ALFRED Design Features

Marco Caramello
Product Development Manager
marco.caramello@ann.ansaldoenergia.com

Agenda

Objective

Setting the base

Staged Approach

From where we are to where we want to be

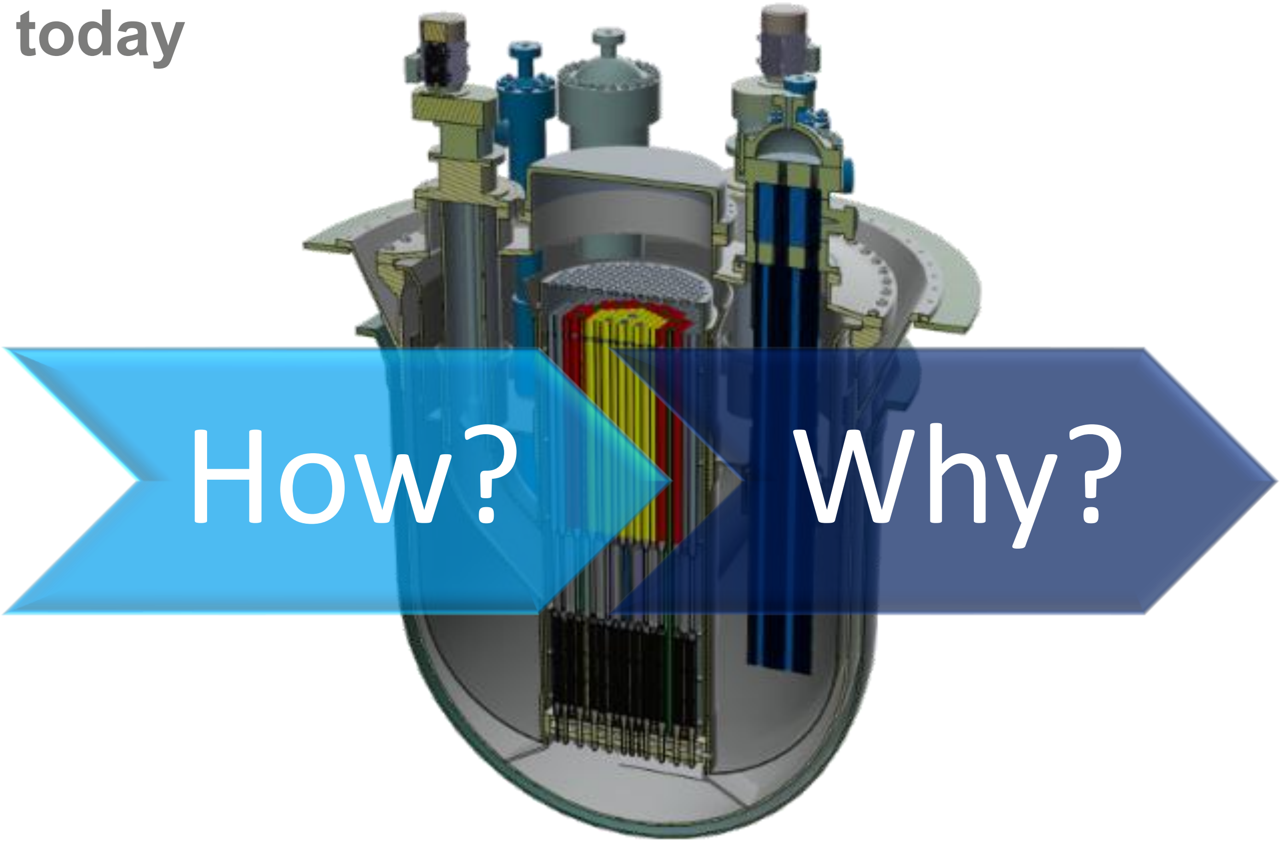
Reactor Block

The how

Safety Systems

Principles of decay heat

Aim of today

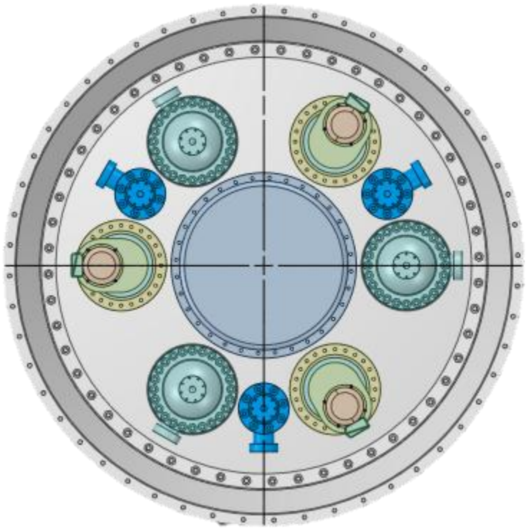


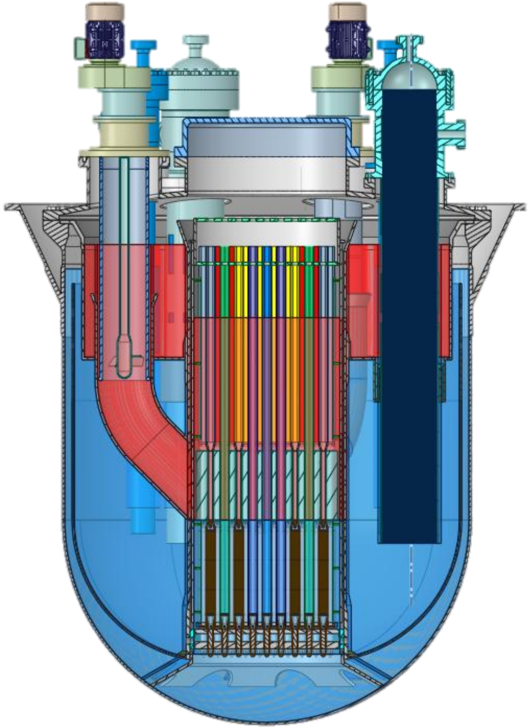
General arrangement

A loop in pool concept

- 1 Inner Vessel
- 1 Internal Structure
- 3 Steam Generators
- 3 Primary Pumps
- 3 Dip Coolers (DHR-2)

Everything can be extracted





Challenges

Design
Gaps in codes and standards

Technology
Innovative features are not tested

Safety
Demonstration requires data

Tools
Models and codes shall be validated

Licensing
There shall be consensus

Technology risk
A FOAK is still a FOAK

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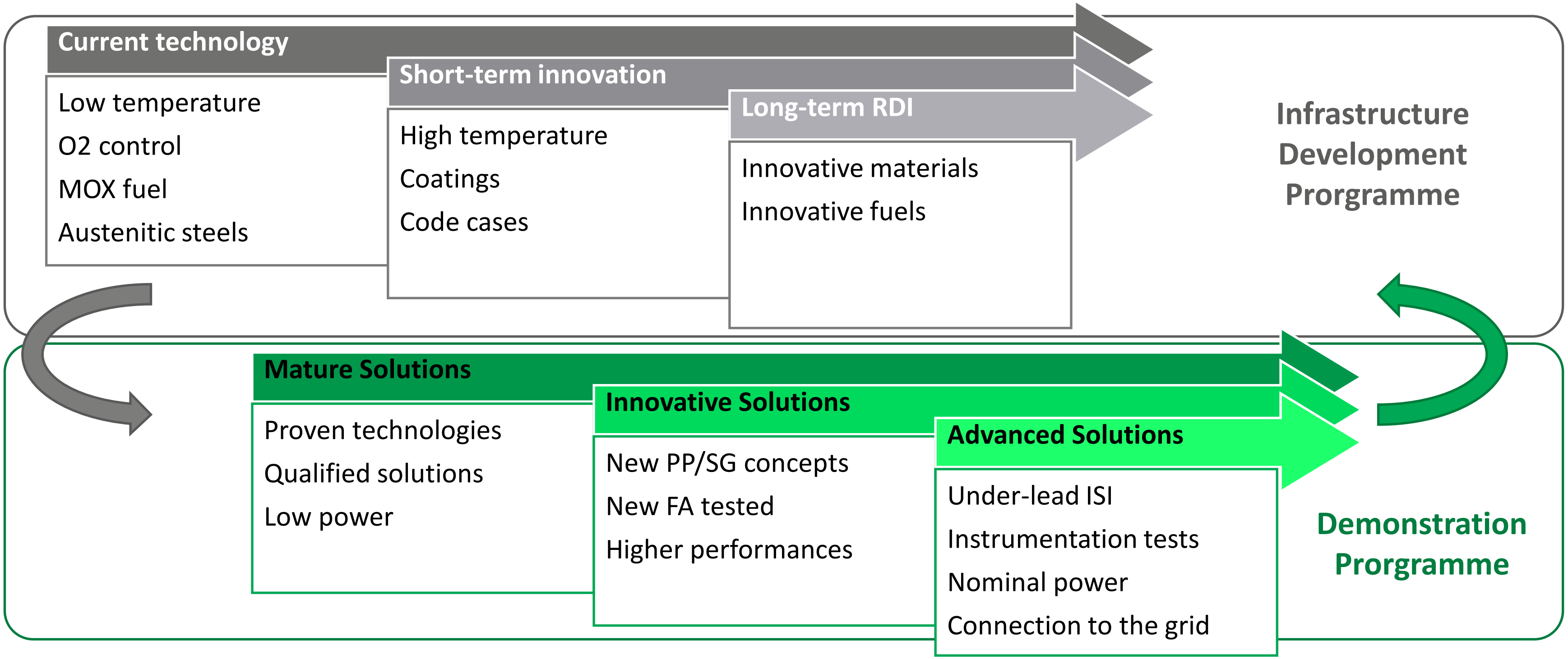
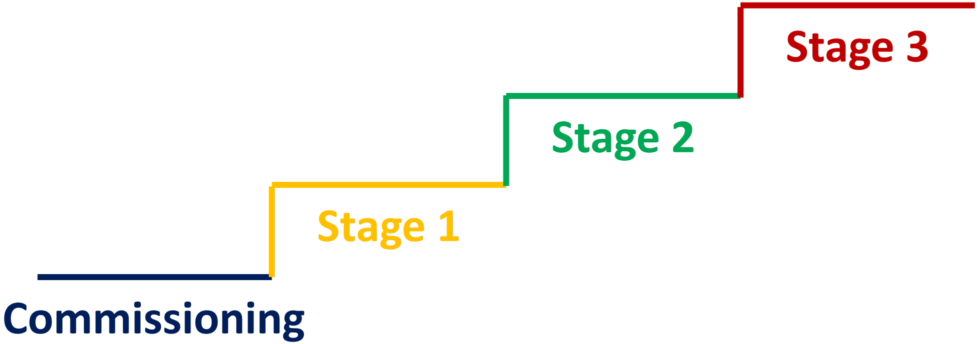
How to approach it



