Materials selection for 
and irradiation capabilities of MYRRHA

Joris Van den Bosch, LANL
H. Ait Abderrahim, SCK•CEN
P. Baeten, SCK•CEN
V. Sobolev, SCK•CEN
S. Gavrilov, SCK•CEN

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Outline

- MYRRHA design (brief)
- MYRRHA materials selection
- Material challenges towards MYRRHA
- MYRRHA material irradiation capabilities
- Summary
MYRRHA an innovative concept

Accelerator

Sub-critical reactor

High reliability

Spallation source

Fast neutron source

Windowless

Lead-Bismuth coolant
MYRRHA components: Accelerator

Linac Front End

Independently-phased Superconducting Section

Beam dump

Spallation target & sub-critical core
Lay out

Inner vessel
Cover
Core structure
Spallation loop
Heat exchangers
Pumps
Diaphragm
Fuel storage
Fuel manipulators
Guard vessel
**MYRRHA components:**

**Spallation target**

- **Tasks**
  - Produce $10^{17}$ neutrons/s to feed subcritical core @ $k_{eff}=0.95$
  - Accept megawatt proton beam
    - 600 MeV, 2.5-3 mA $\Rightarrow$ $\approx$ 1-1.2 MW heat
    - 300 mm penetration depth
    - Pb-Bi eutectic as target material
  - Fit into central hole in core
    - compact target
    - windowless (beam density)
    - Off-axis geometry
  - Match MYRRHA purpose as experimental irradiation machine
    - flexible remote handling
  - Survive (lifetime)
Spallation target loop configuration

- **LBE flow & cooling**
  - Forced convection (10-20 l/s)
  - $T_{\text{max}(\text{LBE surface})}=450^\circ\text{C}$; $\Delta T<100^\circ\text{C}$
  - Heat exchanger to main vessel coolant

- **Vacuum requirements**
  - Pressure above target $<10^{-3}$-$10^{-4}$ mbar
  - Confinement of volatile spallation products

- **LBE conditioning**
  - Corrosion inhibition, Filtering

- **Service by remote handling**
  - Entire spallation unit removable from main vessel after core unloading
  - Separate sub-unit with all active elements
Spallation target

- **Windowless target**
  - space considerations
  - beam density

- **Formation of target free surface**
  - Confluence of Vertical coaxial flow
  - Forced detachment
    - Decoupled inlet-outlet flow
    - Buffer during beam transients
  - Recirculation zone: in check
  - Feedback necessary (slow)
  - Proton beam distribution
    - Avoid recirculation zone heating
## critical parameters of the MYRRHA components

<table>
<thead>
<tr>
<th>Components</th>
<th>Material</th>
<th>Min. Temp. unlimited time (°C) [1]</th>
<th>Max. Temp. unlimited time (°C)</th>
<th>Max. Temp. lasting 1 week (°C)</th>
<th>Max. LBE velocity (m/s)</th>
<th>Max. Neutron damage (dpa/yr)</th>
<th>Max. Mech. stress (MPa)</th>
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<td>Fuel Assemblies</td>
<td>T91*</td>
<td>200</td>
<td>450</td>
<td>550</td>
<td>1.6</td>
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<td>1.54 [2]</td>
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<td>370</td>
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<td>0.032</td>
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<td>Circulation Pumps</td>
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**Notes:**
- MAXTHAL / 316 indicates a combination material used in the target.
- T91 is a stainless steel grade.
- 316L is a variant of 316 stainless steel.
- To be defined indicates a material that is not specified.

**Units:**
- Temperature (°C) is the maximum operating temperature.
-Velocity (m/s) is the maximum LBE velocity.
- Neutron damage (dpa/yr) is the maximum neutron damage rate.
- Mech. stress (MPa) is the maximum mechanical stress.
Approach to MYRRHA fuel element qualification (0)

1. Fuel rod and sub-assembly pre-design
2. Materials screening and selection
3. Preparation of the database of the materials properties
4. Search materials providers and the materials procurement
5. Search manufacturers for components
6. Fabrication (components, rods, SA)
7. Pre-qualification of components
8. Qualification
9. Licensing for the production of SA
Approach to MYRRHA fuel element qualification (I)

Fuel element (sub-assembly) conceptual design

Fuel rod pre-design

Fuel pellets

Cladding

Rod structure elements

Wrapper

SA structure elements

Materials screening and selection

Pu_{0.35}U_{0.65}O_{2-x}

15-15 Ti

HT9

T91

15-15 Ti

Inconel

YSZ

EM-10

T91

T91, ...

