Ongoing RELAP5-3D-related activities at SCK•CEN

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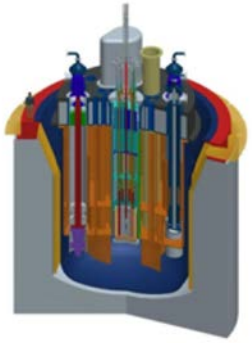
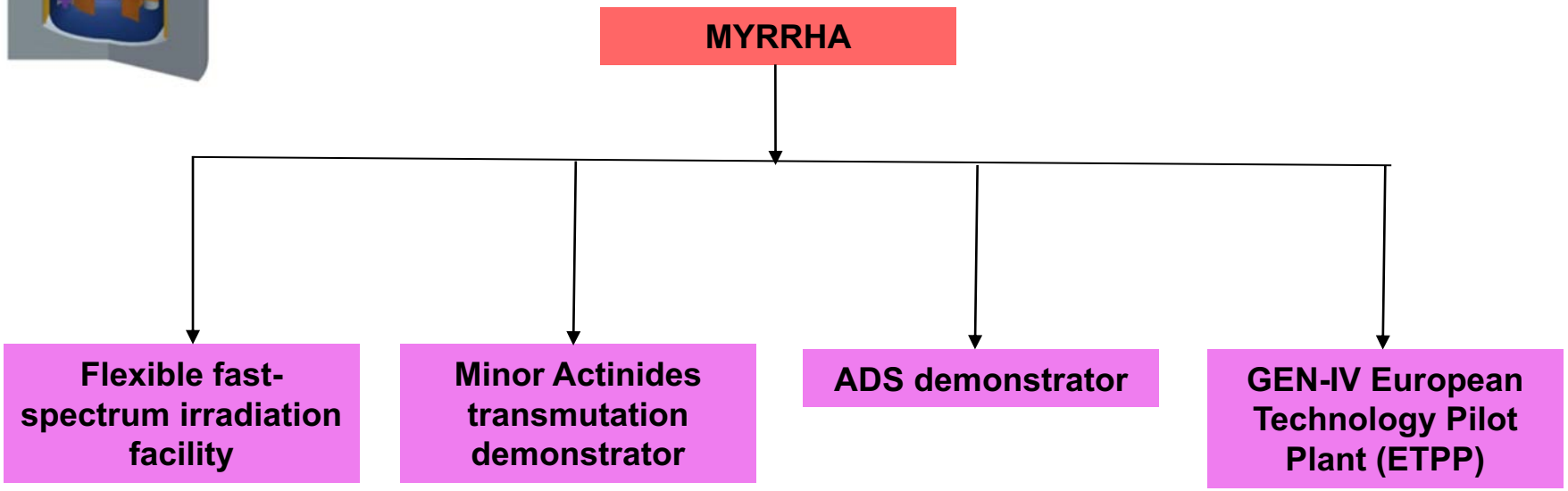
- MYRRHA pre-licensing activities: safety studies
- MYRRHA pre-licensing activities: experiments

MYRRHA plant main features – Main purposes

- MYRRHA: Multi-purpose hYbrid Research Reactor for High-tech Applications at SCK•CEN



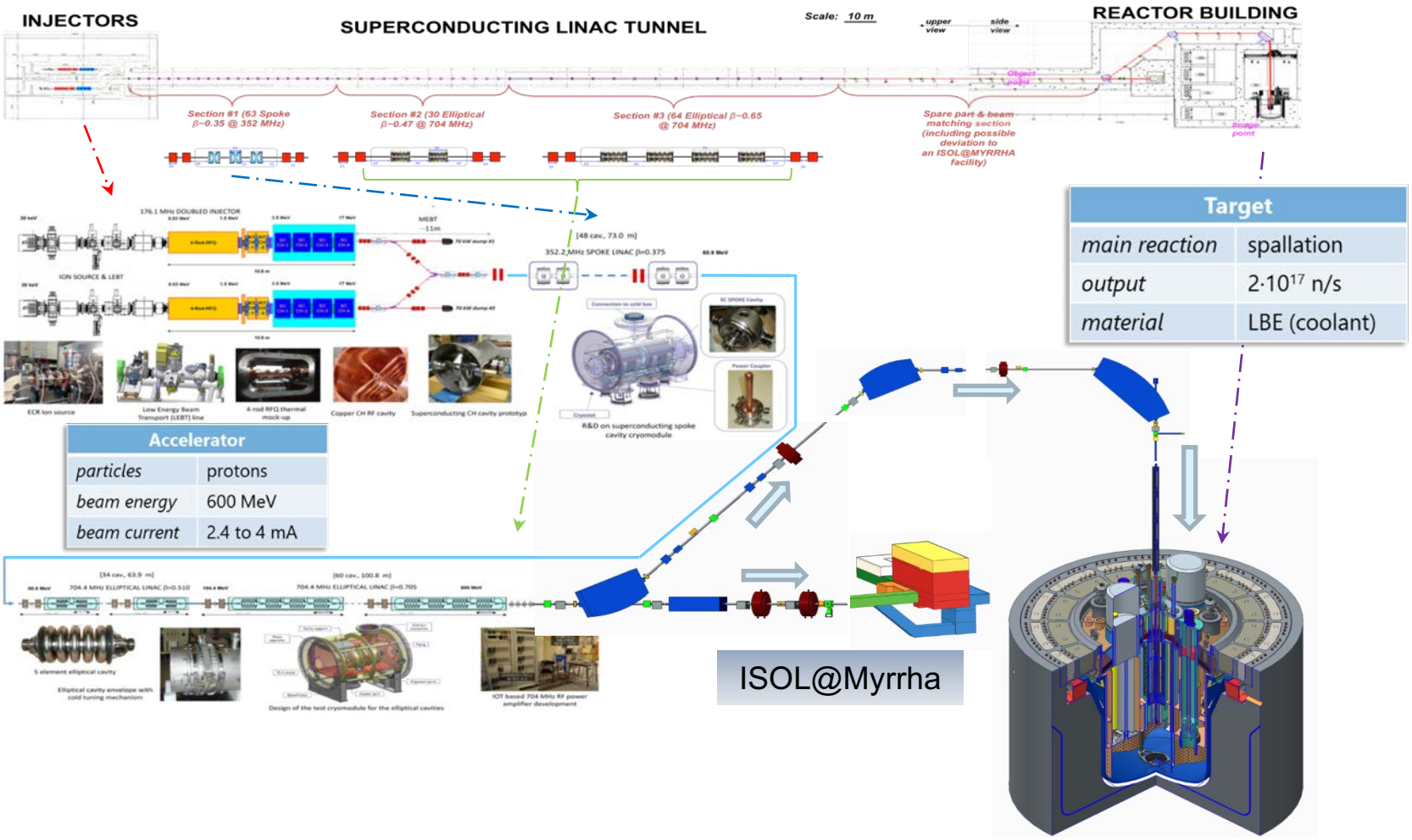
- Pool-type Accelerator Driven System (ADS) with ability to operate also as critical reactor
- Liquid Lead-Bismuth Eutectic (LBE) as primary coolant



