MYRRHA and its impact on fundamental science and medical applications

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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. Carlucc & 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 construction (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
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)
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

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

**Reactor**
- **power**: 65 to 100 MW\(_{th}\)
- **\(k_{\text{eff}}\)**: 0.95
- **spectrum**: fast
- **coolant**: LBE

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

*Slide courtesy of H. Aït Abderrahim (SCK•CEN)*
MYRRHA application portfolio

Multipurpose Hybrid Research Reactor for High-tech Applications

Fission GEN IV

Radio-isotopes

Support to SMR LFR

Fusion

Fundamental research

SNF*/ Waste

*SNF = Spent Nuclear Fuel

Slide courtesy of H. Aït Abderrahim (SCK•CEN)
Transmutation: better solution for Spent Nuclear Fuel

- **SNF 1000**
  - Transmutation of spent fuel: ~300 year
  - Spent fuel reprocessing: +10,000 year
  - No reprocessing: +300,000 year

*SNF = Spent Nuclear Fuel

Duration Reduction 1.000x
Volume Reduction 100x

Slide courtesy of H. Aït Abderrahim (SCK•CEN)
MYRRHA Core and fuel

- 151 positions
- 37 multifunctional plugs

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
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 **Belgian research initiative on eXotic 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

Ion source operated this week at 15 mA (stabilized-beam)
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\textsubscript{x}, ThC\textsubscript{x}]:
  - Neutron-rich fission fragments
  - Spallation region around target material

- Lighter targets [e.g. TiC\textsubscript{x}, CaO\textsubscript{x}]:
  - Light Neutron-deficient spallation products

*FLUKA simulation* - Ratio of cross sections for 100 / 600 MeV protons on U-238
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 ($T_{\text{melt}} = 3140^\circ\text{C}$)
- Target optimized for in-target isotopes production
  - By variation of target material density (g/cm²)
- Detailed FLUKA and ANSYS calculations
  - Optimal distribution of the discs to get uniform target temperature

Temperature profile in 20 TiC discs, total thickness 10 mm:
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 (LaBr₃, Si, plastic scintillator, neutron detectors, ...)
  - Silicon detectors

• Focus on $\beta$- (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
## Essential successful treatment development steps

<table>
<thead>
<tr>
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</table>

- **Tb-IRMA-V: Tb ISOL Radioisotopes for Medical Applications in Vlaanderen**
- Project funded with € 2.2 M by the Flemish Fund for Scientific Research (FWO)

### Project Partners
- KU Leuven
- SCK•CEN
- CERN

### Advisory Board (future users)

- UZ Gent
- ICMI Brussels
- NPL

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**MYRRHA for nuclear medicine**
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 $\alpha/\beta$ emitter
  - Range of $\alpha$ emitters: 30-80 $\mu$m (cell surgery)

- Requires successful combination of various disciplines

![Diagram showing the process of drug delivery involving receptor or antigen, bio-conjugate e.g. antibody, linker, and radioisotope. The diagram also notes the involvement of structural biology, coordination chemistry, and nuclear physics and radiochemistry.]
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!


- **Tb: a unique nuclear medicine**

![Diagram showing treatment, PET, and SPECT results](image-url)
Production of $^{149}\text{Tb}$, $^{152}\text{Tb}$ and $^{155}\text{Tb}$ via ISOL

- High-energy proton-irradiation of Ta-metal targets + Isotope Separation On-Line (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

High level global planning of MYRRHA Project (2018-2040)

Phase 1: ‘18-’26
Phase 1 - MINERVA: 100 MeV Accelerator + ISOL Prototyping, Tendering, and Construction
Phase 1 - R&D: Supporting 600 MeV and Reactor

Phase 2: ‘26-’30
Phase 2 - 600MeV: Total
Phase 2 - 600 MeV Accelerator: Tendering, Construction, and

Phase 3: ‘30-’33
Phase 3 - Reactor: Total
Phase 3 - Reactor: Tendering and Construction

Cut-off decision: Economic / Consortium / FANC-AFCN

Full MYRRHA: pre-licensing
Full MYRRHA: formal
Full MYRRHA: Licensing construction

Slide courtesy of H. Aït Abderrahim (SCK•CEN)
MYRRHA is recognized in Europe to contribute to strategic objectives of both Energy and Knowledge economy.

- MYRRHA is selected by the European Investment Bank (EIB) as a potential project for financing and benefits from advisory services from EIB InnovFin.
- 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

Join us! Visit www.myrrha.be

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
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)
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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
Double Spoke linac 352.2 MHz
\( \beta = 0.51 \) elliptical linac 704.4 MHz

5 element elliptical cavity
elliptical cavity envelope with cold tuning mechanism

200 MeV

\( \beta = 0.70 \) elliptical linac 704.4 MHz
60 cav., 101 m

Design of the test cryomodule for the elliptical cavity

600 MeV

Beam dump casemat

700 MHz Solid State RF amplifier prototyping

Single Spoke linac 352.2 MHz 50 cav., l=73 m

Power coupler

Cold tuning system
100 MeV linac overview

LEBT

4-rod RFQ

RT-CH cavity

Single Spoke linac 352.2 MHz 60 cav.

power coupler

spoke cryomodule

single spoke cavity

cold tuning system

Source: [TBD]
Injector 5.9 MeV in LLN

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