EM-10

T91

Preparation of the database of the materials properties
Approach to MYRRHA fuel element qualification (II)

Search materials providers and the materials procurement

- $Pu_{0.35}U_{0.65}O_2-x$
- 15-15 Ti
- 15-15 Ti Inconel YSZ
- EM-10
- EM-10

Search manufacturers for components

- Fuel pellets
- Cladding
- Rod structure elements
- Wrapper
- SA structure elements

Production of the cladding samples
Approach to MYRRHA fuel element qualification (III)

Fabrication (components, rods, SA)
- Production of the cladding samples
- Production of wrapper samples
- Production of SA structure elements

Pre-qualification of components
- Cladding pre-qualification
- Production of pellets
- Production of rod segments

- Wrapper pre-qualification
- Production of rod elements
- Production of mock-up SA

Qualification...
- Fuel rod qualification
- SA out-of-pile qualification

Licencing for the production of SA for the MYRRHA core...
“Ways” for clad qualification

- **15-15 Ti short track**
  - Visibility of this track should be explored
  - To obtain database of 15-15Ti properties (CEA?)
    - Literature very limited
  - To define list of damaging effects at cladding/coolant boundary
  - To define experimental matrix

- **15-15 Ti long track**
  - To define list of **all** possible damaging effects
  - To define experimental matrix

- **T91 long track**

- **Fabrication**
Scheme of experiments for fuel pin re-qualification

**Out-of-pile**
- Corrosion tests
- Mechanical tests
- Pressurized tubes
- Fuel pins tests
  - stagnant
  - flow

**In-pile**
- Corrosion tests
- Mechanical tests
- Pressurized tubes
- Fuel pins tests
  - stagnant
  - flow

**ASTIR & LEXUR II**
**MYRMAT**
## Preliminary time schedule

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<td>3) Fuel pin (segments irradiation)*</td>
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<td>VII. LICENSING (for fuel fabrication)</td>
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<td>IX. FIRST CORE LOADING</td>
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* ??? - availability of MTR
MYRRHA components: Subcritical Core

- $k_{\text{eff}} \approx 0.95$
- 183 hexagonal macro-cells
- Target-block hole: 3 FA removed
- 72 positions for fuel assemblies (8 IPS positions included)
  - $\approx 30\%$ MOX fuel
- 27 positions for fuel assies or dummy assies (filled with LBE) (yellow)
- 84 additional cells for core reconfiguration
MYRRHA: a Flexible Experimental Facility

Minor Actinides test assemblies

Experimental rigs:
- dedicated contents
- dedicated irradiation
Material Irradiation in MYRRHA

- IPS Location in the core

![Diagram showing IPS, Spallation Target, Fuel Assemblies]
IPS Material Testing  Typical Layout

IPS outside diameter 80 mm
Length for irradiation test 600 mm
Instrumentation: dosimeter, thermocouple,...
Irradiations of materials in XT-ADS

- In IPS closest to spallation target
  - dpa: 18 dpa/EFPY
  - appmHe/dpa: 0.30 – 0.40

- Close to target module for fusion materials
  - dpa: about 31 dpa/EFPY (360 EFPDs)
  - appmHe/dpa: 6.4

- In hottest fuel assembly
  - dedicated irradiation fuel assembly, but no “loop-type”, limited volume
  - results in hottest pin clad:
    - dpa : about 30 dpa/EFPY
    - appmHe /dpa: about 3.8
MYRRHA Core configuration with Radioisotopes production device

Radioisotopes production

\[ T_{irr} = 9 \text{ EFPDs for Mo} \]
\[ 7 \text{ EFPDs for Ir} \]

<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>( \Phi_{tot} ) (n/cm(^2)s)</th>
<th>Activity (Ci/g)</th>
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<tr>
<td>IPS-loop loaded in inner channel</td>
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<tr>
<td>(^{99}\text{Mo})</td>
<td>(2.2 \times 10^{15})</td>
<td>(1.2 \times 10^{3})</td>
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<tr>
<td>(^{192}\text{Ir})</td>
<td>(2.3 \times 10^{15})</td>
<td>(1.8 \times 10^{3})</td>
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<tr>
<td>IPS-loop loaded in outer channel</td>
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<tr>
<td>(^{99}\text{Mo})</td>
<td>(1.4 \times 10^{15})</td>
<td>(0.9 \times 10^{3})</td>
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<tr>
<td>(^{192}\text{Ir})</td>
<td>(1.5 \times 10^{15})</td>
<td>(1.8 \times 10^{3})</td>
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</table>
Radioisotope production for targets: $\text{Ir}^{\text{nat}}$ capsule (left); $^{235}\text{U}$-plates (right)
99Mo Production

Core configuration with IPS position

Production performance in C74 channel
Summary

- Design not final (CDT within European Framework Program 7)
- First choice material selection is final;
- Strong effort needed towards licensing;
  - Cladding is most critical component at this point;
  - Mechanical properties under irradiation while in contact with LBE are critical.
- MYRRHA is to be:
  - A **flexible neutron irradiation** testing facility as **successor** of the SCK•CEN MTR BR2 (100 MW)
  - An attractive **fast spectrum testing facility in Europe** for Gen.IV and Fusion
  - A **full step ADS demo facility** and P&T testing facility
  - A **technological prototype** as test bench for LFR Gen.IV
  - An **attractive tool for education and training** of young scientists and engineers
One picture is better than a thousand words, we are in 2017~2020

Thank You for Your Attention

Questions?

Suggestions?