EASI SMR

Deliverable D2.1: Definition of tests and design components

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3. Summary

This deliverable is the first deliverable of WP2 dedicated to the description of the 9 test facilities of the EASI-SMR project. The test program aims to meet the significant need for experimental data to improve the understanding of physical phenomena in passive systems and to validate thermohydraulic calculation codes for safety studies. Passive systems are indeed considered in many LW-SMR designs, and their safety demonstration is essential to ease the deployment of such SMRs in Europe. The experimental results from 8 test facilities will be used in WP3 to perform benchmarks of various European calculation codes and identify development needs to validate these codes. The results from the ELSMOR II test facility will support the development of reliability assessment methodologies for passive systems in WP4. This deliverable is a preliminary global description of the test facilities, which will be detailed by several deliverables per test facility as the results are obtained and by several internal notes related to milestones to specify the benchmark exercises.

4. Keywords

Experimental tests, facility, Separate Effect Test, Integral Effect Test, Passive Systems, Safety Condensers, data benchmark

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5. Abbreviations and acronyms

C&D	Communication & Dissemination
CHF	Critical Heat Flux
DI Water	De – Ionized water
ECH	Experimental Channel
ERVC	External Reactor Vessel Cooling
FB	Fiber brag probe
IVMR	In Vessel Melt Retention
RPV	Reactor Pressure Vessel
SA	Severe Accident
SACO	Safety Condenser
SETH	separate effect test facility
SMR	Small Modular Rector
TC	Thermocouple
THS-15	Thermal-Hydraulic Stand, est. design 2015
VVER-1000	Water cooled Water moderated Energetic Reactor, 1000 MWe
WP	Work Package
HTC	Heat Transfer Coefficient
DAS	Data Acquisition System
DHRS	Decay Heat Removal System
ELSMOR	towards European Licensing of Small Modular Reactors
E-SMR	European-SMR
HX	Heat Exchanger
LOCA	Loss Of Coolant Accident
MS	Milestone
OD	Outer Diameter
PRZ	Pressurizer
PS CL	Primary Side Cold Leg
PS HL	Primary Side Hot Leg
RTD	Resistance temperature Detector
SBO	Station Black-Out
S-CSG	Safety-Compact Steam Generator
SS CL	Secondary Side Cold Leg
SS HL	Secondary Side Hot Leg
UHS	Ultimate Heat Sink

6. Introduction

The proposed experimental program covers a significant proportion of the uncertainties in the physical models involved in the operation of the passive safety systems implemented in the design of the European SMR reactors under consideration, namely the Nuward SMR reactor, and the LDR50 reactor for district heating. At the beginning of July 2024, the EDF Group has decided to shift its product strategy towards the development of a design based on proven technology bricks only. EDF and its subsidiary NUWARD are now starting the new conceptual design until mid-2026. The new design necessarily involves fewer innovations, and therefore less testing, with the exception of IVR and SACO testing. Nevertheless, the original test program is still relevant, and the EASI-SMR project has chosen to maintain most of the planned tests. Indeed they correspond to a proven lack of knowledge in the validation of thermo-hydraulic codes for passive systems generally employed in advanced light water reactors. For tests very specific to the old NUWARD SMR design, such as FHEASIK, the EASI-SMR project has made the effort to adapt the test facility planned for the project's second LW-SMR of reference, the LDR50, which incorporates several innovations.

As a complement to past experimental projects, and in particular the ELSMOR project dedicated to SMR and PASTELS dedicated to passive systems (Safety Condenser and containment cooling), the set of experiments described in this WP will enable the scientific community to improve, or even validate, the thermohydraulic system codes developed in WP3, with the support of CFD codes.

The range of experimental programs initially planned consisted of eight separate-effects experimental loops for characterizing and validating the physical phenomena driving the operation of several passive systems, and a so-called semi-integral experimental loop dedicated to the production of cooling scenarios using passive systems, with a view to applying statistical methods for assessing functional reliability.

One major modification concerns the FHEASIK experimental loop, where the study of the physical phenomenon initially planned has been modified, in agreement with the various partners involved in the associated code benchmark. Originally, FHEASIK was in charge of helping to validate thermo-hydraulic codes for modelling the natural circulation of a Safety Condenser's ultimate heat sink, in a close loop connected with a waterwall, in a thermal stratification situation. As this physical characterization was closely linked to the specific choice of Safety Condenser design for the old version of the Nuward SMR, we opted for an application dedicated to the assessment of the safety heat removal demonstration for the LDR50 reactor. This changeover remains within the budget initially planned, in particular due to the use of a large atmospheric pool-type component for the new application as well. However, this new application of FHEASIK is no longer a separate-effects experiment, but a so-called semi-integral experiment.

This document brings together the work carried out during WP2.1, dedicated to the definition of tests and the construction of the components of the various experimental loops. Several meetings were scheduled during this action in order to build the experimental program and the associated test set-up for the nine experimental loops. Meetings were also held with those involved in the development of code benchmarks, to converge on the best possible configuration in terms of instrumentation and test matrix.

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7. Definition of experimental tests and dedicated experimental loop

7.1. COSAC

This task aims to collect and define all specifications and design of components that are requested for the construction of COSAC facility. This includes technical specifications of the components and installation, scaling (verification of the conformity of the physical parameters studied between the reactor configuration and that reproduced in the experiment), matrix tests and instrumentation. COSAC experimental tests are the subject of a dedicated action, WP2.2, for which the host of the experimental facility, Framatome GmbH, is responsible.

The technical committee in charge of drawing up this definition action was made up of members of the CEA as WP2 leader, members of Framatome as technical support, and the people in charge of setting up the experimental installation belonging to Framatome GmbH. Additional technical meetings were held to share the design and planned experiments with the PRECISE (ETHZ) experimental loop, in order to obtain comparable experimental results between COSAC and PRECISE. COSAC is dedicated to the validation of thermo-hydraulic codes, while PRECISE focuses more on CFD modelling of condensation film study inside Safety Condenser tubes.

7.1.1. Background to the COSAC experimental facility

The experimental campaigns carried out as part of the ELSMOR project within the Euratom Horizon 2020 framework have enabled significant progress in the understanding and modelling of a two-phase natural circulation loop featuring a safety condenser-type heat exchanger submerged in a pool. This passive system, comprising a safety steam generator integrated into the reactor vessel, extracts thermal power from the core and discharges it to a cold source via a straight-tube vertical condenser (see Figure 1). Experimental tests carried out at SIET on an experimental loop have been produced, following several configurations of loop preparation and startup condition (water filling), presence of non-condensable gas or not, cold source temperature [3]. Following these tests, a benchmark of thermal-hydraulic codes was done, thus confirming the relevance of reproducing the physical phenomena of this natural two-phase circulation loop, particularly regarding the following elements:

- Steam generation induced by the steam generator or source term, in a closed circuit initially under primary vacuum. When a valve is opened to inject the liquid part into the steam generator, the thermal power supplied by the primary circuit in the form of liquid convection boils the loop's liquid inventory and pressurizes the circuit;
- The steam produced in the steam generator is transported to the safety condenser using piping of sufficient size not to induce significant pressure drops in the establishment of natural circulation. The piping is thermally insulated to

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maintain a constant heat balance between the thermal power source and its discharge to the cold source;

- The safety condenser comprises an inlet header, a set of straight vertical cylindrical tubes, and an outlet condensate header. The condensation phenomenon is mainly governed by film flow along the inner walls of the tubes, and several heat exchange regimes succeed one another as the fraction of steam condensed increases. Synthesis of the benchmark of thermo-hydraulic codes shows that there are still inaccuracies in the quality of the various models of condensation and convective exchange within condenser tubes, which justifies the setting up of a separate-effect experimental campaign, dedicated entirely to improving heat exchange models for tube condensation;
- Liquid condensate return piping closes the loop to the steam generator inlet. Sufficient sizing of this piping does not lead to significant pressure drops. It is important to control the liquid inventory present in the loop, as performance in terms of heat power evacuation is highly dependent on the quantity of liquid condensate present in the lower part of the tube before evacuation, in other words on the dynamic gravity drainage rate of the loop. Experimental tests at various initial filling rates have been carried out as part of the ELSMOR project.

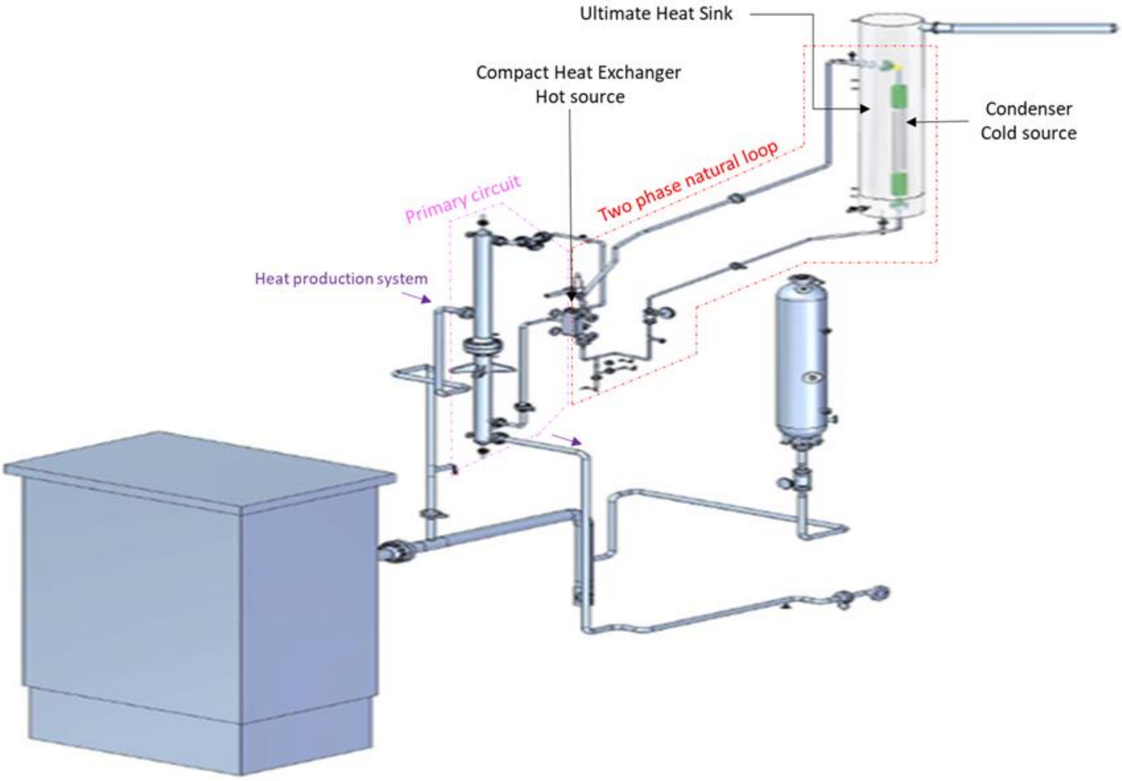

Figure 1: ELSMOR DHRS experimental loop

From the synthesis of the natural circulation code benchmark carried out as part of WP3 of the ELSMOR project, we can deduce the following:

- The initial liquid filling rate in the loop and a perfect knowledge of the total free volume is a very important challenge, as performance in terms of thermal power

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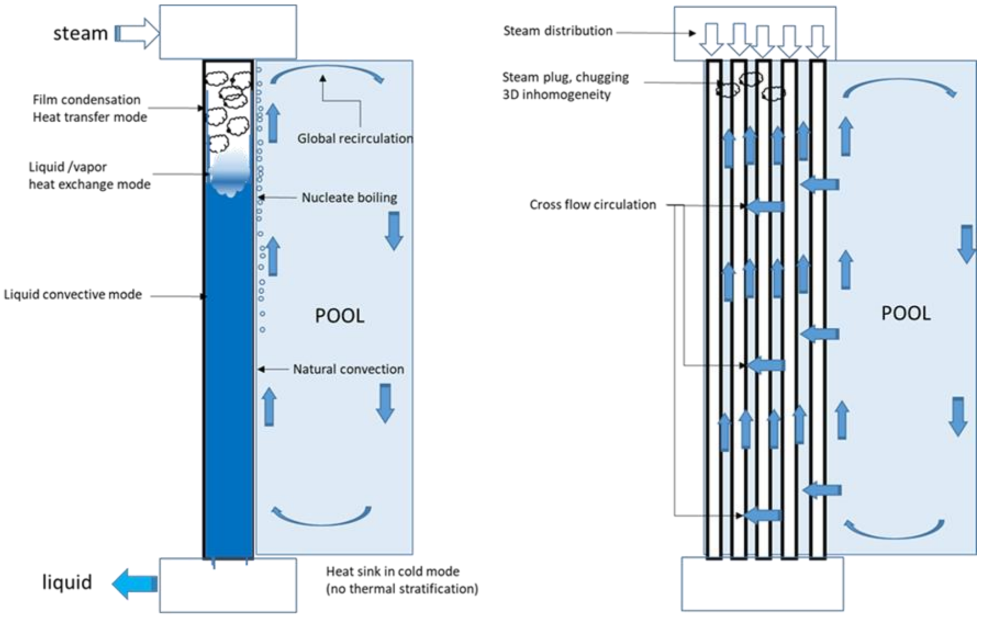
extraction is highly dependent on it. Modelling the gravitational flow of the film along the tube, and its growth until a full liquid level is reached, also has a major influence on the final performance in terms of thermal power exchanged with the ultimate heat sink;

- Uncertainties in film condensation models, heat exchange between vapor and liquid phases (film on wall), and convective liquid exchange (undercooling mode), leads to a consequent final imprecision in the modelling of the two-phase natural circulation loop. The physical parameters relating to the creation of condensate volume, evacuated flow rate and sub-cooling temperature are still subject to significant uncertainty for the various thermo-hydraulic codes used [6]. The steam generator, which normally has a sufficiently large exchange surface area, does not limit the thermal power evacuated from the primary circuit to the heat sink;
- Heat exchange in the condenser tubes involves both condensation and cooling heat flow on the two-phase circulation loop side, and heating heat flow (and boiling) on the heat sink side. Heat exchange by boiling in the outer tube wall is extremely efficient, but natural circulation in volume is complex to model and reproduce by thermal-hydraulic codes, and two-phase thermal-hydraulic CFD codes are not validated. It is therefore necessary to separate the physical parameters characterizing condensation and cooling, on the one hand, from the physical parameters and models characterizing boiling and overall heating of the pool, on the other.
- The use of several condensation tubes, to obtain a high thermal output, complicates the thermo-hydraulic modelling of the cold source and can also lead to a difference in steam distribution at the tube inlet. The recirculation of the cold source between tubes at different heights is difficult to reproduce using thermo-hydraulic codes, making it even more difficult to control the physical parameters of the heat flow transmitted.



Single tube configuration

Multi tubes configuration

Figure 2: Physics of single and multi-tubes condensation in a pool

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Figure 2 shows the physical phenomena described above, in a single-tube condensation configuration submerged in a pool, and the associated multi-tube configuration.

For the various reasons mentioned above, it is therefore necessary to set up specific experimental tests, dedicated to the study of the physical parameters controlling steam condensation in a typical specific tube from a Safety Condenser whose option is still being considered in the new design of the European NUWARD SMR. To achieve this, the following conditions must be met:

- Use a single condensation tube, with dimensions characteristic of those of a European SMR Safety Condenser, to control the flow of injected steam, and avoid problems of recirculation between tubes for the cold source;
- Cover the full range of steam pressures and temperatures likely to be generated in a European SMR safety loop for the most referent deterministic transient design basic accidents;
- Provide a cooling function representative of that obtained in an atmospheric pool, but with physical conditions enabling simple measurement of the heat flow transmitted along the tube, according to the condensation and sub-cooling regimes. In order to obtain simple, reliable measurements (flow rate, temperatures), it is essential to give priority to a liquid convective exchange, rather than boiling;
- Carry out several series of tests at different steam pressures and temperatures, for different gravity flow regimes, leading to a greater or lesser level of liquid in the tube. This study will enable us to cover several initial startup conditions, as well as several conceivable gravity flow or gravity draining heights;
- Prioritize the absence of non-condensable gases in steam production, in order to separate the effect of non-condensable gas from condensation performance with pure steam. A complementary experimental campaign, associated with means of controlled injection of no condensable gas, could be carried out at a later stage.

7.1.2. Definition of the SET COSAC

In the frame of the EU-funded EASI SMR joint-project, the COSAC facility was built as part of Work Package 2 (WP2) to validate models and correlations for heat transfer inside a vertical condensation tube. The condensation tube was modelled to resemble a tube from a Safety Condenser (SACO).

The SACO is a long-term decay heat removal system for LWR with the main objective of replacing active systems by a passive (residual) heat removal system. The point of having passive heat removal systems in a LWR is their ability to remove the residual heat without any continuous AC-power supply and their independence from operator actions. To this end, the COSAC separate-effect test facility will be erected and operated at Framatome’s Technical Center laboratory in Karlstein, Germany to obtain qualified experimental data on heat transport between a condensation tube and the ambient cooling jacket. From this data, the heat transfer coefficient on the inside of the tube under film condensation can be reliably calculated and compared to the coefficients provided by the correlations embedded in Thermal-hydraulic system codes.

The test matrix for the experimental activities is provided in §7.1.2.5precise test conditions and procedures for the individual experiments are provided in §7.1.2.5.

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- The first major section of this deliverable contains a detailed description of the COSAC loop including operational systems, loop layout, such as: general design of the COSAC loop containing the heat source, heat sink and required piping,
- Geometric data of the mechanical design of the mock-up (heights, volumes, pipe lengths, diameters valves, heater powers etc.),
- Instrumentation scheme of COSAC including a list and plans of available measurements detailing types of sensors:
    - Mass flow (e.g., Coriolis- or vortex-type type mass flow, or orifice/Venturi coupled with Δp-sensor etc.) and uncertainties of measurements,
    - Temperature (optical fibre with Bragg-grid, K-type thermocouple and Resistance thermometer),
    - Absolute and differential pressures.

Following the technical description of COSAC, a design review and justification will be provided by EDF which summarises an initial review of the draft design documents issued by FRA-G on the design of the COSAC facility. This design review section in turn consists of two parts: first, the EDF assessment of the overall layout of the facility (based on the information available in early 2025); second, additional considerations on instrumentation used to measure key parameter based on updated information in December 2025 once commissioning test have been completed. The P&ID of the testing facility is shown in Figure 3, and a simplified schematic is shown in Figure 4.

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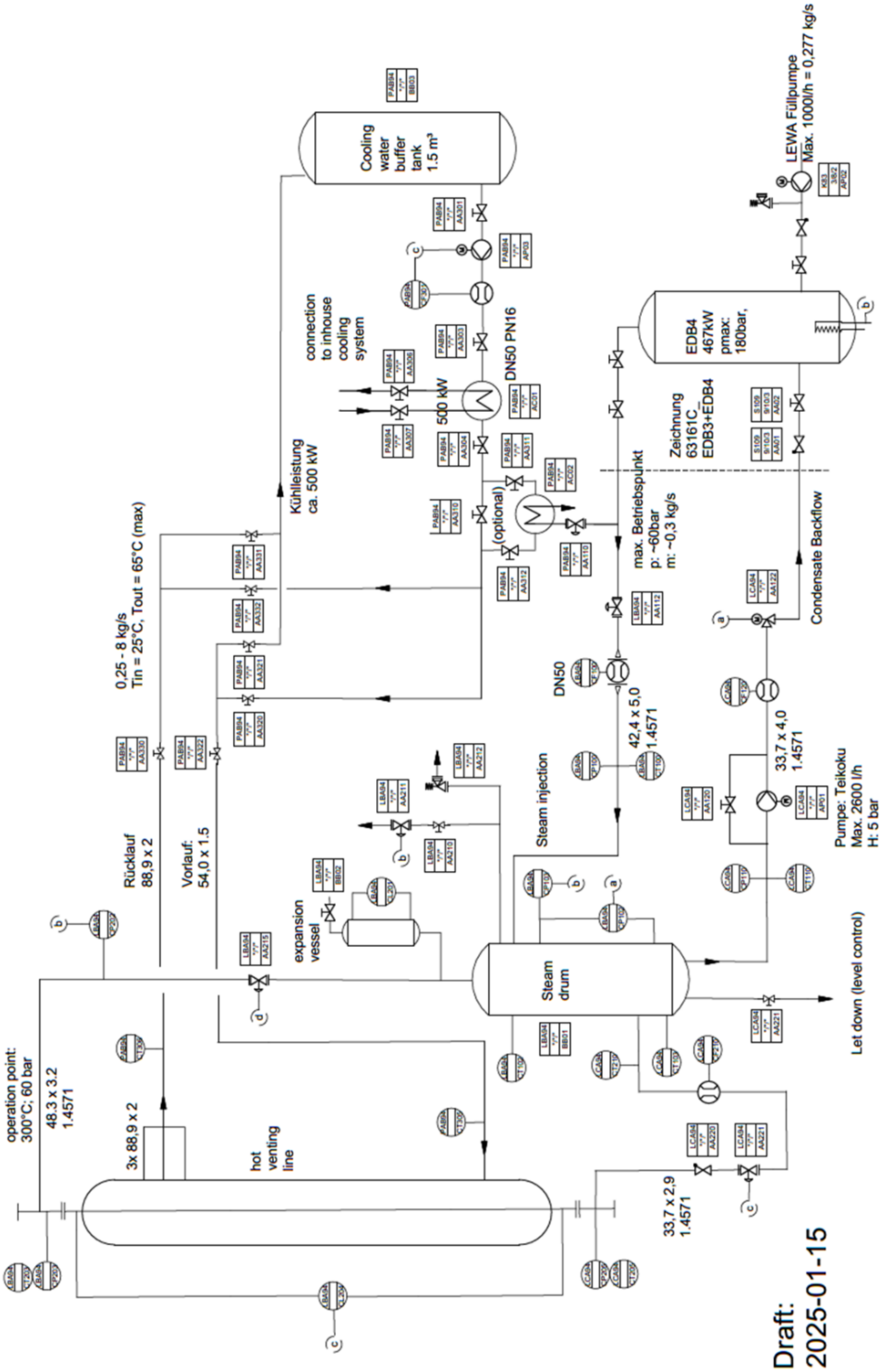

Figure 3: Principal schema of the COSAC test facility

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7.1.2.1. General description of the facility

The COSAC separate effect test facility (SETF) consists of three interconnecting circuits (see Figure 4):

- The Heater Loop: The circuit acting as heat source for the COSAC loop is a closed loop with the electrically heated boiler acting as heat source for the COSAC facility on one side, and the steam drum of the condensation loop acting as interface to the Condensation Loop on the other side. The Heater Loop was designed to deliver heat in form of saturated steam from the electrically heated boiler to the Steam Drum component of the Condensation Loop. The Steam Drum acts as interface between the Heater Loops and the Condensation loop that houses the test section. Heater Loop is described in more details in section 7.1.2.2.Condensation Loop: The condensation loop contains the Test Section and the piping required to guide the steam from the Steam Drum to the Test Section. The Test Section houses the vertical condensation tube where heat removal from the steam to the cooling jacket around the condensation tube causes the steam to condense. The resultant condensate flow is then routed to the Steam Drum by the condensate return line.
- A cooling jacket around the condensation tube acts as heat sink for the condensation loop and is coupled to the Cooling Loop (see below). The Condensation Loop is described in more details in section 7.1.2.3.
- The Cooling Loop: The cooling jacket of the test section is connected to the Cooling Loop which provides the system (valves, pumps, coolers and piping) required for heat removal from the Test Sections' cooling jacket; the cooling circuit is operated with water. The Cooling Loop is described in more details in section 7.1.2.3.1.

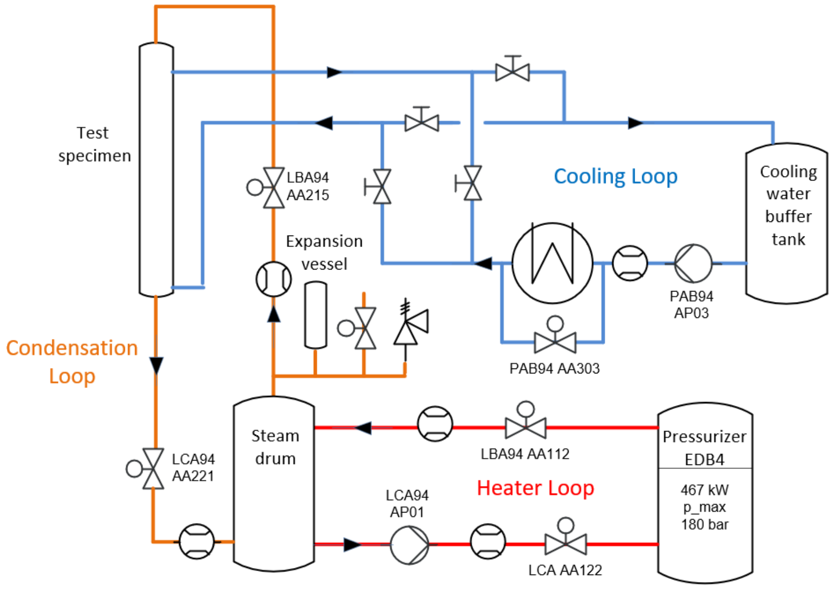

Figure 4: Principal schema of the COSAC test facility

The test section, its cooling jacket and the return line house the key measurements of the COSAC facility (see section 7.1.2.3.2 for detailed description).

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7.1.2.2. Heater Loop

The Heater Loop consists of the following components (see Figure 5: Principal scheme of the heater loop

- **Boiler (EDB4)**

The boiler consists of a pressure vessel designed for 18.5 MPa and 365 °C with a total volume of approx. 1,3 m^3. In the lower part of the vessel the electrical heaters (30 heater rods with 467 kW electrical power) are installed vertically. Sufficient coverage of the heater rods by water is assured by several fill-level measurements and automated control units. For the operation of COSAC, the water level in the upper part of the boiler must be maintained with a certain fill-level range (water-level target value is 1.3 m inside the vessel).

Imbalances between water inventories or loss of water from the Heater or the Condensation Loop are compensated by a drop in water level within the boiler. If the level falls short of a certain value, a boiler-dedicated high-pressure charging pump will be automatically started.

The feeding of fresh feed water to the boiler (and further on to the Heater and Condensation loops) from the boiler feed charging pump should be reduced to a minimum during test conduction due to the intrusion of non-condensable gases outgassing from fresh boiler feed water evaporating into the boiler (by the charging pump which takes suction from an improperly degassed water supply tank).

For test preparation, the non-condensable gases accumulating in the condensation tube must be vented from the Condensation Loop, this is done via dedicated “venting” lines, (see below) directly downstream of the test section.

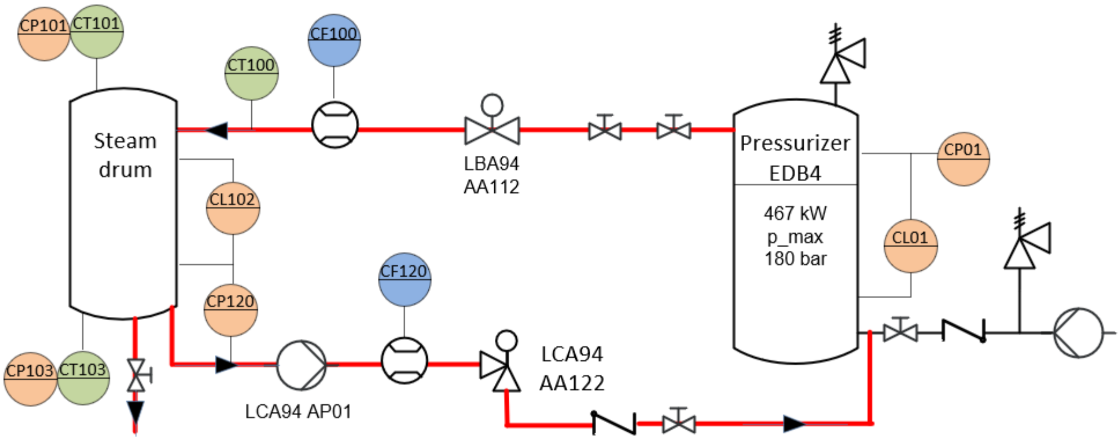

Figure 5: Principal scheme of the heater loop

- **Steam flow control valve (LBA94 / AA112)**

The steam flow control valve is the main control element for the power control circuit. Throttling the steam flow to the Condensation Loop reduces the power input to the COSAC SETF.

- **Stream Drum (LBA94 / BB01)**

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The Steam Drum acts as a collector for the condensate and as a buffer tank for the Condensation Loop.

The steam coming from the boiler is injected downstream of the Steam Drum into the ascending part of the Steam Drum Extension pipe from which the condensation tube – which is part of the test section – is fed (see section 7.1.2.3 below for details of the Condensation Loop).

The steam drum assures pressure equalization up and downstream of the test section (notwithstanding slight pressure variations in between hot and cold ends of the condensation tube due to water level differences). The Steam drum is fitted with a fill-level measurement (on basis of Δp) to track inventory changes in the Condensation Loop.

From the Steam Drum the condensate is pumped back to the boiler by the condensate pump. A let-down line is installed for emptying and adjustments made to the water inventory during testing. The steam drum is made of stainless steel and designed for a pressure of 110 bar at 320 °C. The volume is 135 l.

The steam drum also features temperature and absolute pressure measurements.

- **Condensate Pump (LCA94 / AP01)**

  This is a stainless steel rotodynamic pump that can deliver up to 2600 l/h. The total head is 50 m, and it can operate under max. 203 bar at 350 °C.

- **Condensate flow control valve (LCA94 / AA122)**

  This valve together with the condensate pump are the control element for controlling the level inside the Steam Drum.

- **Flow Control measurements in Heater Loop:** Two flow control measurements are installed in the heater loop up- and downstream of the Steam Drum to track steam in- and condensate backflow to the boiler. Together with the measurements for the physical properties (see section 7.1.2.4) these flow measurements are used to calculate the heat balance for the COSAC facility.

The part of the line from the EDB4 to the Steam flow control valve (AA112) is designed according to the design of the boiler “EDB4”, which is 185 bar saturated steam. The same applies to the piping from the condensate flow control valve (AA122) back to the EDB4. The piping between both flow control valves and the Steam Drum will be designed for 90 bar at 300 °C.

The piping from EDB4 to the Steam Drum (saturated steam) will be in DN32 (42.4 x 5.0). The piping from the Steam Drum back to EDB4 (condensate) will be designed in DN25 (33.7 x 4.0). All piping is stainless steel 1.4571.

