STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

The MYRRHA Project

Safety methodology and challenges

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Safety Engineers.

STRUCTURE

- Introduction
- Objectives
- Current design
  - Accelerator
  - Core and spallation target
  - Cooling systems
- Licensing process
- Safety methodology
- Safety challenges
  - Materials in LBE
  - LBE solidification
  - Confinement of activation/spallation products
- R&D programme
- Conclusions

Introduction

- BR2 MTR, SCK·CEN
  - In operation since 1962,
- Design study of a multi-purpose flexible irradiation facility (>1998)

  Multi-purpose

  h**Y**bride

  Research

  Reactor for

  High-Tech

  Applications
- Successive design versions in the frame of EC FP5 to FP7
- 2012: FASTEF (FAst Spectrum Transmutation Experimental Facility)

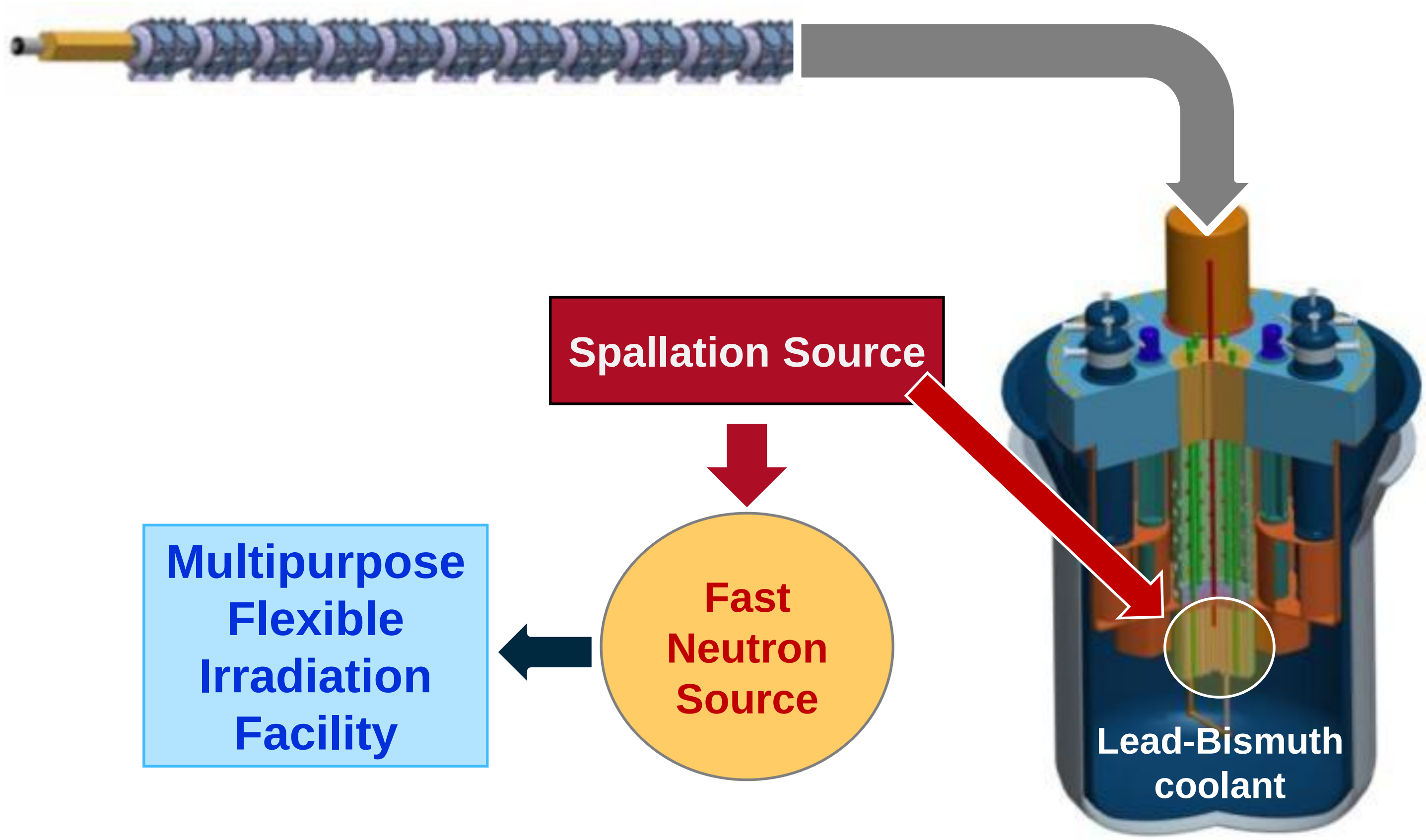
MYRRHA - Accelerator Driven System

Accelerator

(600 MeV - 4 mA proton)

Reactor

- Subcritical or Critical modes
- 65 to 100 MWth



Spallation Source

Fast Neutron Source

Multipurpose Flexible Irradiation Facility

Lead-Bismuth coolant

MYRRHA international reviewing

2003: Review by Russian Lead Reactor Technology Experts (ISTC#2552p project)

2005: Conclusions of the EC **FP5** Project PDS-XADS (2001-2004)

2006: EC **FP6** Project EUROTRANS (2005-2009): Conclusions of Review and Justification of the main options of XT-ADS starting from MYRRHA

2007: Int. Assessment Meeting of the Advanced Nuclear Systems Institute

2008: EC **FP7** Project Central Design Team (CDT) at Mol for MYRRHA detailed design

2009: MIRT of OECD/NEA on request of Belgian Government

The project schedule

2010-2014
Front End Engineering Design

2015-2016
Tendering & Procurement

2017-2019
Construction of components & civil engineering

2020
On site assembly

2021-2023
Commissioning

2024
Progressive start-up

2025-….
Full exploitation

Minimise technological risks	**Accelerator** x	**Spallation target** x	**Sub-critical reactor**
Secure the licensing	**PDP** preliminary dismantling plan	**PSAR** preliminary safety assesment	**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

