Future Advanced Nuclear Systems
And Role of MYRRHA

Multipurpose hYbrid Research Reactor for High-tech Applications
Contributing to the 3rd Pillar of the European Strategy for P&T

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Nuclear energy in Europe

- 152 reactors in 15 countries in EU-27, producing 31% of EU’s electricity
- The largest source of low carbon energy
- Excellent safety record
- Europe, a world leader – but competition is building up (Russia, Japan, USA, China, India)
Fossil and nuclear power generation plants are ageing

Need to invest in plant lifetime management and

Large investments are necessary to build new plants to satisfy demand
- For nuclear, Gen III reactors (Finland, France)

Action is needed now for paving the road for Gen IV!

Decline of fossil and nuclear power generation capacity without renewal (in EU-15)
Nuclear fission contributes today 31% of EU electricity – the largest low carbon energy source

- 2020: Maintain competitiveness in fission technology and provide long term waste management solutions

- For the longer term as indicated in the SET Plan, we need to act now to:
  - Complete the demonstration of Gen IV with closed fuel cycle for increasing sustainability,
  - Enlarge the nuclear fission applications beyond electricity production, namely towards H₂, Heat, H₂O desalination.

Ambitious R&D and Demo programme need to start now to meet the required breakthroughs
A collective vision: endorsers and contributors
SNETP vision:

- Maintain safety and competitiveness of today’s technologies,
- Develop Gen IV FR with closed cycle to enhance sustainability,
- Enlarge the nuclear fission portfolio beyond electricity production: H₂, Heat, H₂O desalination
SNETP vision:
Beyond the 3 pillars, a common trunk of activities:

- Material & Fuel research,
- Simulation, modeling and validation experiments,
- Dedicated / multipurpose research facilities,
- Last but not least: well trained and educated specialists in the various fields related to nuclear fission
Europe is a world leader in nuclear energy and SNETP helps holding this position.

Nuclear energy is competitive and is the largest low carbon source in the energy mix of Europe. It is contributing to Europe's security of supply.

Nuclear energy path towards sustainability:

- Today Gen II = PLIM (2040)
- Tomorrow Gen III = Deployment of new fleet (2010 2030) 2100
- After-tomorrow = Gen IV + Advanced fuel cycle + beyond electricity application, SMRs (R&D 2020, prototypes 2030, deployment beyond)

- Industry & utilities ready to invest in Gen II & III but need a climate of political trust
- Private & public funding & EC contribution needed for the Gen IV EII through new financial vehicle
Some countries decided to consider abandoning or not restarting nuclear energy (DE, CH, IT, …)
Some are still in a position of wait and see (BE, SP, )
Some are not changing their policy even increasing their engagement in nuclear energy (FR, FI, CZ, SK, BG, UK, RO, ROK, CN, RU, IN …)
• **SRA of SNETP is in updating phase => Safety chapter resulting from lessons of the stress tests**
MYRRHA
Multipurpose hYbrid Research Reactor for High-tech Applications
Contributing to the 3rd Pillar of the European Strategy for P&T
MYRRHA - Accelerator Driven System

Accelerator
(600 MeV - 4 mA proton)

Reactor
• Subcritical or Critical modes
• 65 to 100 MWth

Innovative & Unique

Multipurpose Flexible Irradiation Facility

Spallation Source

Fast Neutron Source

Lead-Bismuth coolant
The MYRRHA linear accelerator

Dirk Vandeplassche, Luis Medeiros Romão
### MYRRHA Accelerator Challenge

#### Fundamental Parameters (ADS)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle</td>
<td>p</td>
</tr>
<tr>
<td>Beam Energy</td>
<td>600 MeV</td>
</tr>
<tr>
<td>Beam Current</td>
<td>4 mA</td>
</tr>
<tr>
<td>Mode</td>
<td>CW</td>
</tr>
<tr>
<td>MTBF</td>
<td>&gt; 250 h</td>
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</tbody>
</table>

**Challenge!**

**Failure = Beam Trip > 3 s**

#### Implementation

- **Superconducting Linac**
- **Frequency**: 176.1 / 352.2 / 704.4 MHz
- **Reliability = Redundancy**: Double Injector
- **“Fault Tolerant” Scheme**
Scenario and philosophy

