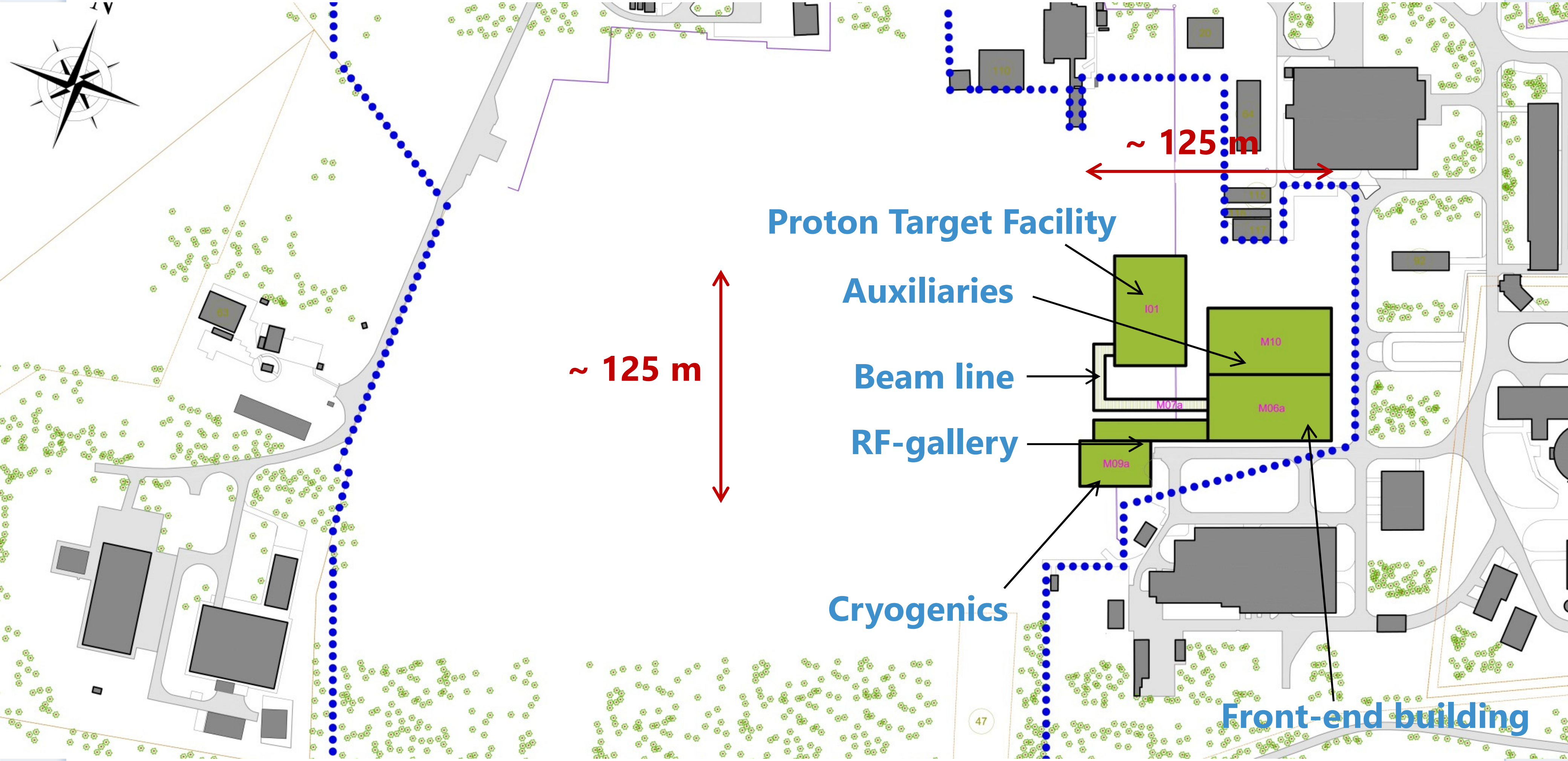
100 MeV Phase 1 / integrated R&D topics



- + R&D on distributed items:
  - Solid State RF amplifiers, LLRF, diagnostics, controls, …