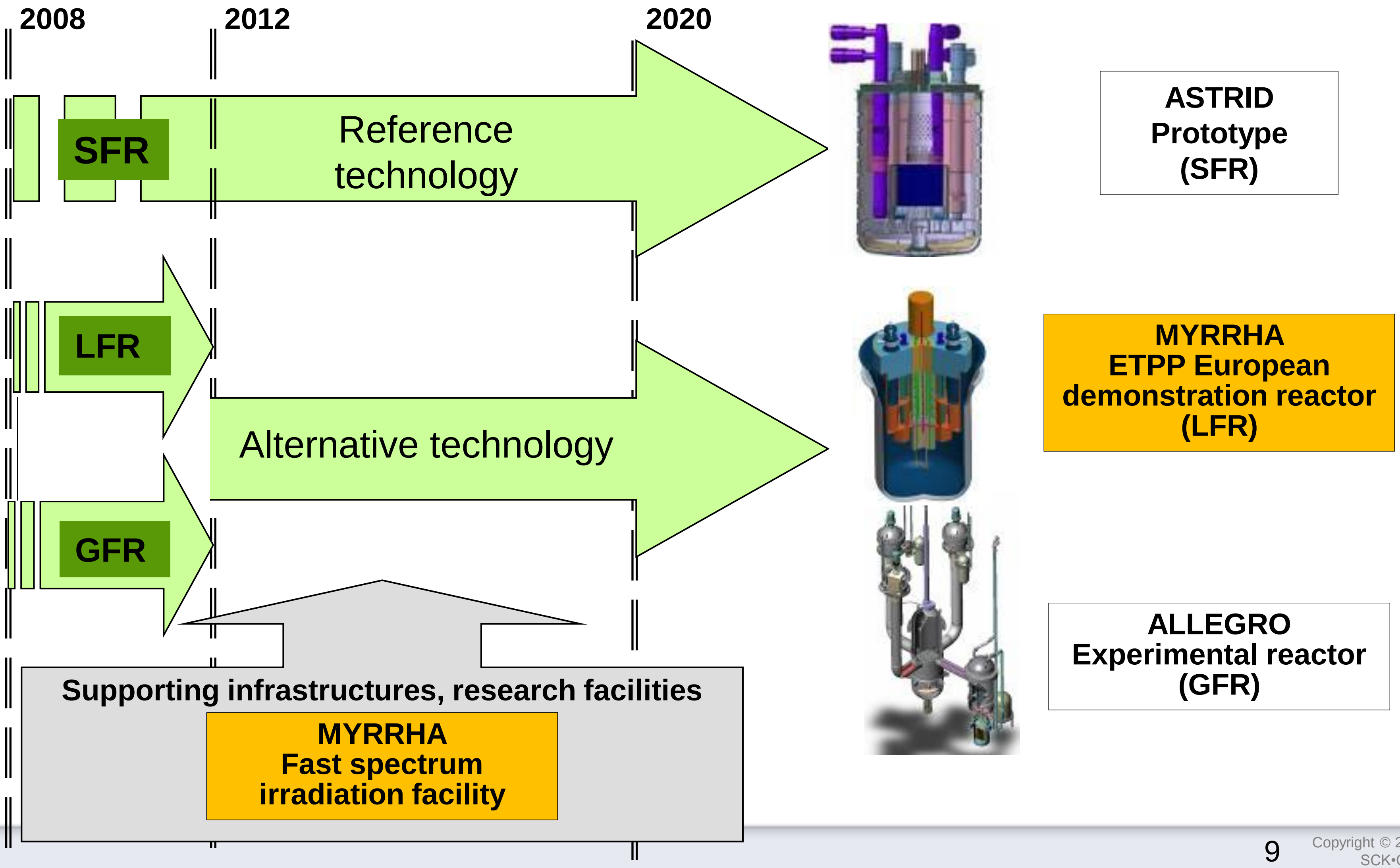
MYRRHA objectives

- Rationale in international framework (P&T/ADS/GEN IV):
  - Need of a sustainable solution for HLLW (MAs, LLFPs)
  - Interest of P&T strategy wrt Geological Disposal (GEN IV initiative)
  - ADS as a possible major component of this P&T strategy
  - ADS demo as a priority of EU Vision document (SRA)
  - Selection of GEN IV concepts by GIF (3 on 6 based on FS technologies)
  - SNETP: Need of an alternative cooling technology (**LFR**, GFR) wrt SFR
  - Flexible FSIF required for mat/fuel technological development

- Study of material development for fusion
- Radioisotopes for medical and industrial applications

- Fundamental nuclear physics research (ISOL@MYRRHA)

The place of MYRRHA in ESNII



2008

2012

2020

SFR

Reference technology

LFR

GFR

Alternative technology

Supporting infrastructures, research facilities

MYRRHA
Fast spectrum
irradiation facility

ASTRID
Prototype
(SFR)

MYRRHA
ETPP European
demonstration reactor
(LFR)

ALLEGRO
Experimental reactor
(GFR)

Multipurpose facility

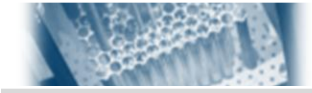
Material research

Φ_{Fast} = 1 to 5.10^{14} n/cm².s

(En>1 MeV) in large volumes

Fuel research

Φ_{tot} = 0.5 to 1.10^{15} n/cm².s



Fission GEN IV

Fusion

Φ = 1 to 5.10^{14} n/cm².s

(ppm He/dpa ~ 10)

in medium-large volumes

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

50 to 100 MWth

Φ_{Fast} = ~10^{15} n/cm².s

(En>0.75 MeV)