How to design a staged approach

	1st stage	Final stage
Power	100 MWth	300 MWth
Thermal cycle	390-430°C	400-520°C
chemistry control	10-6 ÷ 10-8 O2 wt.%	Same, but not effective
Materials	316L, 15-15Ti	Relying on coating or innovative materials



	Stage 0	Stage 1	Stage 2	Stage 3
Core inlet temperature (°C)	390	390	400	400
Core outlet temperature (°C)	390	430	480	520
Core thermal power (MW)	≈ 0	100	200	300

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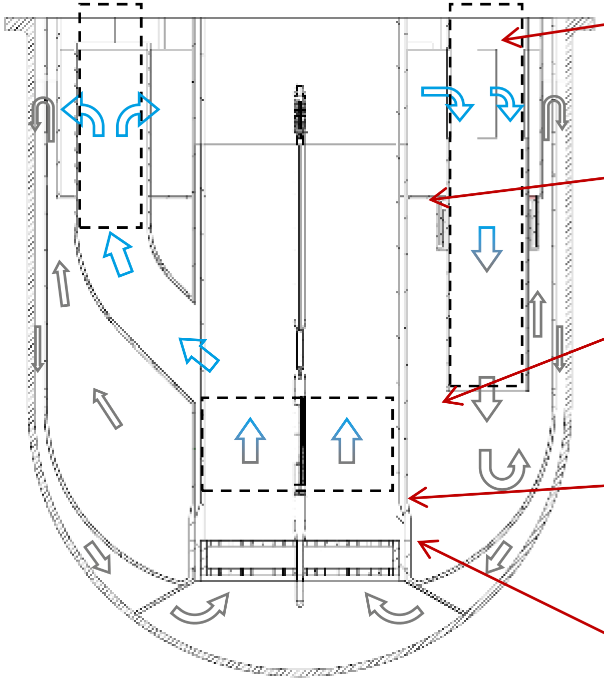
Design implications

Temperature, safety significance, irradiation, replaceability



Main components: separated and extractable for out of vessel inspections

Primary system configuration: separation of components based on safety functions

Lead temperature: limited to 400°C in the cold pool to ensure full compatibility with materials

Core: optimized and provided with a hot channel for qualification of future stages

Neutron irradiation: minimization of components subject to non-negligible neutron irradiation

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Operation implication

Condition	Parameter	Region	Stage 1	Stage 2	Stage 3
Full Power	Maximum Temperature (°C)	HS	450	535	600
		HP	430	480	520
		CP	390	400	400
Shutdown	Minimum Temperature (°C)	All	390	400	400
Accident (short-term)	Maximum Temperature (°C) / Holding time (hours)	HS	520 / 0.01	650 / 0.01	800 / 0.01
		HP	480 / 2,5	590 / 2,5	680 / 2,5
		CP	420 / 1000	430 / 1000	430 / 1000
Accident (long-term)	Minimum Temperature (°C)	All	330	330	330

Safety implications

Component/ Part	Safety Function	Region	Replace-ability	Life-time (years)	Irradiation level (dpa)	Lead velocity (m/s)	Risk Level
FA/cladding	Confinement	HS	Yes	5	100	2	Moderate
IV, core barrel, diagrid	Core restraint	HP	Yes	20	2	<1	Medium
IS	None	HP CP	No	40	Negligible	<2	Medium Low
HEX	Confinement, DHR	HP	Yes	20	Negligible	1	Medium
RCP/shaft, impeller	None	HP	Yes	10	Negligible	10	Medium
RV	Confinement	CP	No	40	Negligible	<<1	Low

Take aways

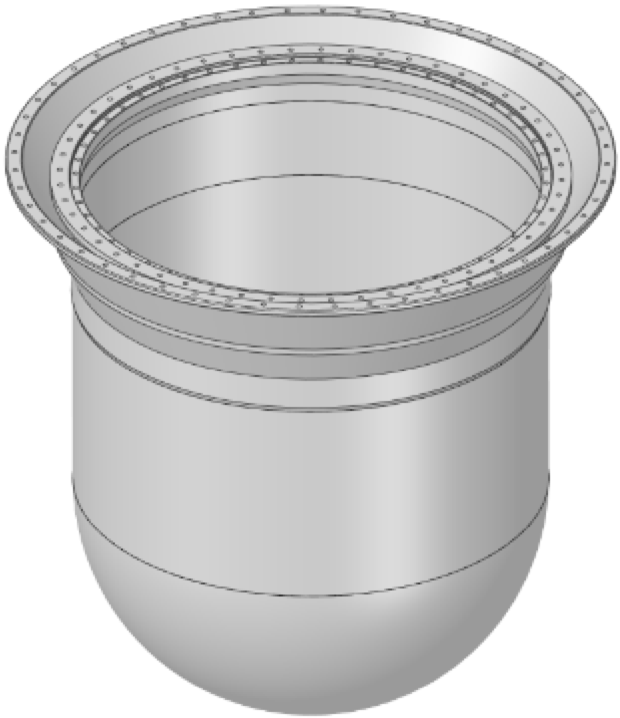
There is a gap between current technology and commercial target

The gap shall be approached with a pragmatic plan

All expected plant condition shall be considered

Reactor Vessel

Parameter	Value	Unit
Inner diameter	8300	mm
Height	10000	mm
Vessel thickness	50	mm
Vessel Y joint thickness	85	mm
Cover and support flange thickness	200	mm
Material	316 LN (or L)	
Corrosion protection measures (all stages)	Oxygen Control	