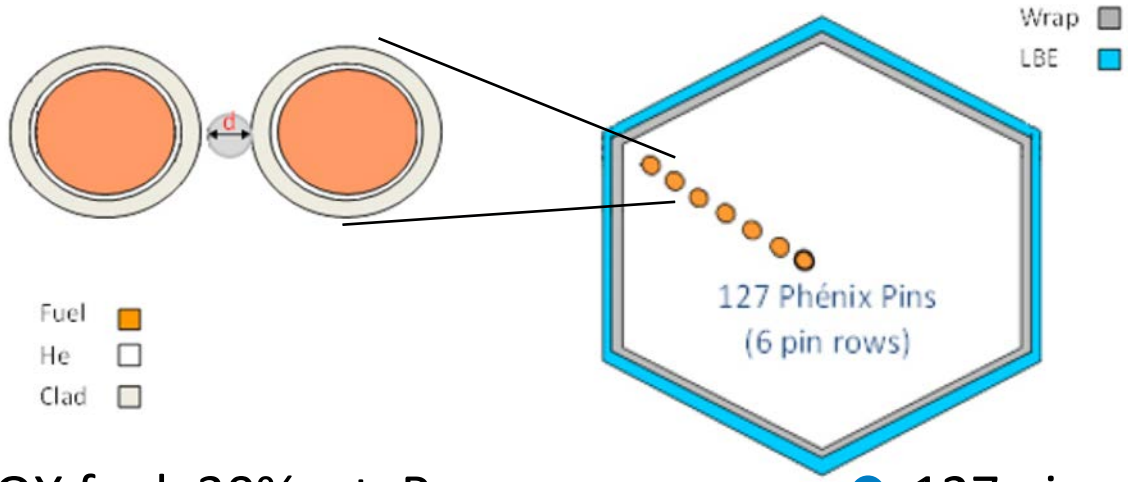
- MYRRHA project recognized as high priority infrastructure for nuclear research in Europe

MYRRHA plant main features – Plant overview

- MYRRHA: accelerator driven system (ADS)

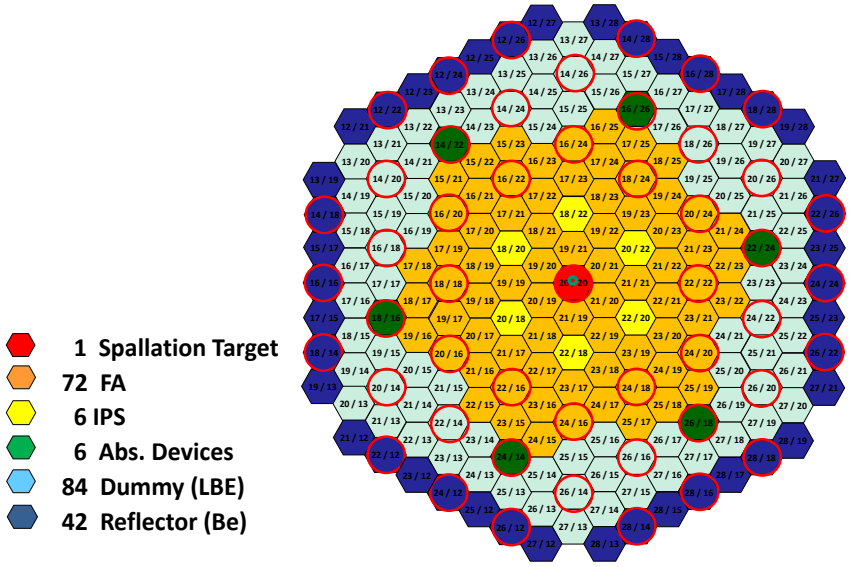


MYRRHA plant main features – Fuel pin and fuel assembly

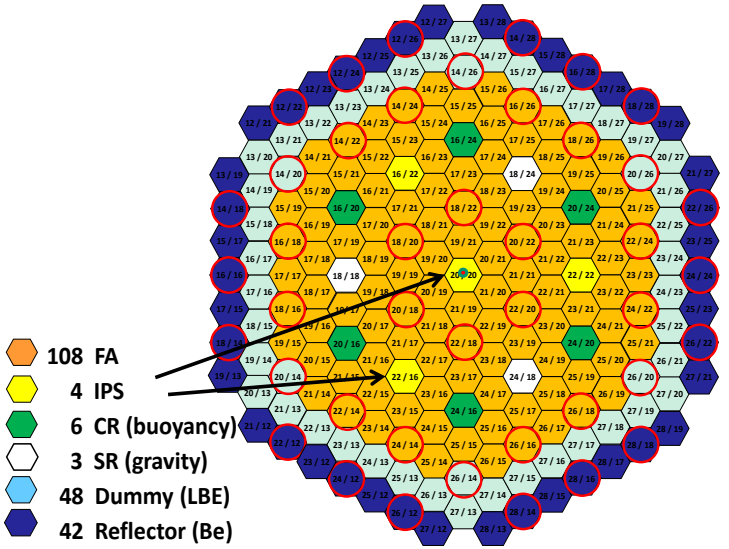


- MOX fuel, 30% wt. Pu
- Fuel pin with wire spacer
  - Less vibrations
  - Easier to fabricate and mount
  - Better for small P/D (otherwise too thick)
- Active length: 65 cm
- 127 pins per Fuel Assembly
  - Hexagonal lattice
- Closed structure
  - Wrapper enclosing pin bundle
- Total length: ~2.5 m
- Flow rate: 71.4 kg/s