Both, upper and lower flanges of the boiler are of ferritic material in steel grade 1.5415. This steel is commonly used for the pressure vessels operated at higher temperatures (>300 °C).

The heat loss to the ambient was not calculated/estimated in advance. To reduce the losses to a minimum, the piping, valves, and the pressurizer are thermally insulated (mineral wool, thickness approx. 20 mm for DN25-32 piping, approx. 50 mm for the

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steam drum). With this the outer surface of the insulation (thin aluminium liner) remains below 60 °C, as required for safety purposes.
For the maximum operating pressure of COSAC at 60 bar and 275 C (Tsat(60 bar)) the maximum boiler power of 467 KW translates into 0.28 kg/s of saturated steam, when vaporizing cool water from approx. 255°C. For different operational points this mass flow will vary.

Table 1: Details of Heater Loop

	Heater Loop		
Pipe section	EDB4 to steam drum	Steam drum to EDB4	Steam Drum
Piping [mm]	42,4 x 5,0	33,7 x 4,0	See APPEMDIX II
Length [m]	21	15	
Volume [l]	17	8	135
Design Parameters	90 bar / 300 °C 185 bar 365 °C	90 bar / 300 °C 185 bar 365°C	110 bar / 320 °C
Insulation	20 mm, mineral wool	20 mm, mineral wool	20 mm, mineral wool

7.1.2.3. Condensation Loop

The Condensation Loop consists of the following key components (see Figure 6: Principal scheme of condensation loop

- **Stream drum (LBA94 / BB01)**

  Parts of the function of the Steam Drum is explained above since the steam drum with its extension pipe is the connection between the Heater Loop and the Condensation Loop.

  At the top of the Steam Drum an extension tube of 360 mm length and an internal diameter of 113 mm connects the Steam Drum and the location where steam from the boiler is injected into the Condensation Loop. operation, the Steam Drum is filled with subcooled water coming from the test section at the bottom and steam from the boiler at the top. Due to heat transfer with the inflowing steam a saturated water layer will establish at the top of the water front.

- **Safety valve (LBA94 / AA212)**

  The Condensation Loop is designed for a pressure of 90 bar at 300°C. The safety valve is set to 80 bar.

  Since the Boiler EDB4 and part of the Heater Loop were designed for higher pressures, the safety valve in the Condensation Loop is a mandatory equipment.

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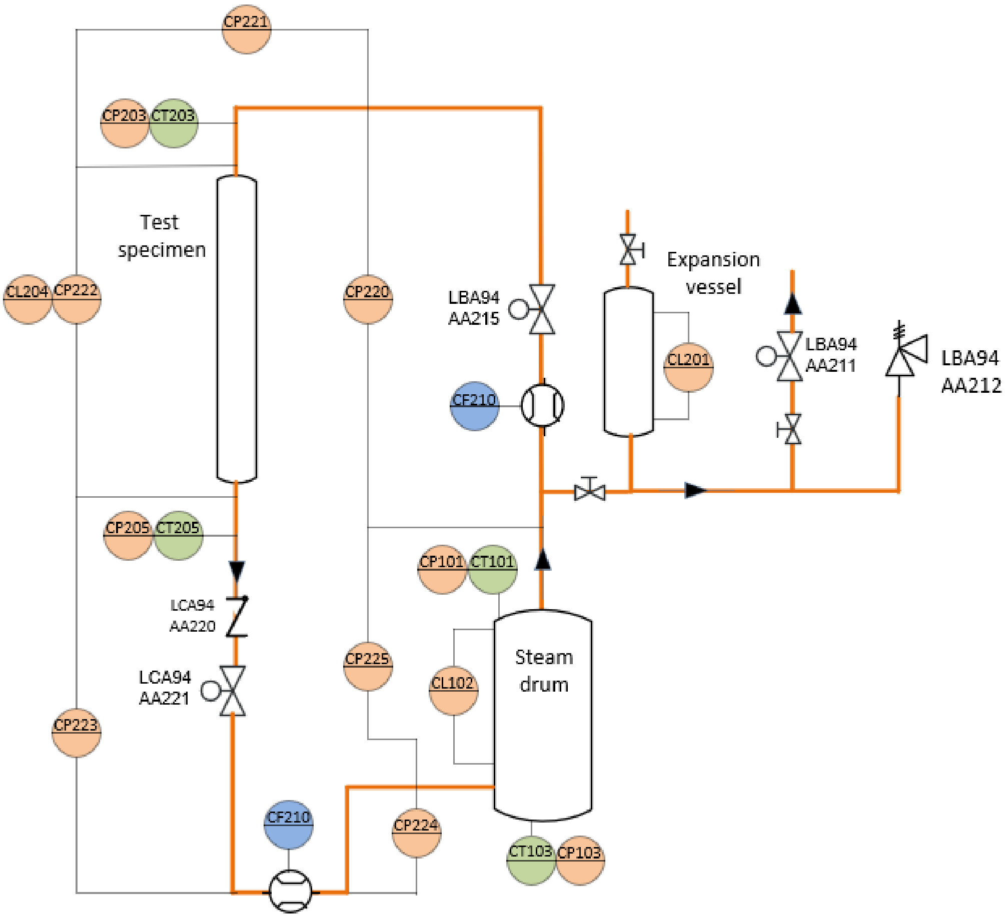

Figure 6: Principal scheme of condensation loop

- **Pressure relief valve (LBA94 / AA211)**

  The pressure relieve valve can be used to reduce the pressure in the Condensation Loop and – if the steam flow control valve in the Heater Loop is also opened – also in the Heater Loop.

  The opening pressure can be chosen; furthermore, the relief valve can be used to conduct a controlled pressure gradient in the Condensation Loop (and in the connected Heater Loop simultaneously – if needed) through steam dump through the steam discharge train.

- **Expansion vessel (LBA94 / BB02)**

  Tests in natural circulation are planned as part of the commissioning to deduce pressure and /or thermal losses for instance. For this purpose, an expansion vessel is needed in which the incompressible water can work against a compressible medium. For these test runs the expansion vessel will be installed which can be filled with compressed air from the top. The expansion vessel will be designed as a piece of pipe with a level measurement. The pipe will be designed as a DN100 Pipe with about 1 m height.

- **Steam flow control valve (LBA94 / AA215)**

  The flow control valve adjusts the flow rate in the condensation tube (by adjustment of the hydraulic resistance downstream of the Steam Drum). The maximum flow speed is limited by the heat removal capacity of the heat sink in the cooling jacket of the condensation tube.

- **Test section ("SACO tube" with cooling jacket)**

  The test section is composed of a single-tube heat exchanger (HX) and its surrounding cooling jacket. In this "SACO" tube the saturated steam enters from the top, condenses, forms a falling film at the inner wall of the tube and leaves the SACO tube at the bottom to accumulate in the return line.

  The inner pipe (the actual "SACO tube" or "condensation tube" is designed in 42.16 x 3.56 mm and is made from INCONEL® 600.

  The Test Section is described in detail in section 7.1.2.3.2.

- **Condensate flow control valve (LCA94 / AA221)**

  This valve controls the fill level of condensate upstream of the valve (and inside the SACO tube).

The Condensate Loop is designed to guide the steam flow from the injection point in the Steam Drum extension pipe to the test section and to route the condensate flow back to the Steam Drum. The piping of the entire loop is designed for 80 bar at saturation condition (300°C). Downstream of the steam injection point a reducer connects the extension tube of the Steam Drum (Di 113mm) to the SACO tube charge line (pipe dimension 42.4x3).

This SACO tube charge line houses a steam flow meter (vortex-type) and the Steam Flow Control valve (LBA94 AP215). The SACO tube charge line guides the steam to the SACO tube (the condensation tube inside the Test Section).

The piping that connects the outlet of the SACO tube to the Steam Drum (routing the condensate flow back to the steam drum) will be designed at DN25 (33.7 x 2.9). Essential components of the return line are the Condensate Flow Control Valve and the Coriolis-type flow meter to measure the condensate mass flow (both described above). The Coriolis flow meter is placed in a thermosiphon to allow installation in upward flow direction. At the bottom of the siphon, let-down lines are installed for emptying the loop.

All piping with exception of the SACO-tube will be designed in stainless steel (1.4571). Downstream of the test section the return line houses a precision (Coriolis-type) mass flow measurement which provides (in conjunction with the reference temperature measurement at the test section outlet) the basis for the calculation of the heat transferred to the cooling jacket.

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Table 1: Details of Condensation Loop

	Condensation Loop		
Pipe section	SACO tube charging line (Steam drum to test specimen)	“SACO tube” Test Section	Test specimen to steam drum
Piping [mm]	42,4 x 3,0	42.16 x 3.56 mm	33,7 x 2,9
Length [m]	15	4,0	10
Volume [l]	16	3.848	6
Design parameters	90 bar / 300 °C	90 bar / 300 °C	90 bar / 300 °C
Insulation	20 mm, mineral wool, 1.4571	-	20 mm, mineral wool, 1.4571

7.1.2.3.1. *Cooling Loop*

The cooling loop consists of the following key components (see Figure 7):

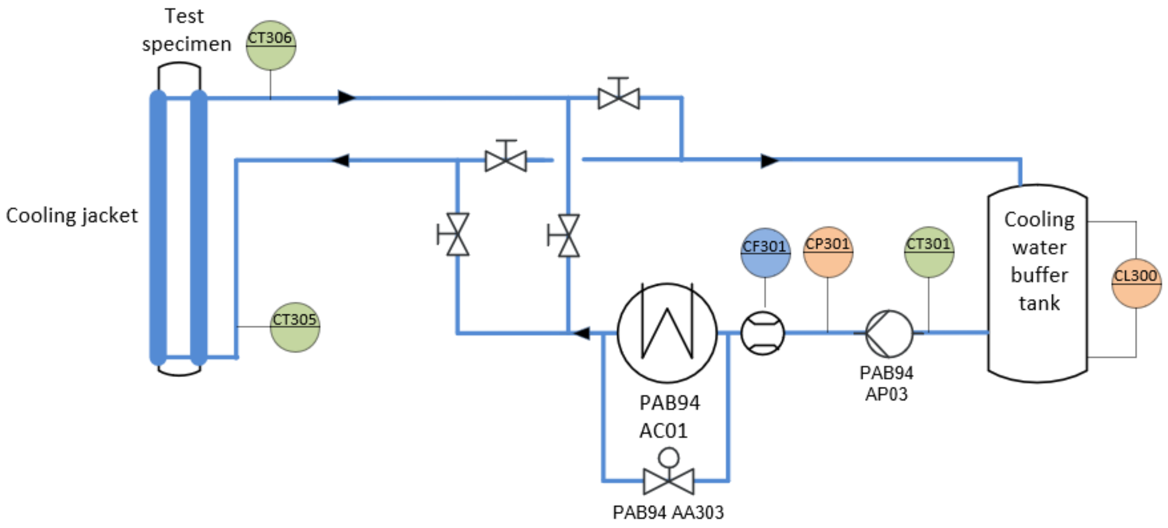

Figure 7 Principal scheme of the cooling circuit

- Cooling jacket around condensation tube. The cooling jacket is composed of an annulus around the condensation tube. Upper and lower sections of the cooling jacket are connected to the Cooling Loop.
- The default flow direction in the cooling jacket is upward direction i.e., in counter-current direction to the entering steam flow. However, a switchover of the flow direction to co-current flow is foreseen in the design of the Cooling Loop.
- Cooling water buffer tank (PAB94 / BB03)
- The buffer tank provides the water for the loop. It is a stainless-steel IBC with a volume of 1.5 m^3. It must not be operated under pressure.
- Cooling water pump (PAB94 / AP03, Type SULZER ZE 40-315)

- The cooling water pump has a maximum flow rate of 9.6 l/s and can operate at a temperature of up to 80°C. The pump flow rate may be adjusted to cover a wide range of possible flow velocities in the cooling jacket.
- The total head is 94 m. The pump will be operated by an electrical generator with frequency converter, that will allow the pump to operate at the desired volumetric flow.
- Heat exchanger (PAB94 / AC01, Type GESMEX XPS 50-62 H 11).
- The plate cooler PAB94 AC01 is designed for 500 kW of cooling power. The maximum temperature at the inlet of this heat exchanger is 100-200 °C. The plate cooler PAB94 AC01 is connected to the inhouse cooling system which provides a controllable cooling water flow to adjust the temperature of the water flow to the cooling jacket.

The cooling water flow in the Cooling Loop is driven by a low-pressure cold-water pump (AP03). Piping and valves in the Cooling Loop are arranged in such a way to allow the operation of the cooling in counter-current or co-current orientation to the steam flow in the condensation tube (which is fixed to downward steam/condensate flow).

After exiting the test section, the cooling water flows back to the cooling water buffer tank. The maximum operation temperature in the cooling loop is limited to 80°C. It is open to the atmosphere so it cannot operate under pressure. The piping from the pump to the test section will be built with the Mapress system (54 x 1.5), the piping going back (88.9 x 2.0). All piping will be designed in stainless steel (1.4571).

Table 3: Details of Cooling Loop

	Cooling Loop		
Pipe section	Cooling jacket charge line (pump to Test Section)	Cooling water return line (cooling jacket to pump)	Cooling water buffer tank
Piping [mm]	54,0 x 1,5	88,9 x 2,0	
Length [m]	20	20	
Volume [l]	40	114	1500
Design Parameters	COSAC design maximum power:467 kW Cooling water design flow rate: 9.6 kg/s Cooling jacket inlet temperature: 35 °C at max. Power Cooling jacket outlet temperature: 65 °C		
Insulation	Thermal insulation from Test Section between measurement positions CT 305 and CT305. Rest of the cooling loop will not be insulated.		

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7.1.2.3.2. Layout of the Test Section

As described above the test section essentially consists of a single-tube heat exchanger. Figure 8 shows the test specimen in an isometrical view, Figure 9 in a cross-sectional view. The total height of the test section is about 6500 mm, of which the length of the condensation tube is 5600 mm (without the flanges).

The condensation tube is sectioned in three different parts:

- Top section provides the upper connection to the Cooling Loop
- Mid-section, the actual measuring section
- Bottom section provides the lower connection to the Cooling Loop

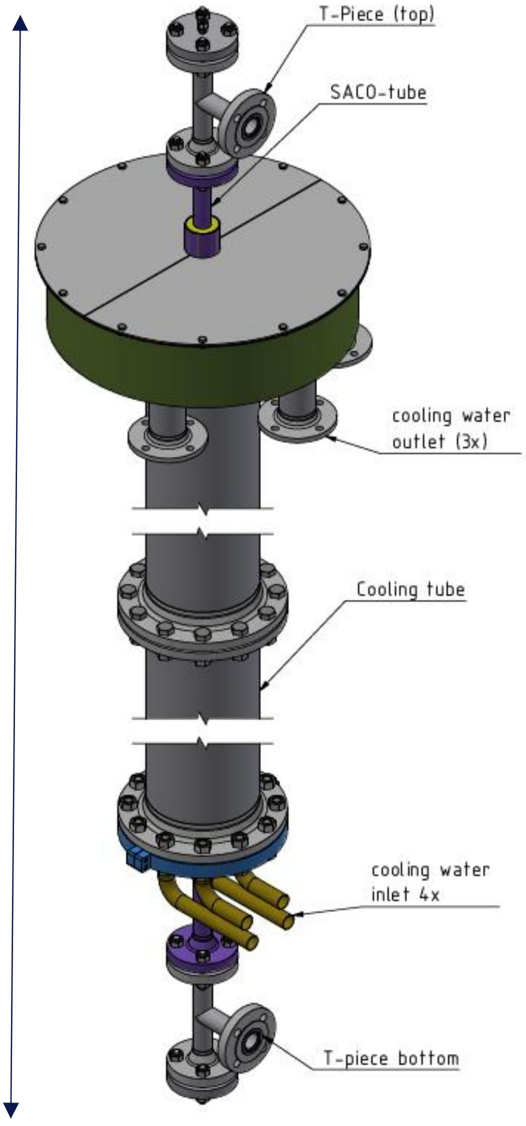

Figure 8 test section

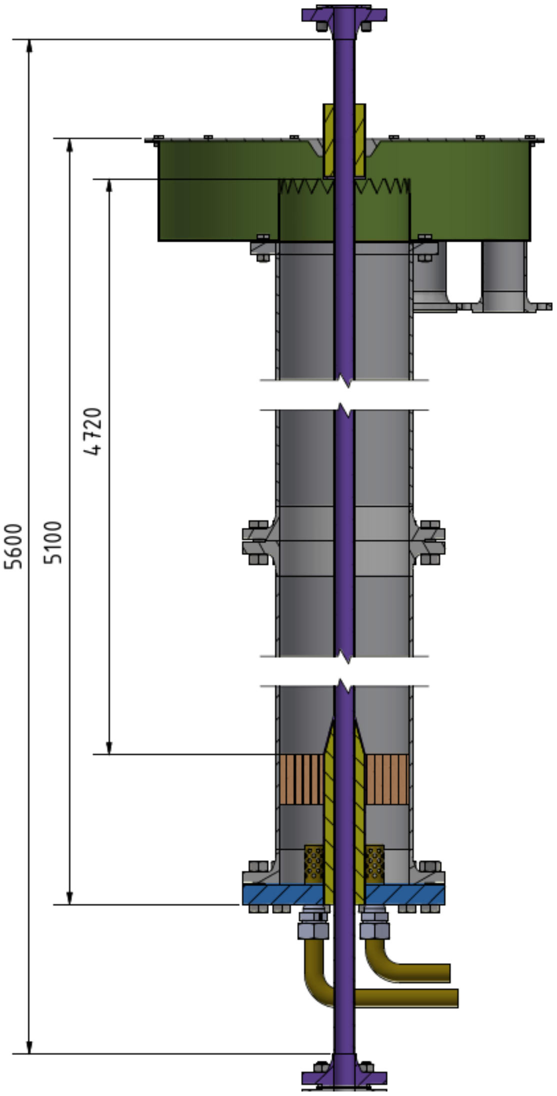

Figure 9 test section, top, mid and bottom sections (cross sectional view)

In between the bottom and top sections, the actual Test Section covers a length of 4000 mm. As for this area the heat transfer coefficients (internal and external) are to be determined of basis of experimental data; to this end, the Test Section (including the

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condensation tube and its cooling jacket) will be equipped with additional instrumentation (see sections 7.1.2.4).

The condensation tube is made of INCONEL® 600 (Di 35mm 42.16 x 3.56 mm). The outer shell of the cooling jacket is designed in 1.4571 (dimension 219,1 x 6,3).

The primary fluid (steam) enters the SACO tube via the T-piece on the top and leaves the test section via the T-piece at the bottom (condensate).

The cooling water can flow into the cooling jacket from top or bottom, which makes it a counter or co-current heat exchanger (the valve battery in the cooling water supply lines comprising AA320, AA321 AA332 and AA331 allow the reversion of cooling water flow inside the jacket).

However, the Test Section design is optimized to run as counter current heat exchanger which constitutes the default flow direction in the cooling jacket. Therefore, the connection on the bottom can be defined as the cooling water inlet and the connection on the top as the cooling water outlet.

The design of the Test Section was done to match requirements regarding flow, pressure, seal tightness, strength and will be explained in the chapters below.

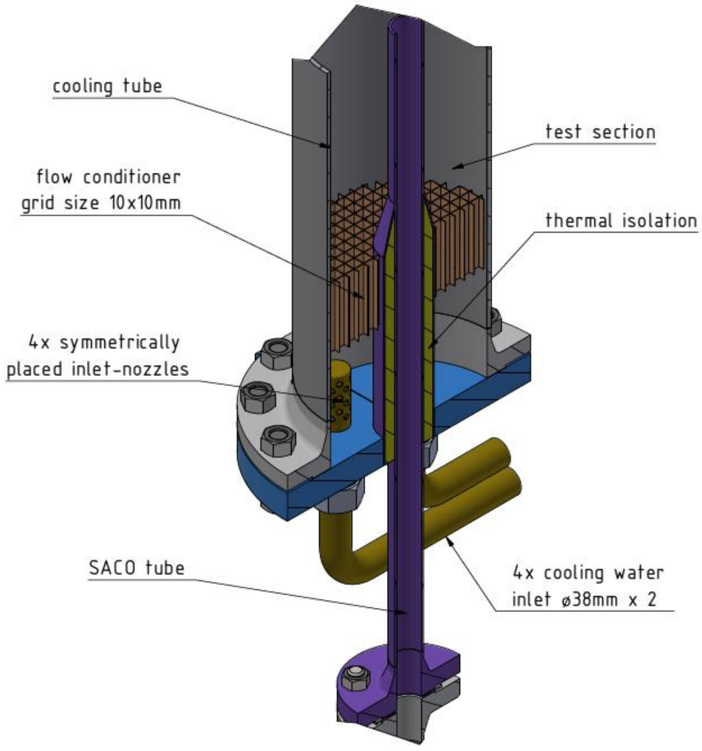

Figure 10 test section (bottom), cross section

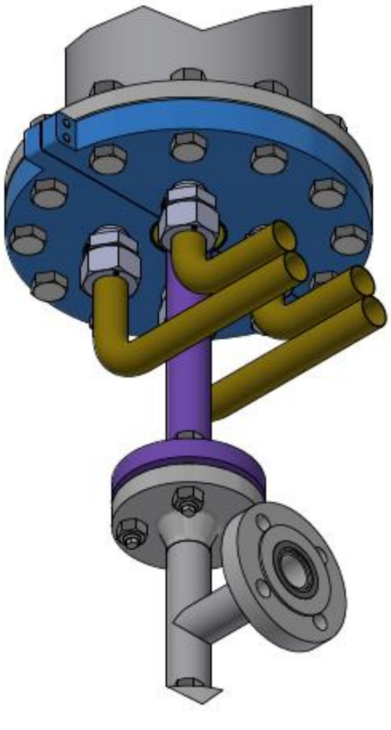

Figure 11 section (bottom), detail

Figure 10 shows the bottom section of test section in cross-sectional view. Water from the cooling circuit enters at the cooling water inlet. The inlet is designed as four pipes 38 x 2 mm being connected to the bottom plate (blue) via pipe couplings. This connection can also be realized with hydraulic hoses. Further on, the water will flow through the inlet nozzles. These nozzles are designed to reduce the vertical velocity by having the

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water enter in a horizontal spray. The cooling water flows inside the cooling jacket and before it enters the actual test section, the flow field is homogenised in a “flow conditioner”. This “flow conditioner” has a grid size of 10 x 10 mm and a height of 100 mm.

At the outlet of the flow conditioner the flow enters the actual measurement section of the condensation tube. As 8 l/s is the maximum cooling water flow, the max velocity will be approx. 4,5 m/s at the cooling water inlet/nozzles and approx. 0.15 m/s inside the cooling tube. This results in small pressure losses (<1 bar) even at maximum cooling water flow.

The cooling jacket houses the condensation tube (purple) which provides the border around the condensation area for the steam coming from the Condensation Loop.

In order to prevent heat transport to the cooling jacket outside of the test section (i.e., along the lengths of the bottom and top sections of the test section), a thermal isolation is applied along the respective parts of the condensation tube. It is designed by an 85 x 2,0 mm shell/pipe around the SACO tube that is filled with 195 mm of isolation wool. The condensate exits the test section bottom part through the T-junction.

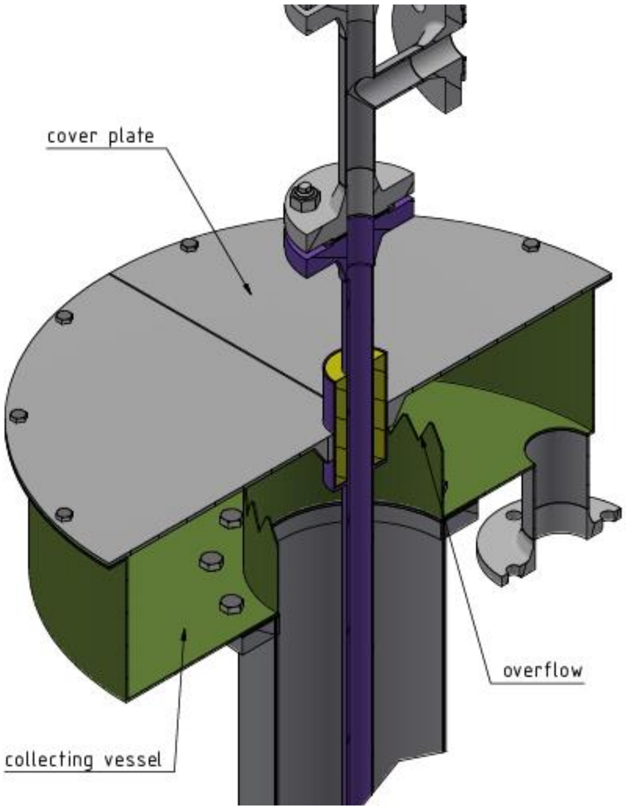

Figure 12 test specimen (top) cross section

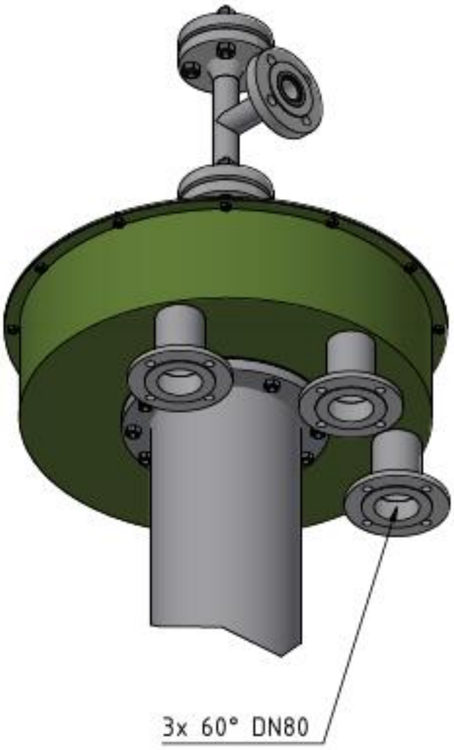

Figure 13 test specimen (top)

Figure 12 shows the top of the test specimen in a cross-sectional view. The upper cooling water outlet of the cooling jacket consists of a symmetrical overflow device that enables the cooling water to exit the cooling tube and to avoid imposing turbulences.

The cooling water is collected in the collecting vessel (green) where it can be drained through three DN80 flange connections and be guided to the cooling water buffer tank.

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Considering that the cooling water inlet nozzles at the bottom of the test section have been designed as four ø32 mm pipes, the diameter at the exit of the cooling jacket is much larger. This is due to the fact, that the collector vessel is designed to be operated at atmospheric pressure and the gravity alone causes the cooling water to exit through the three exit flanges.

The collector vessel is connected to the cooling jacket via flange connection. The tightness is assured by a perforated flange gasket. On the top of the collector vessel, a cover will be fixed which provides sufficient ventilation area to assure atmospheric operating condition in the cooling jacket.

The saturated steam coming from the Steam Drum enters the condensation tube through the top T-junction. To prevent heat transfer from the condensation tube to the cooling water outside of the condensation tube, a double shell with isolation wool is installed in a similar fashion as for the bottom of the test section.

7.1.2.3.3. Levels and Heights of the COSAC Facility

The test facility will be built and operated at the Framatome GmbH Technical Center Karlstein, Germany.

The test field provides a steel framework which is divided in 3 x 3 x 3 m “Test Fields”. Inside those cubes all the components for the COSAC loop are placed.

As the Condensation Loop is designed to operate on basis of natural circulation (convective flow) it is mandatory to respect the positioning of components in relation to each other.

While the Boiler (EDB4) has a fixed position in the field which cannot be changed, the remaining components can be positioned to support operation of the facility.

To this end, the steam drum will be placed about 3 m below the bottom of the test specimen.

Figure 14 provides an overview on the levels and heights of the COSAC components.

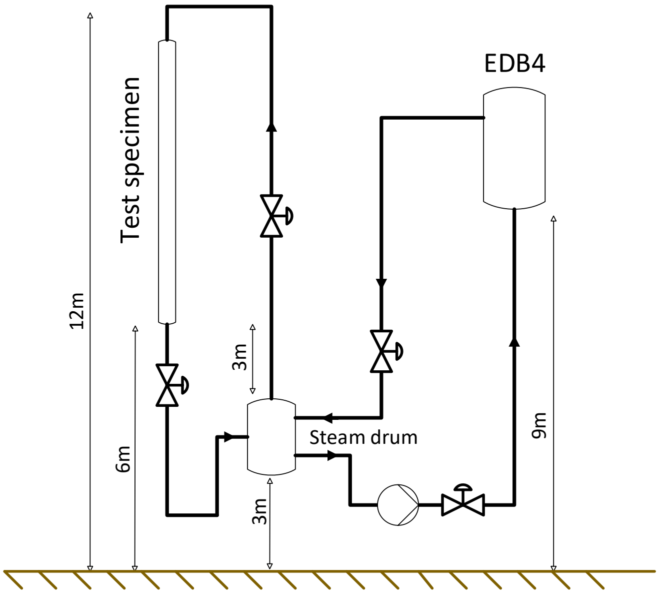

Figure 14 Level overview for steam injection and primary loop

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To get a better understanding of the facility Figure 15 provides an extract of the Test Fields including the ones in which the COSAC loop is located. The figure includes the following:

- Pressurizer (EDB4)
- Steam drum
- Condensate pump (Rotational Pump, Type Teikoku)
- Test section

The simplified drawing shows only the main components of the Heater Loop, the Condensation Loop and the Cooling Loop including a rough overview on the piping systems. The planned piping diameter as well as the lengths are shown in Figure 3, Figure 14 and Figure 15.