No penetrations below lead level

Full reactor lifetime

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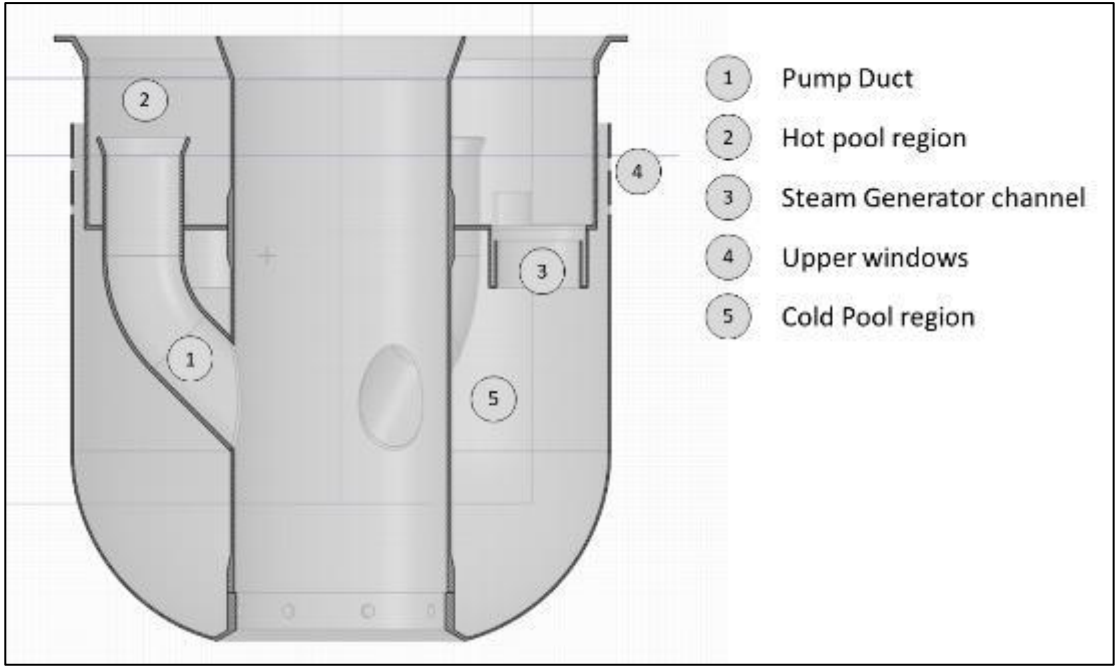
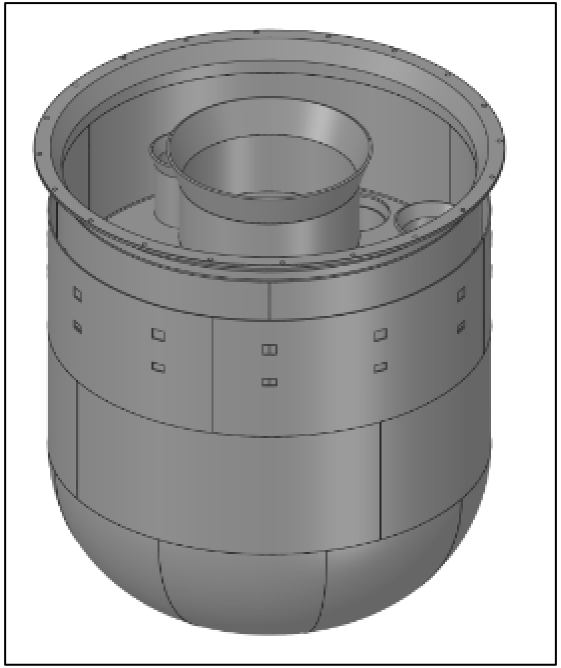
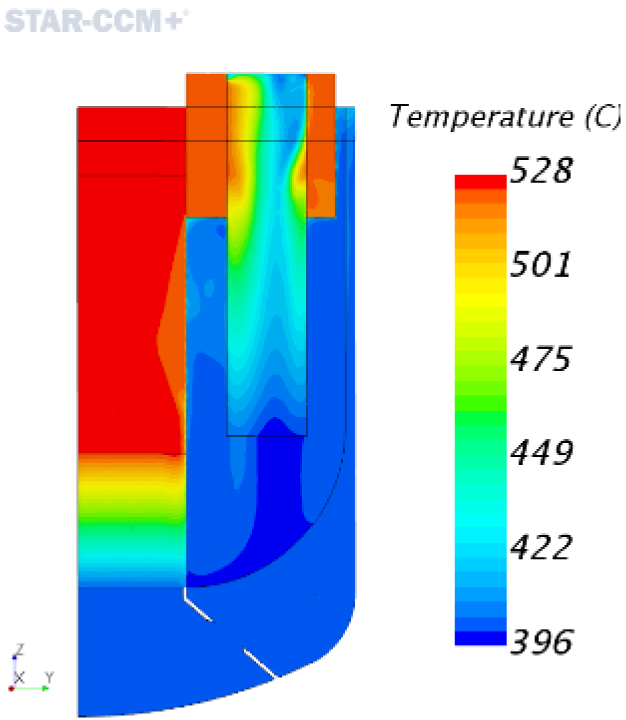
Internal Structure





Flow control, component interface, thermal control

Internal structure



The component brings **essential implications**:

- All the lead is flowing → no stagnant regions
- Reactor Vessel is kept cold → no creep
- No thermal stratification → low thermal loads
- SG / Core forced path → No water entrainment

Hot temperature interface requires coating

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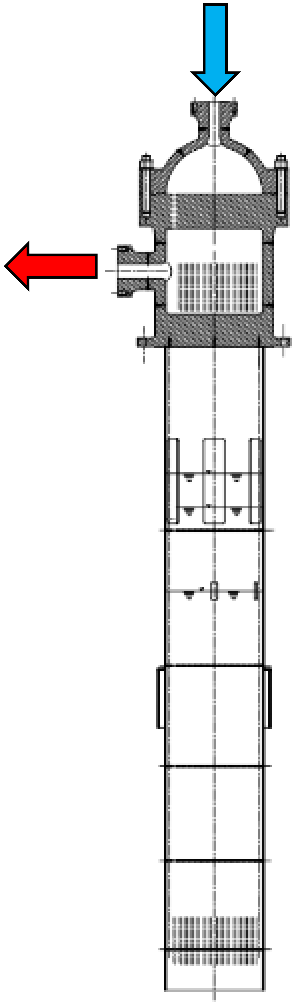
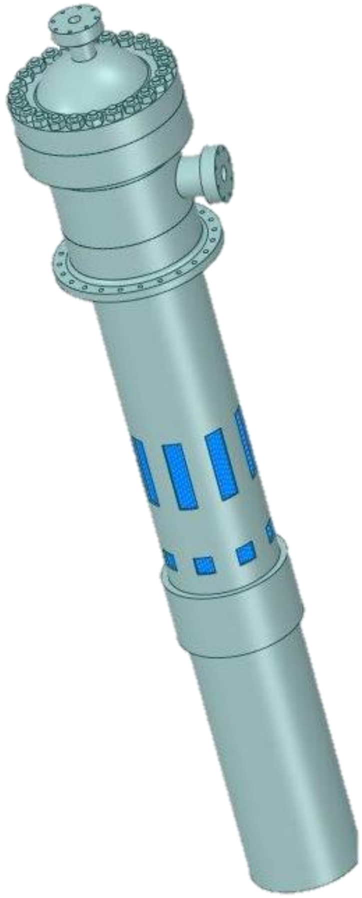
Steam Generators

- Shell & tube (single bayonet tube)
- Superheated steam SG
- Duty 67 MW (Stage 2 design)
- 880 1-inch tubes
- 5 spacer grids in active length
- Primary side pressure drop 0.5 bar

Hot temperature interface requires coating





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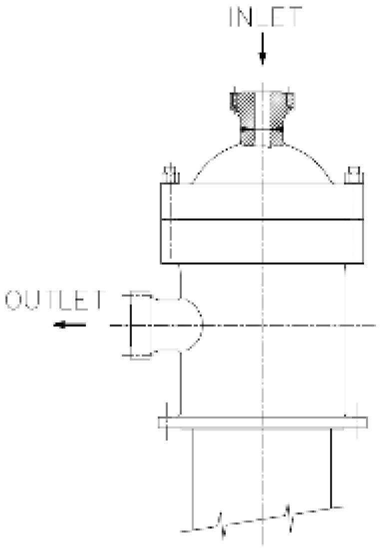
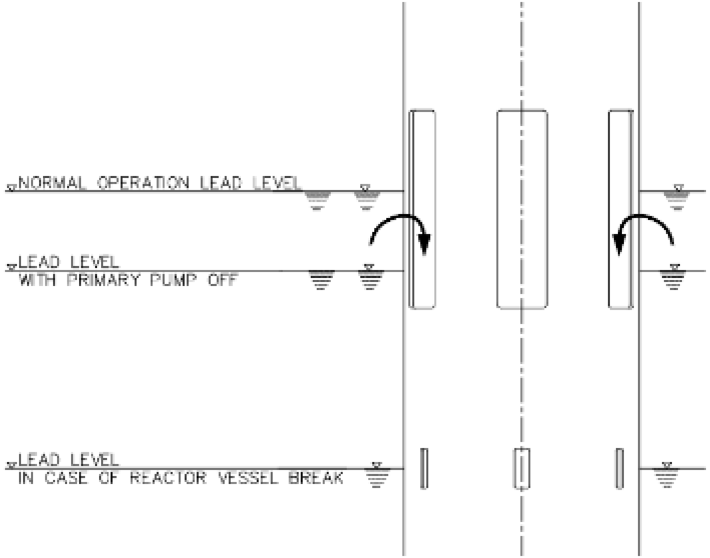
Steam Generators





- Water and steam nozzles outside RV
- Inlet windows for lead to allow inlet flow at different primary level conditions