MYRRHA plant main features – Core layout



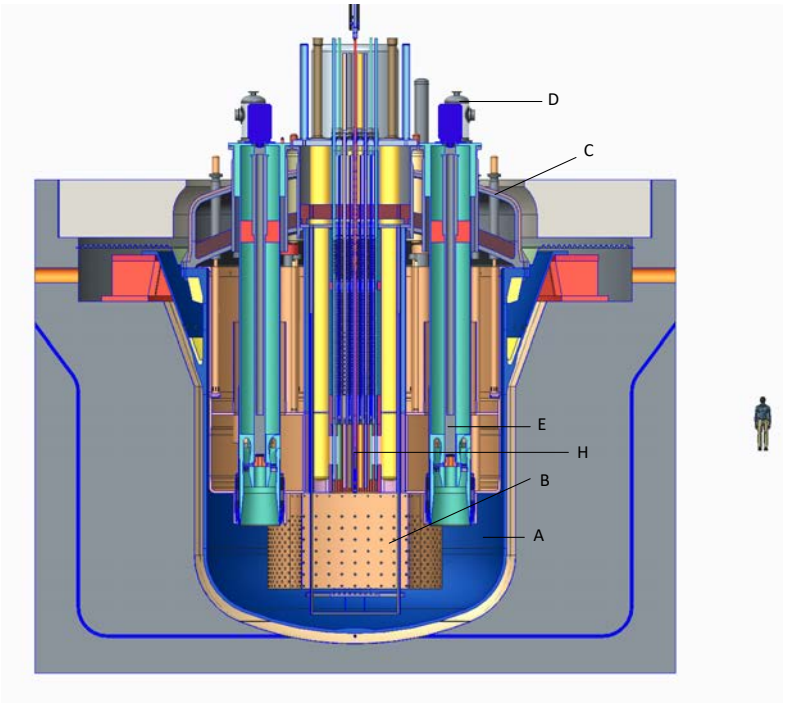
- Smaller core (72 FAs)
- Lower power (75 MW)
- No safety rods required
  - Keff = 0.95 → improved safety
- High and hard flux in core center → MA transmutation
- Proton source + window required
- High peaking factors → Peaked temperature profiles

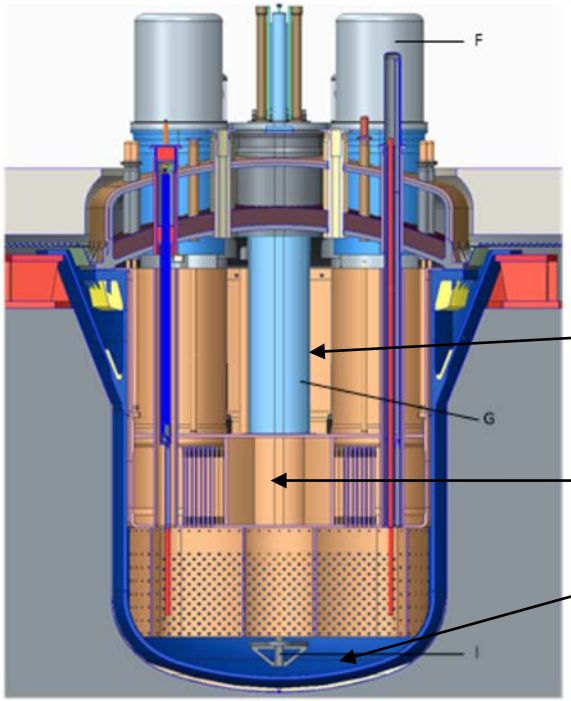


- Larger core (108 FAs)
- Higher power (100 MW)
- Safety rods required
- Lower and softer neutron flux in core center
- No external source required
- Lower peaking factors
- Operating experience

MYRRHA plant main features – Primary cooling system

- Primary system: completely enclosed in primary vessel (pool-type)





- 4 Primary Heat eXchanger (PHX)
- 2 Primary Pumps (PPs)

Upper plenum: 325 °C

Core: 100 MW

Lower plenum: 270 °C

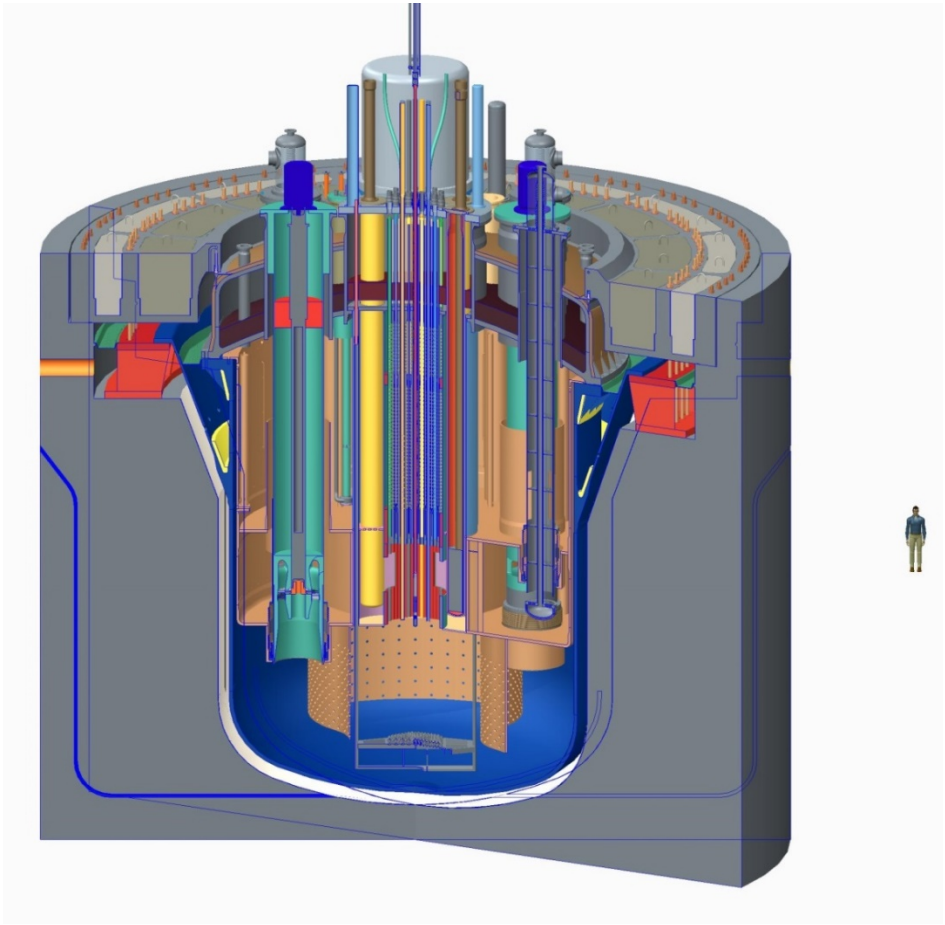
A.	Reactor vessel	F.	In-Vessel Fuel Handling Machine
B.	Diaphragm		
C.	Reactor Cover	G.	Core Barrel
D.	Primary Heat Exchanger	H.	Reactor core
E.	Primary Pump	I.	Core Restraint System

- Cold plenum separated from hot plenum by Diaphragm
- Above LBE free surface: Nitrogen layer