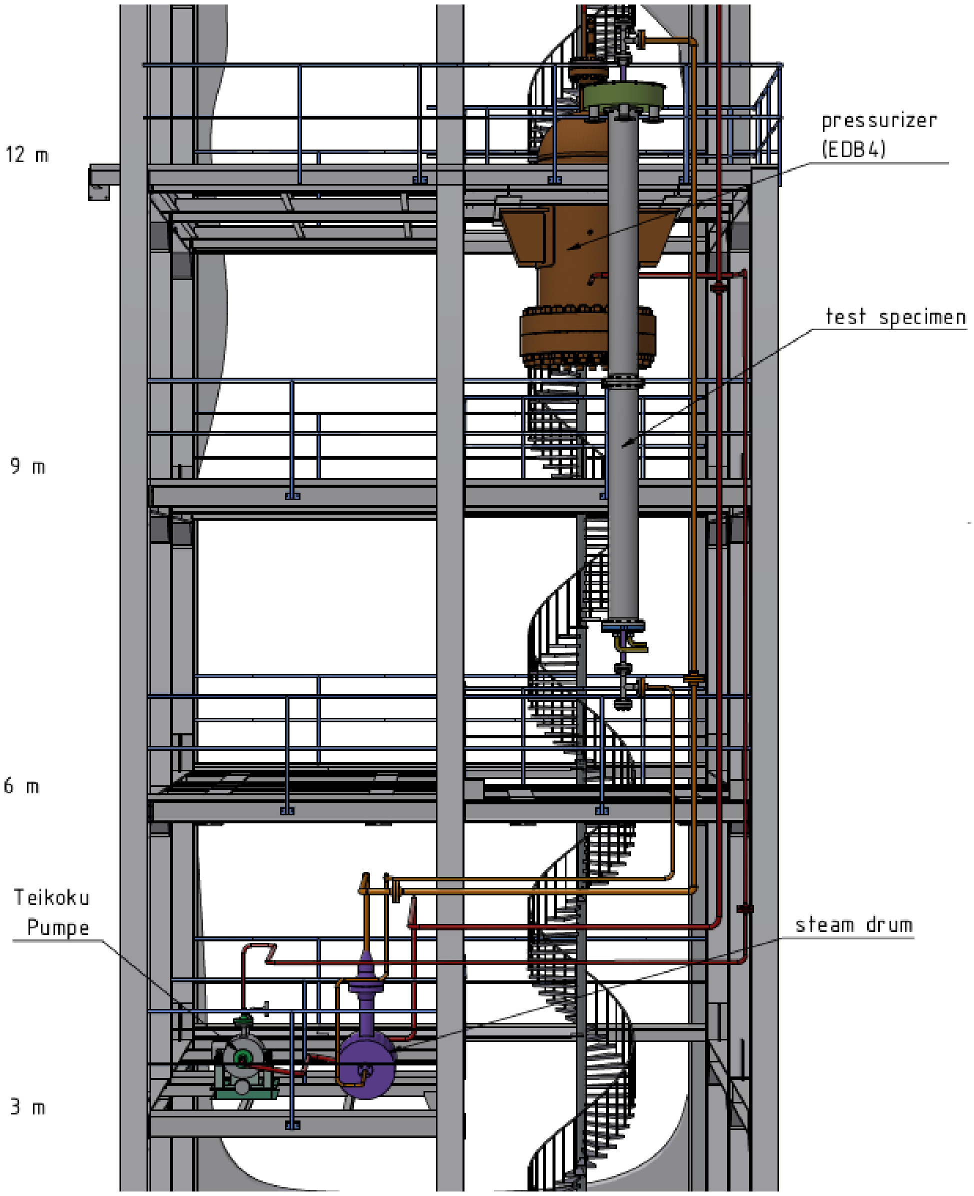

Figure 15 Steam injection and components in test facility

7.1.2.4. Instrumentation and range of thermal-hydraulic parameters

In addition to the instrumentation in the loop necessary to capture key boundary conditions (temperatures, flows, pressures), the test section is equipped with additional instrumentation dedicated to the recording of key parameters required for evaluating the heat transfer models.

Figure 16 provides a schematic of the temperature measurements on basis of conventional thermocouples in the condensation tube and its cooling jacket.

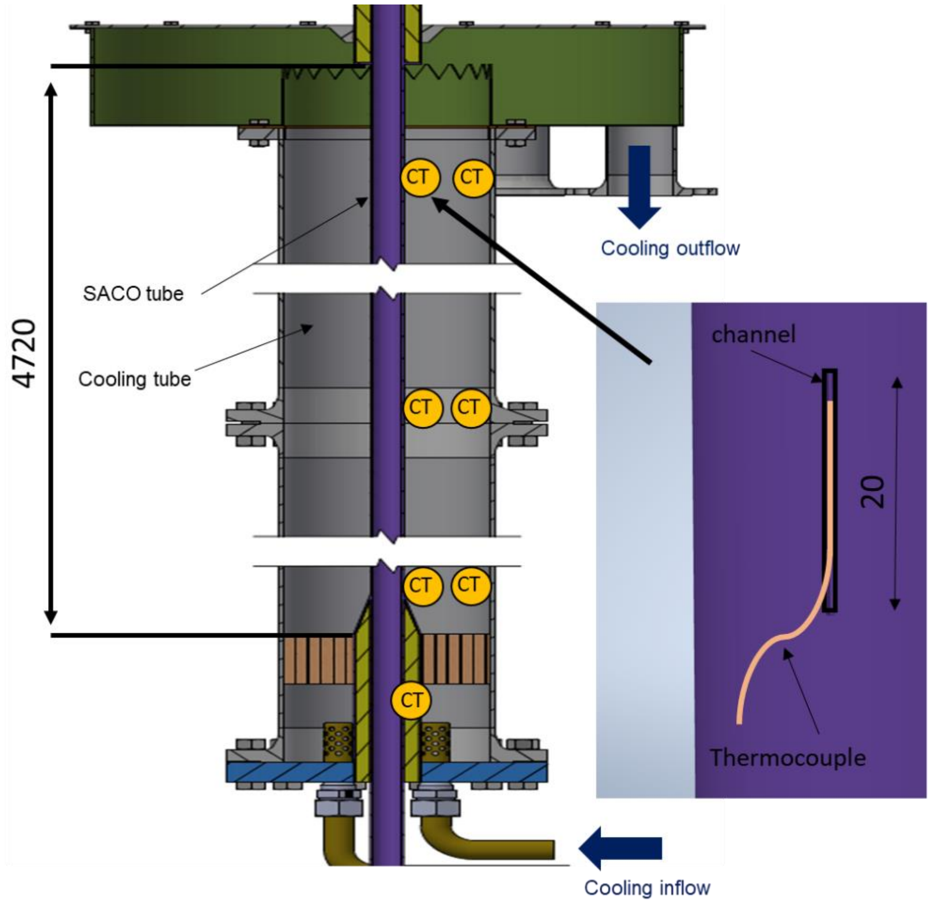

Figure 16 Instrumentation of Test Section

Further instrumentation to measure temperature inside the condensation tube and the cooling jacket will be optical fibres to measure the temperature inside the SACO-tube, in the condensate siphon and on the inside of the cooling tube (highlighted as purple and blue lines).

Commissioning data on the heat conduction coefficient of the condensation tube as well as for the inner and outer wall roughness used in the correlations have been determined as part of the commissioning procedures, the data is summarised in the respective section of the detailed facility description report.

Figure 17 shows the positions of the fiber-bragg probes inside the SACO tube (one FB-probe in centre axis) and inside the cooling jacket (three FB-probes at different radial positions).

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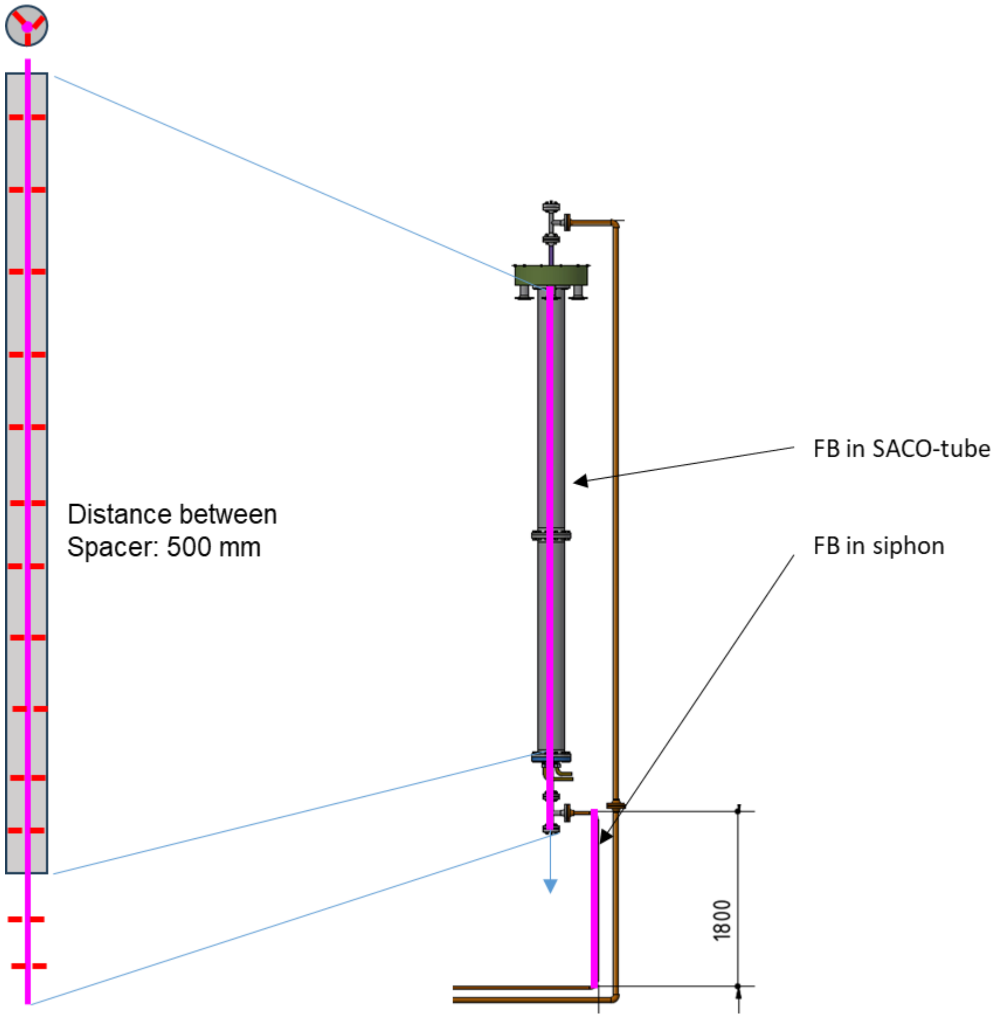

Figure 17 Fiber bragg (FB) probe inside SACO tube and the return line siphon

Inside the condensation tube the FB-probe will be supported by spacers (shown in red) to center the fibre inside the tube. They will be placed every 500 mm. The measurement points inside the SACO tube will be 127 measurement points placed every 31.5 mm. The total length of the FB-probe inside the SACO tube will be around 6000mm (to cover the metering section of 4000 mm plus additional lengths for in- and outlet joints) and for the siphon about 1800 mm, depending on the final length of the piping.

The three FB-probes inside the cooling jacket are supported by a cage. This is shown in Figure 18.

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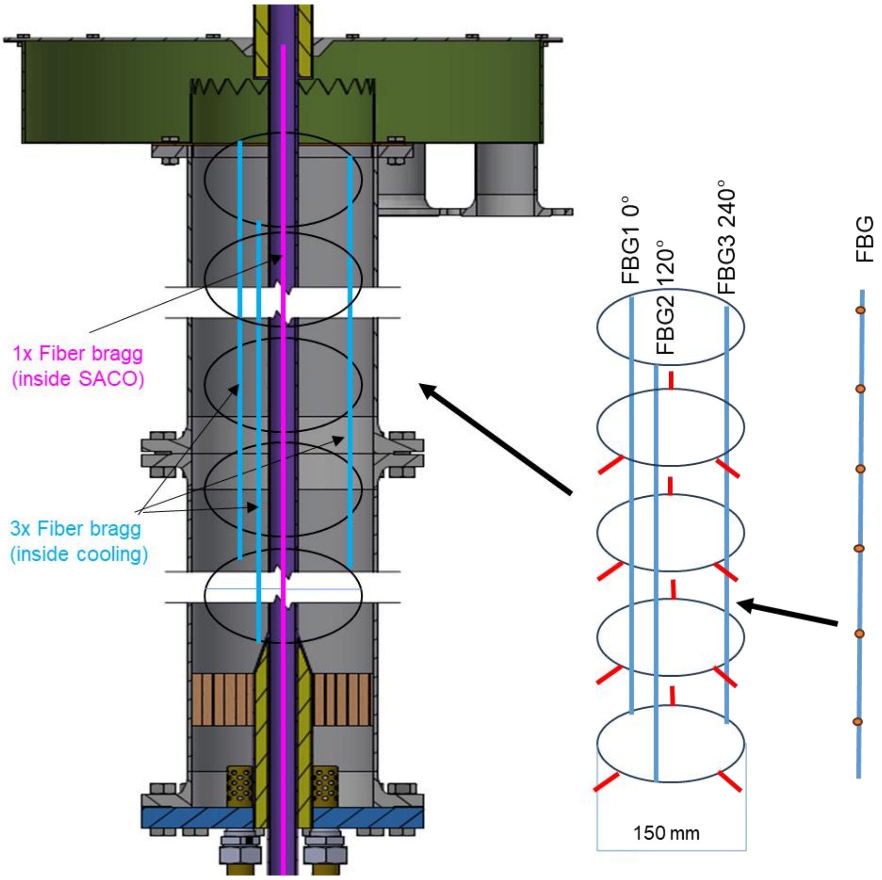

Figure 18 Fiber braggs inside cooling jacket

The Heater Loop features the following measurement installations:

- Temperature measurements:
    - LBA94 CT100 Temperature of the steam before it enters the condensation loop via the injection point in the Steam Drum extension tube.
- Power measurements:
    - EDB4 electrical power
- Flow rate measurements:
    - LBA94 CF100 flow rate from EDB4 to Steam Drum (steam)
    - LCA94 CF120 flow rate from Steam Drum to EDB4 (condensate)
- Pressure and differential pressure measurements:
    - SP109 CP01 absolute pressure in the EDB4 boiler dome
    - SH109 CL01 water level EDB4 boiler

Further instruments are installed to assure the safe operation of the COSAC test facility, without immediate link/relation to the test performance and test results.

The prefixes LBA94 and LCA94 are assigned to all measurements belonging to the Condensation Loop's "hot side" (related to the steam flow) and its "cold side" (condensate flow), respectively.

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The Condensation Loop houses measurements for key parameters:

- Temperature measurements:
    - CT101, Temperature in the upper part of the steam drum
    - CT103, Temperature in the lower part of the steam drum
    - CT203, precise measurement of the temperature of the saturated steam in the upper part of the SACO tube

      This reference temperature measurement is located at the top of the condensation tube, immediately downstream of the steam inlet junction.

      This measurement is a resistance thermometer. The precise recording of the temperature at this point in the tube serves as reference for the optical fibre. It can be easily dismantled for calibration.
    - CT205, precise measurement of the temperature of the condensate flow leaving the lower part of the SACO tube.

      Similar to its top counterpart, this measurement is a resistance thermometer. The precise recording of the temperature at this point in the tube serves as reference for the optical fibre. It can be easily dismantled for calibration
    - CT204.ABCD temperature measurements provided by Fibre-Bragg probe in centre axis of condensation tube. The exact positioning of the metering points along the fibre above the zero level in the condensation tube outlet is provided by a 4-digit designation.

      127 Measurement positions are distributed along the centre fibre, i.e. a measurement point every 31.5 mm along the entire condensation length
    - Thermocouples (K-type) soldered into the outer wall of the condensation tube to capture the external wall temperature of the condensation tube at discrete locations.

      The MST codes are CT4.W.ABCD in which ABCD provides the height above the above the zero level of the metering section in mm
- Pressure and differential pressure measurements:
    - CP101 absolute pressure in the upper part of the Steam Drum
    - CL102 water level in the steam drum
    - CL201 water level in the expansion vessel
    - CP203 absolute pressure downstream of control valve (AA215).

      The precise recording of the pressure at this point in the condensation tube serves as reference for the calculation of the saturation temperature which give a s basis to detect. This precision pressure measurement is used to calculate the saturation temperature inside the condensation tube and thus provides the basis for the identification of non-condensable gases inside the relevant parts of the condensation tube.
    - CP203 absolute pressure in the Steam Drum
    - CL204 water level (on basis of Δp) inside the condensation tube

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  - CP220-225 differential pressure chain around the condensation tube.
    - CP220 is in effect a measurement of the Δp created by the Steam Flow Control Valve (LBA94 AA215)
    - CP222 is a precision measurement to capture the pressure differential across the condensation zone.
    - CP223 and CP224 are Δp interpreted and recorded as liquid levels on both sides of the siphon housing the Condensate Flow Control Valve (LCA94 AA221), the check valve (LCA94 AA220) and the condensate flow measurement (LCA94 CF210).

      During commissioning, the two Δp sensors have been recorded as raw Δp (without conversion into a fill level).
- Flow measurement:
  - CF200 volumetric flow entering the test specimen
  - CF210 (Coriolis-type flow meter)

- The prefix PAB94 is assigned to all measurements belonging to the **Cooling Loop**. The Cooling Loop houses measurements for key parameters to capture the temperature profile in the cooling jacket surrounding the test section, for instance, and the cooling power provided to the COSAC facility: optical fibres in the cooling jacket to measure the fluid bulk temperature in the cooling jacket along the height of the condensation tube. The radial positions of the fibres are 120 ° apart and kept stable by small support struts see Figure 18.
- 63 positions are distributed along the three fibres at identical heights, i.e. a measurement point every 63.5 mm in the cooling jacket along the entire length of the condensation tube.
- Temperature measurements up- and downstream of the cooling jacket to capture in-and outlet temperatures of the cooling water flow to or from the cooling jacket, respectively.
  - CT305 precise measurement of the temperature of the lower cooling water flow; inflow position for default cooling water flow direction (cooling water flow in the cooling jacket in counter-current orientation to the steam inflow)
  - CT306 precise measurement of the temperature of the lower cooling water flow; outflow position for default flow direction in the cooling jacket
- Pressure measurement
  - CP301 absolute pressure downstream of the cooling water pump
- Flow measurement

Flow measurement CF301 (Vortex-type flow meter) to capture the cooling water flow through the cooling jacket.

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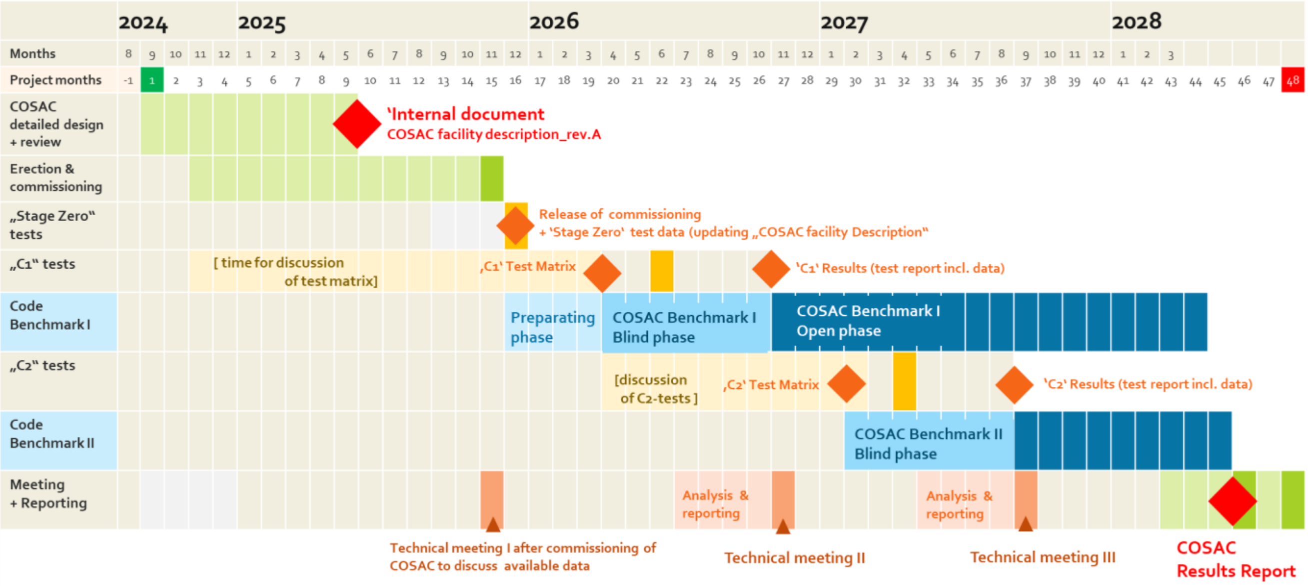
7.1.2.5. Matrix data tests prevision

Test Campaign	Test No.		Description / Objective
Commissioning Tests (stage „Zero“)	C0-Test series	▪ **C0.1**Heat loss tests	Heat input adjusted to maintain constant temperature in condensate loop
		▪ **C0.2**: Pressure loss test in single phase cold water	Constant (controlled) pressure in SACO loop for subcooled, single-phase forced circulation
Phase 1-Tests	C1-Series	▪ C1.1 P_{SACO} as function of pressure in condensation loop	▪ Constant cooling water inlet temperature and flow ▪ **Adjust P_{input} to obtain steady-state pressure steps at 2, 5, 10, 20, 25, 30, 40 and 60 bar in condensation loop** → Change of condensate outlet temperatures and heat transfer along tube → Calculation of heat transfer coefficients α_{inner} and α_{outer} for different sections of the tube
		▪ C1.2 P_{SACO} as function of condensate level in tube	▪ Constant cooling water inlet temperature and flow ▪ **Adjust P_{input} to obtain steady-state pressure steps for constant level in SACO tube (controlled by throttling condensate flow)** → Change of condensate outlet temperatures and heat transfer along tube → Calculation of heat transfer coefficients α_{inner} and α_{outer}
Phase 2-Tests (Options)	C2-Series	▪ C2.1: Impact of NCG	• **Repetition of selected points of C1.1 with defined amounts of NCG** → changes to heat transfer coefficients α_{inner} and α_{outer} ?
		▪ C2.2: Impact of changes to heat sink operating condition	• **Repetition of selected steady-state points of C1.1 with changes to cooling water flow (temperature, mass flow)** → changes to heat transfer coefficients α_{inner} and α_{outer} ?
		▪ C2.3: Transients	▪ Record response of system to step changes in heater power → transient changes to heat transfer coefficients α_{inner} and α_{outer} ?

7.1.2.6. COSAC activity schedule



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7.2. FHEASIK

One of the SMR designs considered in the EASI-SMR project is the Finnish LDR-50, a low temperature district heating 50 MWth reactor, developed by Steady Energy, a spinoff company of VTT. To investigate the performance of some of the unique passive safety features of the LDR-50 design a new test facility called FHEASIK (Final Heat Sink) is being built at LUT University.

Task 2.3 involves building this facility, commissioning it, and providing experiment results as well as creating human and technical resources to achieve expected results. The deliverable associated with this task consists of the description of the test facility, its connection with existing utilities, instrumentation, and a thermohydraulic basic model description. Test data corresponding to the test matrix proposal is delivered as an entry point for the benchmark associated with WP3.

This activity is managed entirely by LUT University. CEA is responsible for monitoring, steering and interfacing the activity with the EASI SMR project and the other WP leaders.

7.2.1. Background to the FHEASIK experimental facility

Most of the European SMR concepts consist of two independent systems extracting heat from the primary circuit like in LDR-50 that is presented in Figure 19. The secondary circuit relies on active pumps and is used in normal operation conditions. The reactor pressure vessel (RPV) is inside a reactor containment vessel which in turn is inside a large water pool forming a passive residual heat removal system to be used in accident conditions. Nitrogen atmosphere together with water/steam is present both in the reactor and containment vessels. In abnormal situations, such as loss of power, internal circulations (eddy flows) could develop around the heat exchangers. Eddy flows could appear also in the containment gas volume. Flow runs upwards and downwards along the vessel walls. Boiling in the large water pool is not necessary to handle transient/accident situations but it could happen in very long transients. Mainly evaporation/condensation in the gap and dome volume dictate the course of the transient.

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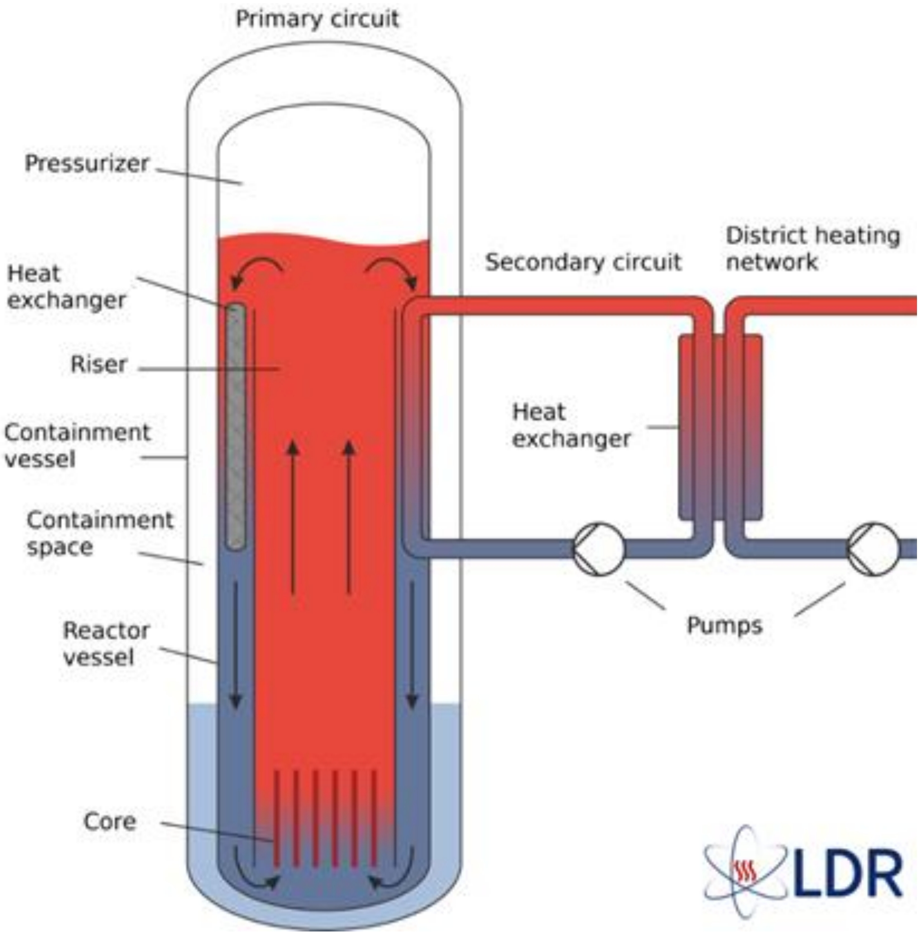

Figure 19. LDR-50 layout (https://www.ldr-reactor.fi/en/technology/). Containment vessel is submerged in a large water pool.

The aim of the FHEASIK experiments is to model heat transfer from the reactor to the water pool through the containment annular gap of LDR-50 in a station blackout (SBO) scenario. The following physical phenomena characterize the system behavior in the above-mentioned scenario.

- Convection heat transfer in the gap filled with water and nitrogen
- Condensation of evaporated steam in the dome part of the containment vessel
- Radiation heat transfer across the gap in the steam/nitrogen section

At the start of operation of the passive residual heat removal system, the water pool is generally cold and isothermal. After several dozen hours, the entire water pool has received enough energy to heat up significantly, but large temperature gradients may occur along the vertical elevation of the pool. Temperature evolution of a large volume of water representing the final heat sink has been studied only a little in the various European projects, and the experimental loops representing the operation of a safety condenser have favored a directly embedded design in a relatively small-diameter enclosure (see Figure 20). It is therefore important to complete the understanding of physics behind the evolution of natural circulation under water wall conditions in a design with only a partly immersed vessel.

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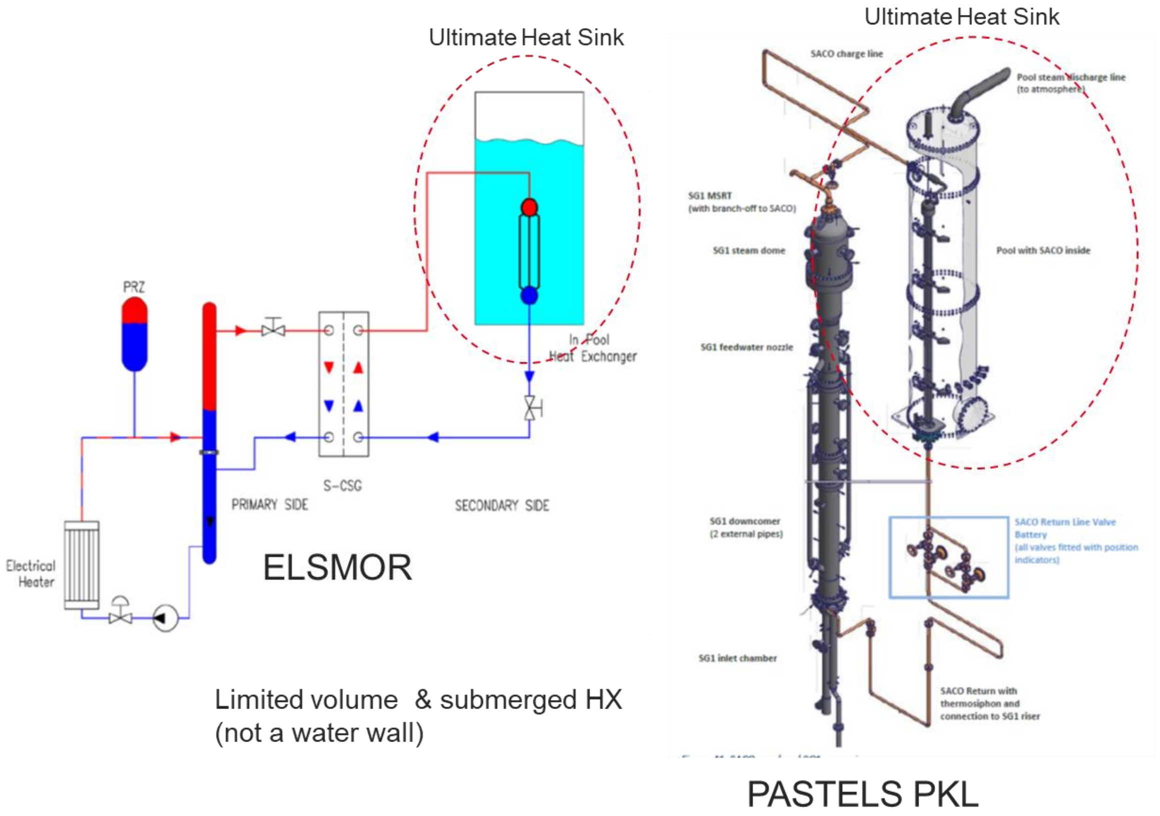

Figure 20. Representation of ultimate heat sink in ELSMOR and PASTELS projects.