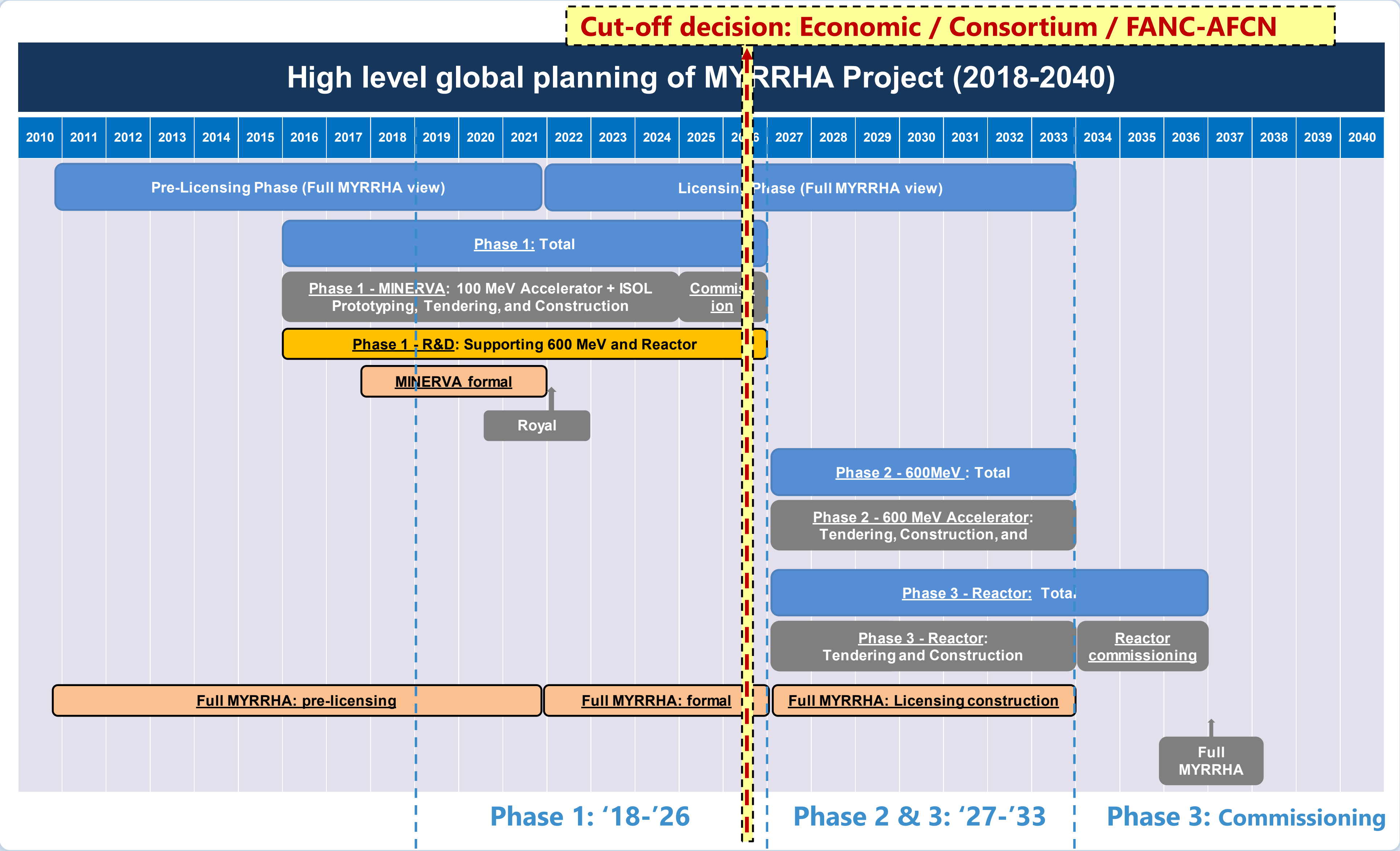
Source: [TBD]