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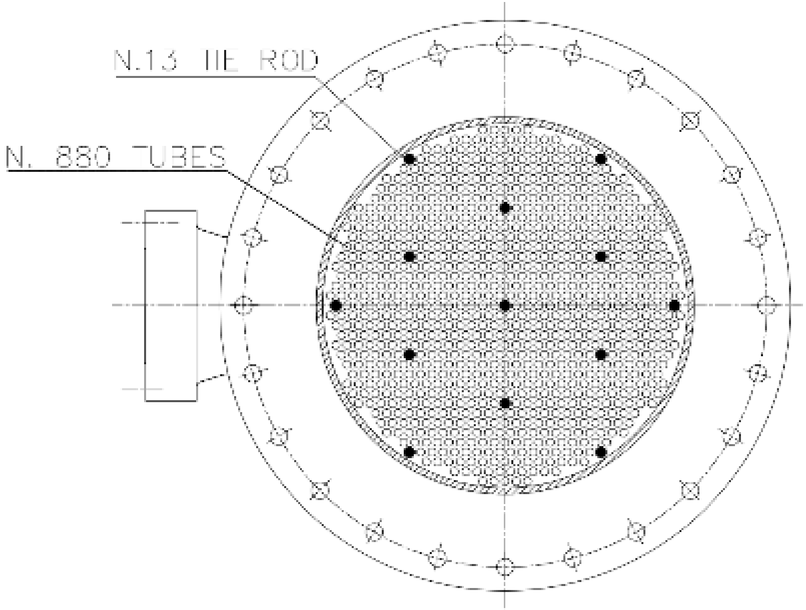
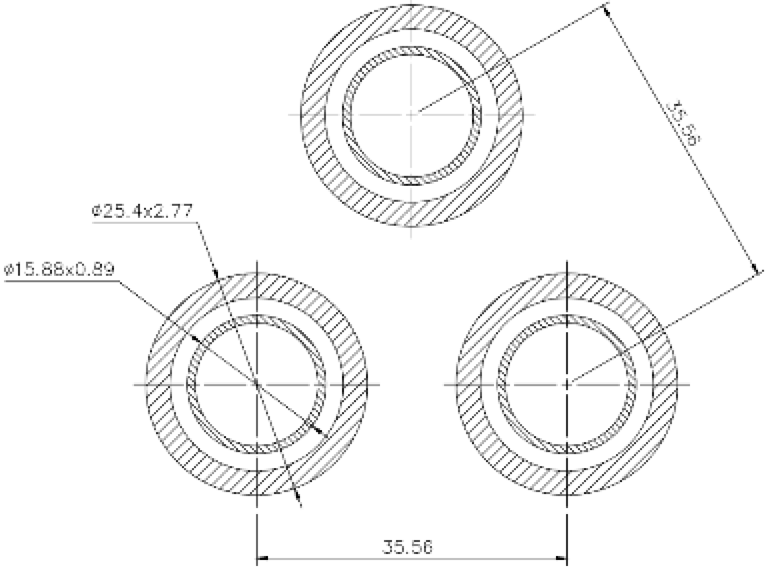
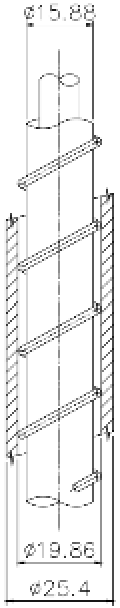
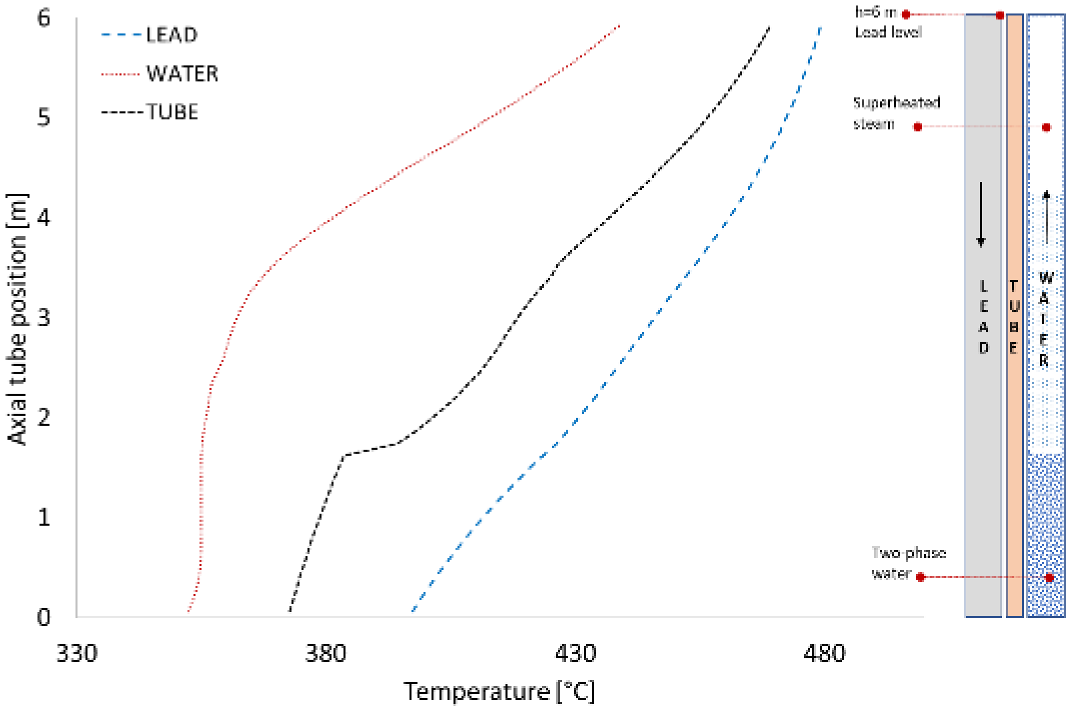
Steam Generators







Steam Generators



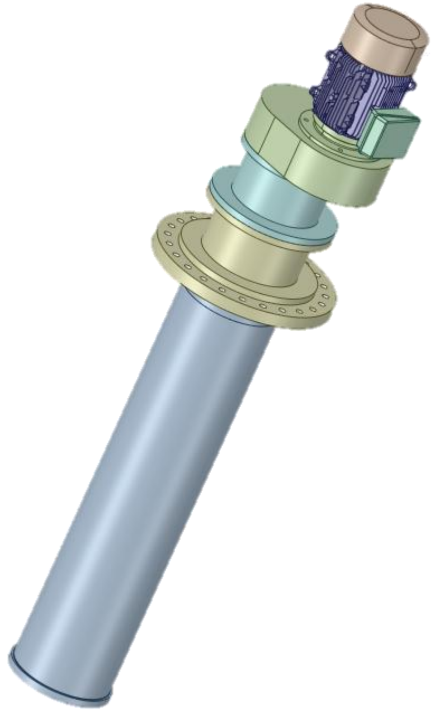
Reactor Coolant Pump

Mounting & Operation: Bolted to Reactor Cover; top motor with inverter;

Environment: Installed in IS duct at highest temperatures; high-speed operation requires corrosion/erosion protection.

Maintainability: No thermal gradients or irradiation; extraction expected to be frequent.

- Axial impeller
- Nominal flow 0.53 m^3/s @ 1.5 bar
- Rotational speed 289 RPM
- Motor power < 200 kW



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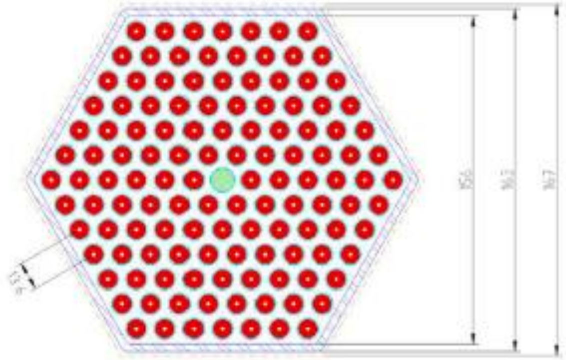
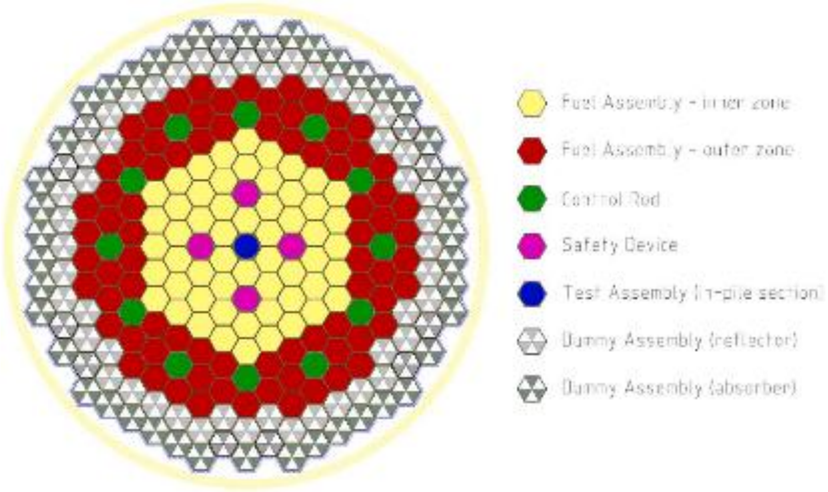
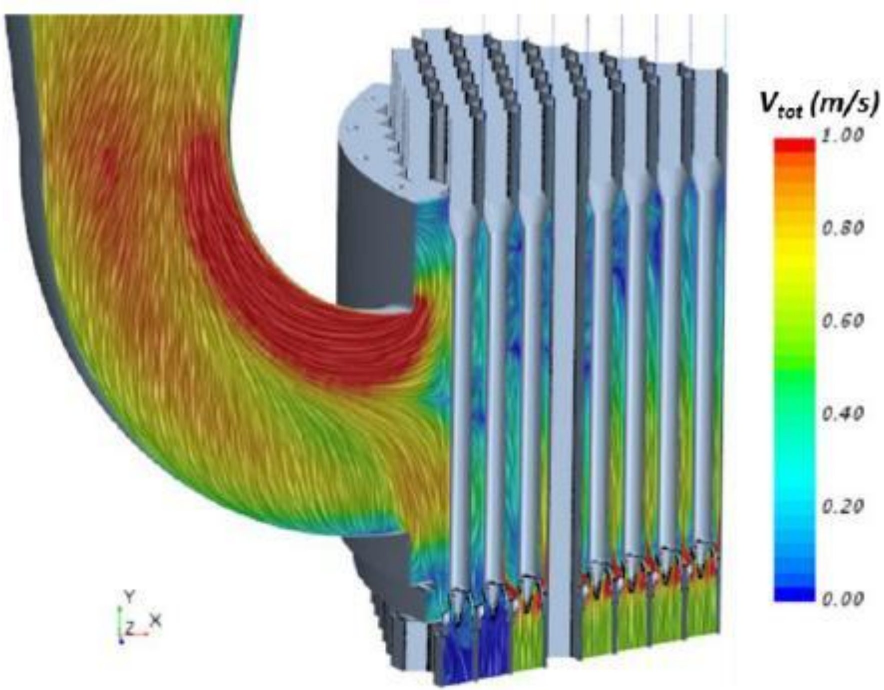
Reactor Core

- Hollowed fuel pins
- 126 pins Hex assembly
- 2 enrichment regions
- 134 fuel assemblies
- Test assembly
- 12 control rods
- 4 safety devices
- 102 dummy assemblies