7.2.2. Definition of the semi IET FHEASIK

7.2.2.1. General description of the facility

The goal of the FHEASIK experiments is to mimic heat transfer from the reactor to the water pool through the containment annular gap of LDR-50 in an SBO scenario at a representative containment pressure and to study temperature stratification inside the water pool. The complete system (RPV + containment vessel + water pool) is modelled with the FHEASIK test facility, but the focus of the research will be on the containment behavior and the pool temperature stratification.

The sketch of the FHEASIK facility is shown in Figure 21. Heat to the test unit is delivered by pumping hot water from the nearby MOTEL test facility to the top of the RPV section. Water cools down in the RPV section, comes out from the bottom, and is returned to MOTEL.

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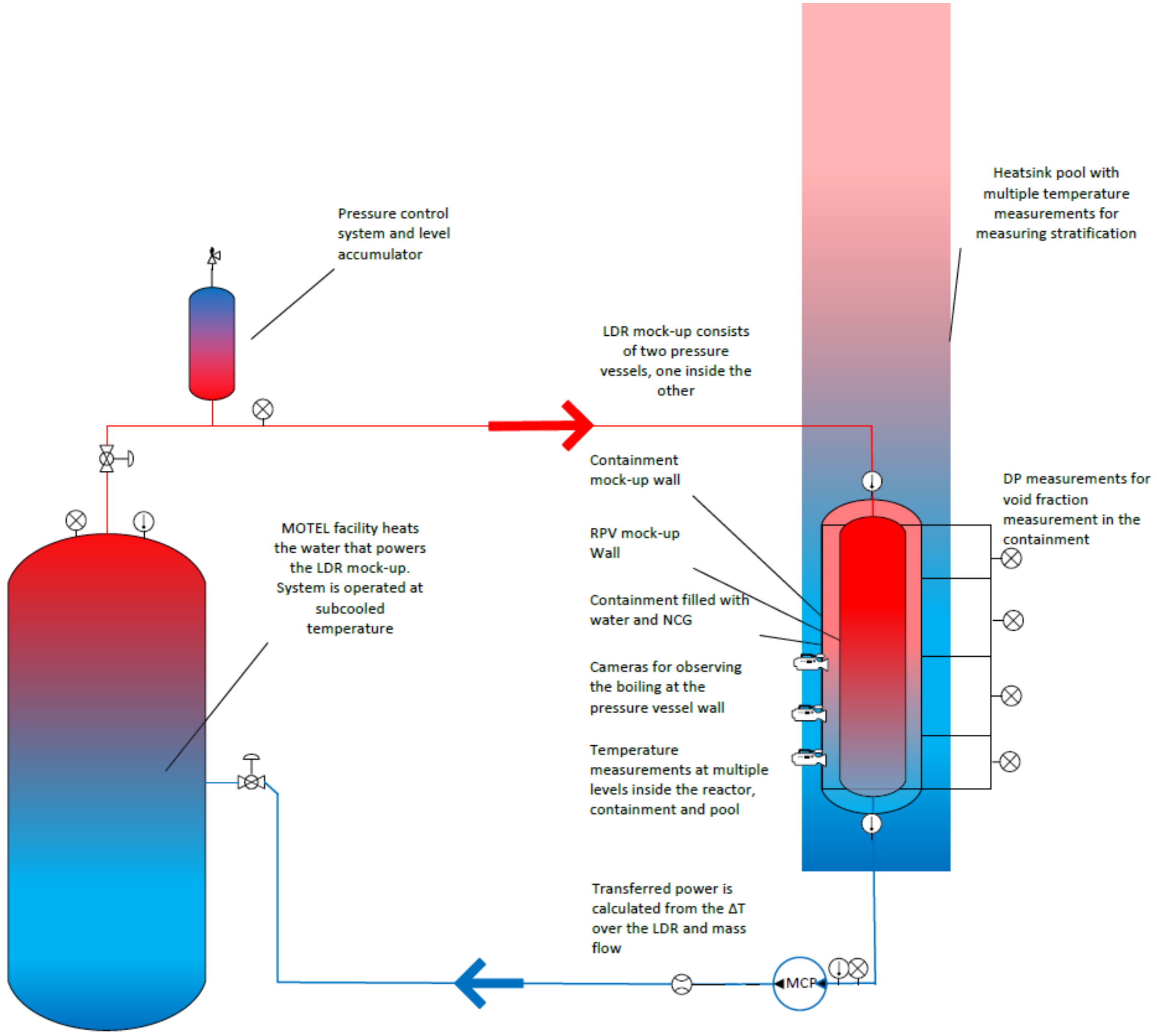

Figure 21. Sketch of the FHEASIK facility.

7.2.2.2. Description of the test loop

In the LDR-50 district heating reactor concept, decay heat removal happens through free convection in the annular gap between the reactor and containment vessels. The gap consists of a long cylindrical section, where the gap width is 0.3 m, and of a dome section with a larger gap between the torispherical surfaces. The bottom section of the gap is full of water, which in off-normal conditions evaporates due to reactor (decay) heat and condenses on the containment wall.

Heat transfer in the gap happens by three mechanisms as mentioned earlier: convection, condensation and radiation. The steam mass fraction in the gap can be assumed to be small. Therefore, the flow in the gas space is controlled mainly by nitrogen circulation. The presence of steam is a second-order factor that can either strengthen or dampen the circulation, depending on operating conditions.

The test facility is scaled in such a way that the aspect ratio, i.e., the height of the containment gas space divided by the containment gap width is maintained in FHEASIK, the gap width being 1:3 with respect to LDR-50. The height of the containment gas space is determined as the distance from the water surface to the secondary circuit pipeline penetrations. The heat flux between the containment and the water wall is scaled at 1:1. The containment pressure is also designed to be 1:1. Free convection in a gap, such as

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the LDR-50 annulus, scales with the Rayleigh number. This is because there is no boundary condition that would fix a reference flow velocity. Fluid natural circulation in the gap is driven by density difference between the hot and cold walls. The plate above the inlet pipe into the vessel limits flow towards the top of the vessel directing the flow downwards. Figure 22 shows the general overview of the FHEASIK water pool and the test unit inside the pool.

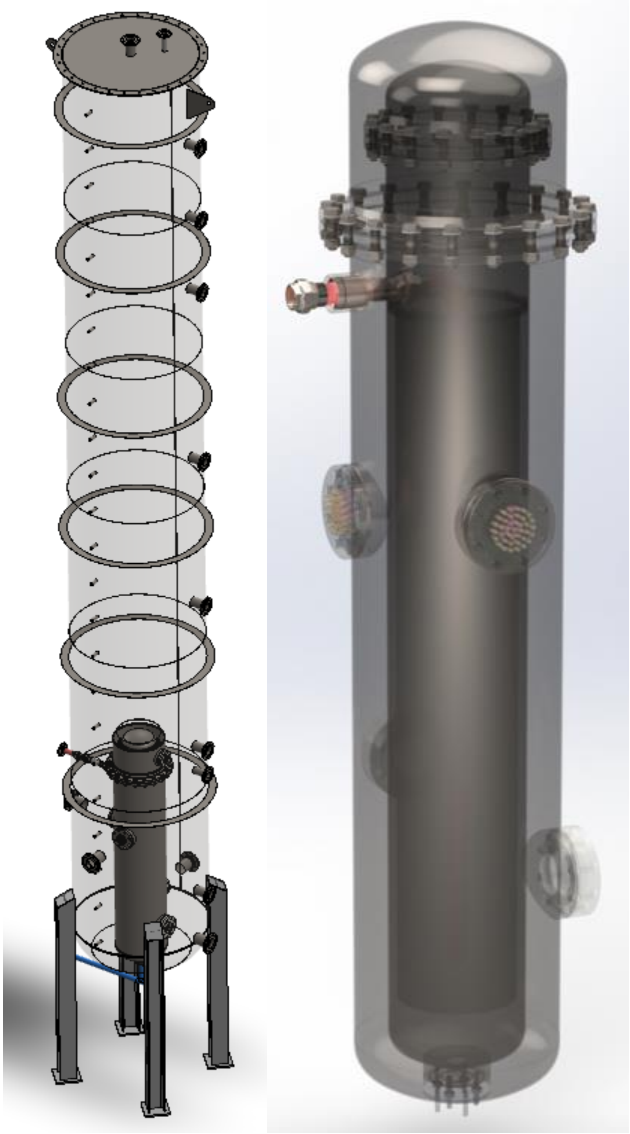

Figure 22. FHEASIK water pool (left, heigh ~10 m) and test unit inside the pool (right, height ~3 m).

7.2.2.3. Instrumentation and range of thermo hydraulics parameters

The basic measured quantities are temperature, pressure, differential pressure and mass flow rate. Additionally, moisture content in the containment and heat fluxes on the RPV and containment walls are measured. These may not be available in all test conditions. The temperature and heat flux measurements are to be installed at the same elevation inside the RPV, containment and water pool where applicable. Additional temperature measurements are located on the top portion of the water pool to measure thermal stratification. The exact number and location of the measurements are to be specified later. There will be windows for cameras on the walls of the water pool and the containment vessel to observe the flow phenomena inside the annular containment gap.

7.2.2.4. Matrix data tests prevision

The main objective of the FHEASIK experiment campaign is to verify that the passive residual heat removal system of LDR-50 is functioning as expected. The goal of the experiments is to mimic heat transfer from the reactor to the water pool through the containment annular gap of LDR-50 in an SBO scenario at a representative containment pressure and to study temperature stratification inside the pool water. The main interest is in the natural convection heat transfer through the containment annular gap and how the temperature stratification in the final heat sink evolves. Furthermore, condensation of evaporated steam in the dome section of the containment vessel is studied. Due to the quite simple nature of the transient in question the decay heat power level is the only test parameter to be varied. Two experiments will be carried out with different heating powers simulating different phases of the SBO scenario. The pool water can be preheated with electrical heaters.

7.2.2.5. FHEASIK activity schedule

An indicative schedule of the activities for the duration of four years of the project related to the FHEASIK facility is presented below. Some overlapping in the tasks is expected. Deadlines of the milestones and deliverables are also shown in the table.

Activity	Project months	Actual months
Facility design	1-8	9/2024-4/2025
Building and shakeup tests	7-18	3/2025-2/2026
Performing experiments	19-25	3/2026-8/2026
Reporting	22-34	6/2026-6/2027
Milestone 1: facility description + pre-test specifications available	18	2/2026
Milestone 2: all test data available + blind specifications	28	12/2026
D2.3 deadline (includes facility description and test reporting)	36	8/2027

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7.3. GRADAC

Task 2.4 involves building the GRADAC (Gravity Driven Accumulator) separate effect test (SET) facility, commissioning it, and providing test results as well as creating human and technical resources to achieve expected results. This experimental campaign consists of reproducing and thermo-hydraulically modelling the behavior of a safety-critical component, as an emergency injection system, in the event of a LOCA-type accident. While the behavior of conventional accumulators pressurized with nitrogen has already been extensively studied and characterized, the same cannot be said of gravity accumulators pressurized with steam. This concerns both the initial preparatory pressurization phase of the accumulator and the gravity injection phase.

During the preliminary construction phase and components supplying, specific CFD studies will be carried out by CEA (4PM) to propose an optimized sparger design to minimize the interaction between the steam jet and the upper liquid surface in the gravity accumulator.

The deliverable associated with this task consists of the description of the test facility, instrumentation, and test results. Test data corresponding to the test matrix proposal is delivered as an entry point for the benchmark associated with WP3. This activity is managed entirely by LUT University. CEA is responsible for monitoring, steering and interfacing with the EASI SMR project and the other WP leaders.

7.3.1. Background to the GRADAC experimental facility

As far as core cooling is concerned, the passive systems generally considered mainly concern the removal of residual heat from the fuel assemblies to the final heat sink. This is why a great deal of effort is focused on both safety condensers and cooling of the third containment barrier. However, the core cooling function requires the entire heat transport chain, particularly at the interface between the fuel rod and the primary fluid. During a loss of coolant accident, the primary water inventory decreases, and safety injection systems are usually promoted to maintain a sufficient coolant level in the reactor vessel thus ensuring a flooded core situation. The concept of a gravity driven accumulator is used in some PWR concepts, like the hydraulic accumulator (HA) in the AES-2006 reactor design or the hybrid safety injection tank (SIT) accumulator in the SMART100 SMR Korean reactor design. The motivation to use such a passive system is to inject some water during a LOCA transient with no dependence on the depressurization rate of primary circuit pressure. With the use of a classical nitrogen pressurized accumulator, a large flow peak appears in the beginning of the accumulator injection, but such a high flow rate is not achieved at the later phase when the primary circuit and the containment ambient pressure get closer to each other. A gravity draining accumulator injects water according to the gravity forces and due to the upper plenum connecting pipe (balance line) pressure in the primary circuit and accumulator is equal throughout the transient. Initially, such an accumulator is at an atmospheric pressure, and the activation of the isolation valve on the balance line lets the pressurization phase continue until equilibrium with the primary pressure is achieved. Direct condensation of the steam injected on the upper cold liquid level of the accumulator, and the heat transfer to the upper metallic wall slow down the pressurization phase and can create some oscillations or perturbations during the gravity draining flow injection phase, by suction effect of the upper gas plenum of the accumulator.

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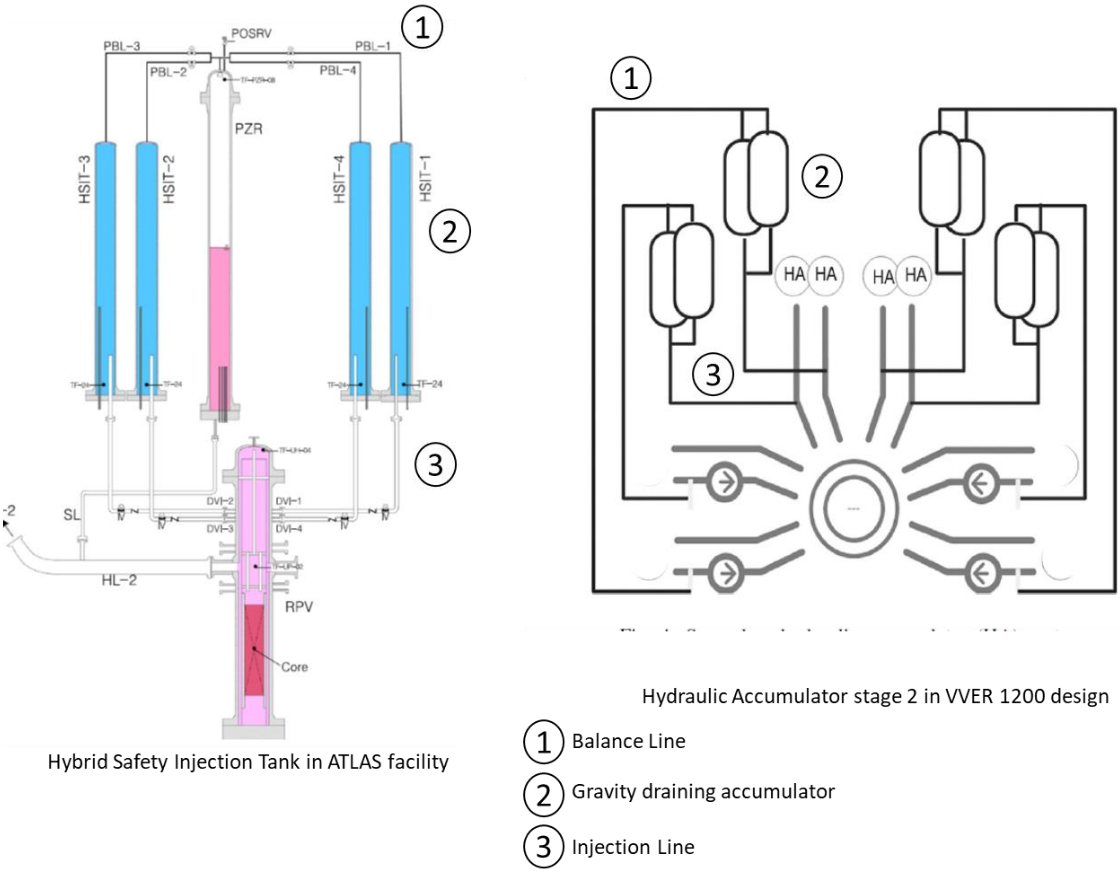
Figure 23 below presents the two different applications of a gravity driven accumulator, on the left a configuration in the ATLAS facility (for advanced Korean reactor concepts) and on the right a configuration for the VVER 1200 Russian design. In both concepts, the gravity driven accumulators are placed at a higher elevation from the reactor vessel to ensure sufficient gravity flow draining performance. The main difference between the two concepts is the location of the balance line connection to the primary circuit: to the cold leg or to the hot leg (specifically to the pressurizer top). To minimize the influence of unwanted steam condensation during the pressurization phase, it is preferable to connect the balance line to the cold leg rather than the hot leg.



Hybrid Safety Injection Tank in ATLAS facility

Hydraulic Accumulator stage 2 in VVER 1200 design

Figure 23. Two different applications of a gravity driven accumulator. On the left a configuration in the ATLAS facility [11] (for advanced Korean reactor concepts) and on the right a configuration for the VVER 1200 Russian design [12].

The study of the thermo-hydraulic operation of this type of safety component will therefore consist of studying the initial pressurization phase as well as the gravity draining injection phase, under primary steam conditions representative of those in a reactor under LOCA-type accident conditions. In the original NUWARD design, the system would have worked as follows. From a low primary pressure threshold detected by the safety instrumentation and control system, one or more isolation valves are opened in the balance line and the pressurization phase is started. At this point of a transient, the primary circuit is mainly in saturation conditions. The diameters of the balance line piping are optimized to reduce pressure drop under sonic steam flow conditions during the pressurization phase. A diaphragm at the inlet to the primary circuit allows sonic flow conditions to be adjusted and reduces the size of break that could occur in the event of a pipe rupture. The diameters of the injection line pipe are optimized to reduce regular head losses during gravity injection, while ensuring sufficient, optimized flow. A diaphragm at the connection with the reactor vessel also regulates the average flow rate during the draining phase and limits the impact of any rupture of this pipe.

7.3.2. Definition of the SET GRADAC

7.3.2.1. General description of the facility

The experimental campaign proposed for the study of a gravity accumulator includes reproducing the initial pressurization phase of this component, until an equilibrium is reached. Condensation of injected steam on the cold free liquid surface will also be studied and modeled, as will the thermal absorption of the upper metal walls. The experimental campaign will focus on the gravity injection regime, flow rate trends, and any disturbances and oscillations that may occur because of pressure equilibration faults in the plenum (residual condensation of incoming steam, pressure drops evolution between the balance line and injection line, etc.).

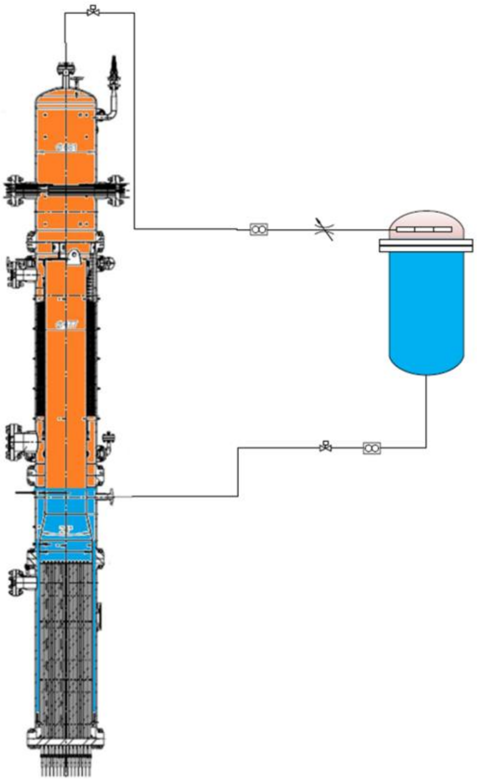


Figure 24. Sketch of the GRADAC facility attached to MOTEL.

To achieve these goals, the hydro accumulator will be connected to the nearby MOTEL test facility simulating an SMR reactor. Steam to pressurize the accumulator is taken from the top of MOTEL. The water from the accumulator is injected into the downcomer of the MOTEL primary side below the water surface. The water level in MOTEL can be kept constant by draining water from the bottom of the facility. Sketch of the GRADAC facility attached to MOTEL is shown in Figure 24.

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7.3.2.2. Description of the test loop

Figure 25 presents the preliminary design of the GRADAC accumulator model (the maximum steam pressure is 40 bar that is the maximum operation pressure of the MOTEL facility). The volume of the vessel (approximately 1 m^3) is optimized by maintaining the L/D ratio of approximately 2.5 and taking into account structural and load limitations. The nominal mass flow rate will be derived on the basis of the initial liquid volume, with specific attention to the limitation of the flow rate measurement device and the pressure drop in the injection line. The vessel is designed according to the pressure vessel design specifications with a dedicated overpressure protection discharge system (safety valves and a discharge line).

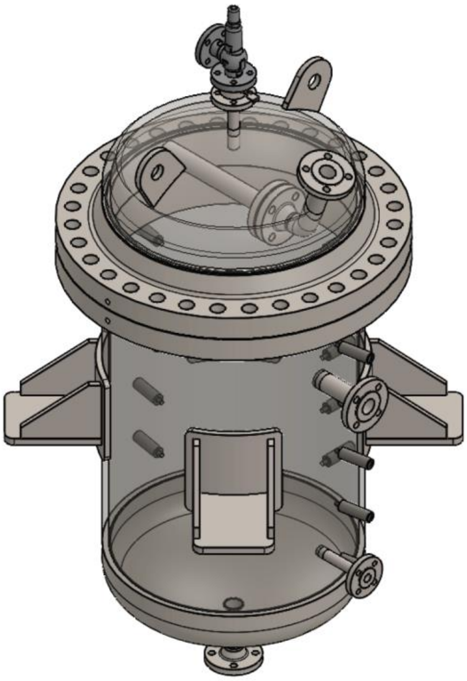

Figure 25. Vessel representing the gravity-draining accumulator model (volume ~1 m^3).

Design of the sparger with CFD tool

CEA is in charge of defining the component designed to diffuse steam from the pressurization line into the upper gas volume of the gravity accumulator. The optimization parameters for this steam injector consist in choosing an optimized shape that enables the accumulator to be pressurized while minimizing physical disturbances to the liquid volume inside. Indeed, the physical phenomena that will contribute to slow down and disturb this pressurization mainly concern condensation and exchanges between the liquid and vapour phases. Maintaining a stable liquid surface reduces the parasitic effect of vapour condensation on the surface by the formation of an upper hot liquid layer, thus reducing surface condensation, which can slow down the pressure rise. Studies on steam injection were initially carried out using a single-phase CFD tool (STAR CCM+), so as to be able to study several steam outlet nozzle configurations, from the simple cylindrical injection orifice at different angles, to the multiple orifice spray bar, with holes or slots. Design optimization criteria are essentially based on the uniformity of the vapour velocity vector distribution in the gas volume, the volume dilution of vapour molecule trajectories, and the most homogeneous possible distribution of

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contact with the liquid surface. In a second step, a comparison with the two-phase CFD tool Neptune CFD is also carried out, in order to take into account vapour absorption and condensation on the upper metal walls of the gravity accumulator, as well as condensation at the liquid-vapour interface. The detailed results of this study will be incorporated into the "MS6 Facility Description" document for the GRADAC experimental facility, and a specification document for the production and supply of the sparger component will also be provided to LUT during 2025.

Table 2: Design configuration list for steam injection optimization in gravity accumulator for GRADAC

	45° injection					Vertical	
single hole	nozzle multi holes	nozzle multi holes	nozzle multi slots	nozzle multislots	single hole	Horiz sparger	Jet splitter
	Confg. 1	Config 2	Config 1	Config 2			
A	B	C	D	E	F	G	H

Calculation set-up

The preliminary design of the gravity accumulator for GRADAC was modelled with SOLIDWORKS, containing both material part (stainless steel upper head vessel, body, and bottom part), liquid volume (cold water), and upper gas plenum (air at 1 bar). Different sparger are modelled and tested. The boundary area of CFD calculation are the metal upper dome and the upper liquid surface. The figure below shows the mesh associated to the vapour region in the volume, with upper and lower boundary conditions, and an example of the metal sparger mesh of one type of sparger. All sparger configurations studied have a total outlet cross-section larger than the inlet cross-section, to avoid compression and sonic blockage of the steam.

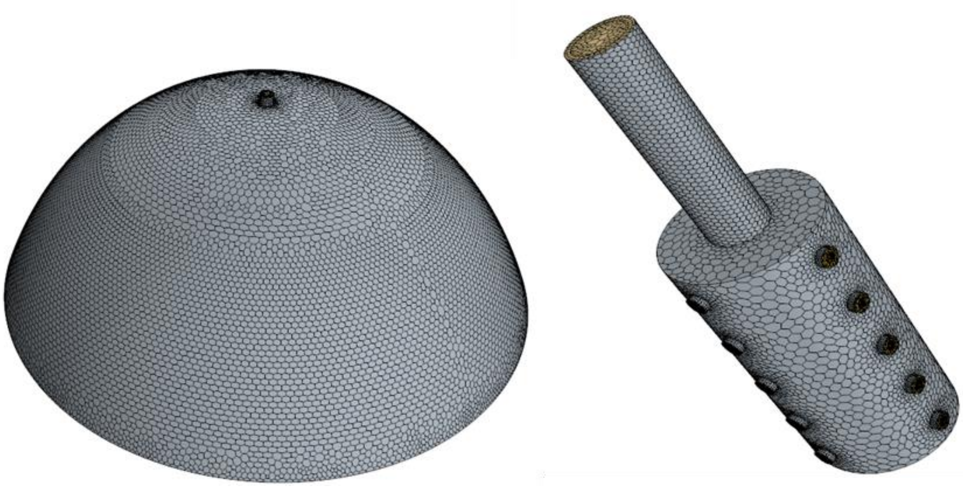

Figure 26. Example of gas expansion volume mesh and sparger type for GRADAC sparger design study

Configuration A:

Direct injection in gas upper plenum with 45° inclination (no sparger). Study is based upon original pressure and steam flowrate specifications (P 75 bar, 0.5 kg/s steam flowrate). Steam inlet diameter: D 18mm. Gas plenum volume : 0.045 m3.

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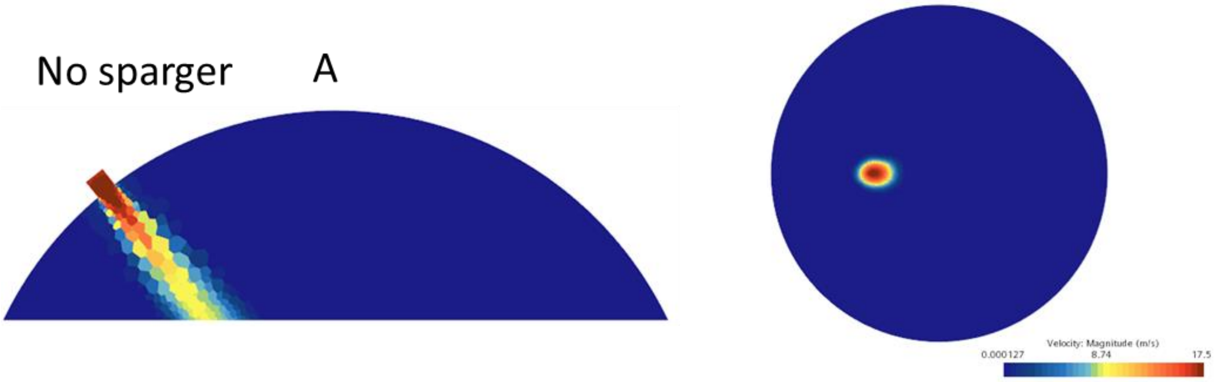

Figure 27. STARCCM+ study of configuration A steam injection

The figure above shows a STARCCM+ CFD calculation of injection according to configuration A, and on the right, the distribution of steam velocity magnitude on the liquid surface. This preliminary study confirms the need for a steam diffusion system to avoid direct impact on the liquid surface.

Configuration B:
Use of a curved hollow tube with multiple holes (2 x 14 holes with variable diameters, **+/- 45°** from horizontal plan). Study is based upon original pressure and steam flowrate specifications (P 75 bar, 0.5 kg/s steam flowrate). Steam inlet diameter: D 18mm. Gas plenum volume: 0.045 m3.
Variable hole diameters are optimized to balance steam outlet flows along the tube.

Figure 28. STARCCM+ study of configuration B steam injection

The figure above shows a STARCCM+ CFD calculation of injection according to configuration B, and on the right, the distribution of steam velocity vector impacts on the liquid surface (vertical view). The results are encouraging, but there are still surrounding areas where impacts are concentrated on the liquid surface.

Configuration C:
Use of a curved hollow tube with multiple holes (2 x 14 holes with variable diameters**, 0° and 180°** from horizontal plan). Study is based upon original pressure and steam flowrate specifications (P 75 bar, 0.5 kg/s steam flowrate). Steam inlet diameter: D 18mm. Gas plenum volume : 0.045 m3.
Variable hole diameters are optimized to balance steam outlet flows along the tube.

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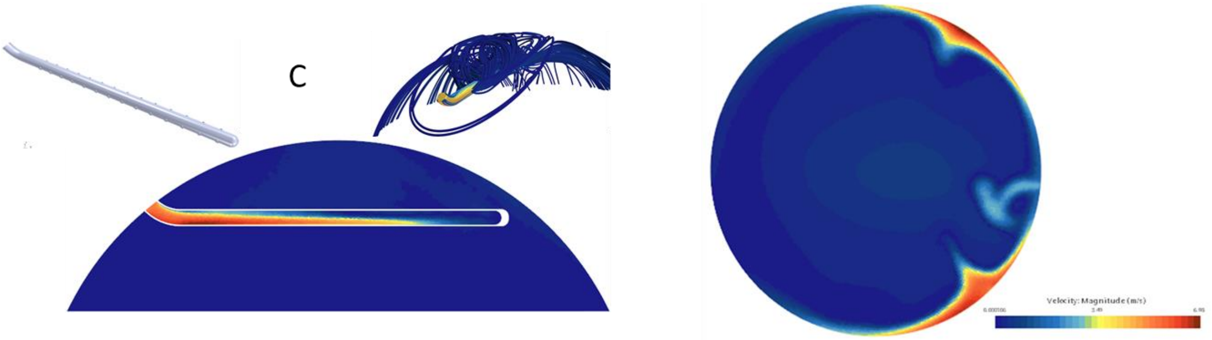

Figure 29. STARCCM+ study of configuration C steam injection

The figure above shows a STARCCM+ CFD calculation of injection according to configuration C, and on the right, the distribution of steam velocity vector impacts on the liquid surface (vertical view). The results are quite similar with B configuration, where there are still surrounding areas where impacts are concentrated on the liquid surface. Optimized final design could be a mix between configurations B and C.

