The MYRRHA Reactor: Approach to Nuclear Safety
Dr Gustavo Rubio Antón on behalf of the MYRRHA team at SCK•CEN

IAEA Headquarters Vienna, Austria, 4-8 September 2017
Outline

• Context – History of MYRRHA

• What is Project MYRRHA?
• MYRRHA technical planning
• Safety of MYRRHA
Context – MYRRHA History

- **1995-1997:** Start of the MYRRHA Project
- **2005:** DG Research of EC selects MYRRHA as the reference project for EU ADS
- **2009:** International independent review conducted by OECD/NEA
- **March 5th 2010:** Commitment Belgium to MYRRHA 2010-2014
- **2015:** Renewal commitment Belgium to MYRRHA
- **End 2017:** Expected decision Belgium regarding construction of MYRRHA

Source: SCK•CEN MYRRHA Project Team
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What is Project MYRRHA?

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

Construction of an Accelerator-Driven System (ADS) consisting of:

- A 600 MeV – 2.5 mA to 4.0 mA proton linear accelerator
- A spallation target/source
- A lead-Bismuth Eutectic (LBE) cooled reactor able to operate in subcritical & critical mode

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Target</th>
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<tbody>
<tr>
<td>particles</td>
<td>spallation</td>
</tr>
<tr>
<td>beam energy</td>
<td>600 MeV</td>
</tr>
<tr>
<td>beam current</td>
<td>2.4 to 4 mA</td>
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<tr>
<th>Reactor</th>
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<tbody>
<tr>
<td>power</td>
<td>65 to 100 MW&lt;sub&gt;th&lt;/sub&gt;</td>
</tr>
<tr>
<td>k&lt;sub&gt;eff&lt;/sub&gt;</td>
<td>0.95</td>
</tr>
<tr>
<td>spectrum</td>
<td>fast</td>
</tr>
<tr>
<td>coolant</td>
<td>LBE</td>
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Source: SCK•CEN MYRRHA Project Team
Minor Actinides have high radiotoxicity and long-lived characteristics, making them difficult to store. They are produced during nuclear fission processes, particularly from actinide isotopes such as Uranium ($U^{235}$ and $U^{238}$), Plutonium ($Pu$), Neptunium ($Np$), Americium ($Am$), and Curium ($Cm$). These isotopes are heat-emitting and require special storage solutions due to their extended half-lives, lasting beyond 1,000 years. The MYRRHA Project Team at SCK•CEN focuses on developing advanced waste management solutions for these challenging materials.
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
MYRRHA application portfolio

- Fission GEN IV
- Fusion
- Fundamental research
- Radio-isotopes
- SMR LFR

**Multipurpose Hybrid Research Reactor for High-tech Applications**

*SNF = Spent Nuclear Fuel

Source: SCK•CEN MYRRHA Project Team, MYRRHA Business Plan
Global challenges for nuclear energy today

- Common needs
- Burning legacy of the past
- Affordability
- Better use of resources
- Enhance Safety

Source: SCK•CEN MYRRHA Project Team

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MYRRHA technical planning

• Safety of MYRRHA
Benefits of phased approach:

- Reducing technical risk
- Spreading investment cost
- First R&D facility available in Mol end of 2024
Core Design (v1.6)

- Core
  - 211 positions
    - 108 FA in critical core
  - 55 MFC
  - Mass flow rate
    - 13800 kg/s
      - Ti: 270°C
      - To: 325°C

Source: SCK•CEN MYRRHA Project Team
Core Design (v1.6)

- **MFC: Multi-Functional Channel**
  - Accommodate an In-Pile Section (IPS) in the core, replacing a fuel assembly
    - Control Rod (CR), Safety rod (SR), Experimental Device, Instrumentation, Surveillance Capsule
  - Position are accessible through the core plug

- **Critical reference core configuration**
  - 6 control rods
  - 3 Safety rod
  - symmetrical core lay-out (preferred)

- **Control Rods will also be used for reactivity compensation in ADS mode**
Reactor – Current Primary System design (v1.6)

- Reactor layout
  - Vessel
  - Cover
  - Core barrel and Multi-functional plugs
  - Above Core Structure
  - Cradle, Core Restraint System, beam line and window target
  - Si-doping units, Mo-irradiation units, control rods and safety rods
  - Primary Heat Exchangers
  - Primary Pumps
  - In-Vessel Fuel Handling Machines, Fuel Transfer Devices, Failed Fuel Detection Devices, Extraction Pumps
  - Diaphragm and support structure
  - Reactor pit, Reactor Vessel
  - Auxiliary Cooling System

Source: SCK•CEN MYRRHA Project Team
Operation and Maintenance (v1.6)

- **Operation**
  - 1 Operational period of 420 days
    - 3 Operation cycles of 90 days
    - 2 Short maintenance intervals of 30 days
    - 1 Long maintenance of 90 days
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Safety of MYRRHA
MYRRHA is to be licensed and built in the site of SCK•CEN in Mol, Belgium.