MYRRHA plant main features – Primary cooling system

- 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

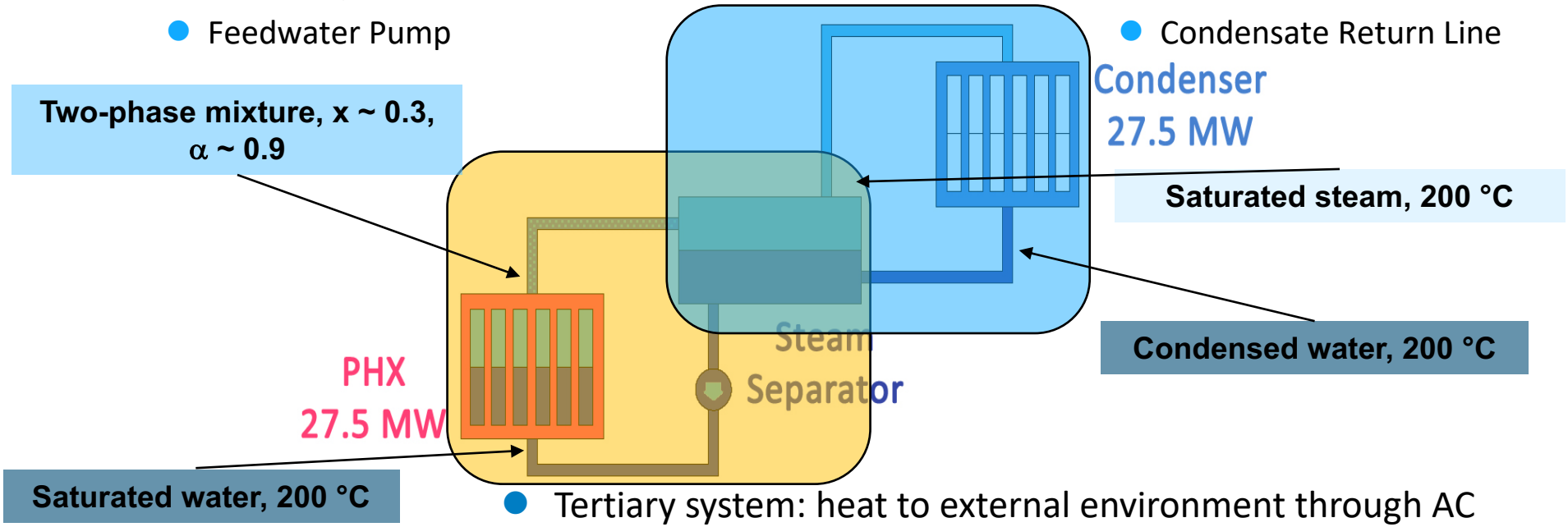


MYRRHA plant main features – STCS

- MYRRHA Secondary Cooling System (SCS):
  - Four independent SCSs loops operated at 16 bar, 200 °C

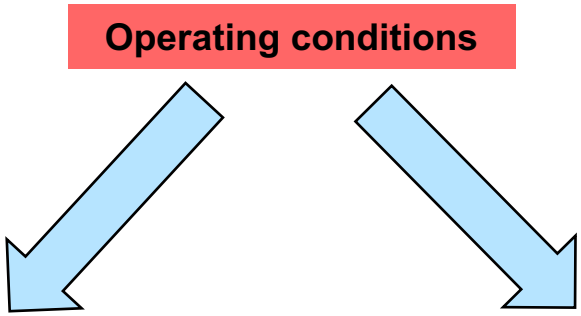
- First sub-loop:
  - PHX
  - Steam Separator
  - Feedwater Pump

- Second sub-loop:
  - Steam Line
  - Aero-Condenser
  - Condensate Return Line



- Tertiary system: heat to external environment through AC

MYRRHA plant main features – Operation conditions



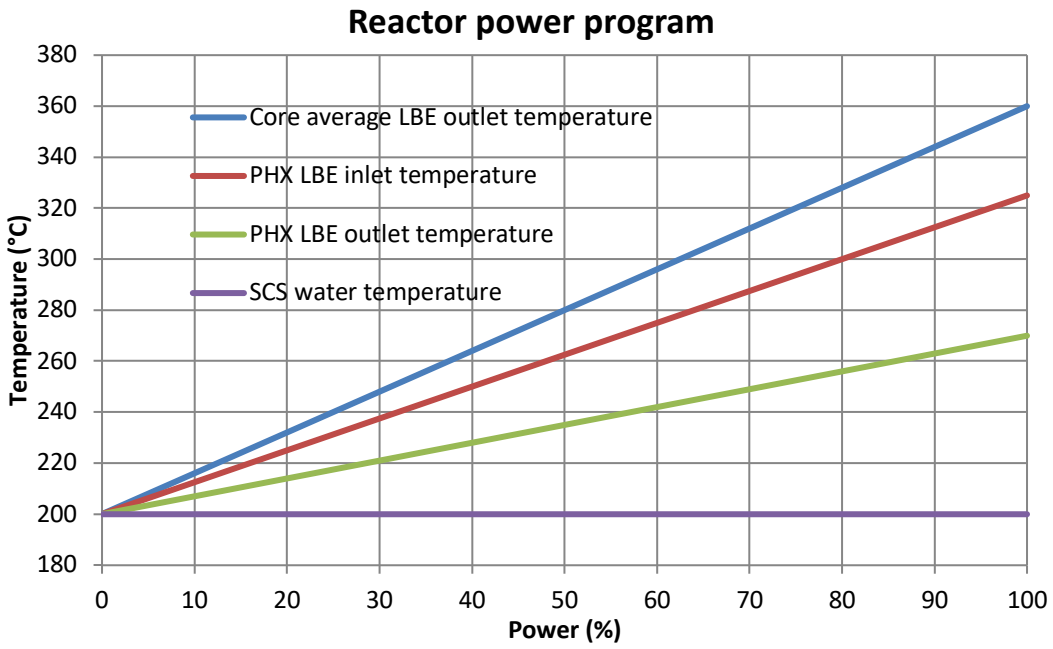
- Normal operation → Plant operating in forced circulation
- Power: 110 MW (maximum)
  - 100 MW → core power
  - 10 MW → additional heat sources:
    - In Vessel Storage Tank (IVST)
    - Po decay heat
    - Pump power
    - γ heating
    - Spallation target power

- Accidental conditions → Plant able to remove Decay Heat in passive mode (natural circulation)
- Two systems to accomplish DHR function:
  - DHR-1: STCS operating in passive mode (if required)
  - DHR-2: Reactor Vessel Auxiliary Cooling System (RVACS)

MYRRHA plant main features – Reactor Power Program

- MYRRHA: Material Testing and Demonstrator Reactor → high degree of flexibility required in terms of operational power

- Power program concept:
  - Primary and Secondary mass flow rate constant at any power load
  - SCS pressure and temperature constant at any power load (16 bar, 200 °C)
  - Primary System temperatures and PHX outlet quality varying with power load