MYRRHA masterplan: Linac 100 MeV + Proton Target Facility



MYRRHA Project Status

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



Source: SCK•CEN MYRRHA Project Team

High level requirements 600 MeV

- beam particle : protons
- beam energy : 600 MeV
- beam intensity : 4 mA
- beam delivery : CW with regular holes
- proton beam extraction → PTF
- beam MTBF : 250 hours, a failure = a beam trip > 3 s
  - rationale of the 3 s limit

Source: [TBD]

High level requirements 100 MeV

- beam particle : protons
- beam energy : 100 MeV
- beam intensity : 4 mA
- beam delivery : CW with regular holes
- proton beam extraction → PTF 100 MeV
- full power proton beam → fusion target

- beam MTBF : tbd, a failure = a beam trip > 3 s
- feed reliability model

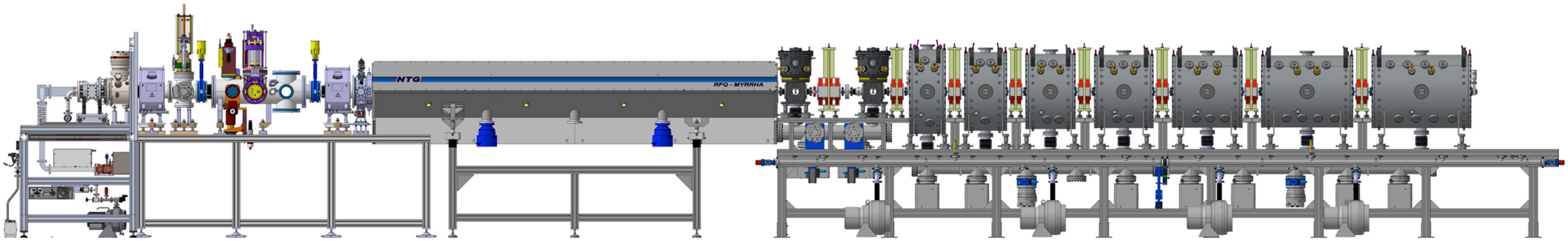
Source: [TBD]

Goals of the Phase 1 accelerator

- evaluation of the reliability of the 600 MeV MYRRHA driver
  - test platform for the fault recovery procedure
  - test platform for redundancy schemes
  - test platform for individual components
- test of industrial approach
  - series of cryomodules
  - control system
- feed of a PTF as a secondary target *in parallel* with the primary target

Source: [TBD]