Such a sparger is usually very easy to build, using hole sizes compatible with conventional drilling tools

Configuration D:

Use of a curved hollow tube with multiple slots (15 upper slots with fixed width and variable penetration depth). Study is based upon original pressure and steam flowrate specifications (P 75 bar, 0.5 kg/s steam flowrate). Steam inlet diameter: D 18mm. Gas plenum volume: 0.045 m3.

Variable penetration depth is optimized to balance steam outlet flows along the tube.

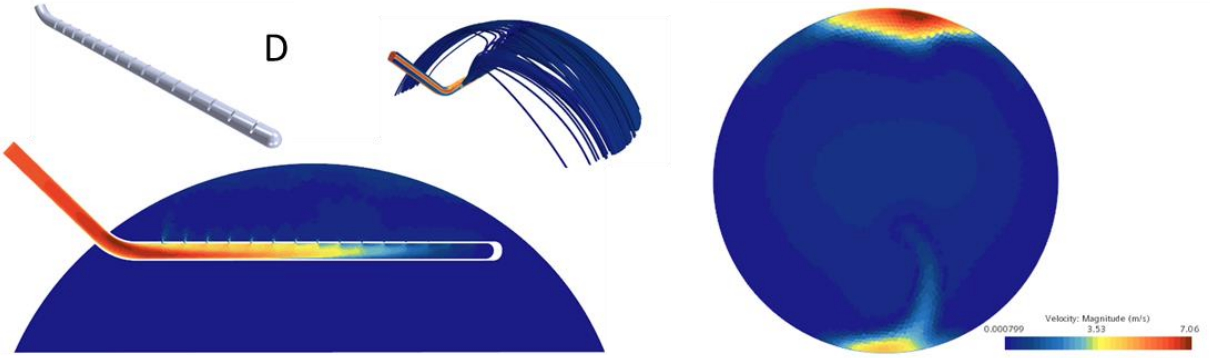

Figure 30. STARCCM+ study of configuration D steam injection

The figure above shows a STARCCM+ CFD calculation of injection according to configuration D, and on the right, the distribution of steam velocity vector impacts on the liquid surface (vertical view). The results are quite similar to the previous configurations, in which there are still important surrounding areas where impacts are concentrated on the liquid surface. There is no advantage to use a milling machine to make slots rather than classic drilling tool.

Configuration E:

Use of a curved hollow tube with multiple slots (2x 15 upper and lower slots with fixed width and variable penetration depth). Study is based upon original pressure and steam flowrate specifications (P 75 bar, 0.5 kg/s steam flowrate). Steam inlet diameter: D 18mm. Gas plenum volume: 0.045 m3.

Variable penetration depth is optimized to balance steam outlet flows along the tube.

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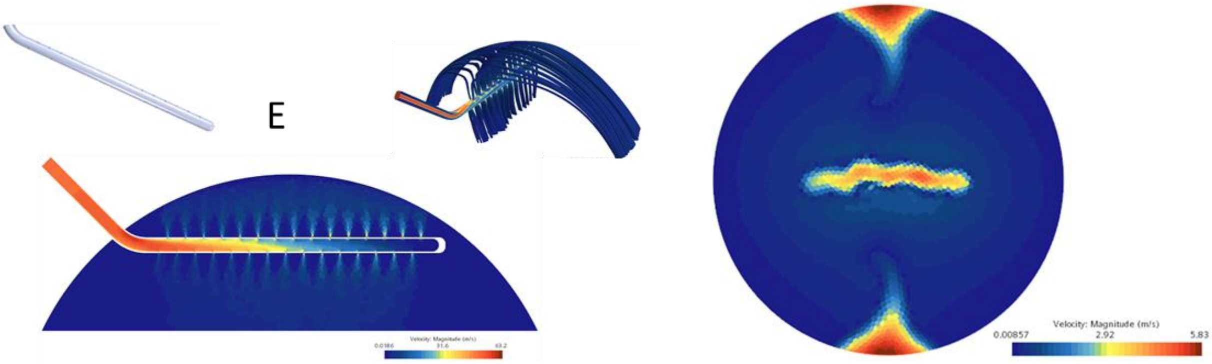

Figure 31. STARCCM+ study of configuration E steam injection

The figure above shows a STARCCM+ CFD calculation of injection according to configuration E, and on the right, the distribution of steam velocity vector impacts on the liquid surface (vertical view). The series of downward-pointing slots doesn't help diffuse the steam onto the central part, but rather adds a focal point. A more optimized shape for the lower slots could be designed to better widen the downward steam jet.

Configuration F:

The following configurations, F, G, H, no longer use a 45°C inclined inlet, but a vertical one. As before, the first configuration consists of direct injection without sparger. Study is based upon original pressure and steam flowrate specifications (P 75 bar, 0.5 kg/s steam flowrate). Steam inlet diameter: D 18mm. Gas plenum volume: 0.045 m3.

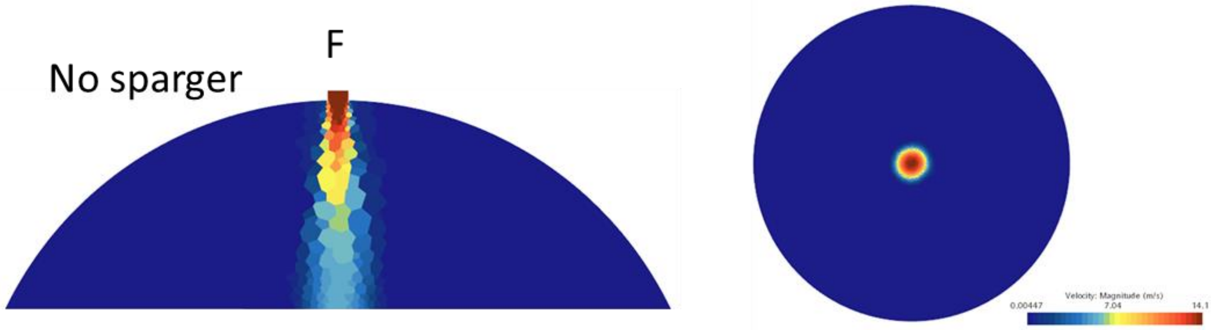

Figure 32. STARCCM+ study of configuration F steam injection

The figure above shows a STARCCM+ CFD calculation of injection according to configuration F, and on the right, the distribution of steam velocity vector impacts on the liquid surface (vertical view). As in the previous configuration of inclined direct injection, we can observe a very focused steam jet at the liquid interface, which should maximize the steam-liquid interaction, and greatly disrupt the pressurization phase.

Configuration G:

The sparger studied is a side-port diffuser, with a closed bottom, and no direct path from the steam outlet to the liquid surface. Study is based upon original pressure and steam flowrate specifications (P 75 bar, 0.5 kg/s steam flowrate). Steam inlet diameter: D 18mm. Gas plenum volume: 0.045 m3.

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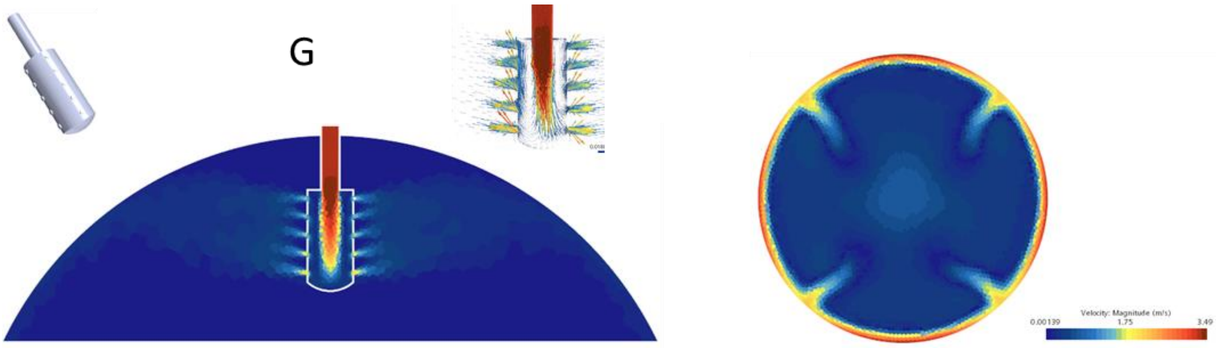

Figure 33. STARCCM+ study of configuration G steam injection

The figure above shows a STARCCM+ CFD calculation of injection according to configuration G, and on the right, the distribution of steam velocity vector impacts on the liquid surface (vertical view). The effect of steam flowing along the metal dome seems to be maximal here, since the velocity magnitude at the periphery of the liquid surface is at its highest. The effect seems more pronounced than for configurations B and C.

Configuration H:

The configuration studied consists of a jet splitter plate. A hollow vertical injection pipe has a plate perpendicular to the outlet section at its end, and lateral outlet ports. The intra-pipe steam jet is thus burst through 360° perpendicular to the outlet. Study is based upon original pressure and steam flowrate specifications (P 75 bar, 0.5 kg/s steam flowrate). Steam inlet diameter: D 18mm. Gas plenum volume: 0.045 m3.

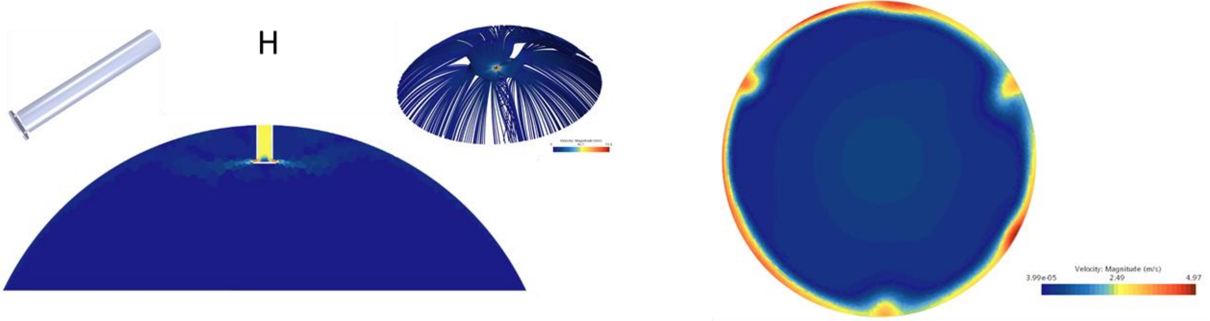

Figure 34. STARCCM+ study of configuration G steam injection

The figure above shows a STARCCM+ CFD calculation of injection according to configuration H, and on the right, the distribution of steam velocity vector impacts on the liquid surface (vertical view). The result on the impact distribution of the vapour jet on the liquid surface is quite similar to the previous configuration, with an edge effect that is still significant and well distributed over the entire periphery.

In terms of sparger design, this is normally the simplest one to create.

Conclusion

Six sparger configurations with different shapes and specifications were studied, with the impact density of the vapour on the liquid surface as the optimization parameter. Studies are currently continuing throughout 2025, with a view to providing specifications for the sparger to be implemented in the experimental test model. The complete corresponding study will be provided in the GRADAC detailed description document, for which LUT is responsible.

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7.3.2.3. Instrumentation and range of thermo hydraulics parameters

Appropriate instrumentation will be required to monitor the thermal stratification of the thin upper layer of hot water during the pressurization phase. Similarly, temperature sensors located on the metal walls of the inner surface will enable the evaluation of the inner wall temperature. A pressure sensor monitors the component's pressure rise in the upper plenum, depending on the pressure conditions of the injected steam.

7.3.2.4. Matrix data tests prevision for phase I and phase II

The main interest in these experiments is in reproducing the initial pressurization phase of the gravity accumulator, the condensation of injected steam on the cold free liquid surface, and the thermal absorption of the upper metal walls (phase I). In the second phase (phase II), the gravity injection will be reproduced in the test matrix. Flow rate trends, and any disturbances and oscillations that may occur because of pressure equilibration faults in the plenum will be studied.
Totally three tests have been planned. The phase I of the tests will be carried out with three different valve opening times (fast, medium, slow). Data from this phase will be used in the benchmark in WP3. In phase II of each test, the water injection line will be opened, and water will flow out from the accumulator by gravity.

7.3.2.5. GRADAC activity schedule phase I and phase II

An indicative schedule of the activities for the duration of four years of the project related to the GRADAC facility is presented below. Some overlapping in the tasks is expected. Deadlines of the milestones and deliverables are also shown in the graph.

Activity	**Project months**	**Actual months**
Facility design	1-8	9/2024-4/2025
Building and shakeup tests	7-24	3/2024-8/2026
Performing experiments	25-36	9/2026-8/2027
Reporting	34-44	6/2027-4/2028
Milestone 1: facility description + pre-test specifications available	24	8/2026
Milestone 2: all test data + blind specifications available	36	8/2027
D2.4 deadline (includes facility description and test reporting)	44	4/2028

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7.4. ELSMOR II

The aim of this task is to collect and define all specifications and new commissioning to adapt the DHRS ELSMOR loop in SIET to the new requirements of the EASI-SMR project. This includes technical specifications of instrumentation, modifications to existing piping, installation of new piping, non-condensable gas injection or sampling lines. The piping upgrades will affect both Phase 1 and Phase 2 of the testing activities, while the non-condensable gas injection will only be tested in Phase 2. Preliminary loop modelling will be initiated ahead of schedule in order to set up SBO-type transients representative of a real accident on a European SMR and to adjust the accident period and appropriate actions to correctly prepare the code benchmark.

The experimental tests of ELSMOR II are the subject of a specific action, WP2.5, under the responsibility of the host of the experimental facility, SIET.

The technical committee in charge of defining this action was composed of members of the CEA, as WP2 leader, and of those responsible for the installation of the experimental facility, belonging to SIET and ENEA. Two experimental test campaigns are planned along with the EASI SMR project time, the first phase for the elaboration of the "SBO transient" data set, both for the benchmark code exercise in WP3 and for the application case of statistical method tools for WP4. The second phase is specifically dedicated to the effect of non-condensable gas accumulation in a compact plate heat exchanger, in the primary circuit, without benchmark code applications.

The ELSMOR Horizon 2020 project included a series of experimental tests to characterise the operation of a safety condenser loop as a Decay Heat Removal System (DHRS) [1] [2]. In the present EASI-SMR project, the semi-integral effect test facility ELSMOR will be upgraded in ELSMOR II to perform a new set of experimental tests and to extend the work done during the ELSMOR project. In particular, transients representative of Station Black-Out (SBO) in single-phase circulation and LOCA in two-phase circulation (considering a degraded operating condition) will be included.

The EASI-SMR tests on the ELSMOR II plant will provide an experimental data set for a code benchmark, in which a more extended modelling will be prepared compared to the ELSMOR project, in order to be more representative of the primary side of the plant and to better simulate the transients performed.

7.4.1. Background to the ELSMOR experimental facility

Synthesis of experimental tests carried out in the ELSMOR project (WP3 Passive Decay Heat Removal System).

The Horizon 2020 project ELSMOR included a series of experimental tests to characterise the operation of a safety condenser loop as a decay heat removal system and primary circuit depressurisation system present in the European integral SMR (E-SMR) inspired by the former Nuward SMR concept [3] [4] [5]. This loop includes a Safety Compact Steam Generator (S-CSG), plate type, a hot leg pipe, a once-through vertical tube safety condenser and a liquid condensate return pipe to the plate exchanger inlet. The condenser is immersed in an atmospheric pressure tank simulating a pool, which is the ultimate heat sink (UHS) .

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Figure 35 shows the scheme of the ELSMOR DHRS experimental facility.

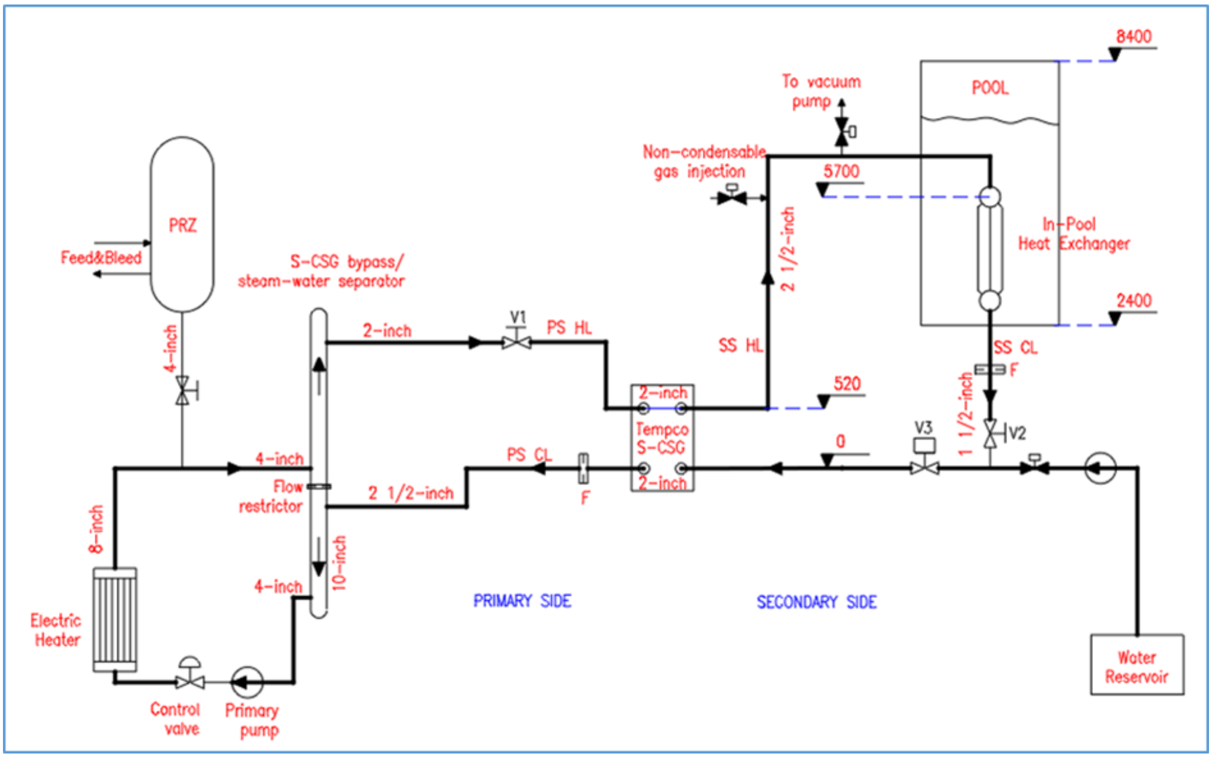

Figure 35: Simplified scheme of the ELSMOR

A benchmark of European thermal-hydraulic codes (CATHARE, AC², APROS) [6] allowed a better understanding of the degree of qualification and validation of the system codes in reproducing the natural two-phase circulation present in this loop, and to assess the relevance of the heat transfer laws at both the hot source (plate heat exchanger) and the cold source (safety condenser). The degradation of the performance of this passive loop due to the progressive addition of non-condensable gases in the secondary circuit was also evaluated. The influence of the initial filling ratio of the secondary circuit, i.e. the amount of water present when the circuit is activated, was also studied, both on the initial pressure rise generated and on the maximum thermal extraction capacity achievable. The final heat sink, of limited volume, was able to rise in temperature to boiling and saturation, with a pronounced stratification level along the height of the condenser tubes. This also made it possible to test several nodalisations and user configuration effects to represent the tertiary circuit [3] [6].

Figure 36 shows the layout of the ELSMOR facility.

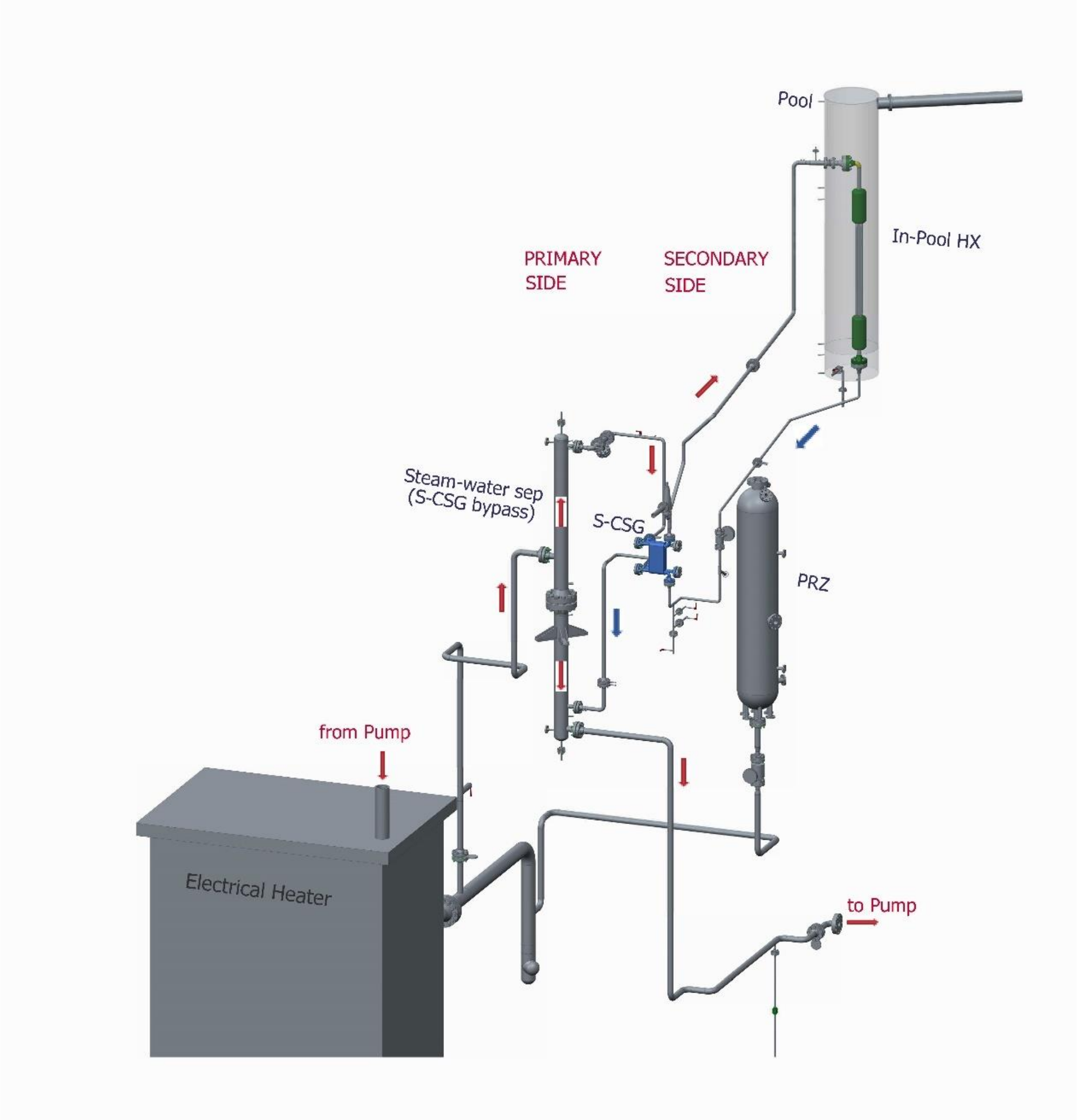

Figure 36: Layout of the ELSMOR facility

7.4.2. Definition of the semi-IET ELSMOR II

The activities carried out in the EASI-SMR project are in line with the DHRS experimental campaign carried out at SIET as part of the ELSMOR project. While taking advantage of the existing installation, additional tests will cover a number of areas of investigation that could not be carried out during the ELSMOR project. In particular, the ELSMOR II test campaign foresees two phases:

- The first phase includes limited modifications to the ELSMOR tertiary loop, which represented the DHRS of the E-SMR with a different kinetics of temperature rise in the cold source (UHS). As a complement to the ELSMOR configuration, it is proposed to perform a series of experimental tests with the main objective of qualifying and validating the thermo-hydraulic codes for passive DHRS systems

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combining SG, thermosyphon loops, SACO and pool heat sinks at conditions typical of a long-term SBO transient.

- An extension of the modelling of the experimental loop, now limited to the two-phase secondary loop, is also foreseen to study the heat transfer with the primary side, in single phase liquid, in order to reproduce the conditions typical of an SBO.

- The second phase, with major modifications, is devoted to the investigation of the heat transfer with the primary side in both single and two-phase conditions and the influence of non-condensable gases on the heat transfer in the primary loop.

In the following paragraphs, more details of the tests to be performed in the two phases are reported.

Experimental Phase 1

The objective is to further characterise the performance of the passive decay heat removal loop with safety condenser by running a long transient over the entire primary pressure and temperature range, e.g. in the initial range of 120 bar, in the primary side down to the minimum achievable (e.g. by switching off the heating source at the end of the tests). To compensate for excessive temperature rise in the final heat sink (limited volume), hot water can be removed from the lower part of the system and replaced by cold water in the upper part, with appropriate instrumentation to estimate the axial temperature gradient.

It is foreseen to generate one or more experimental transients, equivalent to an SBO type transient, based on operational initial conditions derived from the conclusions of the previous ELSMOR WP3. In particular, the absence of non-condensable gas in the secondary circuit is required, with progressive temperature rise of the final heat sink, with or without boiling at the end of the transient. These conditions make it possible to study the influence of the overall average heat sink temperature reached at the end of the scenario on the overall primary depressurisation. This series of transients will provide important data for the reliability methods of WP4, both for PSA studies (RMPS method and equivalent) and for deterministic approaches (BEPU, Risk Informed, etc.).

Experimental Phase 2

The objective is to characterise the effect of the presence of non-condensable gas in the primary circuit, at the primary/secondary heat exchanger level, when the primary inventory level is likely to fall below the plate heat exchanger inlet window. The steam generator will then operate in thermo-siphon mode, with primary steam condensing on the primary side and water boiling on the secondary side. This type of situation is outside the scope of the safety strategy for the E-SMR, but may correspond to a further demonstration of robustness against LOCA-type accidents with insufficient control of the primary inventory.

Simplified LOCA-type transients will be realised, with primary depressurisation (or blowdown) and progressive reduction of the primary liquid inventory. At certain initial primary conditions, a water-steam mixture will be produced at the outlet of the electric heater and subsequently separated in a dedicated tank (representing the vessel) to feed the S-CSG with saturated dry steam. A sufficient liquid level must be maintained in the lower part of the separation tank and the circuit to ensure proper operation of the

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primary pump and electric heater. The gradual injection of non-condensable gas into the upper part of the primary circuit, with the steam entering the S-CSG in a natural circulation driven by the heat exchanger's condensation capabilities, will allow the characterisation of the heat transfer at different amounts of non-condensable gas. Dedicated instrumentation will make it possible to estimate in real time the fraction dissolved in the liquid and that present in the vapour phase for a given quantity of non-condensable gas, and will also highlight the presence or absence of a cliff effect with total blockage of condensation by a gas plug at the inlet and among the plates of the heat exchanger.

7.4.2.1. General description of the facility

The ELSMOR plant simulates the DHRS of the E-SMR, where a plate-type heat exchanger (S-CSG), couples a circuit at the thermohydraulic conditions of the reactor (primary side) to a natural circulation loop (secondary side), which is sufficient to dissipate the Ultimate Heat Sink by means of a vertical tube heat exchanger for the simulation of Station Black-Out transients and long-term accident conditions.
The power to volume scaling factor is approximately 1:50, and the simulation height factor is 1:1. For a better understanding of the loops involved, Figure 35 shows the simplified scheme of the plant, indicating the primary and secondary sides, together with the auxiliary systems for the primary water circulation.

The ELSMOR loop is connected to existing auxiliary systems at SIET, which are sufficient for water supply and drainage, water circulation, heating and pressurisation of the loops. The design conditions of the plant are:

Primary pressure 13 MPa and temperature 330 °C

Secondary pressure 10 MPa and temperature 310 °C

Power 1 MW.

The primary side of the ELSMOR test facility can be operated in both single-phase and two-phase conditions. In single-phase liquid mode, water is circulated by the primary pump through the S-CSG bypass and split partly into the S-CSG and partly back to the pump by means of a suitably sized flow restrictor; in two-phase mode, the water and steam mixture exiting the electric heater enters the steam-water separator (flow restrictor removed) and, by gravity, water returns to the pump and steam enters the S-CSG. In single phase, the pressure is controlled by a feed and bleed method which injects and extracts water according to the specified test conditions; in two-phase, when the specified pressure is reached per feed and bleed, saturation conditions are achieved at the outlet of the electric heater by controlling the supplied power and primary flow.

The secondary side operates in two-phase natural circulation, driven by the heat supplied by the S-CSG (primary side) and dissipated in the water tank (UHS) containing the submerged vertical tube heat exchanger.

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The S-CSG is a commercial TEMPCO plate heat exchanger, model TCBC2102H*130, consisting of 130 plates with a 45° chevron angle (90° angle between channels).

The in-pool heat exchanger consists of five vertical tubes, 2” OD, approximately 2 m long, with cylindrical headers at the top and bottom.

The UHS is a vertical pool, approximately 1 m in diameter and 5.5 m high, which houses the vertical tube heat exchanger. The basin is open to the atmosphere.

From the point of view of the ELSMOR tests as well as for EASI-SMR tests, the primary side pipes of interest are those between the steam-water separator and the S-CSG, identified as the primary side hot and cold legs (PS HL and PS CL), and those between the S-CSG and the in-pool heat exchanger, identified as the secondary side hot and cold legs (SS HL and SS CL), Figure 35.

All pipework and components of the plant are thermally insulated with mineral rockwool, overlaid with aluminum cladding to limit heat losses to the environment.

The plant is equipped with three main valves, sufficient to initiate natural circulation on the secondary side (V3) and to adjust the pressure drop in the loops (V1 and V2). Orifices are installed on both the primary and secondary cold legs to measure the flows through the S-CSG.