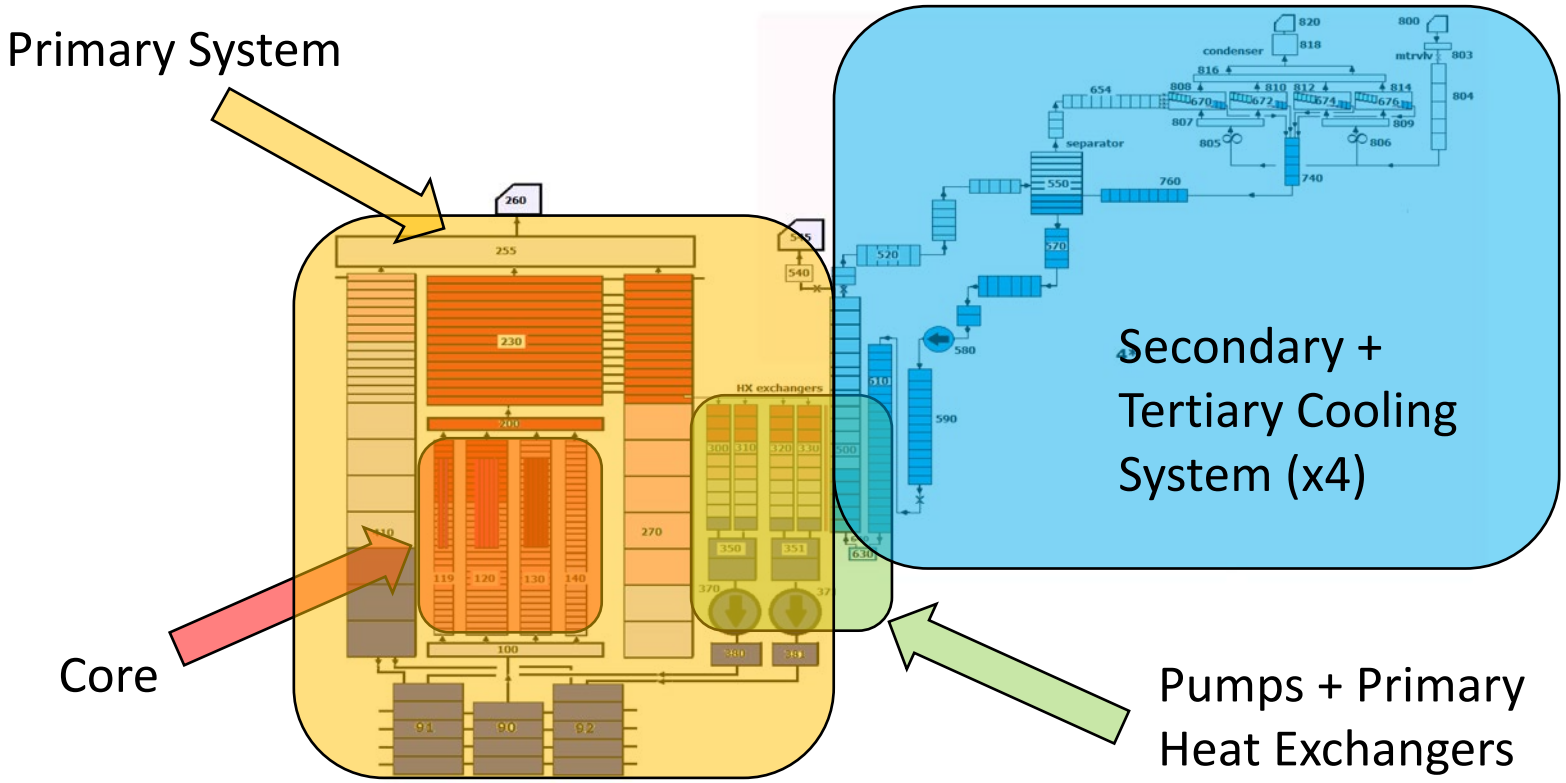


- High SCS pressures at partial loads avoided!

MYRRHA pre-licensing activities: safety studies

- MYRRHA plant main features
- MYRRHA pre-licensing activities: safety studies
- MYRRHA pre-licensing activities: experiments

MYRRHA pre-licensing activities – RELAP5-3D model



- RELAP5-3D MYRRHA plant model:
  - 2518 volumes, 2590 junctions
  - All cooling systems (primary, secondary, tertiary) simulated
  - Main control systems (Control Rods, secondary pressure) included

MYRRHA pre-licensing activities – RELAP5-3D model

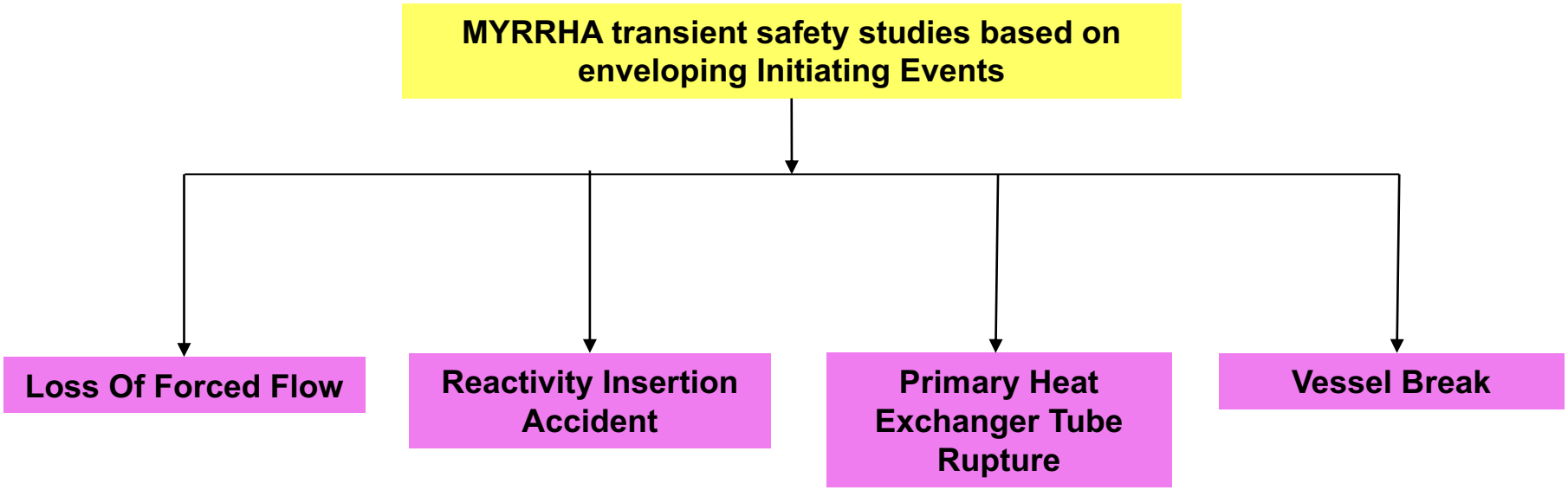
- Main steady state results reported:

Parameter	Unit	RELAP5-3D value	Reference value	Error %
Active core mass flow rate	kg/s	7719.3	7711.2	0.10
Total primary system mass flow rate	kg/s	13833.6	13800.0	0.24
Core inlet temperature	°C	266.0	270.0	-1.48
Core average outlet temperature	°C	351.7	360.0	-2.30
Average core temperature difference	°C	85.7	90.0	-4.78
FA friction pressure losses	Pa	196397	200000.0	-1.80
PP head	Pa	311571	300000.0	3.86
SCS first sub-loop mass flow rate	kg/s	45.9	47.0	-2.34
PHX SCS lower head pressure	Pa	1603210.0	1600000.0	0.20
PHX water outlet quality	-	0.3	0.3	~0

- Good agreement between code-calculated values and design values
  - Limited differences due to different LBE physical properties (mainly C_p)
- Maximum clad temperature ~470 °C
- Maximum fuel temperature ~1600 °C (low value due to low linear power ~110 W/cm)

MYRRHA pre-licensing activities: safety studies – Transients

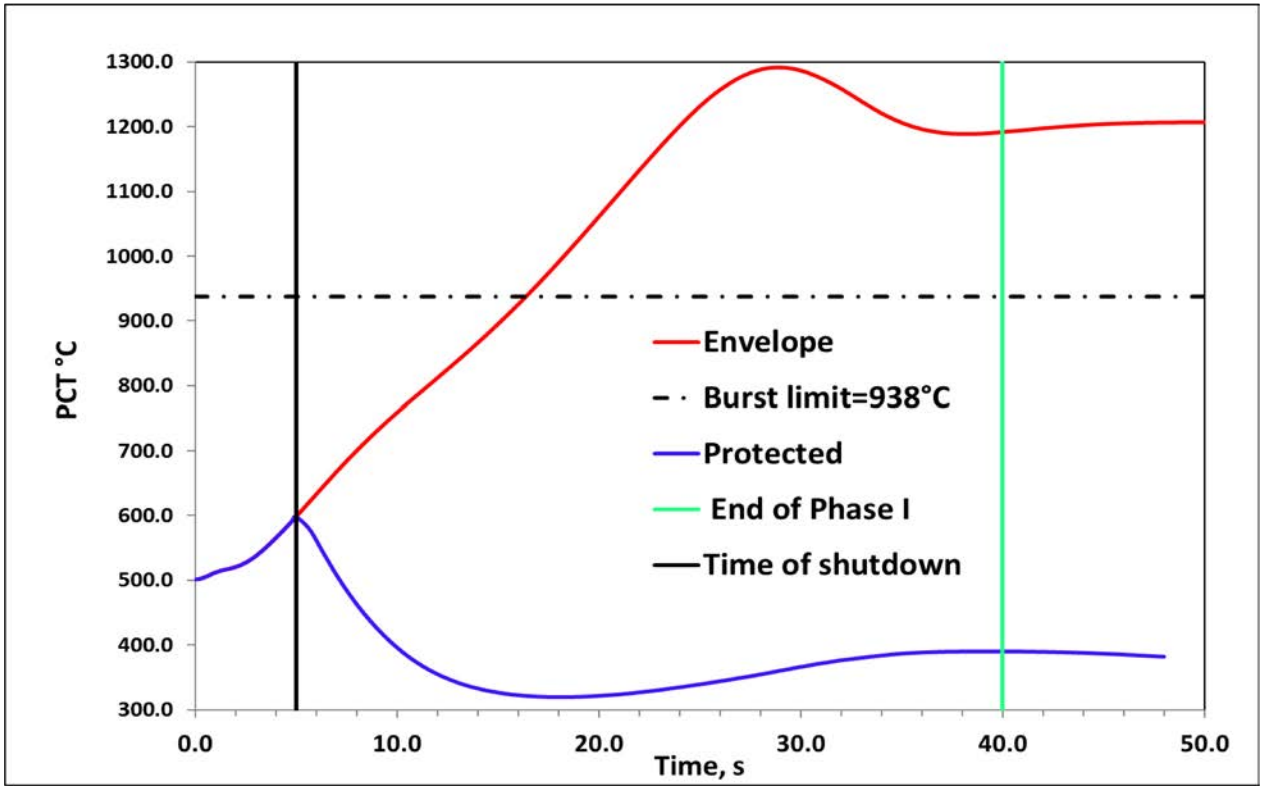
- MYRRHA entered pre-licensing phase (contacts with Belgian Safety Authority started)



- Transients simulated using reference MYRRHA RELAP5-3D model
  - Appropriate boundary conditions assumed to represent enveloping conservative cases

MYRRHA pre-licensing activities – LOFF

- Reference envelope LOFF transient: Loss Of Offsite Power with double locked rotor



- Unprotected transient: limit reached after ~17 s
- Protected transient: safety criterion well respected

MYRRHA pre-licensing activities – RIA

- Reactivity insertion caused by several reasons:
  - Water ingress
  - Core compaction
  - Accidental control rod ejection or withdrawal
- MYRRHA official RELAP5-3D model modified:
  - Secondary Cooling System removed
  - Primary System reduced to core region
  - Core split in 18 channels: different fuel batch → different gap conductance and NK feedbacks
- Conservative case in terms of pin conductivity, thermal expansion and reactivity feedbacks:
  - Maximum step-type reactivity insertion: 211 pcm
  - Maximum slope-type reactivity insertion: 109 pcm/s

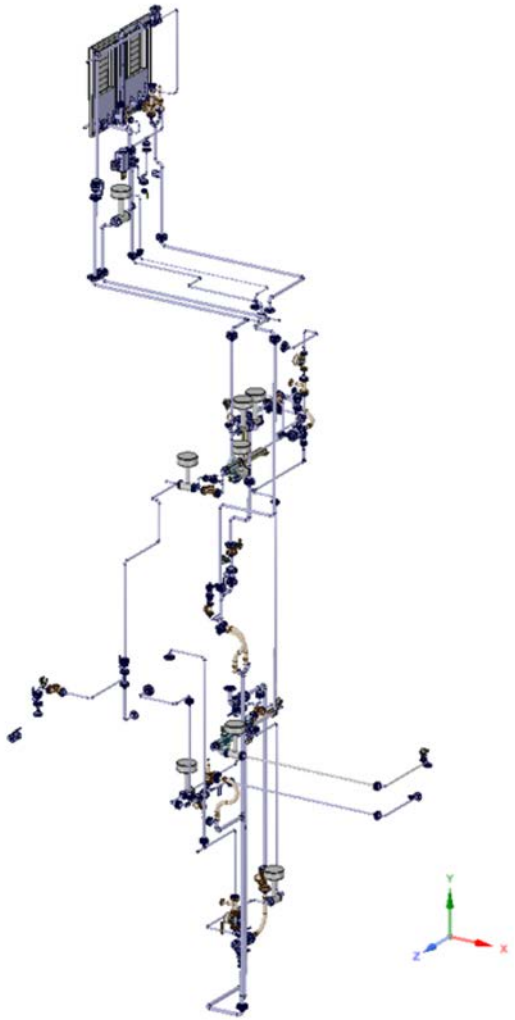
MYRRHA pre-licensing activities: experiments