Waste

High energy LINAC

600 MeV – 1 GeV

Long irradiation time

Fundamental research

Φ_{th} = 0.5 to 2.10^{15} n/cm².s

(En<0.4 eV)

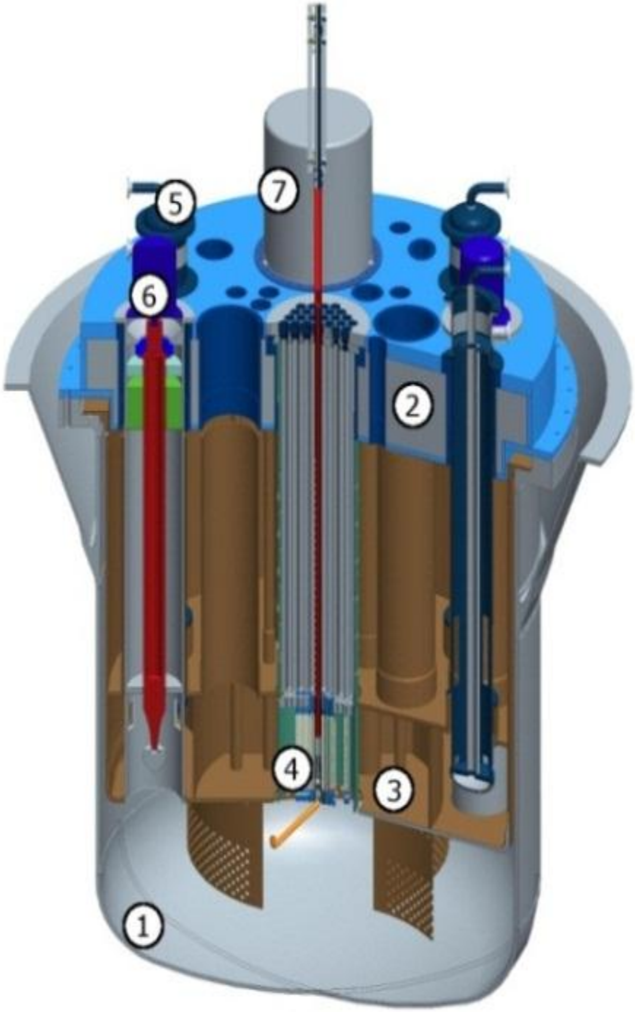
Radio-isotopes

Silicon doping

Φ_{th} = 0.1 to 1.10^{14} n/cm².s

(En<0.4 eV)

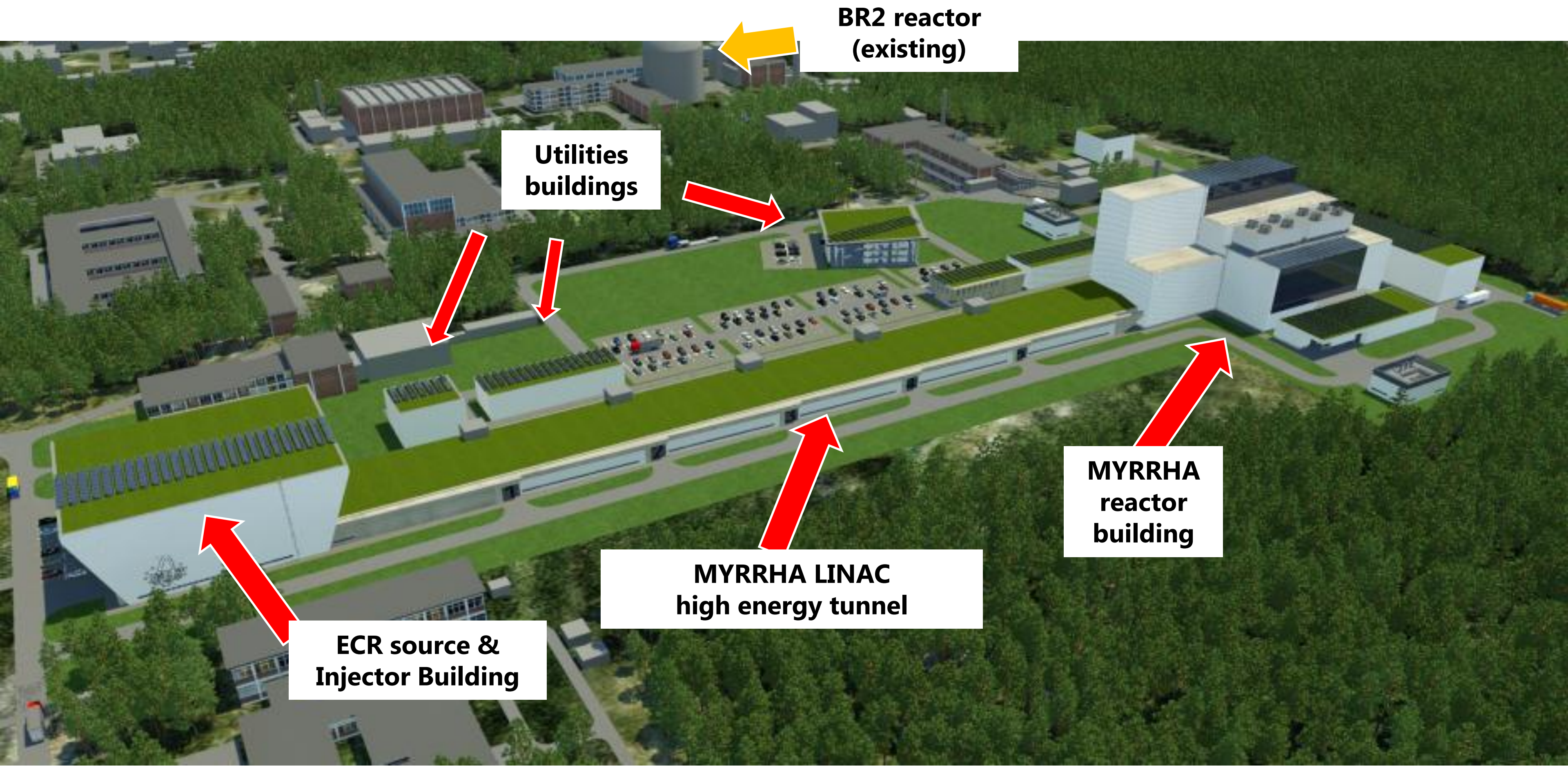
Current MYRRHA design (Primary)