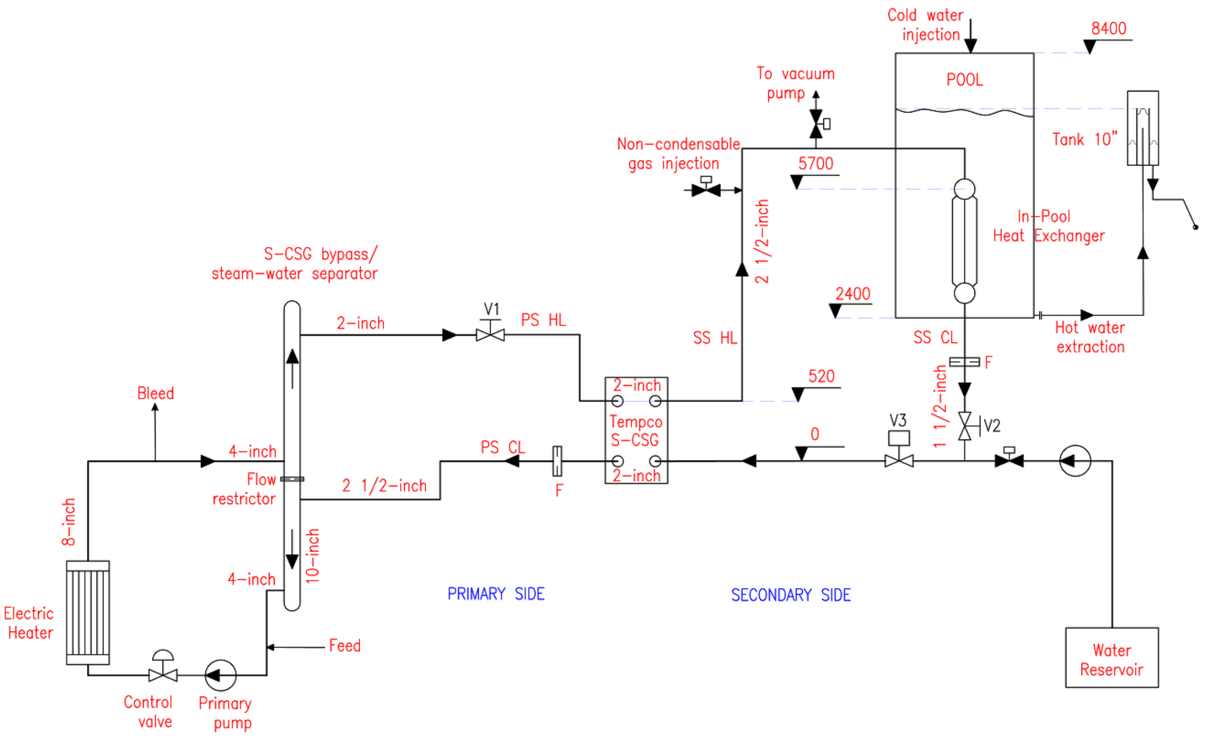

Figure 37: Simplified scheme of the ELSMOR II facility (Phase I)

The EASI-SMR project foresees two testing phases which require some upgrades to the ELSMOR facility.

Minor modifications are required to carry out the tests of Phase 1, which include:

- The upgrade of the feed and bleed system for pressure control in solid (full of liquid) primary loop with additional piping and the disconnection of the Pressurizer (Figure 36) and the connection of the feed and bleed lines at the primary pump suction (feed) and at the electric heater outlet (bleed).
- The realization of new pipes for the control of the UHS water temperature and avoid boiling, in particular pipes for cold water injection and hot water extraction as well as for pool level control.

A simplified scheme of the plant for Phase 1 is shown in Figure 37.

Major modifications are required to carry out the tests of Phase 2, other than those of already listed for Phase 1, which include:

- The installation of a swirl separator inside the S-CSG bypass/steam water separator to help obtain pure steam at the inlet of the TEMPCO heat exchanger and allow to correctly estimate the primary side power in two-phase tests.
- The installation of a tank, at the outlet of the TEMPCO heat exchanger, acting as a liquid seal (for two-phase tests) to maintain the level constant in the S-CSG and as non-condensable gas trap for the measurement of gas concentration.
- The installation of special instrumentation (non- condensable gas characterization Platinum probe) at the S-CSG outlet to detect the presence of non-condensable gas, with a cliff effect, and verify if blockage of condensation by a gas plug occurs.
- The installation of an isokinetic probe at the S-CSG inlet to measure the concentration of non-condensable gas entering the heat exchanger.

A simplified scheme of the plant is shown in Figure 38.

Geometrical details of the ELSMOR II facility will be included in the report related to MS3.

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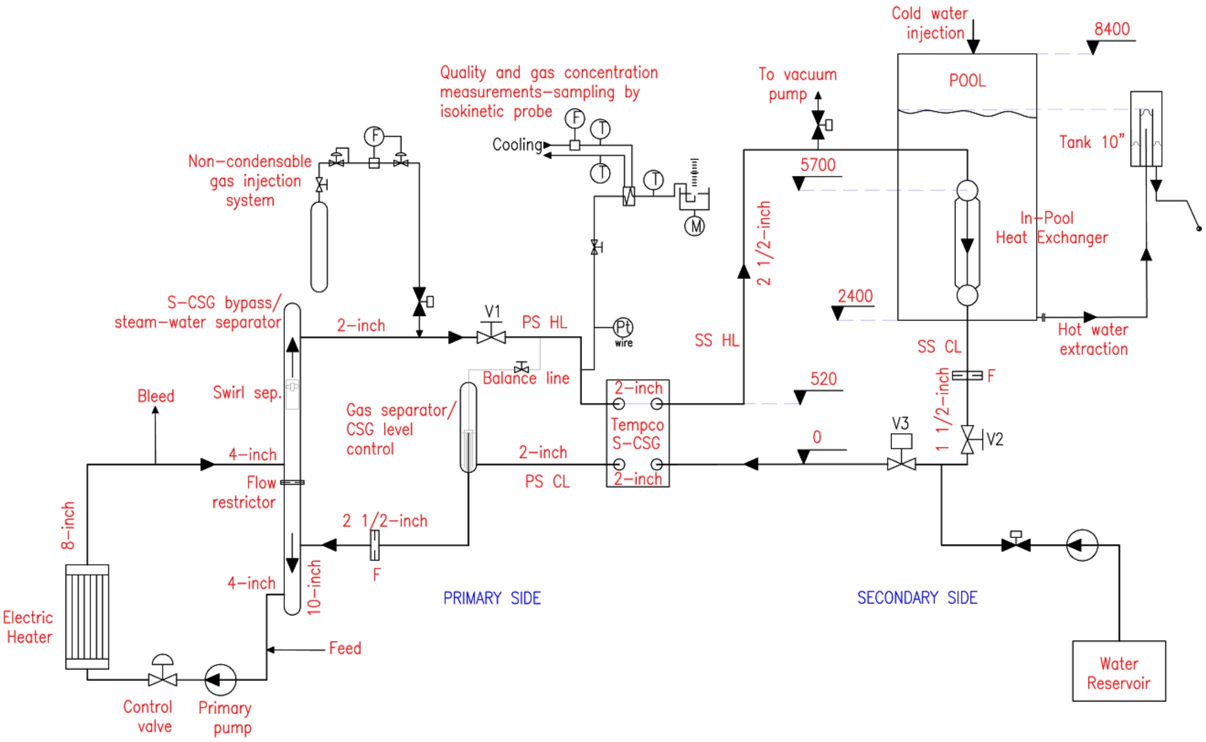

Figure 38: Simplified scheme of the ELSMOR II facility (Phase II)

For the new testing phases, other than the hardware modification already described, modifications in terms of instrumentation and operating conditions are planned as well as the development of new test matrices, as described in the following paragraphs.

7.4.2.2. Instrumentation and range of thermo-hydraulic parameters

The instrumentation installed in the ELSMOR II plant consists of about one-hundred and fifty (150) sensors which include relative and differential pressure sensors (P and DP), Resistance Temperature Detectors (RTD) Pt100, Thermocouples K-type (TcK), together with shunts, current, and voltage meters sufficient to provide auxiliary indications of the electrical power supplied to the heater and other signals mainly dedicated to the management of the plant.

All instruments are calibrated in the SIET laboratory, and calibration constants are entered into the Data Acquisition System (DAS) software to reduce measurement uncertainty. Special instrumentation like the Platinum and isokinetic probes will be tested and verified during the commissioning of the upgraded facility.

Instruments are installed along the piping and on the components with particular attention to the inlet and outlet of the S-CSG, both primary and secondary. The heat exchanger vertical tube is equipped with fluid and wall temperature sensors at various elevations, as is the pool, which houses RTDs at various heights and radii to form a three-dimensional grid.

The DAS consists of National Instruments data acquisition cards connected directly to the cables of the instruments in the field, which, after performing the analogue-to-digital

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conversion, transmit the signals via Ethernet to the main DAS computer, which records the voltages and converts them into engineering quantities (e.g., instrument pressure, differential pressure, etc.) and derived quantities (e.g., mass flow rates, enthalpies, power, etc.).

Instrumentation details of the ELSMOR II facility will be included in the report related to MS3.

The range of the main thermo-hydraulic parameters are reported in Table 3.

Table 3: Range of the main thermohydraulic parameters

Primary side pressure	ambient-12.5	MPa
Primary side temperature	ambient-320	°C
CSG primary side flowrate	0-4	kg/s
Primary side total flowrate	0-30	kg/s
Secondary side pressure	0.05-9.5	MPa
Secondary side temperature	ambient-290	°C
Secondary side flowrate	0-0.9	kg/s
Pool level	0-4.7	m
Pool temperature	ambient-100	°C
Pool pressure	ambient	MPa

7.4.2.3. Matrix test data prevision for Phase 1 and Phase 2

Phase 1 and Phase 2 experimental campaigns have different objectives.
Phase 1 is devoted to explore the DHRS performance in a range of conditions from the full power to the later phases of an SBO.
Phase 2 is devoted to the characterization of the DHRS in the presence of non-condensable gas on the primary side in both single-phase and two-phase conditions at the inlet of the plate-type heat exchanger.
This type of situation is outside the scope of the safety strategy for the E-SMR, but may be considered as a demonstration of robustness versus LOCA-type accident with insufficient control of the primary inventory (e.g. combination of break events or additional aggravation of the availability of individual make-up water safety system). For this, some tests in Phase 2 are dedicated to realize, at the S-CSG inlet, the conditions of a simplified LOCA-type transient with primary depressurization corresponding to a blow down phase.
The non-condensable gas to be used is a commercial gas mixture with 95% He and 5% H_2.

Three tests are foreseen in Phase 1.

Test 1 and Test 3 are the most indicated for the code benchmark in WP3: Test 1 to verify the code capabilities in steady state heat transfer simulation and Test 3 in transient conditions.

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Phase 1, Test 1:

Characterization of the DHRS over the full range of primary side conditions with subcooled water in the pool (maximum performance with infinite cold ultimate heat sink).
This is a steady-state test with the primary side in liquid single phase at full conditions (T = 320 °C, P=12.2 MPa, CSG inlet flowrate 3.4 kg/s, total primary flowrate 25 kg/s); secondary side filling ratio FR 30% (optimized in ELSMOR project); water injection/extraction from the pool (UHS) to maintain it at cold conditions: ~20 °C/50 °C with a flowrate of ~5.5 kg/s (injection from the top and extraction from the bottom).
The main thermohydraulic parameters are reported in Table 4.

Phase 1, Test 2:

Characterization of the DHRS in the conditions typical of an SBO transient with pool temperature rise up to boiling (influence of the enthalpy evolution of the UHS). This is a test with the primary side in liquid single phase with temperature decreasing from 320 to 120 °C in five hours; pression decreasing from 12.2 MPa to 3.3 MPa in five hours (pressure can be maintained higher with a margin to saturation); CSG inlet flowrate 3.4 kg/s, total primary flowrate 25 kg/s); secondary side filling ratio FR 30%; free evolution of temperature in the UHS without water make-up.
The main initial and final thermohydraulic parameters are reported in Table 5.

Phase 1, Test 3:

Characterization of the DHRS with the primary side in liquid single phase and controlled power input, representative of the reactor power, in the full pressure/temperature range (maximum to depressurization). Simulation of a typical long reactor transient as SBO. This is a test with the primary side in liquid single phase with temperature decreasing from 320 to 120 °C in five hours; pression decreasing from 12.2 MPa to 3.3 MPa in five hours (pressure can be maintained higher with a margin to saturation); CSG inlet flowrate 3.4 kg/s, total primary flowrate 25 kg/s); secondary side filling ratio FR 30%; water injection/extraction from the pool (UHS) to maintain it at cold conditions: ~20 °C/50 °C with a flowrate of ~2.3 to 1.5 kg/s in five hours (injection from the top and extraction from the bottom).
The main initial and final thermohydraulic parameters are reported in Table 6.

Table 4: Phase 1 Test 1 test conditions

Primary side pressure	12.2	MPa
Primary side temperature	320	°C
CSG primary side flowrate	3.4	kg/s
Primary side total flowrate	25	kg/s
Secondary side filling ratio	30	%
UHS extraction water temperature	50	°C
UHS injection water temperature	20	°C
Extraction/injection flowrate	5.5	kg/s

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Table 5: Phase 1 Test 2 initial and final test conditions

Primary side initial temperature	320	°C
Primary side final temperature	120	°C
Primary side initial pressure	12.2	MPa
Primary side final pressure	3.3	MPa
CSG primary side flowrate	3.4	kg/s
Primary side total flowrate	25	kg/s
Secondary side filling ratio	30	%

Table 6: Phase 1 Test 3 initial and final test conditions

Primary side initial temperature	320	°C
Primary side final temperature	120	°C
Primary side initial pressure	12.2	MPa
Primary side final pressure	3.3	MPa
CSG primary side flowrate	3.4	kg/s
Primary side total flowrate	25	kg/s
Secondary side filling ratio	30	%
UHS extraction water temperature	50	°C
UHS injection water temperature	20	°C
UHS Initial extraction/injection flowrate	2.3	kg/s
UHS Final extraction/injection flowrate	1.5	kg/s

Four groups of tests are foreseen in Phase 2 which will result in several tests at different amount of injected non-condensable gas into the primary side at the S-CSG inlet.

Phase 2, Group of Tests 1:

Group of tests for the characterization of the DHRS with the primary side in single phase where the amount of injected non-condensable gas is varied; the UHS is maintained at cold conditions.
These are steady-state points with the primary side in liquid single phase at full conditions (T = 320 °C, P=12.2 MPa, CSG inlet flowrate 3.4 kg/s, total primary flowrate 25 kg/s); secondary side filling ratio FR 30%; water injection/extraction from the pool (UHS) to maintain it at cold conditions: ~20 °C/50 °C with a flowrate of ~5.5 kg/s.
Step injections of non-condensable gases are performed with always increasing amounts to verify the heat transfer degradation and blockage.
The main initial thermohydraulic parameters are reported in Table 7.

Phase 2, Test 2:

Steady state test for the characterization of the DHRS with the primary side in two-phase conditions without non-condensable gas; the UHS is maintained at cold conditions.
For the execution of this test, the flow restrictor in the CSG Bypass/steam-water separator must be removed and the swirl separator installed inside it.

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A liquid level is maintained in the S-CSG (about half of its height) which guarantees the presence of steam at the inlet and liquid at the outlet. This ensures a sufficient liquid level in the lower part of the circuit for the correct operation of the primary circulation pump.
Primary side in two-phase at full conditions (T = 320 °C, P=12.2 MPa, CSG inlet steam flowrate ~0.4 kg/s; total primary flowrate 5-10 kg/s); secondary side filling ratio FR 30%; water injection/extraction from the pool (UHS) to maintain it at cold conditions: ~20 °C/50 °C with a flowrate of ~5.5 kg/s.
The main initial thermohydraulic parameters are reported in Table 8.

Phase 2, Group of Tests 3:

Group of tests for the characterization of the DHRS with the primary side in two-phase conditions where the amount of injected non-condensable gas is varied.
For the execution of this group of tests, the flow restrictor in the CSG Bypass/steam-water separator must be removed and the swirl separator installed inside it.
A liquid level is maintained in the S-CSG (about half of its height) which guarantees the presence of steam at the inlet and liquid at the outlet. This ensures a sufficient liquid level in the lower part of the circuit for the correct operation of the primary circulation pump.
Primary side in two-phase at full conditions (T = 320 °C, P=12.2 MPa, CSG inlet steam flowrate ~0.4 kg/s; total primary flowrate 5-10 kg/s); secondary side filling ratio FR 30%; water injection/extraction from the pool (UHS) to maintain it at cold conditions: ~20 °C/50 °C with a flowrate of ~5.5 kg/s.
Step injections of non-condensable gases are performed with always increasing amounts to verify the heat transfer degradation and blockage.
The main initial thermohydraulic parameters are reported in Table 9.

Phase 2, Group of Tests 4:

Group of tests for the characterization of the DHRS with the primary side in two-phase conditions in a depressurized phase, where the amount of injected non-condensable gas is varied.
For the execution of this group of tests, the flow restrictor in the CSG Bypass/steam-water separator must be removed and the swirl separator installed inside it.
A liquid level is maintained in the S-CSG (about half of its height) which guarantees the presence of steam at the inlet and liquid at the outlet. This ensures a sufficient liquid level in the lower part of the circuit for the correct operation of the primary circulation pump.
Primary side in two-phase at depressurized conditions (T = 276 °C, P = 6 MPa, CSG inlet steam flowrate ~0.4 kg/s; total primary flowrate 5-10 kg/s); secondary side filling ratio FR 30%; water injection/extraction from the pool (UHS) to maintain it at cold conditions: ~20 °C/50 °C with a flowrate of ~5.5 kg/s.
Step injections of non-condensable gases are performed with always increasing amounts to verify the heat transfer degradation and blockage.
The main initial thermohydraulic parameters are reported in Table 10.

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Table 7: Phase 2 Group of Test 1 initial test conditions

Primary side temperature	320	°C
Primary side pressure	12.2	MPa
CSG primary side flowrate	3.4	kg/s
Primary side total flowrate	25	kg/s
Secondary side filling ratio	30	%
UHS injection water temperature	20	°C
UHS extraction water temperature	50	°C
Extraction/injection flowrate	5.5	kg/s

Table 8: Phase 2 Test 1 initial test conditions

Primary side temperature	320	°C
Primary side pressure	12.2	MPa
CSG primary side steam flowrate	0.4	kg/s
Primary side total water flowrate	5-10	kg/s
Secondary side filling ratio	30	%
UHS extraction water temperature	20	°C
UHS injection water temperature	50	°C
Extraction/injection flowrate	5.5	kg/s

Table 9: Phase 2 Group of Test 3 initial test conditions

Primary side temperature	320	°C
Primary side pressure	12.2	MPa
CSG primary side steam flowrate	0.4	kg/s
Primary side total water flowrate	5-10	kg/s
Secondary side filling ratio	30	%
UHS injection water temperature	20	°C
UHS extraction water temperature	50	°C
UHS Extraction/injection flowrate	5.5	kg/s

Table 10: Phase 2 Group of Test 4 initial test conditions

Primary side temperature	276	°C
Primary side pressure	6	MPa
CSG primary side steam flowrate	0.4	kg/s
Primary side total water flowrate	5-10	kg/s
Secondary side filling ratio	30	%
UHS injection water temperature	20	°C
UHS extraction water temperature	50	°C
UHS Extraction/injection flowrate	5.5	kg/s

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7.4.2.4. ELSMOR II activity schedule phase 1 and phase 2

The time schedule for the ELSMOR II testing activities is reported in Table 11.

Table 11: ELSMOR II testing time schedule

Task	Item	Start date (DD/MM/YYYY)	End date (DD/MM/YYYY)
1	Project Management, Quality assurance & Safety Management	02/09/2024	01/03/2027
2	Design of the ELSMOR II modifications	02/09/2024	30/06/2025
3	Facility description (MS-7) + Pre-test specification (WP3 MS-14)		
4	Procurement (instrumentation and materials)	03/04/2025	02/07/2025
5	Test facility modification for Phase 1	10/04/2025	04/06/2025
6	Test facility commissioning for Phase 1	21/05/2025	02/07/2025
7	Testing for Phase 1	03/07/2025	31/07/2025
8	Data Validation and Reporting for Phase 1 Test Data set available for WP3 and WP4 (MS-7), Blind specification for WP3 (MS-22)	11/07/2025	31/08/2025
9	Test facility modification for Phase 2	18/09/2025	17/12/2025
10	Test facility commissioning for Phase 2	04/12/2025	04/02/2026
11	Testing for Phase 2	05/02/2026	04/03/2026
12	Data Validation and Reporting for Phase 1 and 2 with as-built details of the facility (D2.5)	05/03/2026	01/03/2027

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7.5. IVR LOOP

This task aims to collect and define all specifications and adaptation of the THS15 experimental facility already existing in UJV facility. This includes technical specifications for both heat power application range, scaling (verification of the conformity of the physical parameters studied between the reactor configuration and that reproduced in the experiment), matrix tests, and specific instrumentation for a correct benchmark of codes exercise. IVR LOOP experimental tests are the subject of a dedicated action, WP2.5, for which the host of the experimental facility, UJV, is responsible.

The technical committee in charge of drawing up this definition action was made up of members of the CEA as WP2 leader and the people in charge of setting up the experimental installation belonging to UJV. Additional technical support has been done by EDF, both for pool boiling specification tests, and CFD calculations for a correct thermos siphon flow performance estimate. Two experimental tests campaigns are scheduled along the EASI SMR project time, first phase for the pool boiling characterization phase study, and second phase concerning the liquid thermos siphon cooling vessel performance, with a benchmark exercise application for WP3.

7.5.1. Background to the IVR LOOP experimental facility

The THS-15 experimental facility was built in 2018 within the IVMR H2020 project (Grant Agreement No. 662157), where it was operated to fulfil 2 deliverables in the experimental part of the project (WP4). The main objective was to demonstrate RPV containment during the final phase of a severe accident, using the IVMR strategy. The design of the device has been proposed for the VVER-1000 reactor configuration where conditions are difficult for the success of the IVMR strategy due to e.g., the need to flood the reactor cavity with active systems, the need to contain the water level into the cavity, the need to ensure the supply of coolant to the cavity and the need to remove steam/coolant from the containment area, etc. Therefore, among other things, the experimental facility was designed as a forced circulation cooling circuit. Nevertheless, the experimental work has produced interesting results regarding the external vessel cooling under different severe accident scenarios and has increased the level of understanding regarding the Critical Heat Flux (CHF) and the safety margin to the CHF [10]. The observations may be useful for newly designed reactors, including SMRs. The advantage of using the experimental channel is the shape of the RPV bottom, which is elliptical and can thus conservatively well simulate the heat removal from the surface of an SMR reactor, where corium distribution is assumed to be mainly in the curved reactor bottom. The RPV outer surface is simulated by ferritic steel, which is (in composition and properties) equivalent to real RPV steel. The power capacity and pressure range are sufficient for most scenarios envisaged for SMR reactors.

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7.5.2. Definition of the SET IVR LOOP

7.5.2.1. General description of the facility

Large scale facility, so called THS-15 (Thermal Hydraulic Stand, est. design 2015) was constructed to provide data to collect information about the thermal-hydraulic conditions in VVER cavity during the IVMR. The main goals were to:

- Evaluate the External Reactor Vessel Cooling (ERVC) efficiency during a severe accident by means of IVMR strategy.
- Receive experimental data necessary to check and validate the design model of RPV cooling during IVMR, and particularly to receive data regarding the CHF phenomena.
- Check the experimentally possible methods for the intensification of heat removal [9].

To meet the objectives of the EASI SMR project, two types of experimental phases are planned (see chapters below), each requiring specific modifications to existing equipment. For both phases of the experiments, a common principle of operation of the experimental facility is given.

The IVR LOOP is designed as a closed circuit with pressurized water as a coolant. The geometry of the main experimental pressure vessel is designed to be as close as possible to that of the RPV and the RPV cavity in which it is installed. The geometry of the main experimental pressure vessel (Experimental Channel - ECH) tries to be as close as possible to the geometry of the RPV and the RPV cavity in which it is stored. The coolant in the ECH is heated by the heating system through the RPV steel layer. The heat source that is simulating the residual heat generated from corium during SA is a heating system based on a copper matrix with electric heating cartridges. The water in the ECH is heated and the steam produced goes through piping to the condenser where it is condensed. The amount of water thus evaporated is refilled into the ECH by a pump so that the ECH maintains a defined water level during the experiment. The ECH has been designed at a scale of 1:1 with the VVER 1000 reactor conditions and is approximately 7 m high, the length represents the radius of the RPV including the cavity area, i.e. approximately 2.8 m. The ECH represents a vessel cut-out of approximately 1:95, which represents a channel width of 15 cm. A description of the function of the particular components of the experimental circuit is described below Figure 39.

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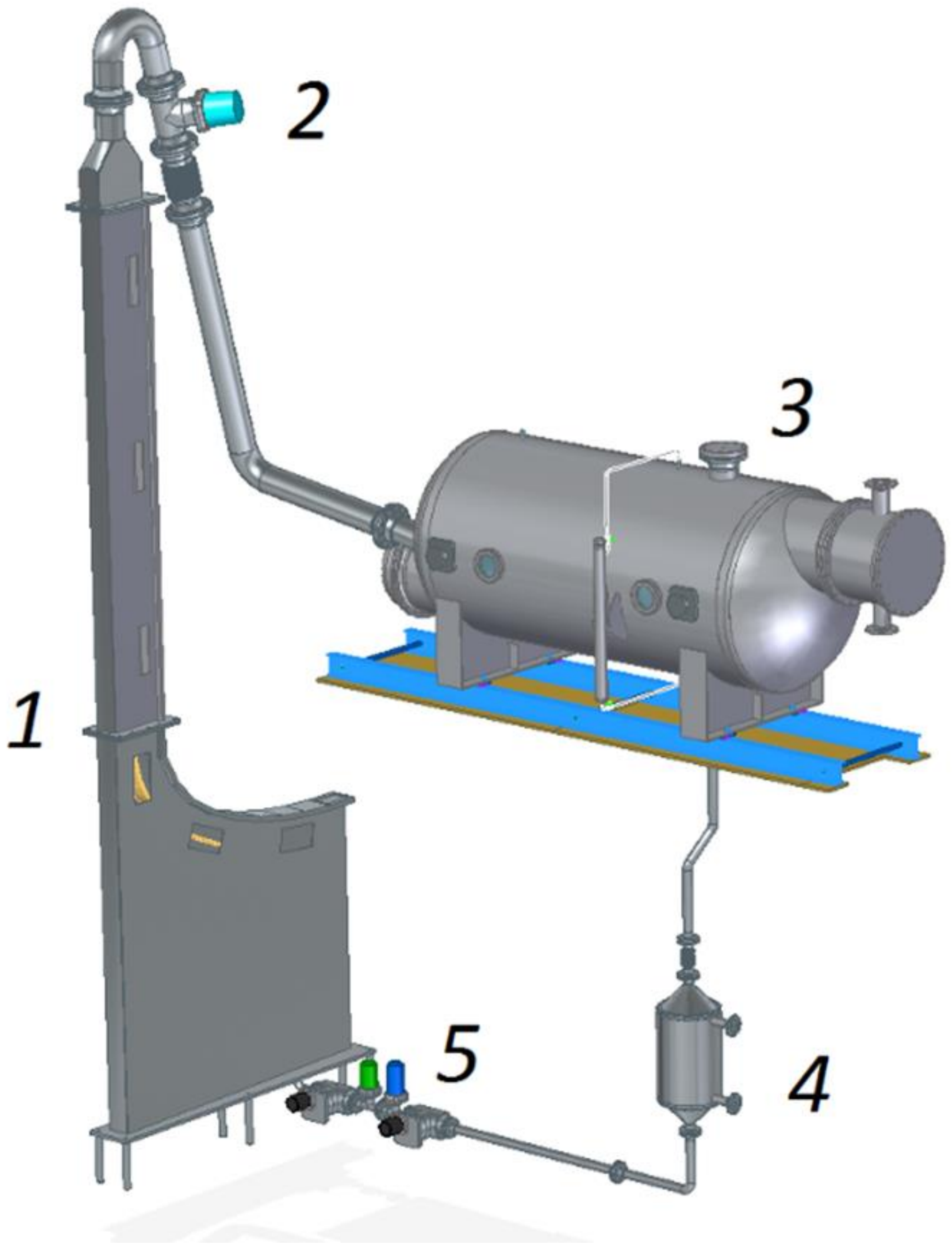

Figure 39: 3D model of THS-15 experimental circuit

Description of the experimental circuit functions - at Figure 39:
The water in the reactor cavity model /1/ circulates using the gravity principle (either in pool boiling or thermos-siphon mode). Part of the water evaporates and goes through the pipeline (DN200) and the regulation valve /2/ into the condenser /3/ - this part can model a steam release gap around the supporting ring of the reactor into the containment. The condenser also serves as a reservoir of the cooling media of the experimental loop. The condensate proceeds into the "sub-cooler" (plate heat exchanger) /4/, where it is cooled down to 20°C - 100°C. The cooled down water is transported by a pump /5/ back into the reactor cavity model /1/.

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7.5.2.2. Description of the test loop (phase I and phase II)

The description of the test loop can be divided into two parts, depending on which type of experiments are planned to be performed (pool boiling or thermo-siphon tests). The parts of the technology that are common to both types of tests are described in general below, the expected modifications required by each type of experiment are listed in the respective subsections. The geometry details and detailed parameter values will be described in the "Facility Description" technical deliverable (separate report).

1. **Experimental channel (ECH):**

Experimental channel consists of two main parts connected by a flange. Lower part (approx. 6 tons) is representing the cavity under the VVER 1000 RPV. Upper part (approx. 12 tons) represents the (elliptical shaped) RPV and its external surface and a gap between RPV and side wall of a cavity. 2D model of ECH and its drawing with general dimensions are shown on Figure 40. Maximum pressure range is 0 – 6 bars and maximum temperature (of water) 150 °C. The volume of water depends on the experimental conditions (water level setting) and is approximately 1.5 - 2 cubic meters.
Heating panels are made from copper blocks explosively welded with RPV steel (3 mm thick) and then welded to the construction of experimental channel. Copper matrix is filled with electric cartridge heaters (see Figure 41). Shaped heating panel is divided into 19 heating sections where each section can be regulated separately. Maximum temperature of heating panel is 950 °C and capable heat flux distribution range is from 1.5 MW/m^3 (RPV bottom part) to 2,3 MW/m^3 (horizontal RPV part). Total installed electric power is approx. 1,5 MW (the installed capacity is higher than maximum allowed power during tests which is 0,7 MW). The effectives of heating panels (electric → thermal power) was estimated as 92 %.