- MYRRHA plant main features
- MYRRHA pre-licensing activities: safety studies
- MYRRHA pre-licensing activities: experiments

MYRRHA pre-licensing activities – HEXACOM

- Heat EXchanger At COMplot (HEXACOM): two-phase pressurized water loop simulating MYRRHA PHX and SCS
  - Maximum power: 100 kW
  - Design pressure: 25 bar

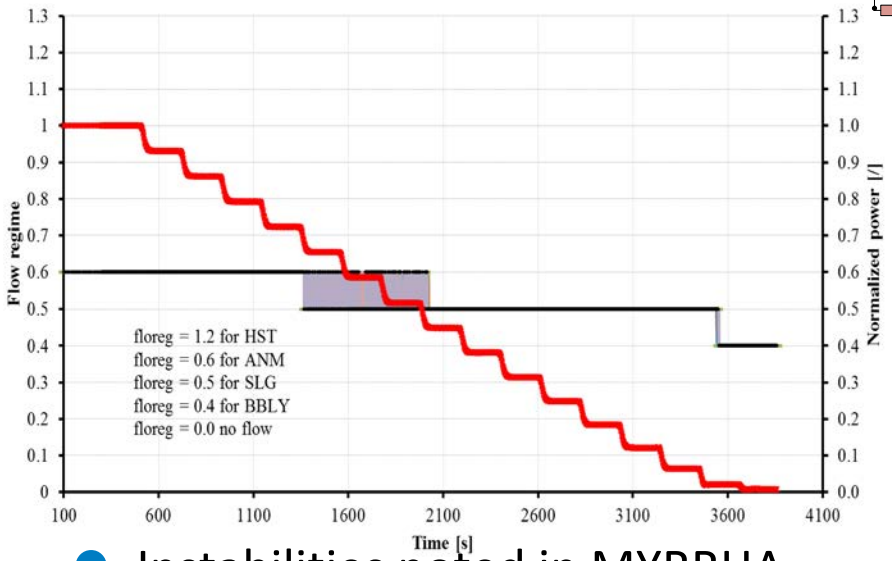
- Main objectives:
  - Investigate PHX configurations heat transfer performances
  - Develop and validate HTC correlations for HX bundles in LBE
  - Improve knowledge on two-phase phenomena at p < 20 bar
  - Obtain experimental databases for model development
  - Study two-phase phenomena in support of MYRRHA design



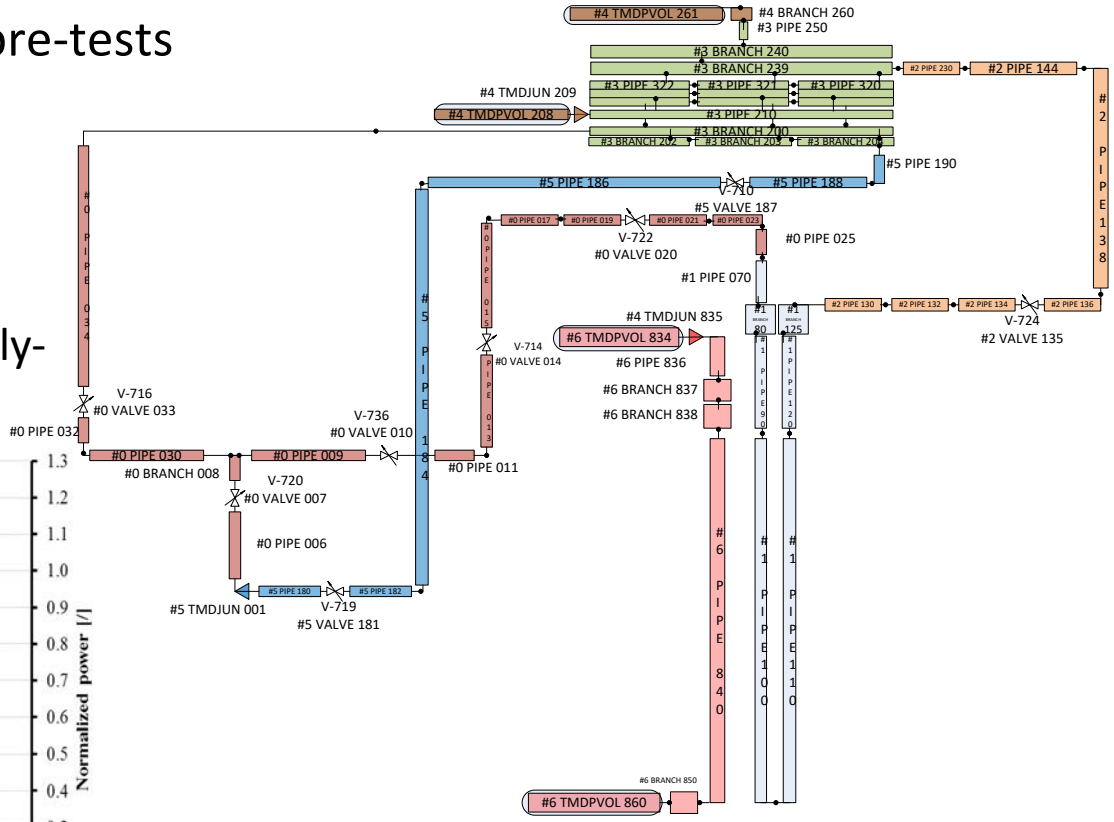
- Facility commission foreseen for end 2018

MYRRHA pre-licensing activities – HEXACOM

- HEXACOM RELAP5 model for pre-tests
- Full power: as expected
- Partial loads: instabilities in vertical line PIPE 138
  - Flow regime transitions: bubbly-slug and slug-annular