Pool-type ADS with LBE coolant
Critical/Subcritical modes
Melting point: 125°C
IVFS: Bottom fuel loading
IFVHM (SCARA)
MOX (30% Pu)

1. **Reactor vessel**
2. **Reactor cover**
3. **Diaphragm**
4. **Core**
5. **Primary heat exchanger**
6. **Primary pump**
7. **In-vessel Fuel-handling machine**

MYRRHA


BR2 reactor
(existing)
Utilities
buildings
MYRRHA
reactor
building
MYRRHA LINAC
high energy tunnel
ECR source &
Injector Building

MYRRHA Linac Accelerator

Key concepts

- Conservative technological solutions
- Modularity for fault tolerance

Key challenge

- MTBF > 250h (Failure= beam trip > 3s)

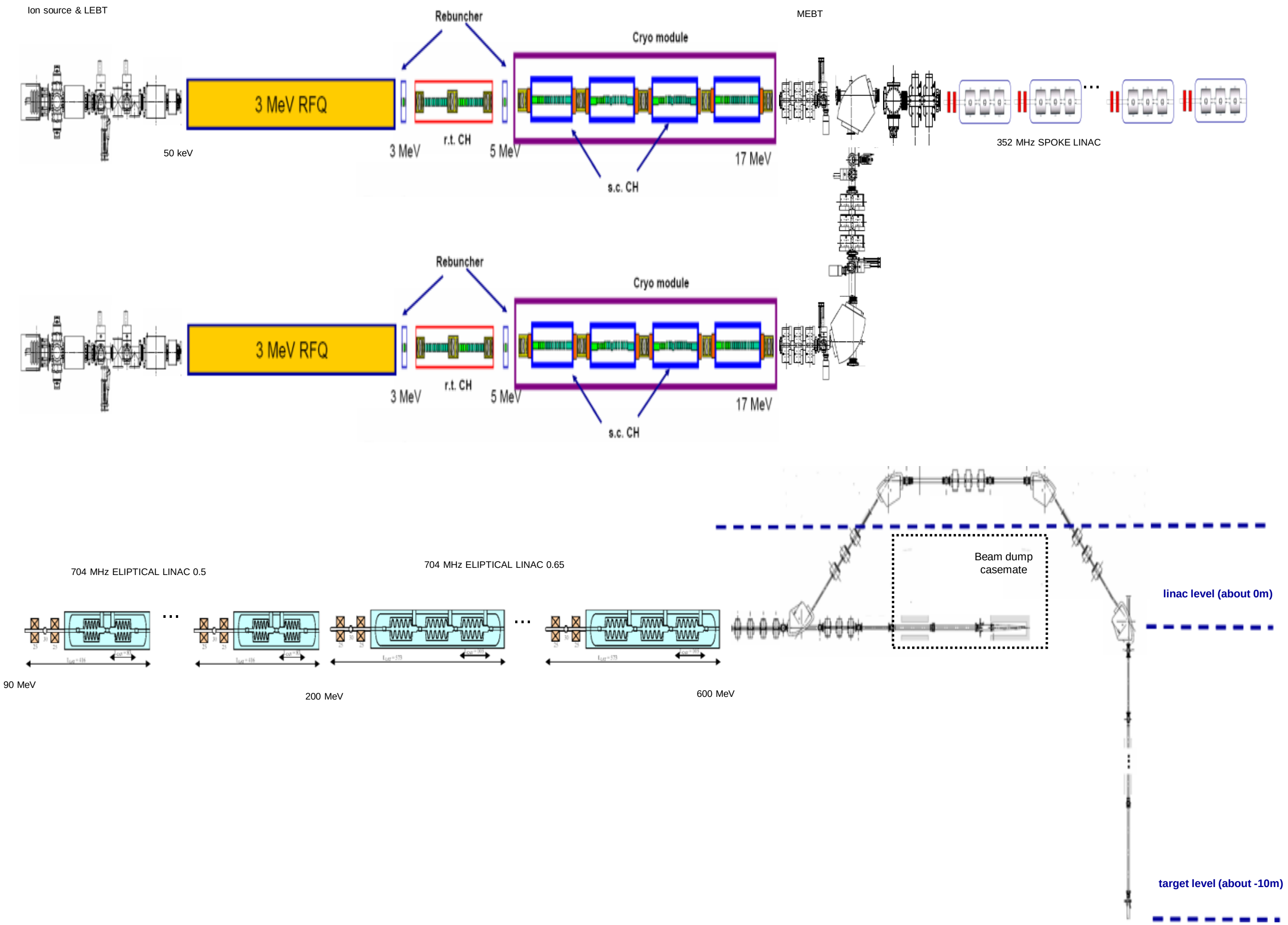
Keys to reliability (availability) and fault tolerance

- Redundancy
- Powerful diagnostics: predictive & self-diagnostics
- Strict MTBF control
- Repairability