- **Structure of collaborations**
  - Euratom Framework Programmes 5 – 6 – 7
  - core partners
    - CNRS/IN2P3 – IPN (Orsay)
    - CEA – IRFU (Saclay)
    - U. Frankfurt – IAP
    - INFN – LASA (Milano)
  - bilateral agreements with research institutes (MoU's)
    - University of Louvain
    - CNRS (several labs)
    - IAP
  - privileged industrial partnerships
    - for components (ECR source, RF amplifiers, ...)
    - for global systems (cryogenics, controls, ...)
    - for integration
  - CERN
  - GANIL/Spiral2
  - ESS
requirements from reactor design

structural tolerance:

| Table 1: Range of Parameters for Accelerator Driven Systems for four missions described in this whitepaper |
|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| Transmutation Demonstration | Industrial Scale Transmutation | Industrial Scale Power Generation with Energy Storage | Industrial Scale Power Generation without Energy Storage |
| Beam Power | 1-2 MW | 10-75 MW | 10-75 MW | 10-75 MW |
| Beam Energy | 0.5-3 GeV | 1-2 GeV | 1-2 GeV | 1-2 GeV |
| Beam Time Structure | CW/pulsed (?) | CW | CW | CW |
| Beam trips (t < 1 sec) | N/A | < 25000/year | <25000/year | <25000/year |
| Beam trips (1 < t < 10 sec) | < 2500/year | < 2500/year | <2500/year | <2500/year |
| Beam trips (10 s < t < 5 min) | < 2500/year | < 2500/year | < 2500/year | < 250/year |
| Beam trips (t > 5 min) | < 50/year | < 50/year | < 50/year | < 3/year |
| Availability | > 50% | > 70% | > 80% | > 85% |
About beam trips
INJECTOR BUILDING

Section #1 (Spoke $\beta \sim 0.35$ @352MHz)

Courtesy of Jean-Luc Biarrotte, IPN
• key concepts
  • moderate requirements
  • "conservative" technological solutions
  • modularity for fault tolerance

• keys to reliability (availability) and fault tolerance
  1. redundancy
     • common sense, experience
     • modeling confirms
  2. powerful diagnostics: predictive and self-diagnostics
  3. strict component MTBF control
  4. repairability
Linac components: injector

176 MHz, 5 mA (MAX)

0.03 MeV  1.5 MeV  3.5 MeV  17 MeV

4-Rod-RFQ

10.6 m
Linac components: spokes
Linac components: spokes
Linac components: elliptical
Linac components

- power RF: Solid State envisaged
- LLRF for fault recovery < 3 s: 2 digital loops
  - RF loop
  - tuning loop: adaptive and predictive system evaluated
- power converters: modularity
- cryogenics: 2K
- controls: EPICS
MLA R&D program

1. reliability focused

2. yield vision on MTBF > 250 h
   - reliability modeling for choice of components
   - fault modeling with error analysis
   - on line linac simulation and matching
   - self-diagnostics
   - predictive diagnostics

3. address critical issues through prototyping
   - RFQ
   - cryomodules
   - non-interceptive beam diagnostics
   - robust controls

avoid false interlocks
4. investigate future oriented solutions
   - SS RF
   - modular power converters
   - μTCA for Physics
   - White Rabbit

5. initiate collaborations with industry
   - ECR ion source
   - control system
   - cryomodule
RFQ@UCL Phase 1

INJ@UCL Phase 2 RT-CH

INJ@UCL Phase 3 SC-CH

MAX FP7

Cryomodule prototypes
- engineering
- construction
- test

SC-CH spoke elliptic Prod

elliptic Prod

elliptic Prod
Concluding remarks

- Linac for MYRRHA has a credible design
- reliability goal is fundamentally realistic
- conditions are favourable:
  - wide effort on SC RF, synergies between many HPPA applications, reliability is common concern
  - more reliable and fault tolerant auxiliaries (e.g. SS RF amplifiers, modular power converters) contribute to our reliability goal being more practically realistic than ever.
- Reactor Vessel
- Reactor Cover
- Core Support Structure
  - Core Barrel
  - Core Support Plate
  - Jacket
- Core
  - Reflector Assemblies
  - Dummy Assemblies
  - Fuel Assemblies
- Spallation Target Assembly and Beam Line
- Above Core Structure
  - Core Plug
  - Multifunctional Channels
  - Core Restraint System
- Control Rods, Safety Rods, Mo-99 production units
- Primary Heat Exchangers
- Primary Pumps
- Si-doping Facility
- Diaphragm
  - IVFS
- IVFHS
  - IVFHM
Core and Fuel Assemblies