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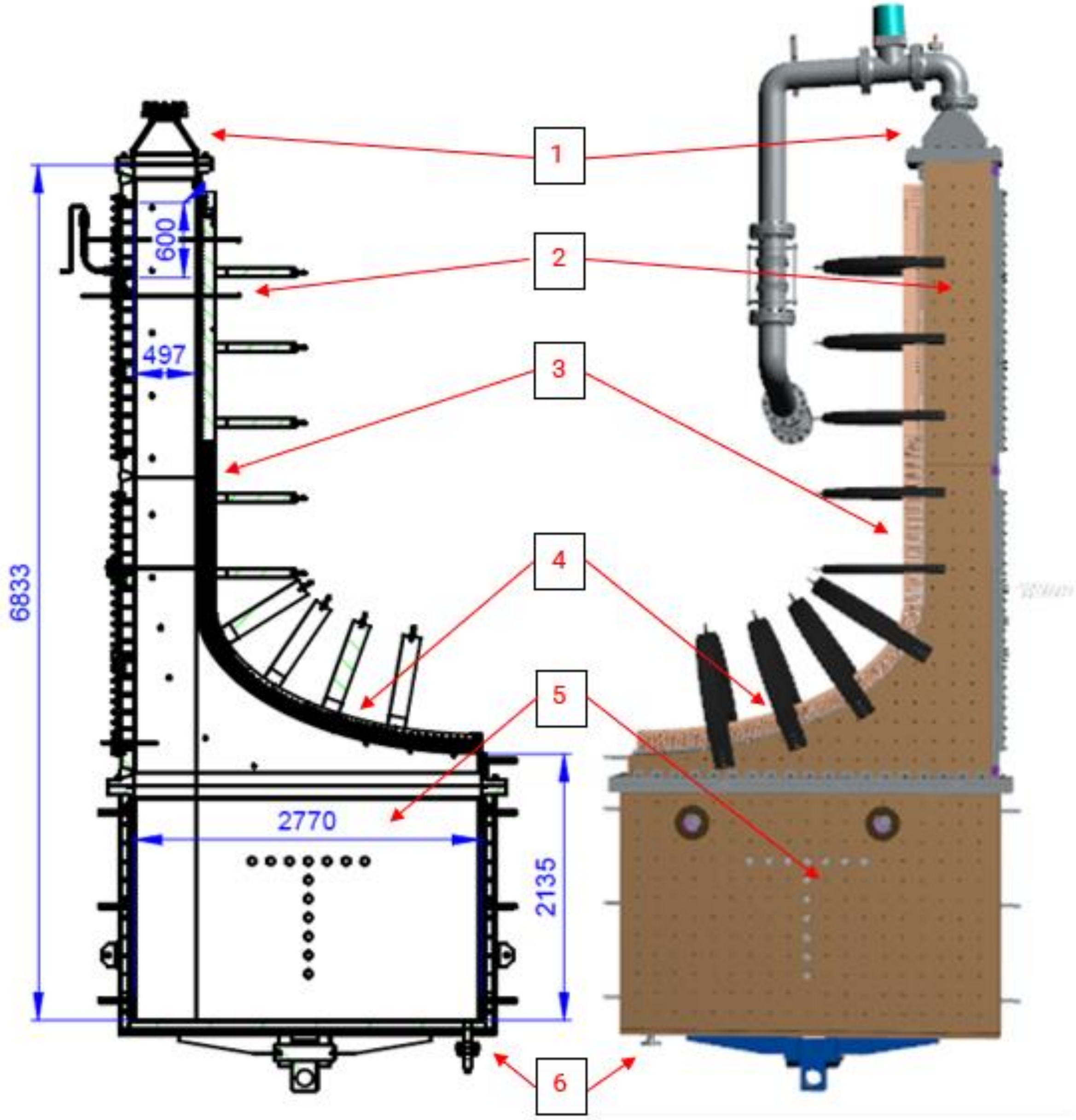

Figure 40: Drawing and 2D model of THS15 experimental mock-up

Description of the experimental channel parts on Figure 40:/1/ - Upper end for steam outlet, /2/ - Approximate level of water, /3/ - Vertical part of vessel, /4/ Ellipse shaped heating system, /5/ - Space for water below RPV (according to VVER 1000 cavity dimensions), /6/ - Flange for water inlet;

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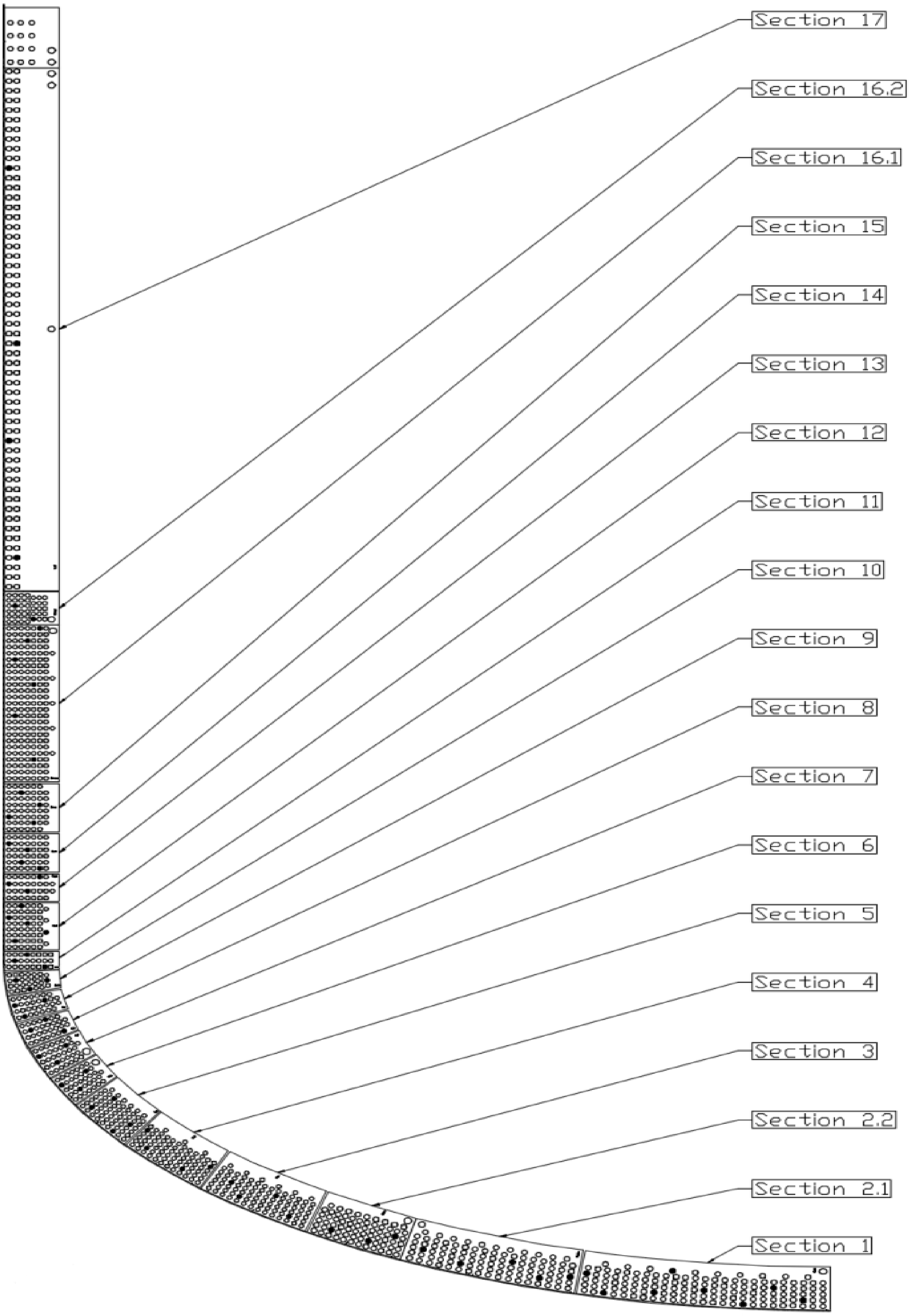

Figure 41: Distribution of heating segments (cartridges in black contain thermocouples)

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2. Condenser:

The condenser is constructed with required cooling power of min. 600 kW and consists of the main body (primary part) and tube sheet (secondary circuit). There are also auxiliary measurement systems (water level, temperatures, pressure) and a safety valves. It is made from austenitic steel. The demineralized water is usually used as a primary cooling media (tap water with impurities is also possible to be used) and tap water (with antifreeze) is circulating in secondary (tube) side.

3. Steam pipeline (Hot leg) and Water pipeline (Cold leg):

The two main components of the experimental circuit, mentioned above, are connected by pipelines, which are equipped with important parts including instrumentation. The hot leg (for steam outlet) consists of a stainless-steel pipe DN200. This pipe section includes a control valve that can reduce the flow cross-section and thus regulate the pressure in the experimental channel. Cold leg (for filling water into the ECH) is a DN50 pipe section. A plate heat exchanger (so-called sub-cooler) is installed on this line, in which the temperature of the water entering the ECH can be adjusted. This route also includes a feedwater pump that adds the necessary amount of water to the ECH (usually this amount is equal to the steam output from the ECH).

A. Description of the test loop in phase I – POOL BOILING TESTS

Pool boiling tests are not part of the benchmark (BENCH_5) which is planned to be solved in WP3.

For the EASI SMR project, the original equipment must be modified to obtain the necessary results and data. The experimental channel has been equipped with a new water level sensor in order to be able to measure the water level over a larger range. To minimize heat losses, the ECH was provided with insulation, including the insulation of "cold leg" pipeline described above.

During the pool boiling test phase, the experiments are conducted in a similar way as in previous research projects. The water that evaporates from the ECH into the hot leg is returned through the condenser and through cold leg back to the bottom of the ECH (as described in the previous section). The aim of the experiments is to investigate the CHF phenomenon at chosen RPV positions and under specific conditions close to the configuration of a generic SMR reactor. An important aspect is the attempt to provide conservative conditions for obtaining CHF values along RPV. The most important pool boiling initial test conditions (all of them can influence CHF values) are:

- Heat flux distribution along the RPV height (see Figure 42),
- Atmospheric pressure at the outlet from ECH,
- No sub-cooling,
- Water chemistry DI water,
- Water level in the ECH,
- Gap for a coolant inside ECH,
- RPV surface without any treatment, etc.

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An example of a reference heat flux profile that will be used as one of the initial conditions for pool boiling tests is shown in Figure 42. The heat flux distribution is based on the benchmark in the ELSMOR project for the "E-SMR" reactor.

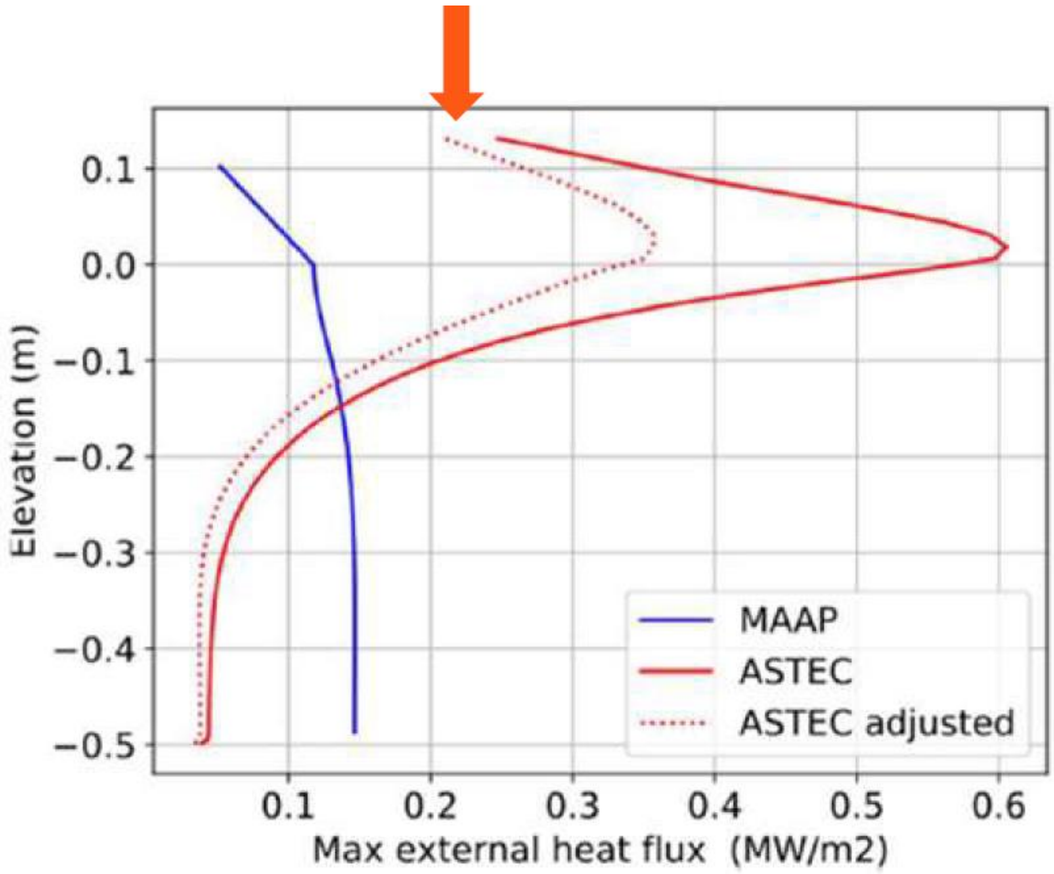

Figure 42: Heat flux distribution as one of initial condition for pool boiling tests (for IVR LOOP, "ASTEC adjusted" curve has been chosen, see orange arrow) [8]

The main difference between pool boiling tests and thermo-siphon tests is that when a gap is defined by a deflector in pool boiling tests, the water level is always below the level of the upper end of the deflector (Figure 43). This measure should ensure that water does not naturally circulate intensively inside the cavity and the coolant parameters (especially mass flux) are conservative enough to obtain CHF values.

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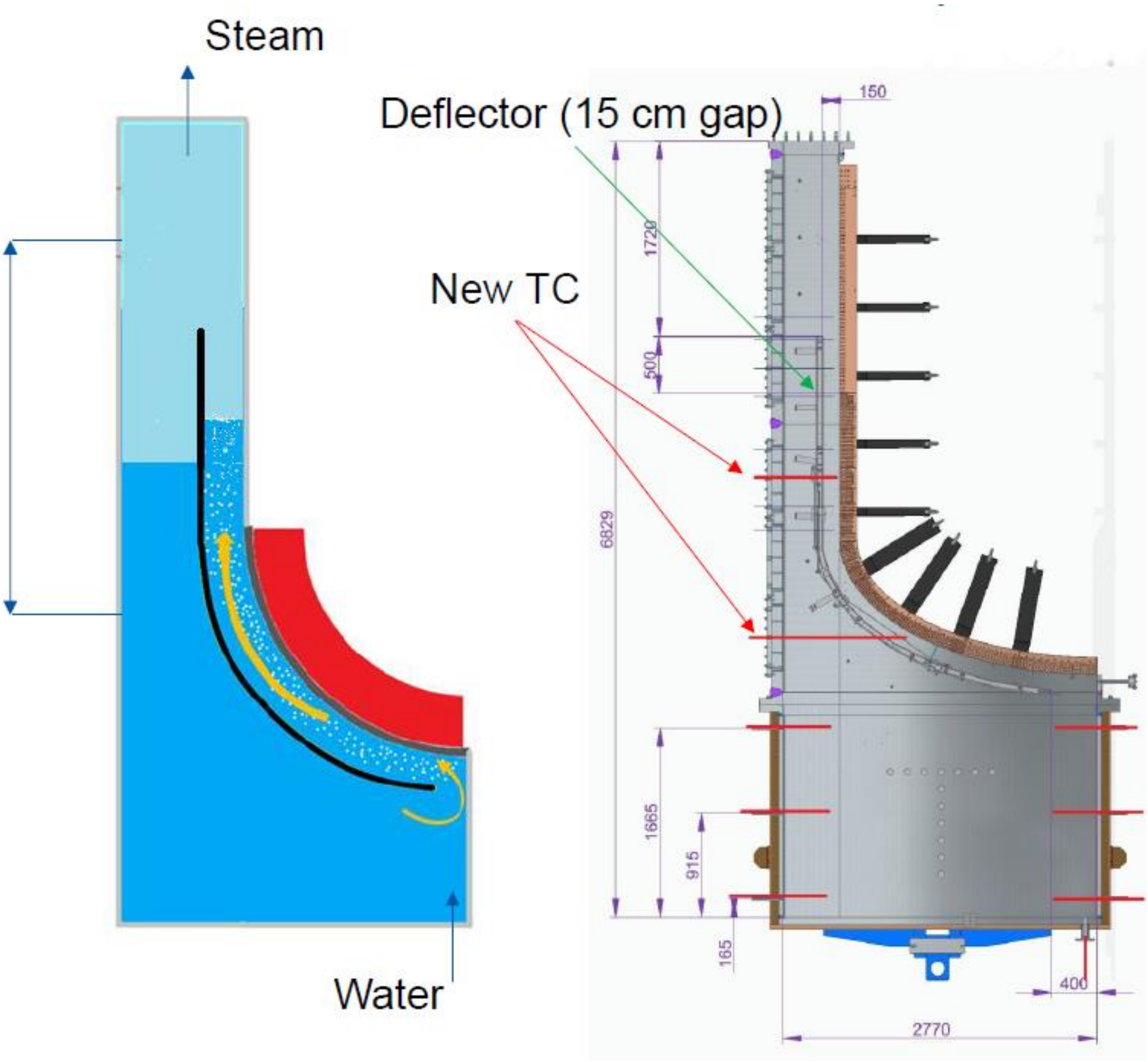

Figure 43: Water level inside RPV cavity in frame of pool boiling tests (left figure), when deflector is installed (defining 15 cm gap). New thermocouples installed inside a cavity with deflector (right figure)

B. Description of the test loop in phase II – THERMO-SIPHON TESTS

The Thermo-siphon mode of experiments is planned to be used for benchmarking in the WP3 solution. Thermo-siphon configuration of IVR LOOP will be targeted to thermal-hydraulic (TH) data collection and TH codes development. Natural circulation inside THS-15 pressure vessel is assumed, where the “cold” (liquid) branch and “hot” (two-phase) branch are separated by hydraulic guidance plates (or deflector) in a defined position and distance from RPV surface. It is planned to use 2 configurations of the deflector, which define a gap for the "two-phase branch" of 5 cm and 10 cm respectively. Mass flux/flow shall be measured at the inlet of two-phase branch, as well as temperature field inside the experimental vessel.

An important aspect of thermo-siphon experiments is that (in contrast to pool boiling tests) the water level in the experimental channel should always be above the level of the upper end of the deflector (Figure 44). If such condition is provided, the coolant will circulate at a sufficient rate to be measurable by a flow meter at the inlet (lower end of

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the deflector). Compared to the bool boiling tests, the deflector has a different design at its bottom, where the dimension of the entrance to the gap between the deflector and the RPV surface is defined by the equivalent of the flow cross section. The basic design of the deflector for thermo-siphon tests is shown in Figure 44 on the right. During the experiments, water level is controlled, produced steam is extracted to "hot leg" pipeline and equivalent amount of coolant is refilled in lower part of the experimental vessel ("bleed and feed" coolant management system, similar to previous types of tests on THS-15 facility). The system pressure can be controlled by heat extraction through a secondary circuit in the condenser, or in combination with a flow reduction on the hot leg steam line where the control valve is located (see Figure 39, component No. 2).

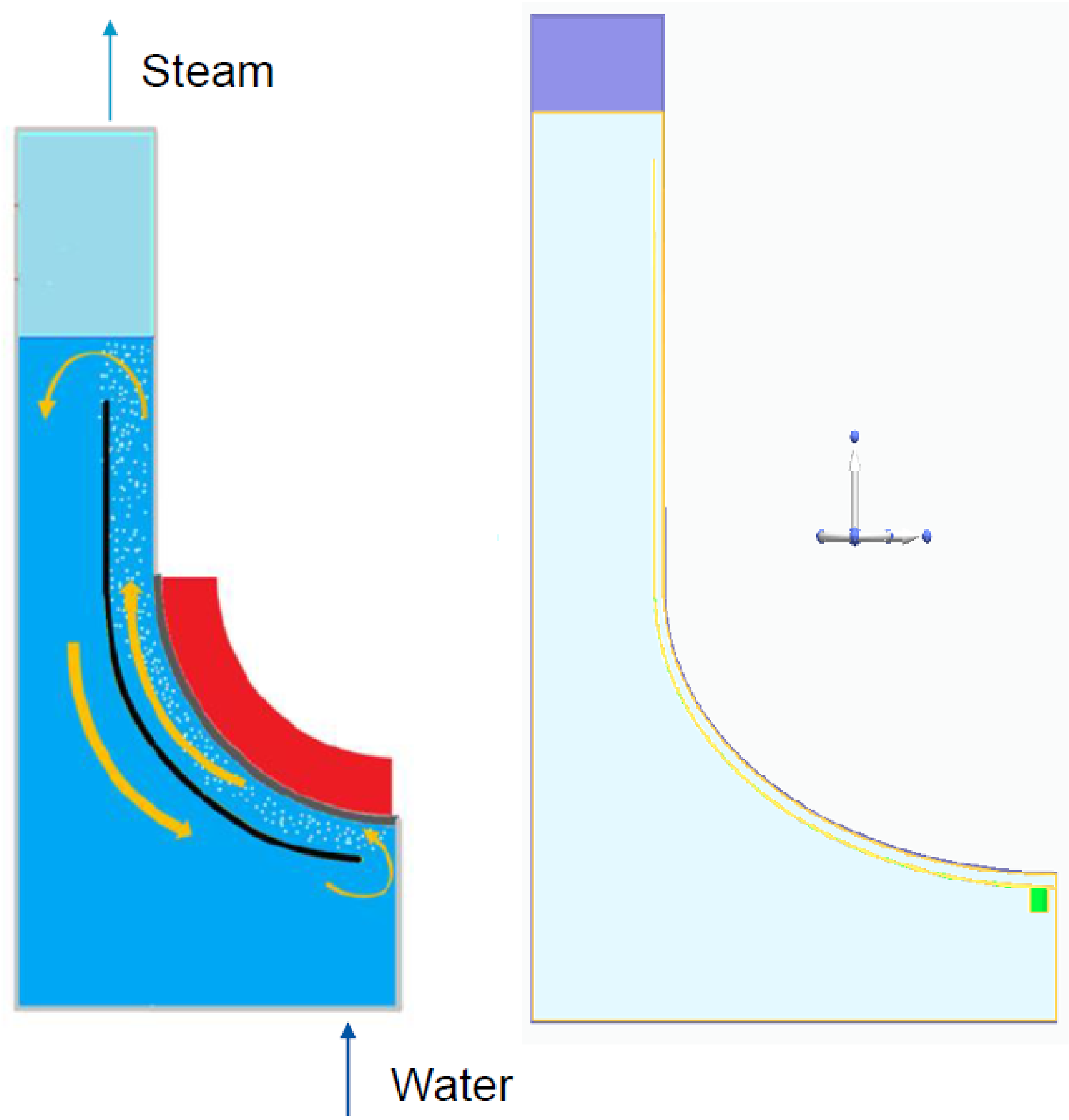

Figure 44: Water level above the upper end of the deflector for thermo-siphon tests principal configuration of IVR LOOP (left figure), design of deflector defining 50 mm gap (on the right figure in yellow), position for a new flow meter installation in green

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The most important thermos-siphon initial test conditions are:

- Heat flux distribution along the RPV height,
- Deflector gap geometry,
- Pressure range inside ECH,
- Temperature of water at the inlet to the ECH, etc.

7.5.2.3. Instrumentation and range of thermo hydraulics parameters

Instrumentation during the experiments is provided by a number of sensors, a list of which (within the primary experimental circuit) is described in the following Table 12:

Table 12: List of sensors in IVR LOOP experimental circuit

Measured parameter (unit)	**Location of sensors (measured substance)**	**Number of sensors (event. Type)**
Temperature (°C)	Heating sections (copper - on the upper surface, inside heating cartridges)	64 (K-type thermocouples - TC)
	"Surface" of the RPV sample (copper/RPV steel)	83 (K-type TC)
	Inlet/exit into/from the experimental channel (water/steam)	2 (Pt-100)
	Experimental channel (water)	8 (6xPt-100/ 2x K-type TC)
	Circuit piping - behind the condenser, under the sub-cooler, inside a condenser (water/steam)	4 (K-type TC)
Pressure (MPa)	Inlet into the experimental channel	1
	Exit from the experimental channel (before the regulation valve)	1
	Condenser	1
Mass flow rate (Kg/hour)	Circuit piping (hot leg for steam, cold leg for water)	2
Flow rate/fluid velocity (m^3/s) *	Inlet of thermo-siphon deflector	1

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Measuring water level (mm)	Experimental channel, condenser	2

* To be installed for Thermo-siphon phase of tests.
The range of the main thermo-hydraulic parameters are shown in Table 13:

Table 13: IVR LOOP - range of thermo-hydraulic parameters

Thermo-hydraulic parameter	**Range**	**Unit**
Pressure in the experimental circuit	(atmospheric) 0 – 0,5	MPa
Temperature in the experimental circuit	20 - 150	°C
Mass flow rate	0 - 1000	Kg/hour
Power into heating segments	0 - 600	kW
Temperature in heating sections	0 - 950	°C
Heat flux from heating sections to the coolant	0 – 2,3	MW/m^2

7.5.2.4. Matrix data tests prevision for phase I and phase II

In total, approximately 8 experimental weeks are planned, of which 4 weeks are dedicated to pool boiling tests (phase I) and 4 weeks to thermo-siphon tests (phase II).

The matrix of experiments is ready for pool boiling tests (Phase I). The aim is to obtain conservative CHF values depending on the position/angle of the RPV. In the sensitivity study, some of the initial conditions of the experiments are varied to evaluate the effect of the changed conditions on the CHF values. CHF values are measured at different RPV inclination angles, 2 heat flux profiles, 2 water levels in the experimental channel and 2 gaps (1x without deflector = gap 500 mm, 1x gap 150 mm) are selected. All (pool boiling) experiments will be performed at atmospheric pressure. The predicted preliminary matrix of experiments is shown in the Table 14 and counts with a minimum of 36 CHF measurements.

For the thermo-siphon tests, the experimental matrix is not yet precisely defined; it is planned to agree on the conditions during 2025. Initial test conditions such as the heat flux profile and the pressure inside the ECH will be optimised. It is considered that tests will be performed with deflectors defining a gap of 50 mm or 100 mm in the channel between the deflector and the RPV surface. Preliminary test matrix for thermos-siphon tests is shown in Table 15 counts with a minimum of 32 measurements.

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Table 14: IVR LOOP - predicted test matrix for Phase I (pool boiling tests)

Parameter as initial condition	**Range / listing**	**Number of tests**
Polar angle	30°, 45°, 60°, 75°, 90°	5
Heat flux distribution	2 profiles	2
Repeatability	yes	2
Subtotal number of measurements (5*2*2 tests)		***20***
Parameter as initial condition – sensitivity study	**Range / listing**	**Number of tests**
Submergence	2 water levels	2
Gap size	2 gap sizes	2
Polar angle	45°, 90°	2
Repeatability	yes	2
Subtotal number of measurements – sensitivity study (2*2*2*2 tests)		***16***

Table 15: IVR LOOP - predicted test matrix for Phase II (Thermo-siphon tests)

Parameter as initial condition	**Range / listing**	**Number of tests**
Cooling channel gap	50 mm, 100 mm	2
Heat flux distribution	2 profiles	2
Pressure in the system	0 MPa, 0,1 MPa, 0,2 MPa, 0,3 MPa	4
Repeatability	yes	2
Total number of measurements (2*2*4*2 tests)		***32***

7.5.2.5. IVR LOOP activity schedule phase I and phase II

In order to meet the project objectives, Pool boiling experiments (Phase I) were the first to be initiated, as the start of the programme did not require major modifications of the technology. In parallel, the definition of the conditions for the Thermo-siphon tests (Phase II) is being finalised. Similarly, modifications to the equipment for Phase II are being prepared. As the project milestones for the IVR LOOP are mainly related to Phase II, which has an associated Benchmark in WP3, the Phase I of the tests will be split into 2 parts and the second part will be completed after the Thermo-siphon tests. The expected progress and a list of technical outputs is shown in the Table 16:

Table 16: IVR LOOP - expected activity schedule

Testing phase	Activity	Project months	Dates
Phase I (Pool boiling)	Setting the test conditions	M1 – M3	09/2024 – 11/2024
Phase I (Pool boiling)	Performing experiments (part A)	M4 – M12	12/2024 – 08/2025
Phase II (Thermo-siphon)	Setting the test conditions, basic design (of modifications needed)	M1 – M10	09/2024 – 06/2025
Phase II (Thermo-siphon)	Detailed design and facility modifications	M11 – M23	07/2025 – 07/2026
Phase II (Thermo-siphon)	Performing experiments and data submission	M24 – M30	08/2026 – 02/2027
Phase I (Pool boiling)	Performing experiments (part B) and data submission	M31 – M36	03/2027 – 08/2027
Type of document (WP)	**Description of the document**	**Project month**	**Due date**
MS5/MS15 report (WP3)	Facility description of IVR LOOP and pre-test specifications	M18	02/28/2026
MS9 report (WP3)	Delivery of data results for IVR LOOP benchmark	M30	02/28/2027
MS23 report (WP3)	IVR LOOP blind specifications (boundary and initial test conditions)	M30	02/28/2027
D2.6 report (WP2)	SET IVR/ERVC LOOP deliverable report – Description of experimental test facility and data results	M36	08/31/2027
MS31 report (WP3)	IVR LOOP benchmark result	M42	02/29/2028

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7.6. PANDA

This task aims to collect and define all specifications and adaptation of the PANDA facility in PSI experimental facility. This experiment is devoted to investigation related to SMR with focus on heat removal by the containment using passive safety systems. Some designers are considering integrated SMR concepts in which the 3rd barrier containment is immersed in a large water pool. This is the focus of the PANDA test facility as part of the EASI-SMR project. During a postulated severe accident, steam will be released inside the containment and therefore the heat will be transferred from the containment wall to the surrounding water pool. Depending on the accident sequences, this ultimate heat sink will be thermally stratified.