Reactor Core



- Local core power depends on location
- Same flow on all FAs results in uneven flow distribution
- Mixing evaluation performed with CFD calculations
- Pressure drop estimation in complex flow path

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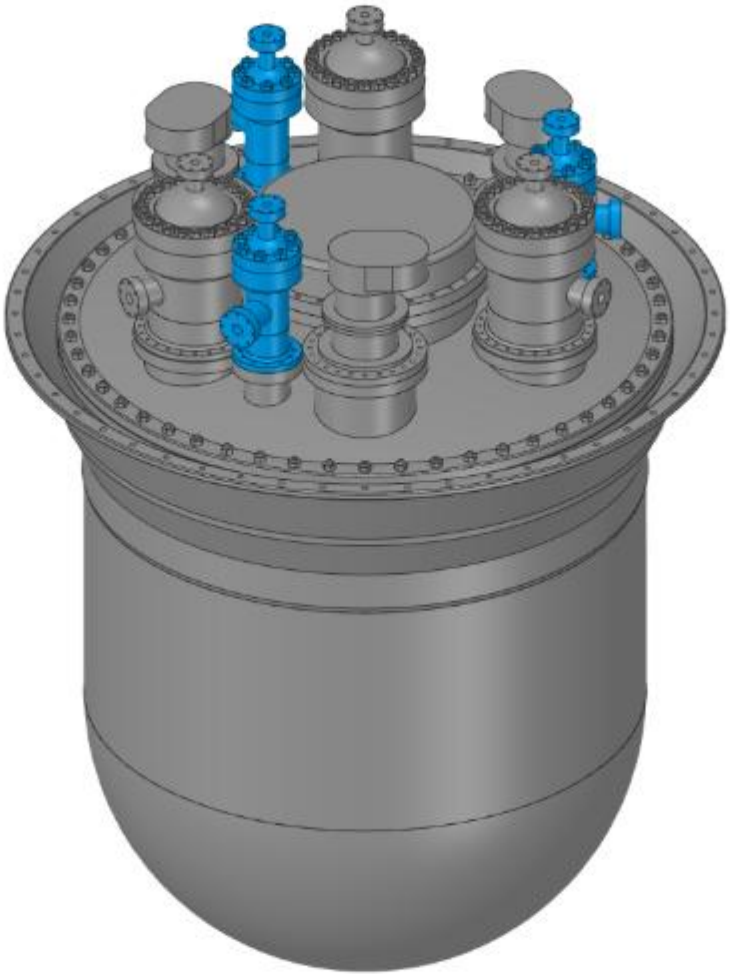
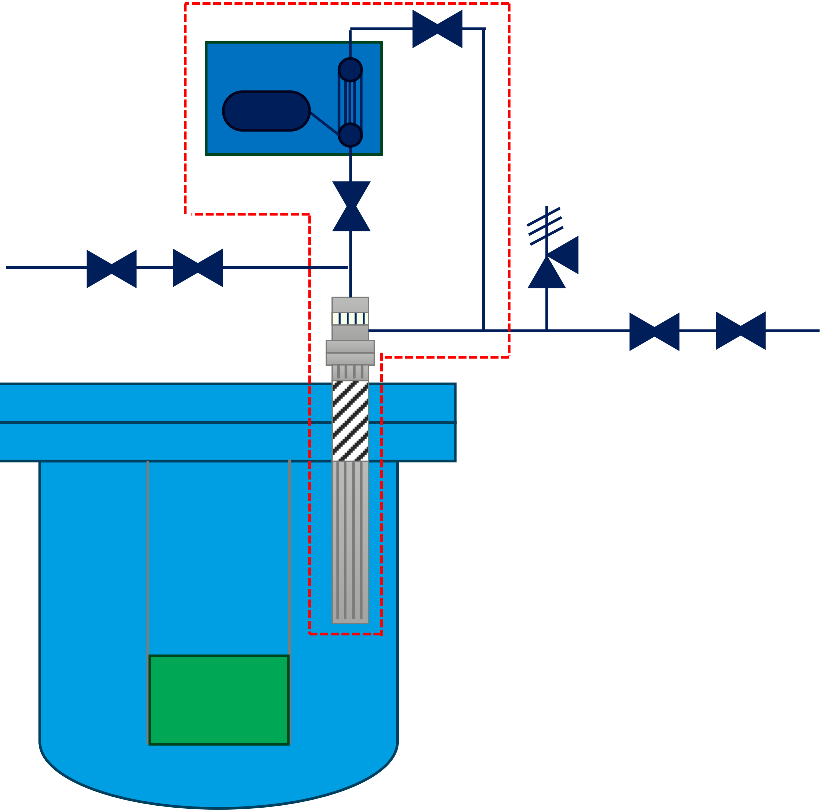
Dip Coolers

- **Configuration**: Dip Cooler sized with shell & bayonet-type tubes, similar to SG; double-bayonet tubes with helium gap preferred.
- **Integrity Monitoring**: Double-tube design enables continuous integrity checks in stand-by and safe water injection during E-DHR activation.
- **Performance**: Gas gap lowers heat-transfer efficiency and kW/m^2, partly offset by the smaller thermal duty of the Dip Cooler vs. the SG.



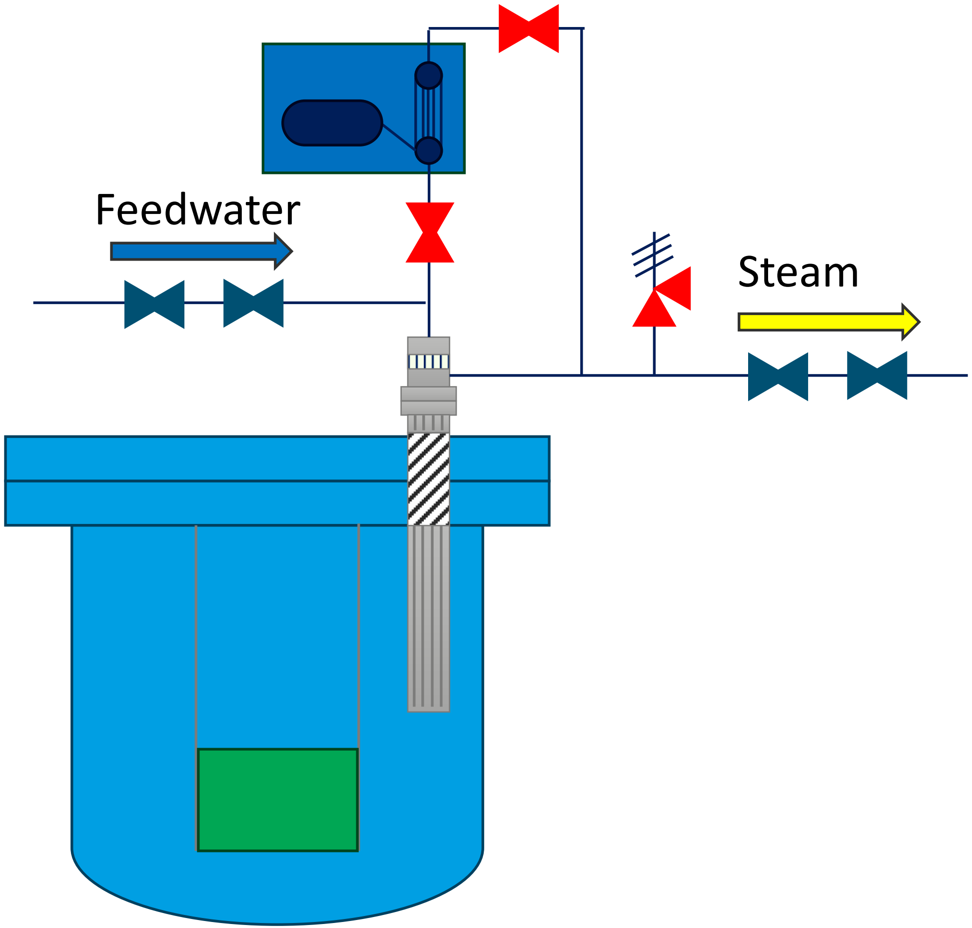
DHR1 - Description

- DHR system is a **closed loop** directly connected to feedwater line and steamline
- Adopts the **SG as main heat transfer item** for the RCS
- Rejects heat to the environment through a **heat exchanger immersed in a water pool**
- System loops provided with:
  - physical separation
  - Independence
  - Single failure proof at system level



DHR1 - Standby

- Under nominal condition each system is **isolated from SG**
- Noncondensable gases (N, Ar, He…) are trapped under pressure within the isolation condenser