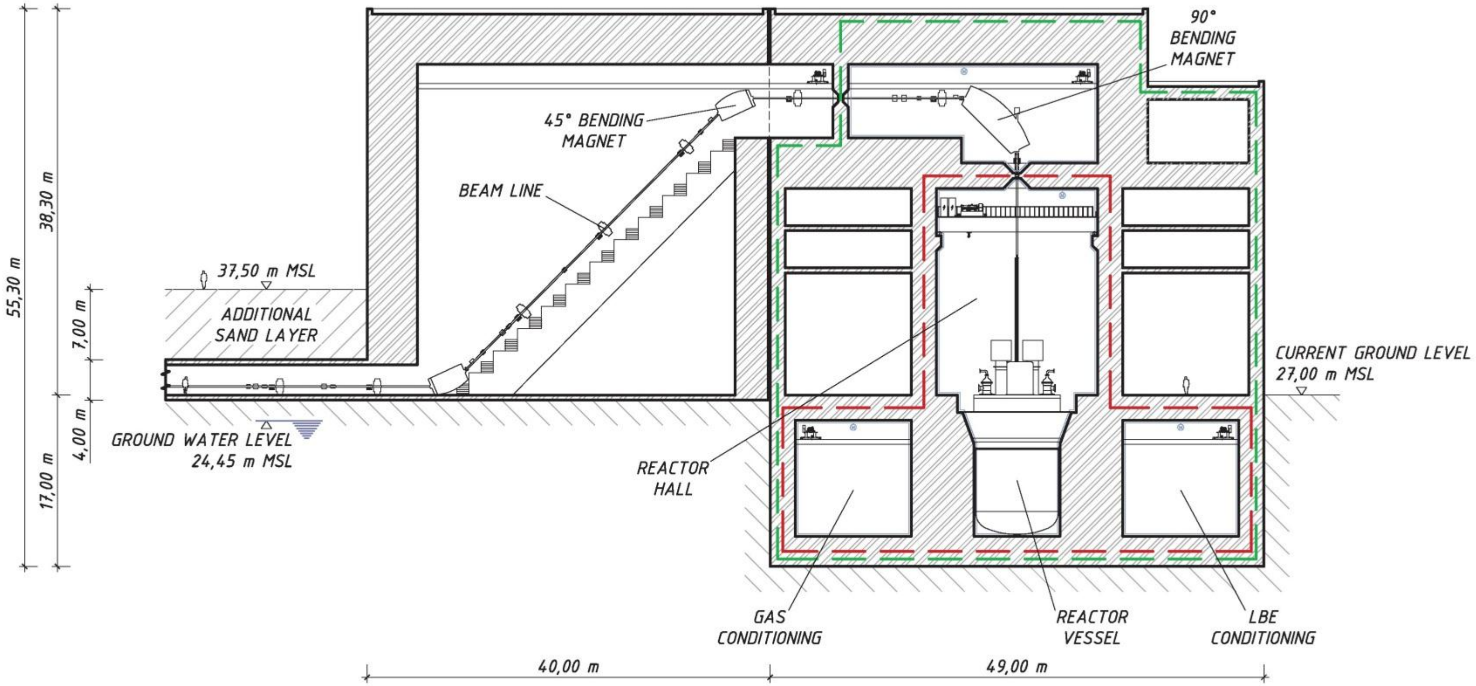
Critical issues adressed through prototyping

- RFQ, Cryomodules
- Non-interceptive beam diagnostics
- Robust controls

MYRRHA Linac Accelerator – Reference design

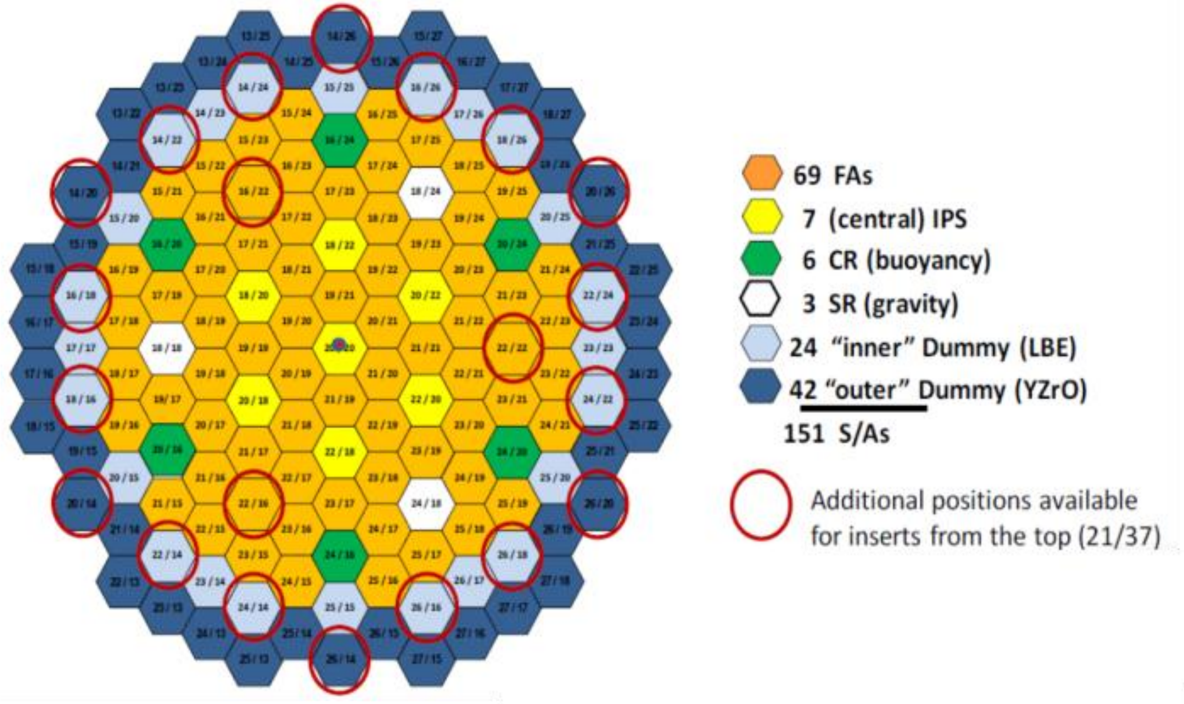


BEAM FROM TUNNEL TO REACTOR BUILDING



Core and Fuel Assemblies (CDT)