- 151 positions
- 37 multifunctional plugs
Core and Fuel Assemblies

- Fuel
  - Cladding in 15-15 Ti
  - Wire wrap
  - Wrapper in T91
Cooling systems

- Decay heat removal (DHR) through secondary loops
  - 4 independent loops
  - redundancy (each loop has 100% capability)
  - passive operation (natural convection in primary, secondary and tertiary loop)
- Ultimate DHR through RVCS (natural convection)
Integration into building
Integration into building
Multipurpose facility

- **Fuel research**
  \[ \Phi_{\text{tot}} = 0.5 \text{ to } 1.10^{15} \text{ n/cm}^2\text{s} \]

- **Material research**
  \[ \Phi_{\text{Fast}} = 1 \text{ to } 5.10^{14} \text{ n/cm}^2\text{s} \]
  (En>1 MeV) in large volumes

- **Fission GEN IV**
  50 to 100 MWth
  \[ \Phi_{\text{Fast}} = \sim 10^{15} \text{ n/cm}^2\text{s} \]
  (En>0.75 MeV)

- **Fusion**
  \[ \Phi = 1 \text{ to } 5.10^{14} \text{ n/cm}^2\text{s} \]
  (ppm He/dpa \~ 10)
  in medium-large volumes

- **Waste**
  \[ \Phi_{\text{th}} = 0.5 \text{ to } 2.10^{15} \text{ n/cm}^2\text{s} \]
  (En<0.4 eV)

- **Radioisotopes**
  \[ \Phi_{\text{th}} = 0.1 \text{ to } 1.10^{14} \text{ n/cm}^2\text{s} \]
  (En<0.4 eV)

- **Silicon doping**
  High energy LINAC
  600 MeV – 1 GeV
  Long irradiation time

- **Fundamental research**
  \[ \Phi_{\text{th}} = 0.1 \text{ to } 1.10^{14} \text{ n/cm}^2\text{s} \]
  (En<0.4 eV)
Motivation for transmutation

- **Transmutation of spent fuel**
  - Duration Reduction: 1.000x
  - Volume Reduction: 100x

- **Spent fuel reprocessing**

- **No reprocessing**

Relative radiotoxicity vs. Time (years)

- Uranium naturel
The implementation of P&T of a large part of the high-level nuclear wastes in Europe needs the demonstration of its feasibility at an “engineering” level. The respective R&D activities could be arranged in four “building blocks”:

1. Demonstration of the capability to process a sizable amount of spent fuel from commercial LWRs in order to separate plutonium (Pu), uranium (U) and minor actinides (MA),

2. Demonstration of the capability to fabricate at a semi-industrial level the dedicated fuel needed to load in a dedicated transmuter,

3. Design and construction of one or more dedicated transmuters,

4. Provision of a specific installation for processing of the dedicated fuel unloaded from the transmuter, which can be of a different type than the one used to process the original spent fuel unloaded from the commercial power plants, together with the fabrication of new dedicated fuel.
Why ADS Transmutation

- In the frame of the Waste Management research programme of the EC since FP5 till FP7, various project (IP-ADOPT, PATEROS, EUROTRANS, ARCAS) various options of the fuel cycle have been studied and showed the need to consider the progress of ADS R&D and demonstration to allow future decisions when considering:
  - Efficient burning of the LWR MA stockpile legacy
  - Considering the double-strata closed fuel cycle
  - Minimise the MA quantities in the electricity production park (even in the future FR park)
  - Allow regional approach for accommodating various national policies related to nuclear energy
FP6-PATEROS
A European approach to P&T