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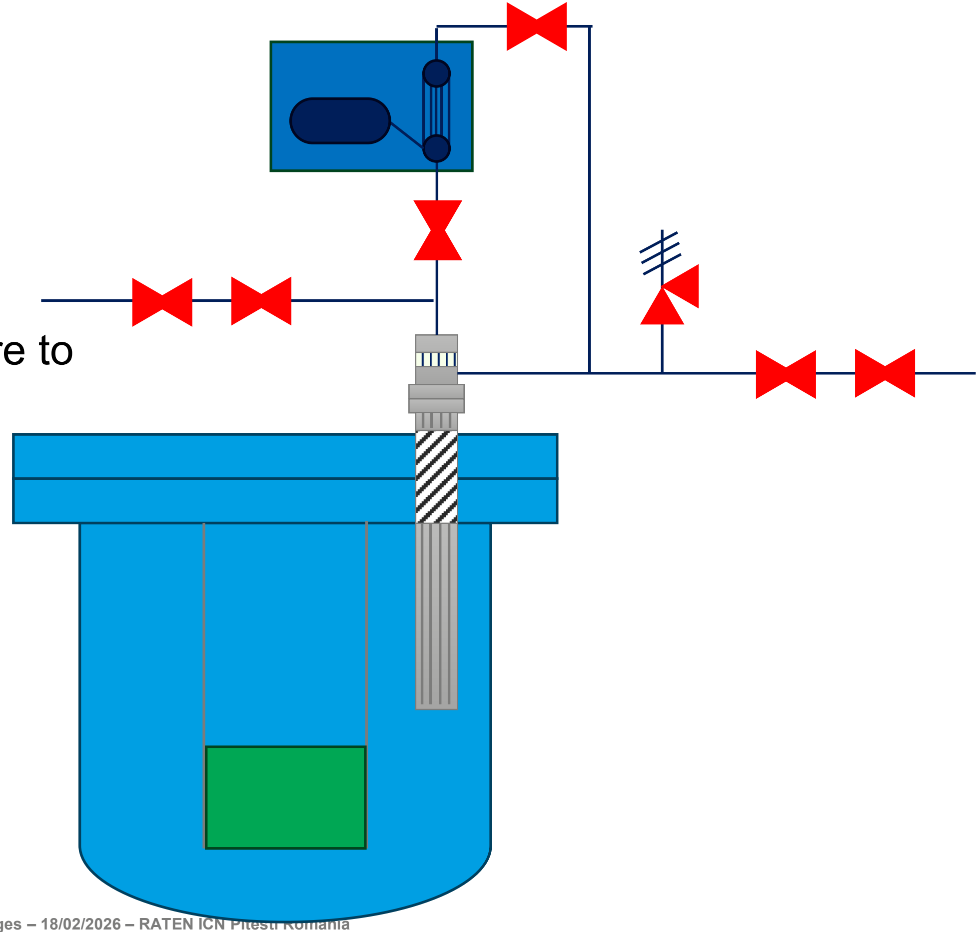
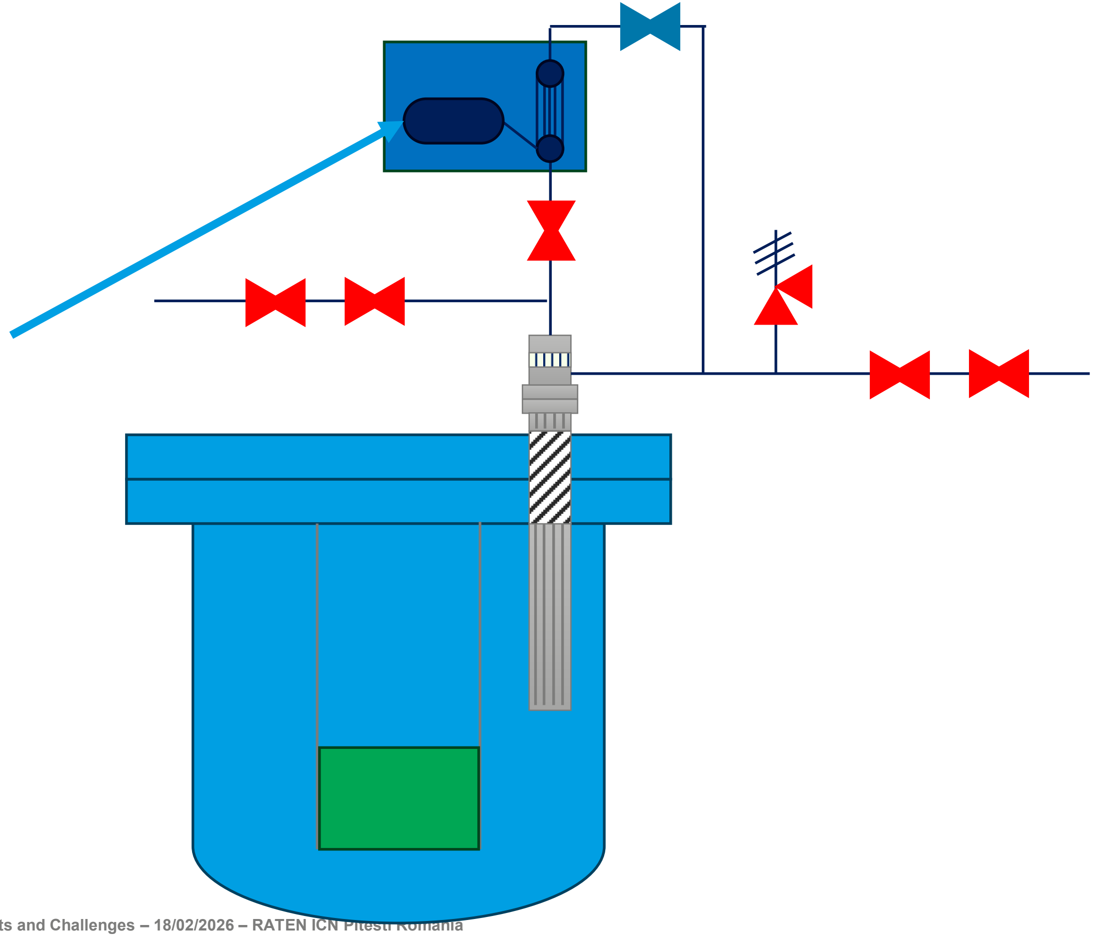
Call to Operation

- Under selected PIE feedwater and steamline isolation valves close
- Water/steam trapped in the SG and heated by lead cause system pressure to increase



Actuation

- Isolation condenser admission valve opens as a result of ovepressure
- Steam pushes NC gases in the **tank** and condenses



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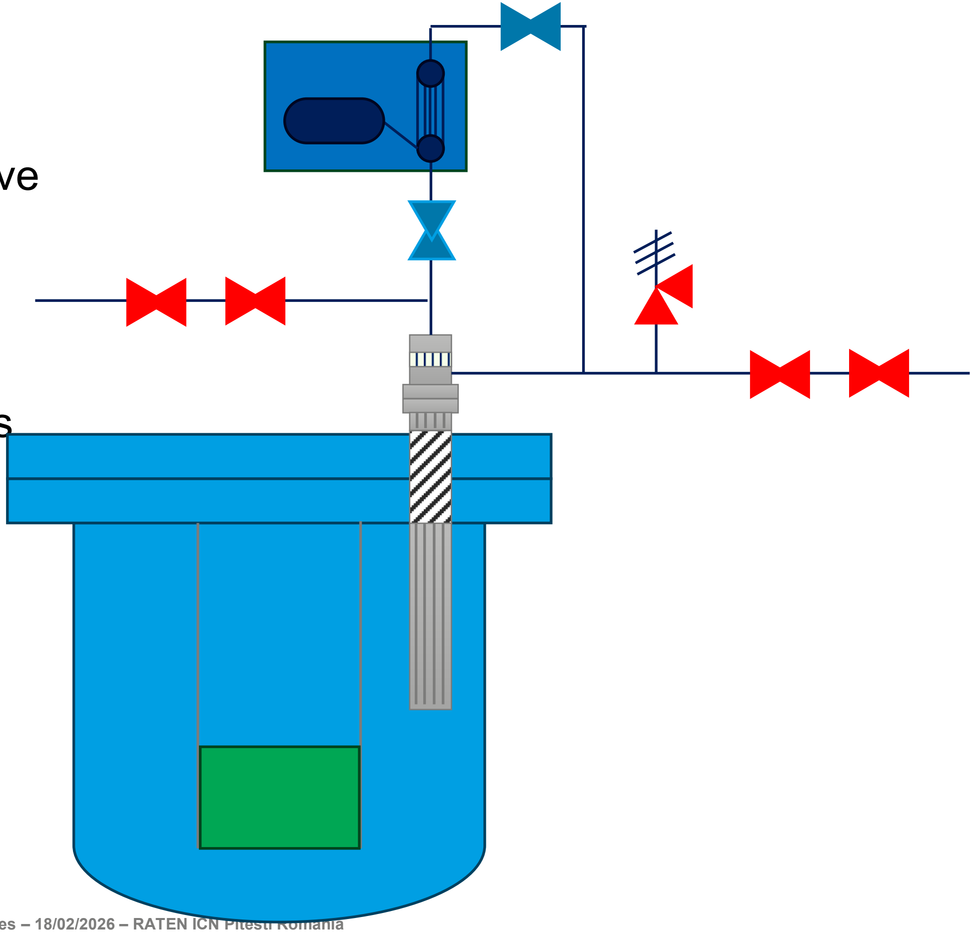
Operation

- At a given time delay the IC outlet valve opens
- Natural circulation is established and systems is in full operation
- No further action required for 72 hours