- 151 positions
- 37 multifunctional plugs



Core and spallation target

- Core
  - High intensity fast neutron flux is obtained by:
    - Optimizing the core configuration geometry
    - Maximizing the power density
  - Use of LBE allows to lower the core inlet operating T° down to 270 °C (decreasing risk of corrosion)

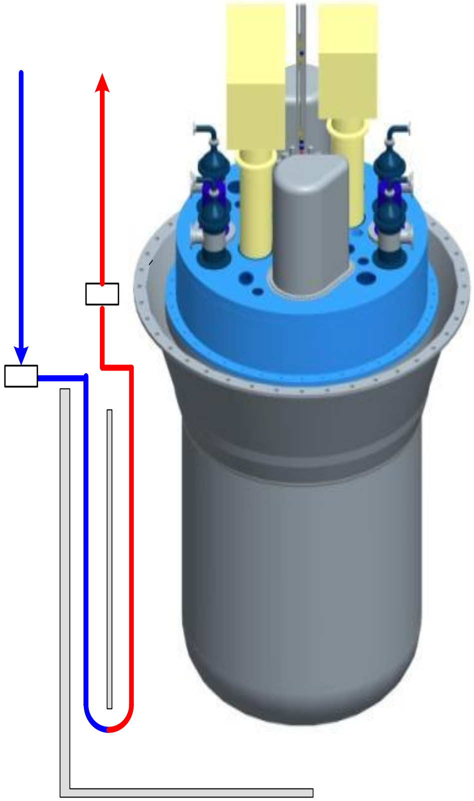
- Spallation target assembly
  - Evacuates the spallation heat deposit
  - Guarantees the barrier between LBE and reactor hall, and
  - Ensures optimal conditions for the spallation reaction

Cooling systems

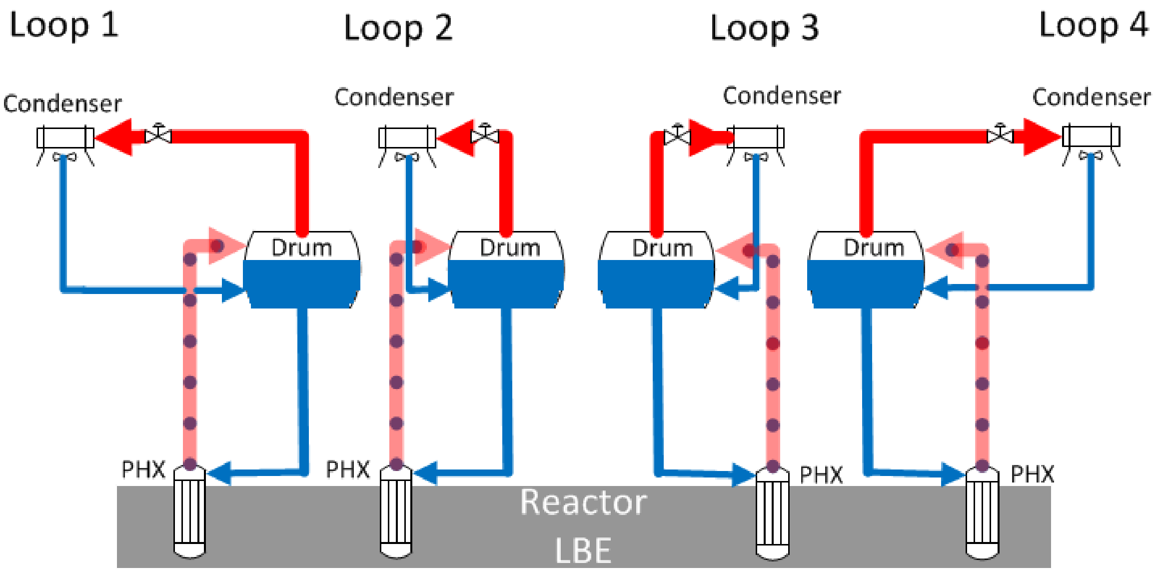
- Average coolant temperature increase in the core in nominal conditions is 140°C with a velocity of 2 m/s
- 2 pumps (flow rate of 4750 kg/s to the core)
- 4 PHX connecting I to II systems

- Decay heat removal (DHR) through secondary loops
  - 4 independent loops (one/PHX)
  - redundancy (each loop has 100% capability)
  - passive operation (natural convection in primary, secondary and tertiary loop)

- Ultimate DHR through RVCS (natural convection)



DHR – SCS



SCS: saturated water/vapour as heat transfer medium

TCS: aero-condensers to release heat to atmosphere

Licensing process

- *Consideration of a pre-licensing phase*
  - **For** a complex nuclear installation relying on new technologies like MYRRHA
  - **To** timely communicate on design development and its expectations in terms of nuclear safety and security requirements, and safeguards provision
  - **By** implementing instruments providing guidance to the owner/designer
- *Pre-licensing phase approach*
  - Identification and evaluation of “Focus Points” (FPs), new or not mature enough issues specific to MYRRHA that may have an impact on the safety of the facility by jeopardizing any of the 3 safety functions
  - Elaboration of a Design Options and Provisions File (DOPF)
- *Pre-licensing phase objective*
  - To converge satisfactorily, through an iterative process, after info exchange and consultation of the regulatory authorities, to a fixed design that comply with requirements
  - Once this demo is achieved, attest can be delivered that provides the applicant with a solid basis and confidence for the licensing of the facility