- P&T useful for countries
  - in phase out
  - with active nuclear programme

- Reduction of volume & heat load of waste

- P&T should be seen at a regional/European level

- Scenario studies: 4 country groups
  - A: stagnant or phase-out
  - B: continuation and Pu optimisation for FRs
  - C: subset of A in “nuclear renaissance”
  - D: non-nuclear to go nuclear
Scenario 1 objective: elimination of A’s spent fuel by 2100

- ADS shared by A&B
- ADS burn A’s Pu and A&B’s MA
- Pu in B is mono-recycled PWR and later used in FR
### MYRRHA international reviewing

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>International Strategic Guidance Committee</td>
</tr>
<tr>
<td>2002</td>
<td>International Technical Guidance Committee</td>
</tr>
<tr>
<td>2003</td>
<td>Review by Russian Lead Reactor Technology Experts (ISTC#2552p project)</td>
</tr>
<tr>
<td>2007</td>
<td>International Assessment Meeting of the Advanced Nuclear Systems Institute</td>
</tr>
<tr>
<td>2008</td>
<td>European Commission FP7 Project Central Design Team (CDT) at Mol for MYRRHA detailed design</td>
</tr>
<tr>
<td>2009</td>
<td>MIRT of OECD/NEA on request of Belgian Government</td>
</tr>
</tbody>
</table>
European context

ESFRI
European Strategic Forum for Research Infrastructure

SET Plan
European Strategic Energy Plan

Knowledge Economy

Energy Independence

27.11.2010
Confirmed on ESFRI priority list projects

15.11.2010
in ESNII (SNETP goals)
Belgian commitment: secured
International consortium: under construction

Belgium 60 M€
(12 M€/y x 5 y)

Belgium 324 M€
(36 M€/y x 9 y)

2nd phase (11 y)
others 576 M€

960 M€
(2009)
The project schedule

- **2010-2014**: Front End Engineering Design
- **2015**: Tendering & Procurement
- **2016-2018**: Construction of components & civil engineering
- **2019**: On site assembly
- **2020-2022**: Commissioning
- **2023**: Progressive start-up
- **2024-2022**: Full exploitation

### Minimise technological risks
- Accelerator
- Spallation target
- Sub-critical reactor

### Secure the licensing
- PDP: preliminary dismantling plan
- PSAR: preliminary safety assessment
- EIAR: environmental impact assessment

### Secure a sound management and investment structure
- Central Project Team
- Owner Consortium Group
- Owner Engineering Team

**FEED** (Front End Engineering Design) 2010-2014
MYRRHA: an international project

PSI Colloquium, May 31, 2012, Villingen (CH)
International Members Consortium – Phase 1
As of early 2012

Primary «investors»
Belgian Federal Ministry of Energy (50%)
Belgian Federal Ministry of Science Policy (50%)
Major European partners
A major Asian partner
EU FP7 (RTD) / SET-Plan (Energy)
ROW

Participation vehicle (Consortium members)
SCK•CEN
(on behalf of Belgian Federal Government)

Contribution to investment capital (960 M€’09)
40 %

25-30 %
15 ~ 20 %
2 -10 %
0 -10 %

«ERIC» (*)

IPR management rules tbd

BE

EU countries

Asian country

EU participation

ROW participation

EU

ROW

(*) European Research Infrastructure Consortium
Joining the MYRRHA project

- Belgium is welcoming international participation in the MYRRHA consortium
- Membership eligibility for the international MYRRHA consortium is based on a balanced in-cash/in-kind contribution

Until end 2014:

- Partners are invited to express their interest in a participation in the MYRRHA programme by sending an **Expression of Interest** to SCK•CEN by end of **August 2012**.
- After having received this Expression of Interest, the candidate Partner will confirm the contribution level of its commitment by sending a **Commitment Letter** by end of **December 2012**.
- After having received the Commitment Letter, the candidate Partner and SCK•CEN will enter immediately into negotiation on their co-operation aiming at the signature of a **Bilateral Agreement** covering the Investment Phase and/or the Operation Phase. This Bilateral Agreement should be signed and enter into force before the **mid 2013**.
MYRRHA: EXPERIMENTAL ACCELERATOR DRIVEN SYSTEM

A pan-European, innovative and unique facility at Mol (BE)