The regulatory authority in Belgium for the safety of nuclear facilities is the Federal Agency for Nuclear Control (FANC).

MYRRHA is a “Class 1 facility”, the highest hazard class.

MYRRHA is going through pre-licensing.
• Objectives of the pre-licensing phase are:
  • Identification of potential safety issues that could jeopardize a license application
  • Development by the FANC of the objectives for safety and security of MYRRHA
  • Establishing a description by SCK•CEN of the safety options
  • Development by SCK•CEN of answers and justifications to specific nuclear safety issues

Ensure the feasibility of the project in terms of licensing MYRRHA as a class I facility
Regulatory context

- MYRRHA is a research reactor.
- SCK•CEN will apply power reactor requirements (if applicable)
- New requirements and guidelines might need to be developed for specific issues
- MYRRHA follows the principle of defence-in-depth as per in the FANC regulatory guidelines
- A number of legally and non-legally binding references are used in the nuclear safety approach of MYRRHA
Regulatory context

• Legally binding references
  • Belgian regulatory framework
  • European directives

• References considered as binding (non-legally)
  • WENRA safety reference levels
  • IAEA safety standards
  • National Regulatory Commission guidelines and NUREGs
  • Applicable FANC guidelines
MYRRHA will incorporate the most advanced and stringent standards and requirements on nuclear safety.
Application of IAEA specific safety requirements to MYRRHA

- A conceptual design of MYRRHA has been developed by SCK•CEN
- Some components have been developed to a level of preliminary basic design
- MYRRHA has adopted the IAEA fundamental safety principles SF-1
- Application of safety requirements is challenging at a very early stage
Application of IAEA specific safety requirements to MYRRHA

- Implementation of safety requirements depends on design decisions made at different stages of design

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<td>Principal technical requirements</td>
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<tr>
<td>General plant design</td>
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<td>Design basis</td>
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<td>Design of specific plant systems</td>
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<td>Reactor core</td>
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Application of IAEA specific safety requirements to MYRRHA (principal technical requirements)

• Challenges in the application of *principal technical requirements*
  
  • Choice of LBE as a coolant and the generation of Po$^{210}$ (Req. 5)
  
  • Qualification of TH codes (Req. 9)
  
  • Understanding the properties of LBE as a barrier (Req. 7)
  
  • Lack of OPEX (Req. 6)
  
  • Lack of safety assessment methods (Ref. 10)
  
  • Long term effect of LBE on material properties (Reqs. 7/9)
  
  • LBE freezing temperature (Req. 4)
Application of IAEA specific safety requirements to MYRRHA (principal technical requirements)

- Challenges mostly related to the introduction of innovative design features

- Main activities in SCK•CEN to overcome those challenges
  - Ambitious fundamental research projects in:
    - LBE Chemistry
    - LBE Thermo-hydraulics
    - Materials
  - Experimental campaigns for performance tests and equipment qualification
Application of IAEA specific safety requirements to MYRRHA (principal technical requirements)

- Fundamental advances through R&D in:
  - Polonium chemistry for source term assessment
  - LBE properties as a barrier (volatility of Po$^{210}$)
  - Conditioning of LBE by oxygen control to prevent corrosion
  - Corrosion limits for materials exposed to high temperature LBE
  - Production and transport of oxides in LBE
  - Pool thermo-hydraulics
  - Validation of heat transfer and pressure drop correlations in LBE
Application of IAEA specific safety requirements to MYRRHA (general plant design requirements)

- **General plant design requirements** to be implemented mostly during the licensing phase

- Important impact on the philosophy adopted for DiD

- Implementation of DiD for FOAK reactors is an iterative process
Application of IAEA specific safety requirements to MYRRHA (general plant design requirements)

- Challenges in the application of general plant design requirements
  - Not all fundamental technology decisions have been made
  - Finalizing the list of internally initiated events, internal and external hazards (Reqs. 16/17)
  - Understanding design basis accidents and design extension conditions (Reqs. 19/20)
  - Identification of all safety systems, support systems and mitigating features (Reqs. 27/30)
  - Safety classification of systems, structures and components (Req. 22)
Application of IAEA specific safety requirements to MYRRHA (general plant design requirements)

- Requirements at the level of general plant design have a strong influence in the ability of the facility to provide protection against a wide variety of transients, incidents and accidents.

- The nature of the different hazards influence the required number and strength of lines of defence.

- Understanding the hazard and the response of the plant to the hazard is essential for the implementation of DiD in a FOAK innovative reactor.
Conclusions

• When designing an innovative reactor, the definition of nuclear safety requirements is an iterative process

• R&D and equipment qualification programs are fundamental to understand the threats to nuclear safety and the plant response to those threats

• As the design advances and aspects of the technology are better understood, better decisions can be made in the implementation of barriers

• Plan the approach to nuclear safety in line with the different phases of your design

• Close collaboration with the Regulator and its Technical Support Organization is very important
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