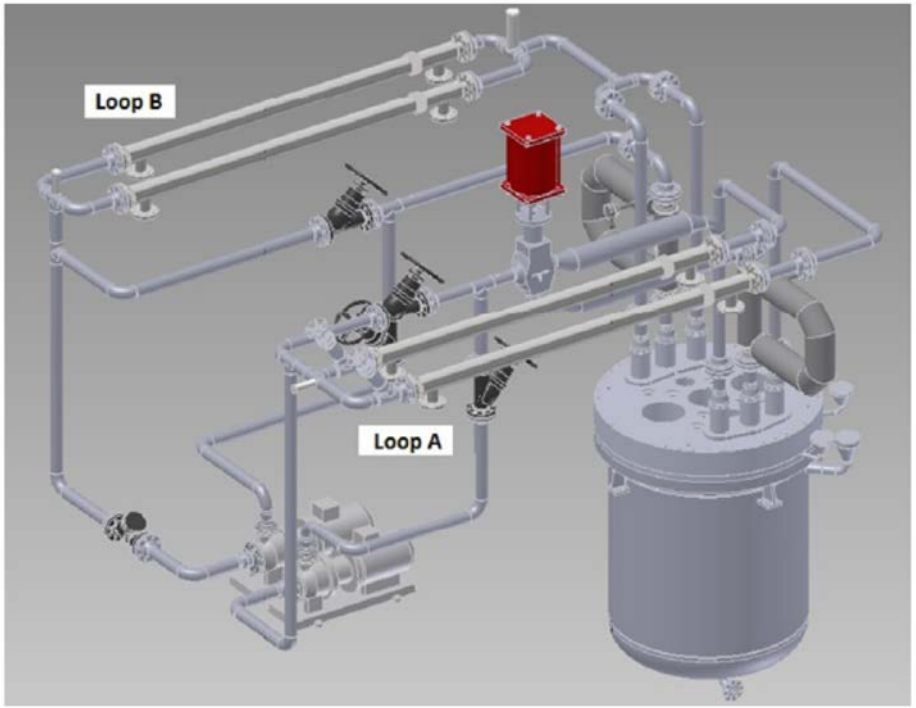
- Instabilities noted in MYRRHA model as well!



- 0 → 40%, 70% → 100%: stable
- 40% → 70%: unstable (slug ←→ annular)
- ~5%: unstable (bubbly ←→ slug)

MYRRHA pre-licensing activities – E-SCAPE

- European SCAled Pool Experiment (E-SCAPE): thermal hydraulic 1/6-scale model of the MYRRHA primary system
- Main objective: represent 3-D temperature and velocity fields (convection patterns, flow mixing, stratification)
- Power: 10 kW

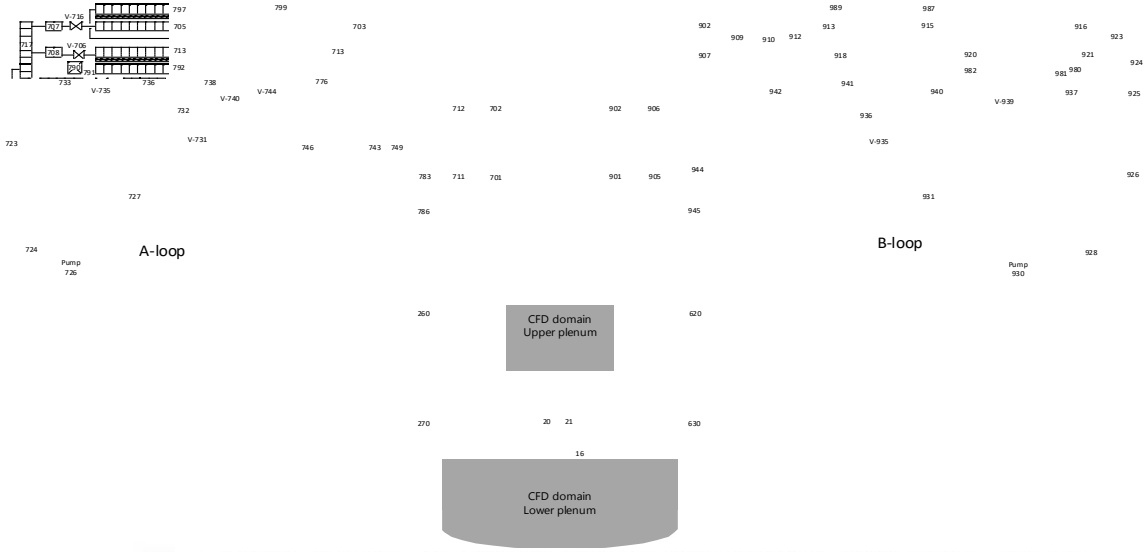


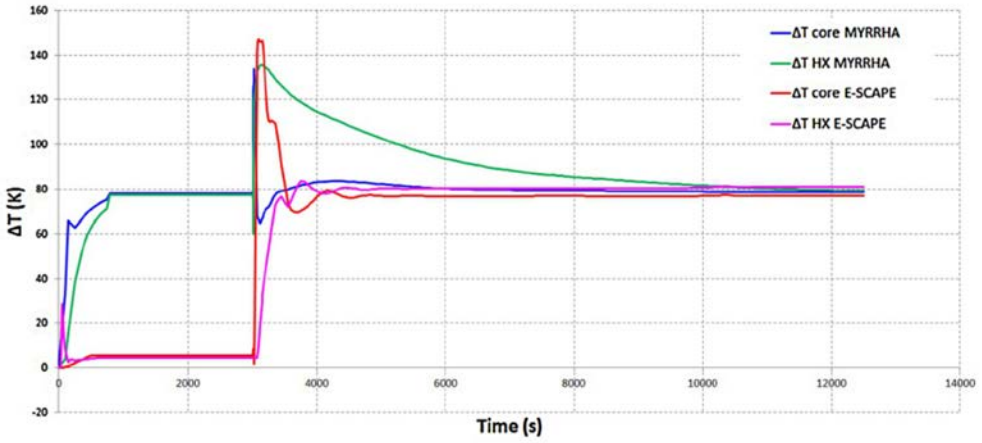
- Two main working conditions:
  - Forced circulation
  - Natural circulation
    - Correct temperature increase!
- Test matrix:
  - Full/reduced power operation
  - Single/multiple PHX or pump failure
- First steady-state tests recently finalized!

MYRRHA pre-licensing activities – E-SCAPE

- E-SCAPE RELAP5-3D model for pre-tests

- Model built to pre-test system performances and data post-test
  - Initially developed as RELAP5-3D stand-alone
  - Coupling with ANSYS-FLUENT
    → Two CFD domains included
- Transient tests post-tests to be finalized by April 2019 (EU H2020-MYRTE project)





- Loss Of Forced Flow pre-test simulation (MYRRHA vs. E-SCAPE)

Conclusions

- MYRRHA plant currently under development at SCK•CEN
  - Pre-licensing contact with Belgian Safety Authority started
  - Several safety studies delivered
  - Ongoing R&D program to better issue remaining open items

- RELAP5-3D: tool selected for design support and safety analysis
  - MYRRHA reference model
  - Pre- and post-test studies on experimental facilities → Contribution to code validation:
    - Lead-Bismuth Eutectic as primary coolant
    - Pool-type reactors 3-D velocity and temperature fields
    - Low pressure (< 16 bar) applications