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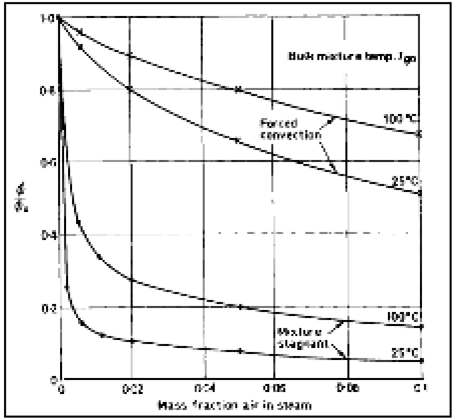
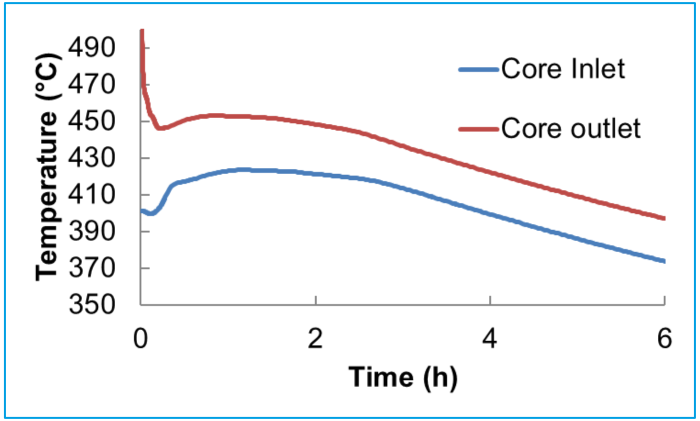
Noncondensable Gases

- The system shall be sized to reject power in the short term & avoid overheating
- Decay heat reduces over time
- The final heat sink is at lower T than lead freeze
- **A PSS is prone to freezing**



NC impact on heat flux

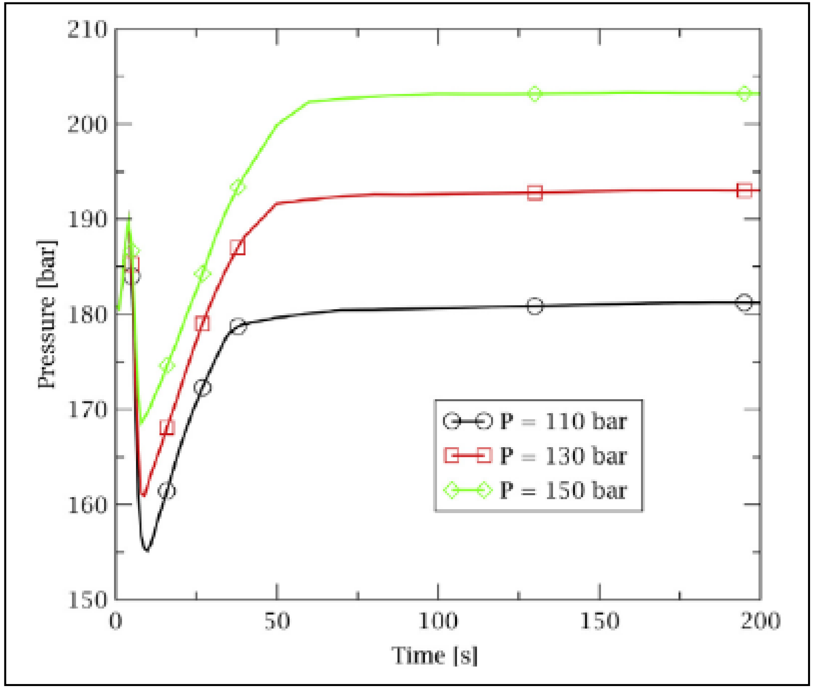


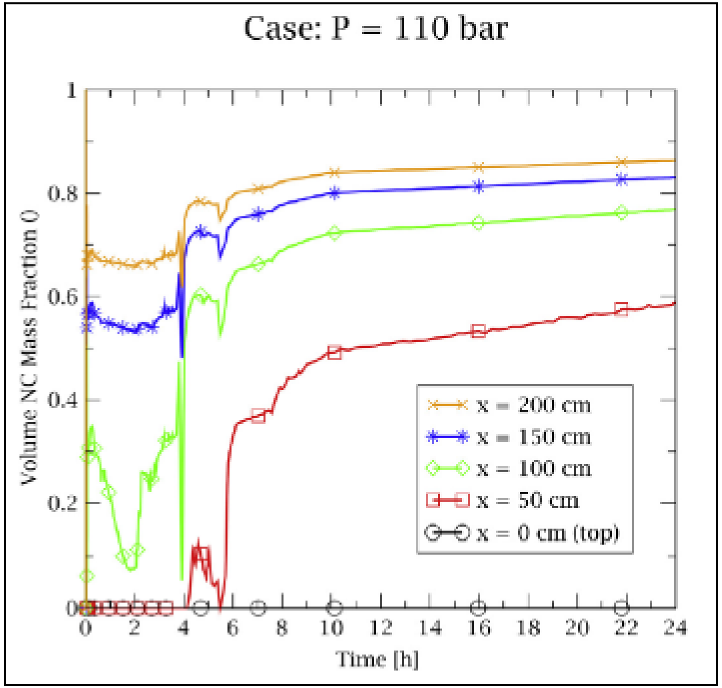
Trend example without NC gases

Noncondensable gases within a condensing system are known to reduce efficiency

System patent by Ansaldo Nucleare

Transient Example





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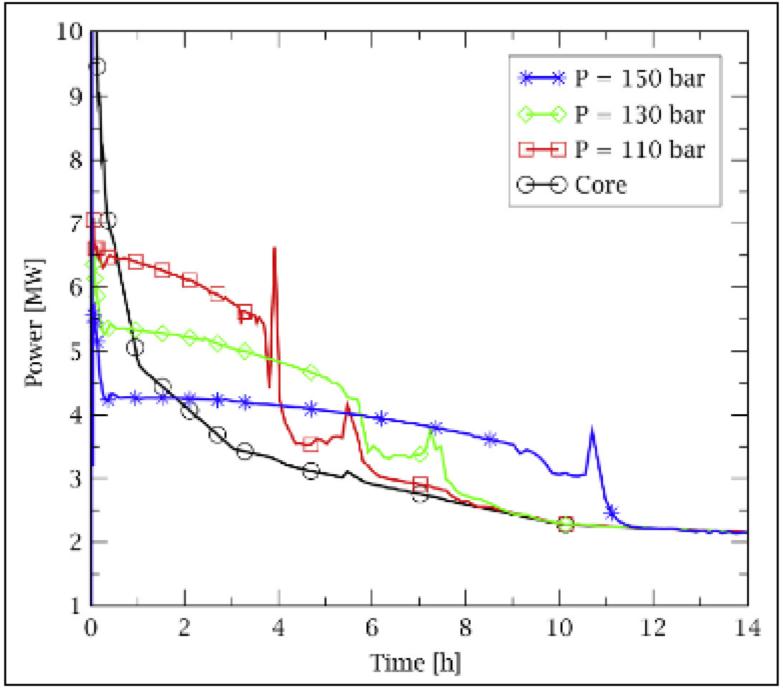