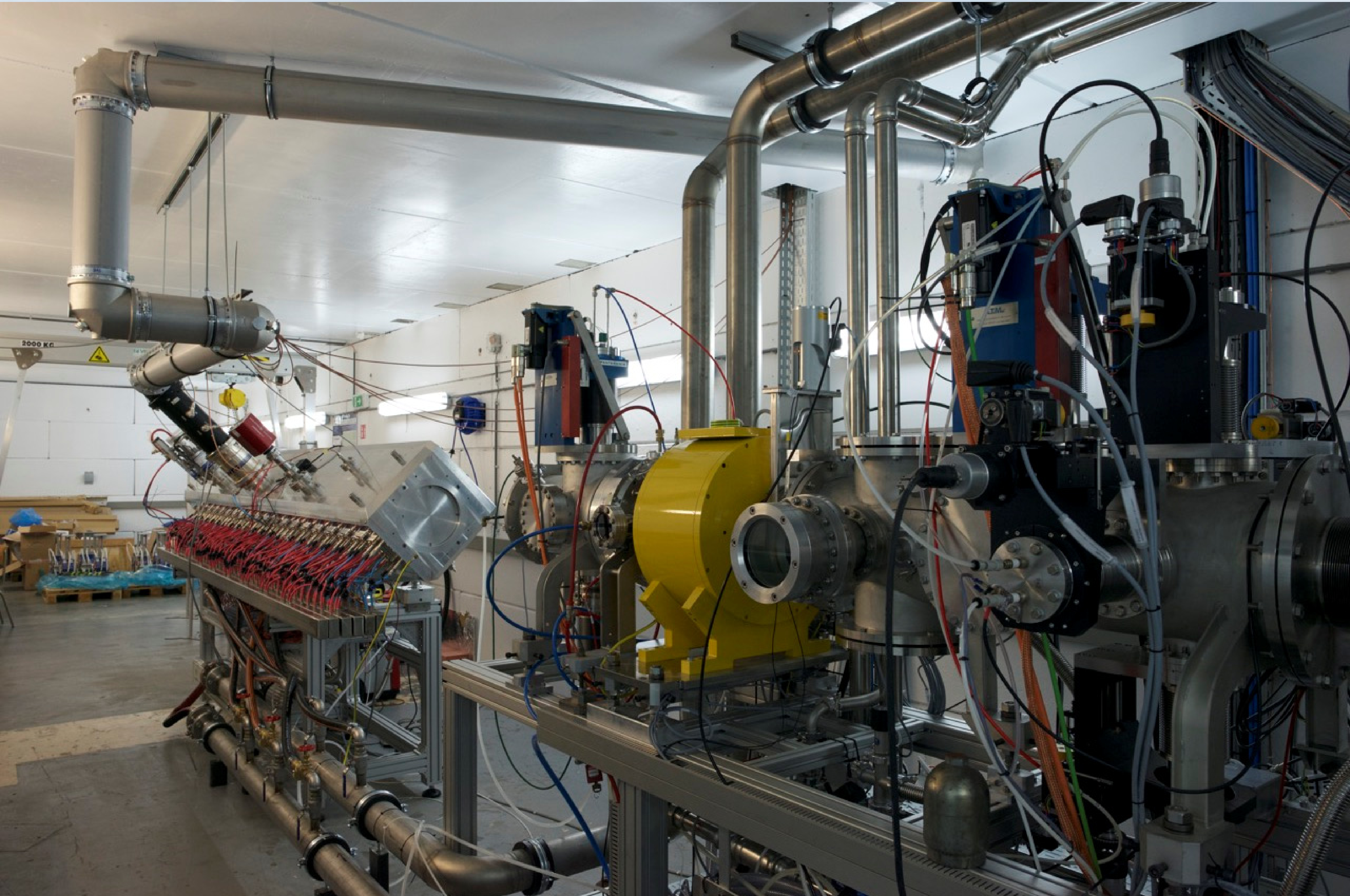
Integrated prototyping : inj @ LLN



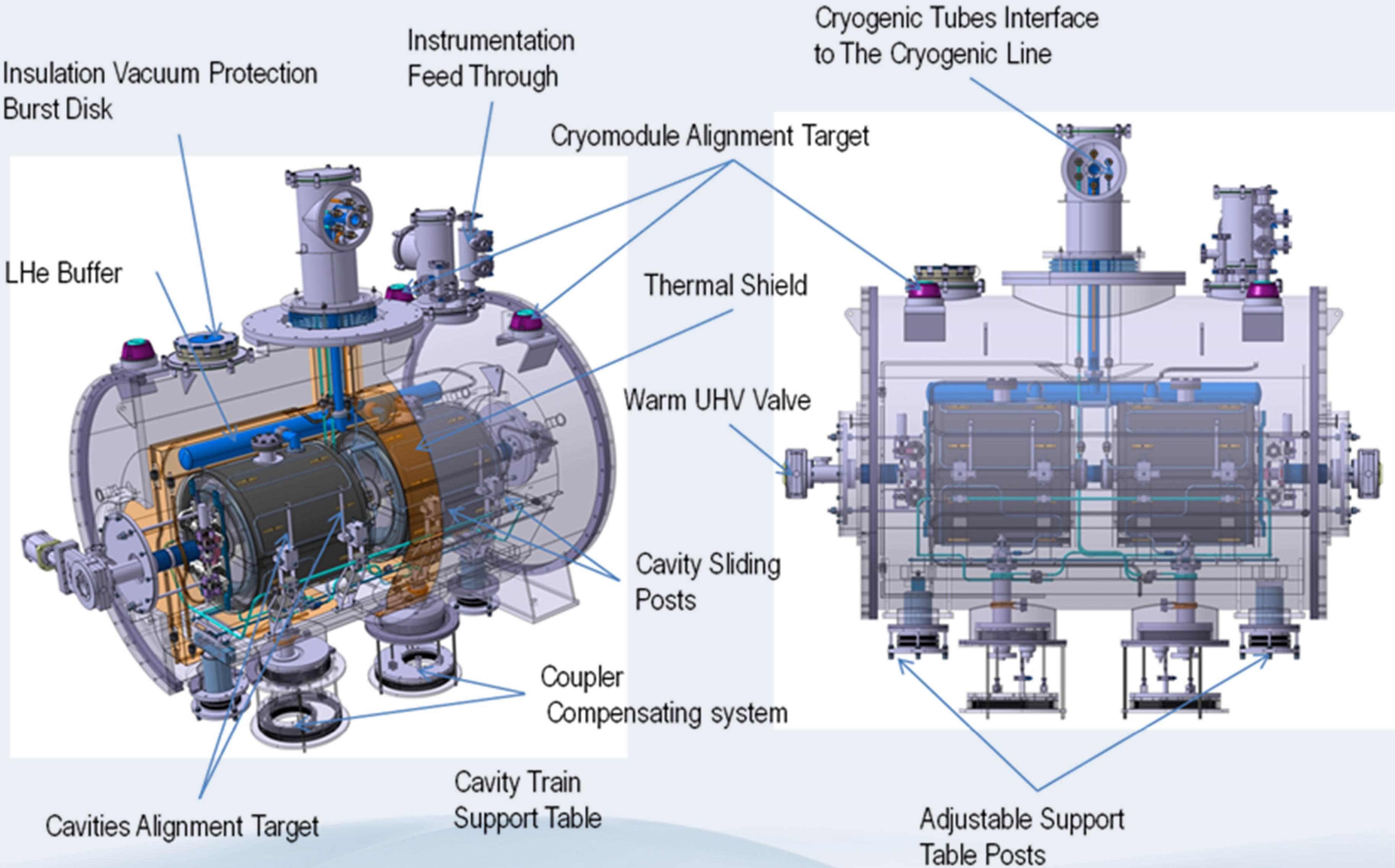
Injector, at LLN up to 5.9 MeV

- Overview
  - full injector = 17 MeV : 15 copper CH cavities, separated function design
  - 5 mA max → 4-rod RFQ

Source: [TBD]


2000 KG

Integrated prototyping : spoke cryomodule



Source: [TBD]

Integrated prototyping : spoke cryomodule

Single Spoke cryomodule, by IPN Orsay

- Cavities
  - 2 new single spoke cavities under fabrication
  - treatment procedures finalized (excellent test results)
- Cryostat : manufacturing launched
- Power couplers : new development by LPSC
  - dedicated coupler test stand to be set up at LAL Orsay
  - cold test cavity+coupler to be foreseen "asap"
  - 4 couplers under call for tender (2 versions)
- Valve box : for prototype cryomodule, file ready
- Cold Tuning System : special development, compatible with fault recovery
  - final design stage

IPN
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

Source: [TBD]

Integrated prototyping : controls

Control system : industrial scenario

- fundamental role in
  - overall reliability → need for "redundancy-compatible" architectures
  - fault recovery procedure and MPS
- present status
  - covering very basic needs for now
  - fundamental EPICS central services : soon
  - towards a coherent global framework : following ESS
  - first steps into µTCA

Source: [TBD]

The approach to Fault Tolerance

- Initial approach : intuitive, experience based
- reliability of individual components
  - ranking & selection
  - increase the MTBF by operation point
- global linac design
  - → margins for reliability
  - → margins for *fault tolerance*
  - given the prerequisite of *modularity*