SAFETY Methodology

- Approach: DiD, meeting GEN III requirements, striving to GEN IV ones, as a step towards demo of GEN IV LFR technology

- Objectives: general (ARBIS), specific (FANC) requirements based on WENRA (future reactors) & IAEA standards (MYRRHA relevant)

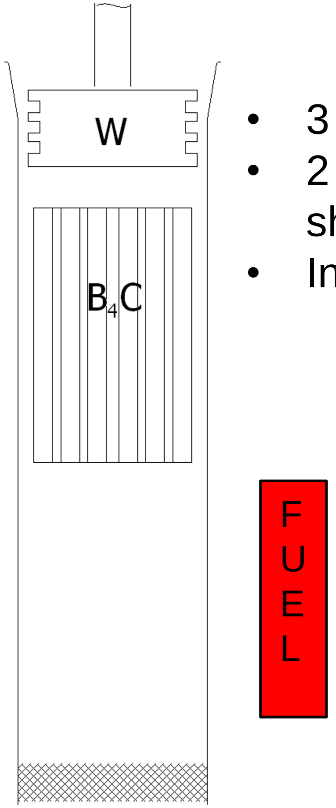
- Functions: similar to other types of reactors: control of reactivity, DHR, confinement of radioactive materials

- Principles and goals:
  - All major safety functions as passive as possible and at least independent of any external support system
  - Minimize human intervention for the mitigation of design basis accidents: operator grace time of 72 hours is aimed for
  - Practical elimination of severe accidents by high reliability, redundancy and diversity of safety functions

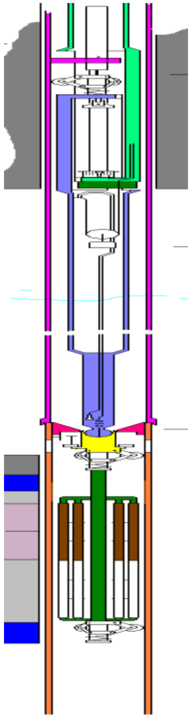
Reactivity Control

- *Subcritical core:*
  - Subcritical by ≅ 4000 pcm   keff = .96
  - Inherently safe for reactivity insertion events
  - Shutdown by beam interruption
- *Critical core:*
  - Two shutdown systems:
    - Fail safe
    - Mutually diverse

Control of reactivity: safety/control rods



- 3 safety rods
- 2 have sufficient shutdown anti-reactivity
- Insertion by gravity



- 6 control rods for reactor control & scram
- 5 sufficient for shutdown
- passive insertion by floating capacity
- diverse from safety rods

SAFETY Challenges (1/2)

Three examples for LBE

1. **Materials**
   - Structural material degradation by corrosion
     - Industrially available and qualified materials (also for timing)
       - Titanium stabilized austenitic stainless steel 15-15Ti (DIN 1.4970)
       - Ferritic martensitic steel T91
       - Austenitic stainless steel 316L
     - New challenges: LBE, lower temperature range, p&n irradiation

2. **Solidification**
   - Critical safety issue in relation with flow and DHR
     - Necessary provisions foreseen (insulation, electrical heaters)
     - Special attention to contact with cold surfaces and secondary feed water under transient conditions (control, monitoring)
   - Danger for integrity of primary circuit equipt (impurities, vol. changes)

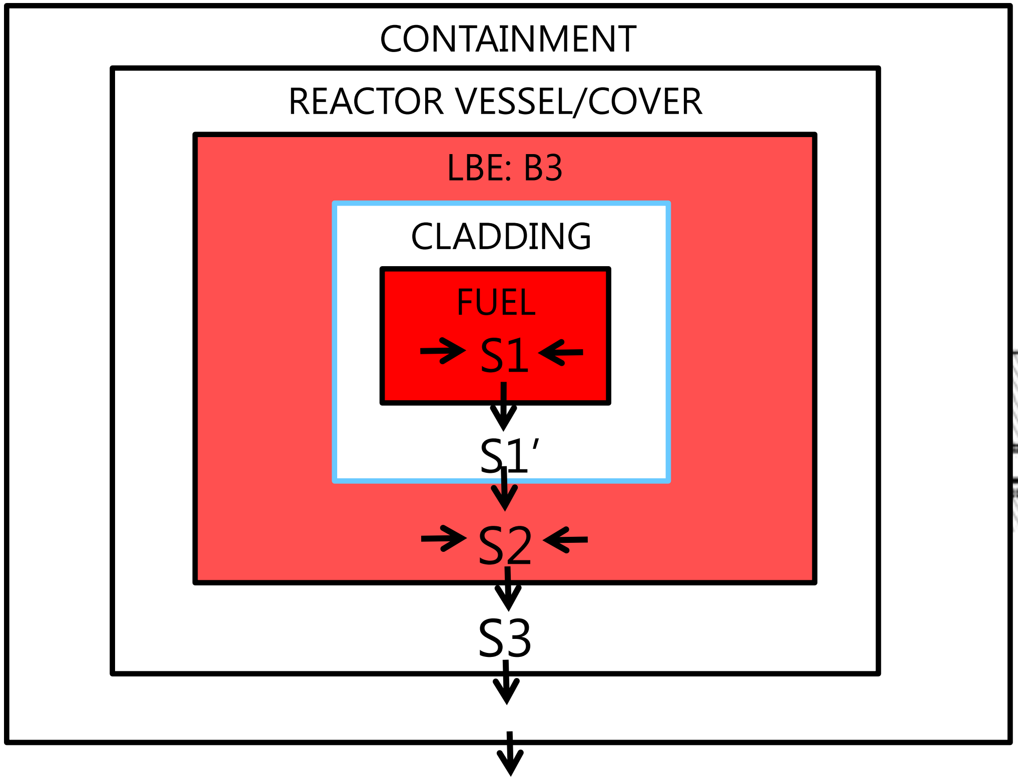
SAFETY Challenges (2/2)

3. Confinement of radioactive products

- Formation of important quantities of RN in the spallation target

- Important radiation protection challenges
  - Isotopes of practically all chemical elements produced by different nuclear reactions, including +/- volatile elements at LBE operating temperature;
  - ^{210}Po, highly radiotoxic, formed by neutronic capture on either ^{209}Bi, or ^{208}Pb. This requires safe operation and handling of systems/materials (RV).;
  - Mercury, very volatile, also produced in large quantities;
  - Fissions products formed by high energy protons on LBE, including e.g. I, Ar, Kr, Xe.
  - At higher temperature, evaporation of volatile products to cover gas plenum (Hg, Po, I, Cs), reducing the number of barriers left.