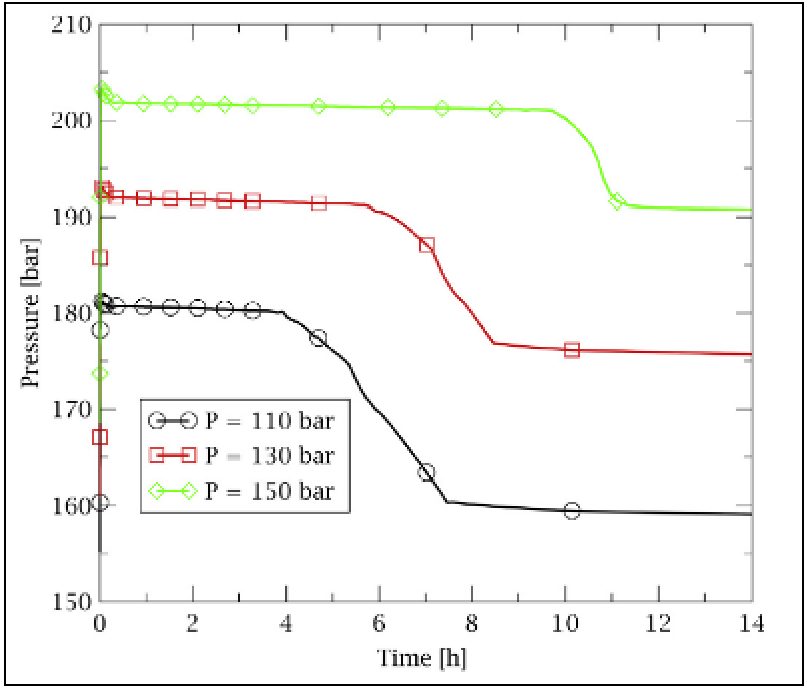

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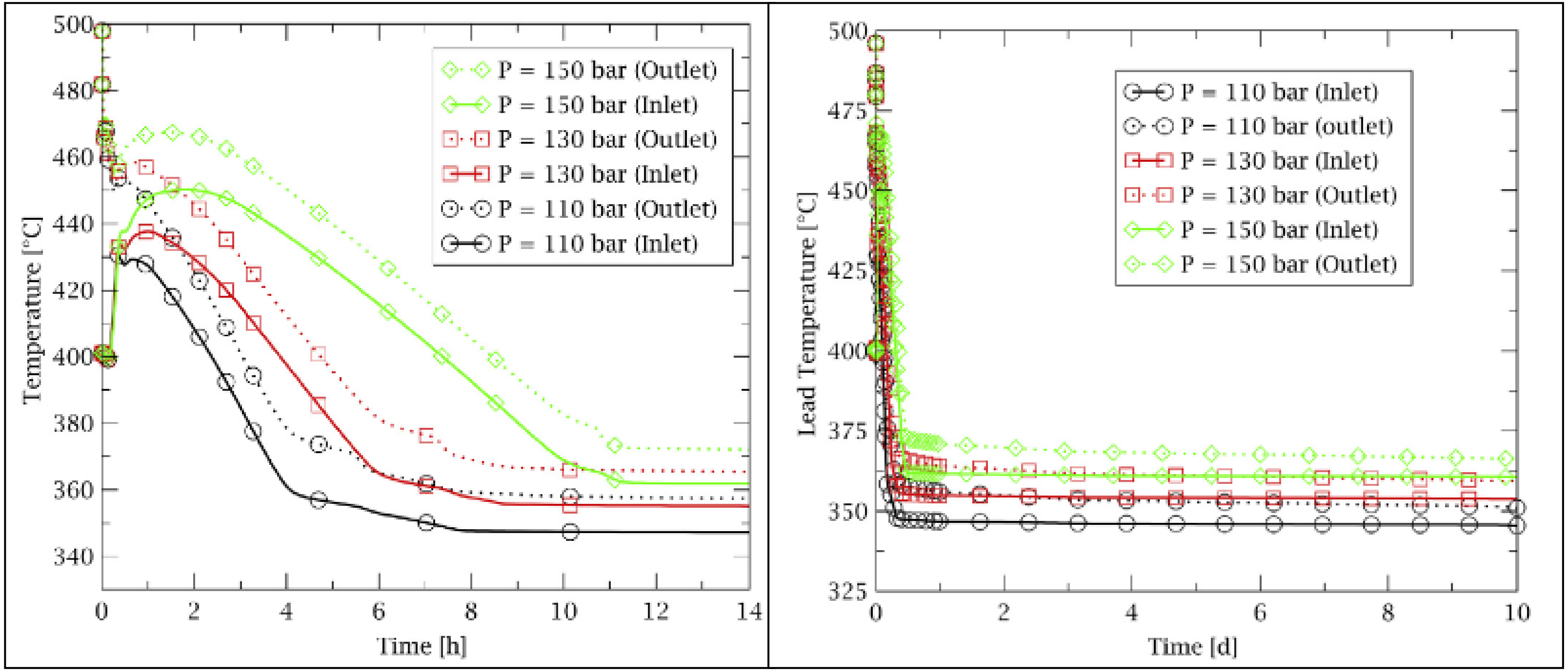

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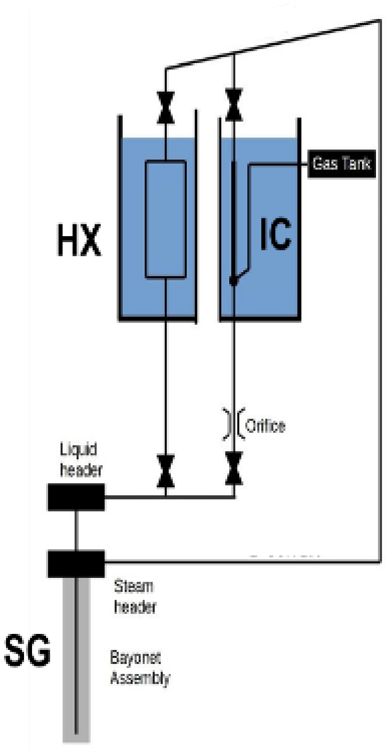
System qualification – SIRIO



An experimental rig has been built to validate the physical principles (1:47 scale)

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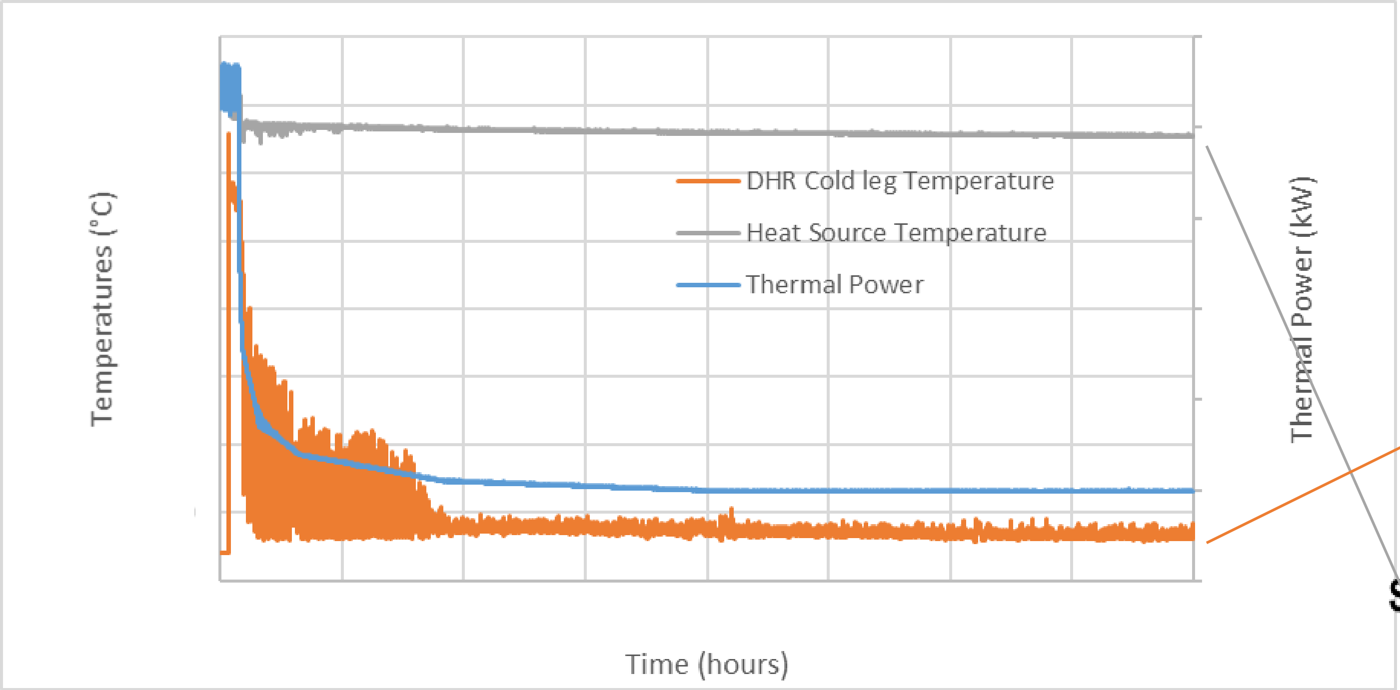
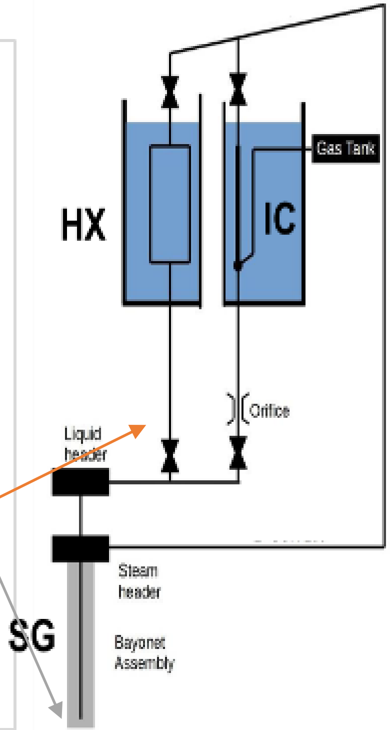
Results example





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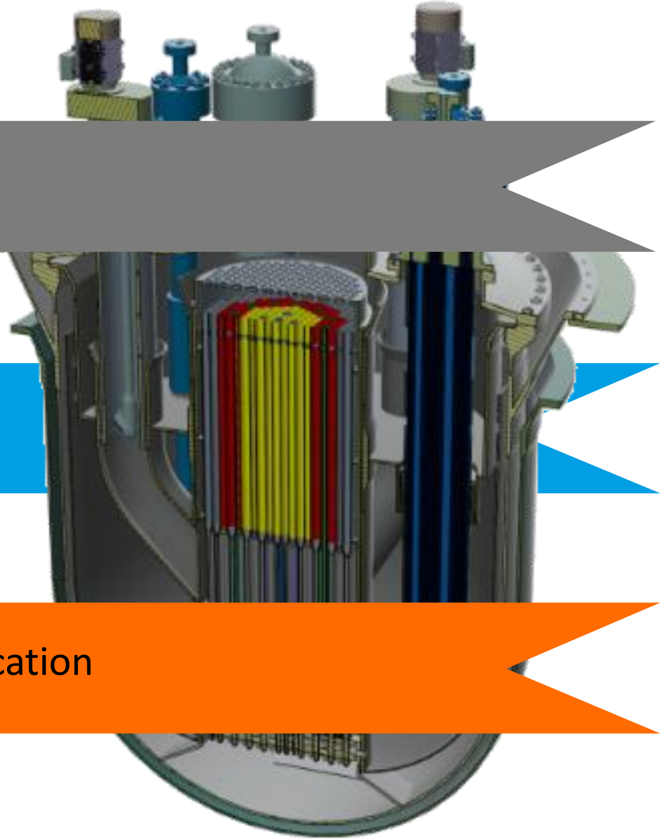
Conclusions



ALFRED Design is a concrete answer to uncertainty

Yet, some design choices have residual risk

Each innovative solution requires a consistent qualification