Source: [TBD]

The approach to Fault Tolerance

- The mechanism(s) of fault tolerance : some form of redundancy
  - at the level of the modular linac : serial redundancy
    - the adjacent cavity scenario
    - requirement 1 : individually powered cavities
    - requirement 2 : 3 seconds recovery time

fault recovery procedure

  - at the level of the individual cavity linac : parallel redundancy
    - requirement : 3 seconds recovery time

fast switching

Source: [TBD]

The approach to Fault Tolerance

- other applications of *serial* redundancy :
  - Solid State RF power amplifiers
- other applications of *parallel* redundancy :
  - power converters
  - hardware components of the control system

effective needs to be obtained from modeling

- beam diagnostics : redundancy from overdetermined systems
  - statistical methods
  - model fitting
  - decision taking, fault identification or (better) fault prediction

Source: [TBD]

The approach to Fault Tolerance

- Further basic requirements for effective redundancy :
  - reproducible modules
    - control of the process of industrialisation / serialisation
    - well organized QC
  - control of MTTR (design)

Source: [TBD]

Summary of the challenges for MINERVA 100 MeV

- Beam dynamics supporting the fault tolerance
  - start-to-end simulations
  - error studies
  - optimisation of the longitudinal acceptance
- Fault recovery procedure
  - 3 seconds : the rationale is operational
  - 3 seconds : 3 main tasks
    1. fault detection / identification of the cause
    2. reconfiguration
       - obtain new configuration
       - install new configuration
       - i.c., fast cavity detuning

Source: [TBD]

Summary of the challenges for MINERVA 100 MeV

3. beam recovery

- fast tools (esp. for 2.)
  - data base applications (storage of alternate configurations)
  - simulations (calculation of alternate configurations)
  - decision taking
- Reliability modeling
  - compulsory for making the step phase 1 (100 MeV) → phase 2 (600 MeV)
    - predictive model
  - collaboration with CERN being set up
    - modeling
    - fault tracking tools : feeding the models with data

Source: [TBD]

Summary of the challenges for MINERVA 100 MeV

- Machine Protection System
  - main fault indication system
  - HPPA → MPS with 10's of μs response is vital
  - false interlocks must be identified immediately
- *compatible* Control System
  - procured from industry
  - compatible in performance
    - demands from reliability
    - Fault Recovery Procedure
  - compatible in its own reliability (and redundancy)
  - capabilities of "virtual operator" → AI tools

Source: [TBD]

Solid State RF Amplifiers

- Linac fault statistics : RF share of 40 – 50%
  - redundancy ? (CW for MYRRHA)
- search for serial redundancy → modularity
  - transistor-based approach offers this
  - cfr. Soleil = pioneer
- search for a compact realisation
  - IBA's interest
  - partnership through MYRTE (H2020)
  - → RFQ amplifier 192 kW CW, 176 MHz
  - connected to RFQ cavity, no circulator

Source: [TBD]

Solid State RF Amplifiers

- RFQ amplifier by IBA
- 176 MHz, 192 kW CW
- very positive initial testing (1 retrofit campaign)
- connected to RFQ cavity without circulator
- ready for long duration tests
- other amplifiers (176 and 352 MHz) through a bilateral collaboration agreement

Source: [TBD]

Conclusion

- MYRRHA : medium term ADS demonstrator in view of
  - transmutation of minor actinides
  - production of innovative medical radioisotopes
- reactor R&D (Pb-Bi cooled, pool type) is ongoing
- accelerator reliability (availability ?) is of *vital* importance
- need for scenarios, tools, methods, … and a new way of thinking. SRF is obviously a key design element in the fault tolerance scenario
- Cfr. many future accelerator projects : need for reliability becomes a common concern
- Common problems should be tackled in common : collaborations
- 100 MeV prototype will be built for learning, hopefully to the benefit of the community

Source: [TBD]

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