Confinement/Containment



CONTAINMENT

REACTOR VESSEL/COVER

LBE: B3

CLADDING

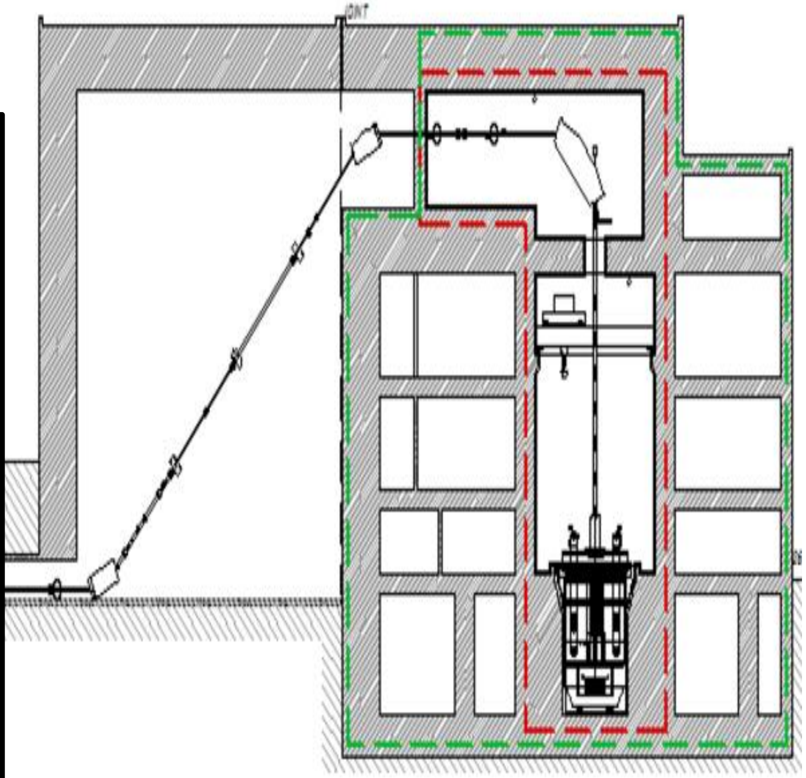
FUEL

S1

S1’

S2

S3



R&D programme (1/2)

- In response to such challenges, an R&D programme covers e.g.:
  - Chemical conditioning of the coolant to minimize dissolution of structural materials and core internals and to prevent the formation and precipitation of oxides by filtration and trapping of impurities;
  - Purification of the evaporated gasses by evaporation and capture of volatile and/or highly toxic elements from the cover gas.

- Challenges further imply issues to be dealt with through studies and demonstrations (loops and mock-ups):
  - Reliability of submerged components (IVFHM): component qualification test but also integrated test of a complete fuel manipulation operation in LBE;
  - Experimental and numerical analysis of TH behaviour;
  - Coolability confirmation of the target window (collaboration JAEA);
  - Experimental validation of models describing control and safety systems (scram);
  - Development of sensors to measure dissolved oxygen concentration in the coolant.

R&D programme (2/2)

- Construction/commissioning of LBE test facilities are running or planned in Belgium and abroad, like:
  - FA thermal-hydraulic tests prepared as part of the FP7 programme SEARCH (KALLA THEADES loop at KIT, NACIE and HELENA loops at ENEA).
  - Design of a thermal-hydraulic scaled model of MYRRHA using water as fluid within the DEMOCRITOS (DEmonstration of Myrrha Operation and CRITical Objects for Safety) project at Von Karman Institute (VKI), also including sloshing experiments and tests related to hydraulic/mechanical primary pump design;
  - Addressing the reactor pool phenomena, E-SCAPE (European Scaled Pool Experiment) at SCK·CEN and an upgrade of the LBE CIRCE facility (ENEA) in the frame of FP7 project THINS (Thermal Hydraulics of Innovative Nuclear Systems).

- Development and validation high- and low-resolution Computational Fluid Dynamics (CFD) models to support the design while numerical activities will be performed by KIT, NRG and SCK•CEN.

Conclusions

- To fullfil the objectives and safety requirements of a flexible irradiation facility like MYRRHA using a Generation IV nuclear power system's type technology (LBE cooled fast neutron reactor), quite a lot of safety challenges have to be solved.
- Focus has been put here on the current design of the primary system by identifying more precisely some of the challenges we have to face and the actions we are developing to deal with them.
- Inherent safety features with respect to reactivity control, subcriticality, passive DHR removal systems, confinement performance of barriers are excluding several possible initiators and scenarios (“Safety built in”)
- The European collaboration at all steps of project development within 3 FP’s underline the technical/scientific interest for the MYRRHA project.
- Begin 2013, the contribution of the FEED contractor will first allow, after consolidating the proposed design, to further assess and analyse SSC's performance with a view to **enhanced safety robustness** for the MYRRHA project, and to support substantially most of the demonstration and validation exercises still today required for licensing purposes.

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