The technical committee in charge of drawing up this definition action was made up of members of the CEA as WP2 leader and the people in charge of setting up the experimental installation belonging to PSI. Two experimental campaigns are scheduled along the EASI/SMR project.

7.6.1. Background to the PANDA experimental facility

This PANDA configuration for the EASI/SMR tests is based on the P1A5 series of the OECD/NEA PANDA project, which investigates the effect of the initial water temperature with the large buoyancy flow (high Rayleigh number). All design and dimension are based on scoping analysis simulated by EDF with code_saturne.

The experiments aim to investigate natural convection heat transfer from the containment simulator (CS) indicating the containment of SMR to the water pool. The CS will be installed at the center of the PANDA vessel (Drywell 1) and will be fully immersed in water.

The CS will be heated using a steam injection system from the steam generator of PANDA. Natural convection with turbulent flow will occur in the water under the pressurized condition, thermal evolution occurs in the water from the top of the vessel as being consistently heated on the CS.

Figure 45 shows a schematic of the PANDA experiments with CS (shown in red) immersed in the water pool. Table 17 lists the main phenomena which are expected to take place in the water pool during the heat transfer process. It should be noted that the PANDA experiments focus on natural convection heat transfer at high Ra_H while considering thermal stratification on the water. The characterization of phenomena such as transition from laminar to turbulent flow and detached boundary layer are foreseen in further work and therefore are beyond the scope of the EASI/SMR project.

In this project the test matrix will be addressed the presence of non-condensable gas (NCG) inside the SMR containment with various of the amount of NCG and steam inside the containment. It can be potentially leading to a non-uniform temperature distribution along the outer wall of the containment.

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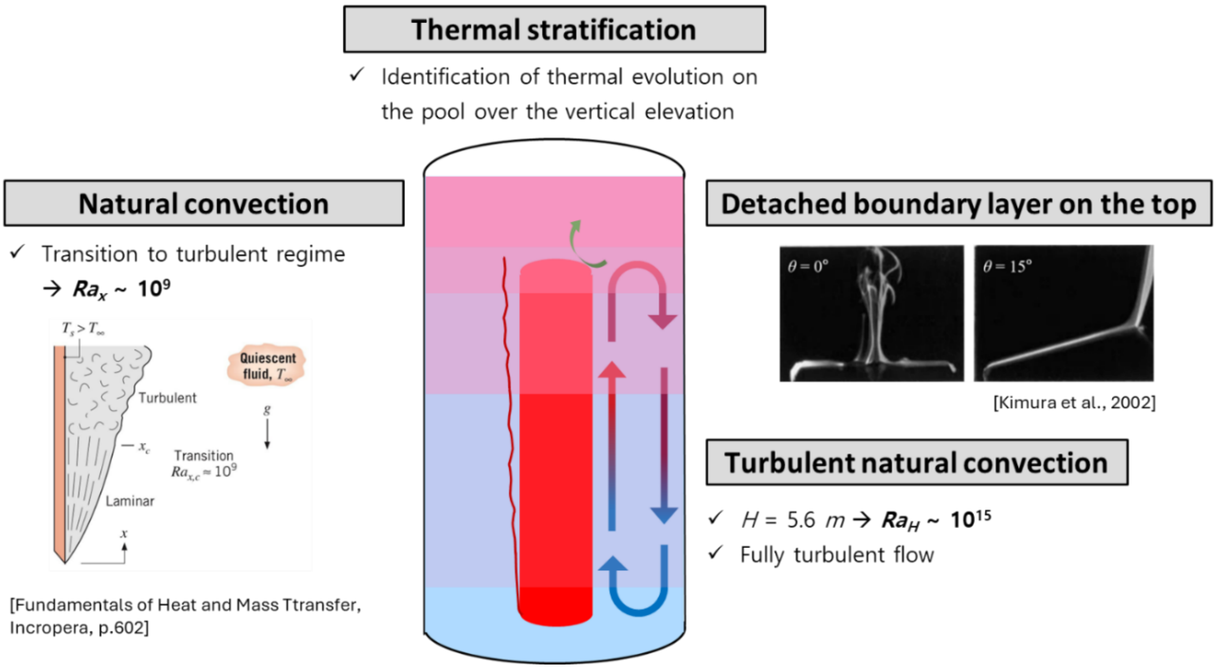

Figure 45: Phenomena of interest studied in PANDA experiments [13].

Table 17: List and main phenomena during the experiments [13].

Phenomena	Comment
Natural convection	The main heat transfer mechanism, characterized by high Rayleigh numbers
Transition from laminar to turbulent	Expected to take place in the lower region of the containment simulator
Thermal stratification over the pool height	Expected to develop and influenced by the heat source and geometric parameters
Detached boundary layer on the top of CS	Boundary layer detachment will vary depending on the geometry at the top of CS

7.6.2. Definition of the SET PANDA

7.6.2.1. General description of the facility

The experiments will be conducted in PANDA Vessel which has a diameter of 4 m and hight of 8 m. Figure 46 shows a rendering of PANDA vessel set-up for the experiments proposed in the Project. The CS, featuring curved upper and lower domes, had a height of 5.6 m and a diameter of 0.5 m, is located in the central region of the vessel submerged in 7 m of water. The thickness of the stainless steel 1.4404 is 0.0098 m. When the temperature ranges from 100 °C to 204 °C, its thermal conductivity varies from 17.16 W/m·K to 19.61 W/m·K.

To achieve high Rayleigh numbers in single phase the vessel will be pressurized (maximum 10 bar). And optical accesses ports in the PANDA vessel will allow to characterize velocities using Particle Image Velocimetry (PIV).

The heat source will be provided by injecting high temperature saturated steam (max. 170 °C) under 8 bar generated by RPV. The steam will be injected from the top of the CS and drainpipe will be installed at the bottom of the CS to remove the condensed water. To maintain the desired pressure inside the CS, a low level of water must remain at the bottom. This level can be adjusted using a control valve. The condensed water can either be directed to the wetwell, which is at the same pressure, or returned to the RPV. The drain line connection will be determined based on technical considerations.

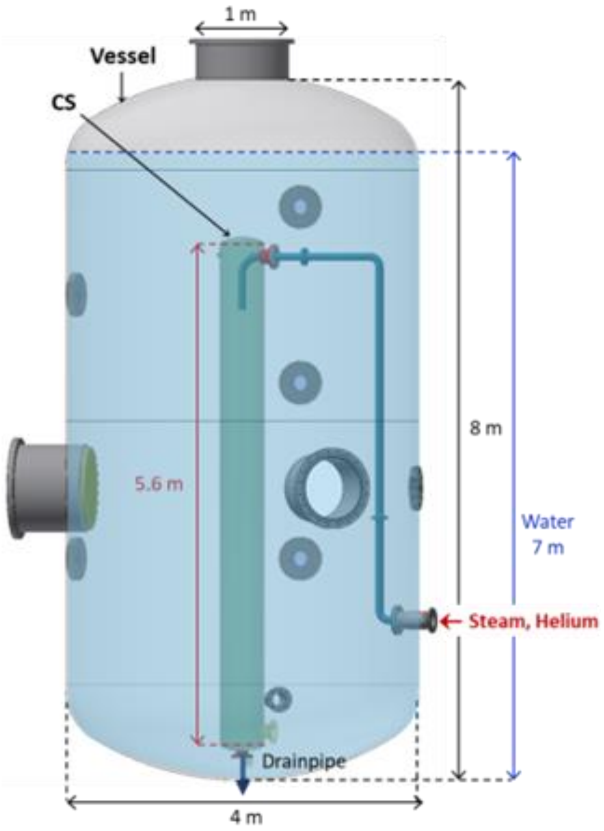

Figure 46: PANDA facility for the natural convection in the water pool.

7.6.2.2. Description of the test loop

Figure 47 illustrates the tentative test loop of PANDA. To achieve a uniform and desired initial water temperature, a heat exchanger will be operated prior to the experimental phase as part of the preparation. Then, to allow the containment simulator to act as a heat source, saturated steam will be injected through the main steam line by adjusting the control valve. To introduce NCG into the CS, a helium injection line is installed along the main steam line.

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A drain line from the containment simulator to the RPV will be installed to remove the condensed water while maintaining a certain water level inside the containment simulator. The water will then flow back to the RPV via a pump located on the drain line. Additionally, a vent line will be installed separately on the drain line.

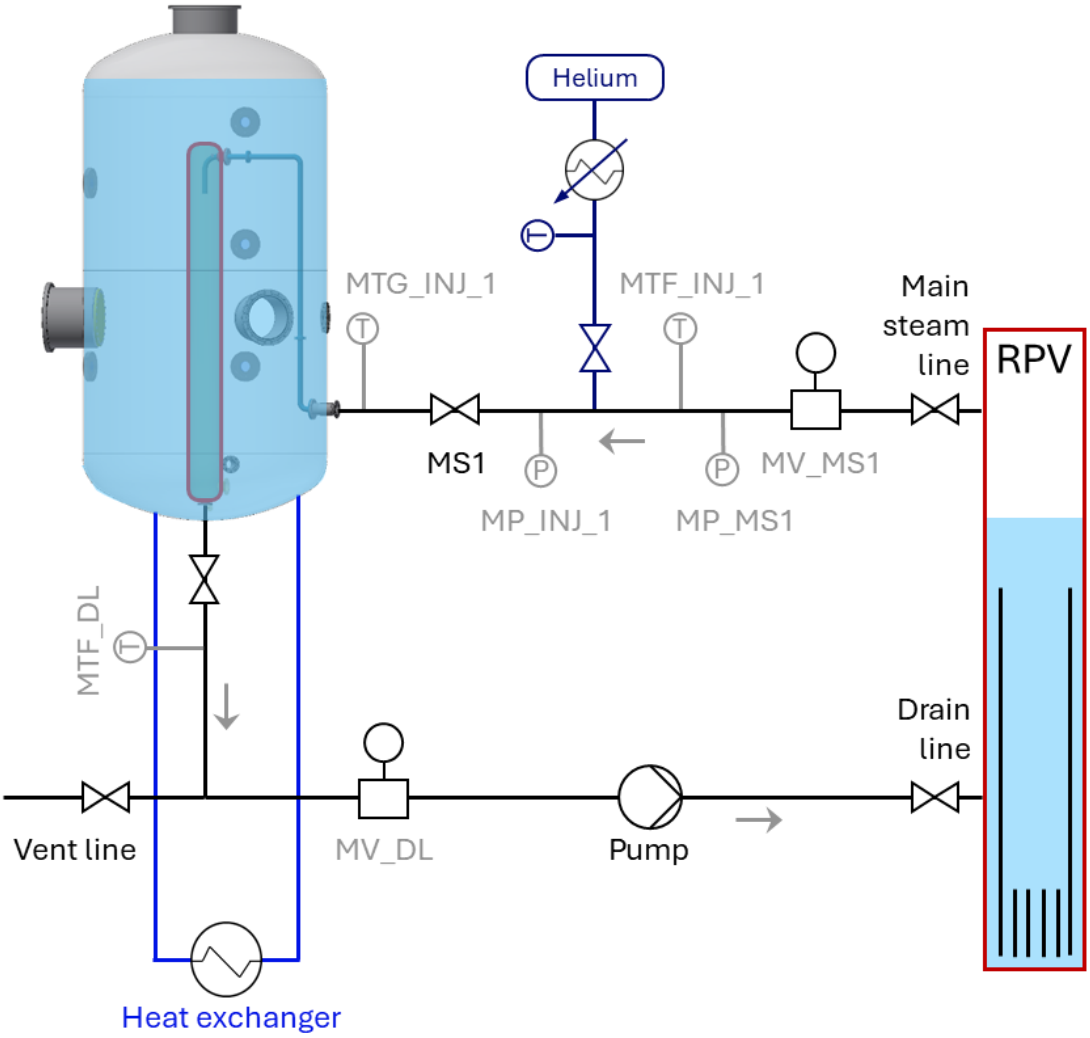


Figure 47: Test loop of PANDA experiments.

7.6.2.3. Instrumentation and range of thermo hydraulics parameters

Inside CS

To measure the temperature of the gas mixture (steam, helium), six K-type thermocouples are installed inside the CS at different elevations. Their positions from the bottom of the CS are 0.4 m, 1.3 m, 2.5 m, 3.5 m, 4.5 m, and 5.3 m, each located 0.05 m from the wall. A pressure sensor will be installed at the top of the CS, and a water level sensor at the bottom. Figure 48 shows the positions of the instrumentation described above.

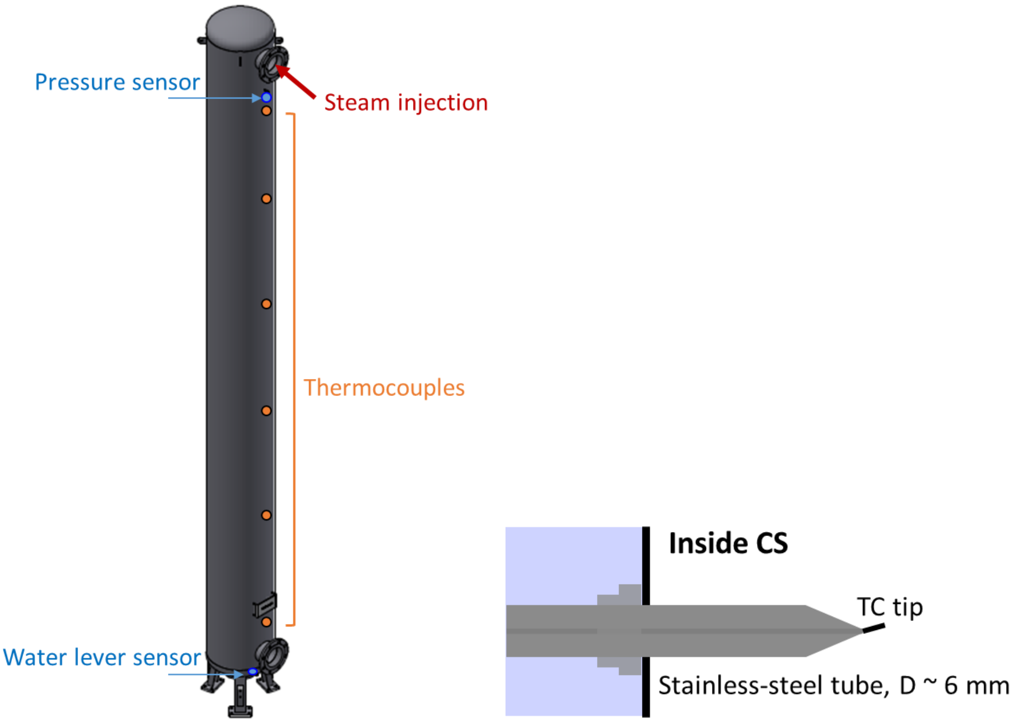
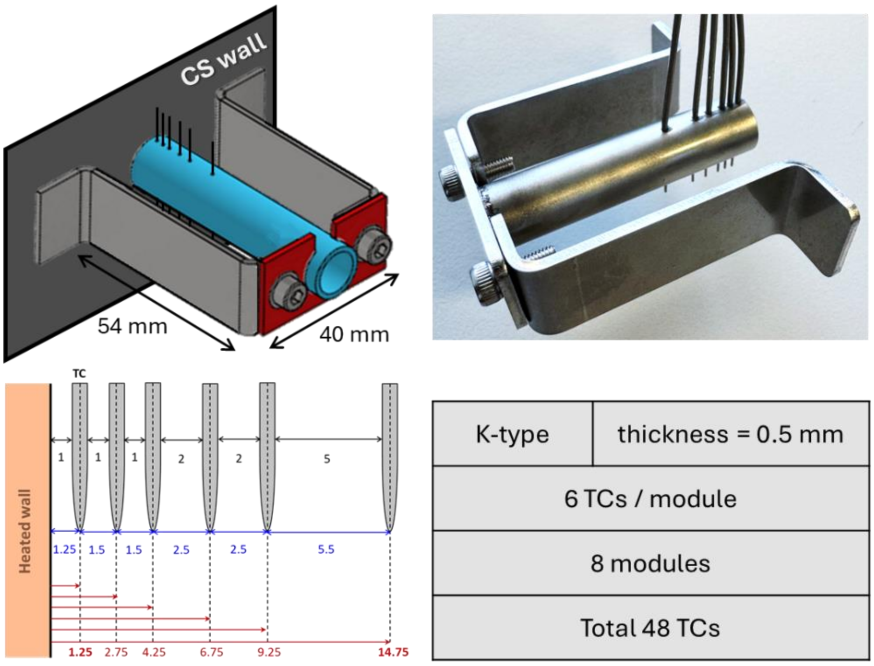


Figure 48: Rendering of the instrumentation with CS.

<u>Outside CS</u>

A thermal boundary layer will be developed on the CS as it acts as a heated wall. To measure the thickness of the boundary layer and temperature distribution near the wall, total 8 thermocouple modules will be installed along the elevation of the CS. Each module (Figure 49) contains six thermocouples arranged along the cylinder, with the closest positioned 1.25 mm from the CS wall and the farthest at 14.75 mm.

Heat flux sensors will also be installed at different elevations to derive the heat transfer coefficient. These sensors will be attached to the outer wall of the CS. A maximum heat flux of approximately 140 W/m² will be measured using the FHF06 sensor from Hukseflux (as shown in Figure 50).



K-type	thickness = 0.5 mm
6 TCs / module	
8 modules	
Total 48 TCs	

Figure 49: Thermocouple module.

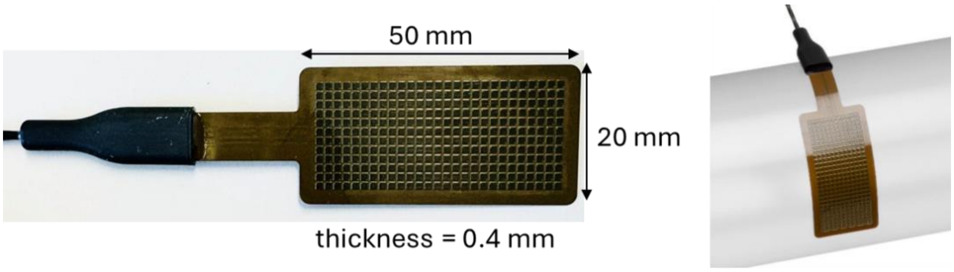


Figure 50: Heat flux sensor.

During natural convection near the CS, thermal stratification occurs in the pool due to the adiabatic wall of the vessel. Approximately 100 thermocouples will be installed in the pool region at varying distances, as shown in Figure 51. Their placement is based on scoping analysis conducted by EDF using the SATURNE code.

Velocity measurements in the fully turbulent flow region are planned using PIV (Particle Image Velocimetry) experiments. The field of view for these measurements will be located in the upper part of the CS.

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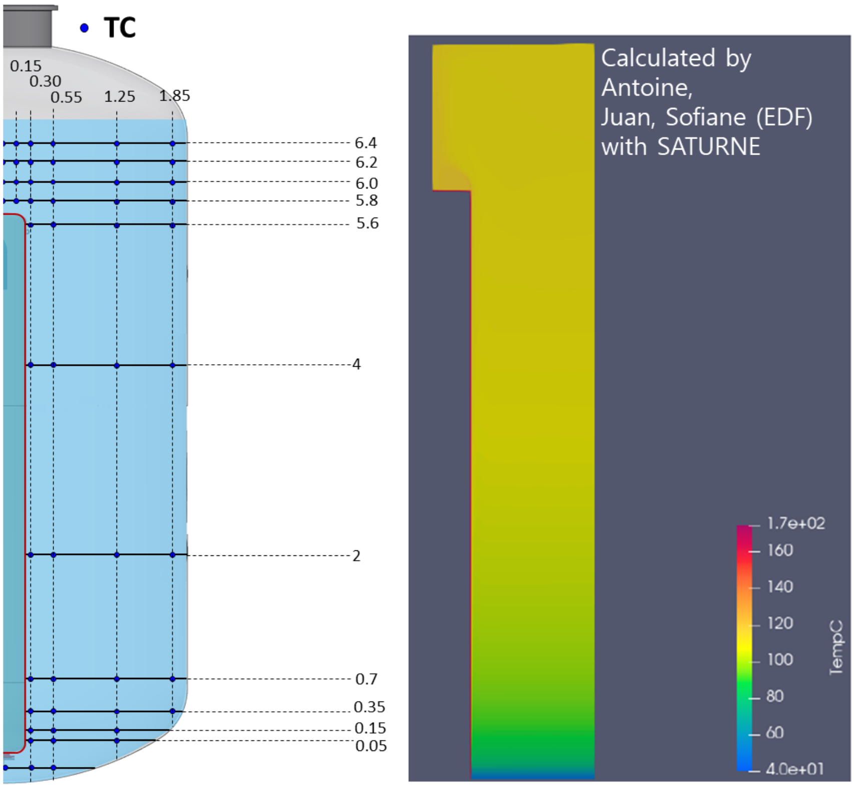

Figure 51: Thermocouple positioning defined based on simulation results by EDF.

7.6.2.4. Matrix data tests prevision

The test matrix includes two cases the presence of NCG mixed with steam inside the CS, based on a high Rayleigh number. The mixture of steam and NCG within the CS can cause thermal stratification, which may lead to non-uniform temperature distribution along the outer wall.

The tentative initial condition for the EASI/SMR PANDA experiments is shown in Table 18. Demineralized water of 20 ℃ is filled into the vessel, which is pressurized with air to 6 - 7 bar to prevent the water from boiling. Saturated steam at 160 ℃ will be injected into the CS. The expected temperature of the outer wall is to be approximately 110 ℃ obtained by conductive heat transfer with stainless steel material. Based on the maximum temperature difference between outer wall of CS and initial water with height of CS, the Rayleigh number will be achieved approximately 1015. A detailed test procedure description will be developed based on shake-down tests.

It is foreseen that to establish the initial condition, the CS will first be brough to a vacuum state inside CS as a preconditioning step. Also, vacuum will be created above the water pool and kept for several hours, in order to reduce air content in the water.

Table 19 presents the tentative test matrix (to be discussed in WP2) for these experiments, covering two different cases without NCG and with NCG, which are currently nominal and tentative. The evolution of thermal stratification is influenced by the presence of the NCG inside CS. During the experiments the condensed water is to be accumulated at the bottom of the CS. At a certain condensed water level will be remained at the bottom of the CS (0.3 m - 0.5 m) to retain the pressure specified in the test matrix.

The preliminary test matrix will be discussed within the WP2 and finalized according to the feedbacks which we will receive by the EASI/SMR project participants.

Table 18: Tentative initial conditions for EASI/SMR PANDA experiments.

Initial condition		**Nominal value**	
		CS	**Vessel**
Pressure		~ 6 bar	6 - 7 bar
Molar fraction		Steam 100 %	Water 100 %
Water level		-	7 m
Temperature	**Fluid**	160 ℃	20 ℃
	Wall	~ 110 ℃ (expected)	20 ℃

Table 19: Tentative test matrix for the EASI/SMR PANDA experiments ($Ra_H \sim 10^{15}$).

Cases					**EASI CG**	**EASI NCG**	
			Parameters	Unit			
Vessel			Initial P	bar	6 (constant)	6 (constant)	
			Initial temp.	℃	~ 20	~ 20	
RPV			Power	kW	~ 500	~ 500	
			Initial P	bar	~ 6	~ 6	
			Initial temp.	℃	~ 160	~ 160	
CS	**Phase 1**	Steam	Initial P	bar	~ 6	~ 6	
			Initial temp.	℃	~ 160	~ 160	
			Flow rate	g/s	~ 240	~ 240	
			Duration	s	7200 (2hrs)	3600 (1hr)	
	Phase 2	Steam +He	Temp.	℃	-	~ 160	120 - 160
			Flow rate	g/s	-	~ 240	~ 1
			Duration	s	-	50	50
	Phase 3	Steam	Duration	s	-	3550	-

The PANDA base case EASI-CG is proposed by PSI for the benchmark, because at the moment there is not so much experience in the analyses of these phenomena at high Ra numbers and the EASI-CG has a simpler phenomenology.

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7.6.2.5. PANDA activity schedule

The experimental parameters, namely the design of the containment vessel and instrumentation layout are based on computational analyses carried out by EDF with Neptune_cfd and code_saturne CFD computational tools.

The PANDA experimental results will be used to benchmark a variety of computational tools ranging from advanced system codes with 3D capabilities to CFD codes (e.g. based on open-source solvers).

It is required (or recommended) a previous experience:

- in creating meshes for complex geometries
- in analyzing containment phenomena in particular "water pool phenomena" e.g.:
    - Heat transfer to large water pool
    - Formation and propagation of thermal stratification
    - Natural convection at large scale, etc.

January - September 2025

- **Construct experimental facility and install instrumentation**

– Design and construction of experimental components, and auxiliary systems
– Design of instrumentation layout considering the experimental geometrical specifications and test scenarios
– Implementation of experimental components and instrumentation
– Verification of instrumentation and control system and preparation of the related documentation
– Technical note: Facility description and pre-test specifications of PANDA (30/06/2025)

October 2025 – January 2026

- **Conduct experiments and process the data**

– Development of experimental procedures for facility preconditioning
– Perform shake-down tests to verify the test procedures and the overall facility response
– Perform the experimental campaign

Processing the experimental data and verify the instrumentation

February - August 2026

- **Finalize the document of experimental results**

– Select the sensors that are relevant for the investigated phenomena and arrange the experimental data in ASCII format
– Write technical reports with 1) description of PANDA facility configuration and instrumentation and 2) test specifications phenomenological analyses of the experimental results
– Technical note (WP3): Delivery of data results for benchmark for PANDA / Blind specification (31/08/2026)

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<u>August 2026 – 2027</u>

- **Complete the description of experimental and benchmark reports**
  - Technical note: Description of experimental and benchmark results (31/08/2027)
  - Deliverables D2.7: Description of experimental test facility and data report (31/12/2027)

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7.7. PRECISE

This task aims to collect and define all specifications and adaptation of the PRECISE facility from ETHZ in PSI experimental facility. This includes technical specifications for components, test ranges, and instrumentation. PRECISE separate effect tests are the subject of a dedicated action, WP2.8, for which the host of the experimental facility, ETHZ, is responsible.
The technical committee in charge of drawing up this definition action was made up of members of the CEA as WP2 leader and the people in charge of setting up the experimental installation belonging to ETHZ. Additional technical meetings have been held with COSAC experimental facility members, to ensure the consistency of similar experimental steam condensation tests. While COSAC is dedicated to the validation of thermo-hydraulic codes, PRECISE focuses on high-resolution measurement of condensation film behavior for the validation of CFD simulation of the film condensation.

7.7.1.Background to the PRECISE experimental facility

The evaluation of passive cooling system performance requires experimental data and models that can encompass a wide range of thermal-hydraulic conditions. In particular, in-tube condensation heat transfer within the vertical tube bundle of a safety condenser is mainly influenced by liquid condensate film thickness and the local composition of non-condensable (NC) gases. In this manner, to enhance the understanding of film condensation phenomena and develop physics-based models with improved accuracy, it is required to establish a high-resolution measurement on condensate film thickness which is closely linked to the condensation mechanism. Although various intrusive measurement techniques, such as conductive probes and wire mesh sensors, have been employed to investigate the film condensation phenomena, their specific limitations in terms of physical interference and their limited applicability make them difficult to apply to high-temperature, high-pressure conditions or certain working fluids. To address these limitations, radiation-based measurement techniques offer significant advantages. High-speed X-ray radiography, in particular, has been identified as a suitable method due to its ability to achieve high temporal and spatial resolution across the flow domain. This technique is especially effective for capturing film thickness in a condensation tube and quantifying void fraction for two-phase flow, which is required for extensive CFD model validation.

With X-ray radiography technique, the PRECISE experimental campaign intends to design a sophisticated condensation test section and provide high-resolution data under well-defined boundary conditions that complement the KARLSTEIN COSAC experiments. These data will support the validation of system codes and CFD simulation for film condensation, with and without the presence of NC gases.

To achieve this goal, the following should be considered in the experimental design:

- A single condensation tube with dimensions representative of a European SMR safety condenser will be considered with reference to the specifications of the KARLSTEIN

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COSAC experiments. To enhance the accuracy of X-ray radiography, minimization with thin wall thickness or low-Z materials such as titanium will be a design priority.

- The experiments will cover the primary ranges of steam pressure expected to occur in a European SMR safety system during the transient accidents. Attention will be given to the relatively low-pressure conditions below 10 bars, which has been reported as areas with limited validation in safety analysis code.

- Optimization of the cooling jacket size and shape will be required to minimized test uncertainties as associated with heat loss and entrance effects, ensuring accurate and reliable data for CFD benchmark.

- To support X-ray radiography, the cooling channel gap will be optimally selected to reduce X-ray attenuation and enhance the heat transfer coefficient which prevents subcooled boiling at the outer wall of the condenser tube.

- The experimental campaign will include NC gases injection, including nitrogen and helium, as affordable and safe substitutes for air and hydrogen, respectively.

- The design will enable both upward and downward steam injection, allowing experiments to cover various flow regimes. This approach will enhance the applicability of the experimental data and the range of code validation.

7.7.2. Definition of the SET PRECISE

7.7.2.1. *General description of the facility*

A simplified schematic of the PRECISE test facility is shown in Figure 45. The facility is subdivided into three main subsystems – the primary and the secondary loops, and X-ray measurement system. The primary loop comprises of the steam generator and the condensation test section and associated NC gas injection system, while the secondary loop includes a cooling water loop. The cooling jacket design will be carefully designed to ensure well-defined boundary conditions, enabling reliable CFD validation. The test facility is currently in the design phase and is scheduled to be constructed during the first year of the project. In the PRECISE facility, steam and NC gas mixture will be utilized and the local heat flux and condensation heat transfer coefficient (HTC) data will be obtained. In addition, the facility is equipped with a high-resolution X-ray radiography system to investigate the liquid film thickness and hydraulic behaviour at selected locations along the test section. Currently, reliable experimental data on the condensation film thickness are limited, so the detailed measurements of condensation HTC and film thickness are expected to provide valuable benchmarks for CFD validation, supporting the development and improvement of film condensation models.

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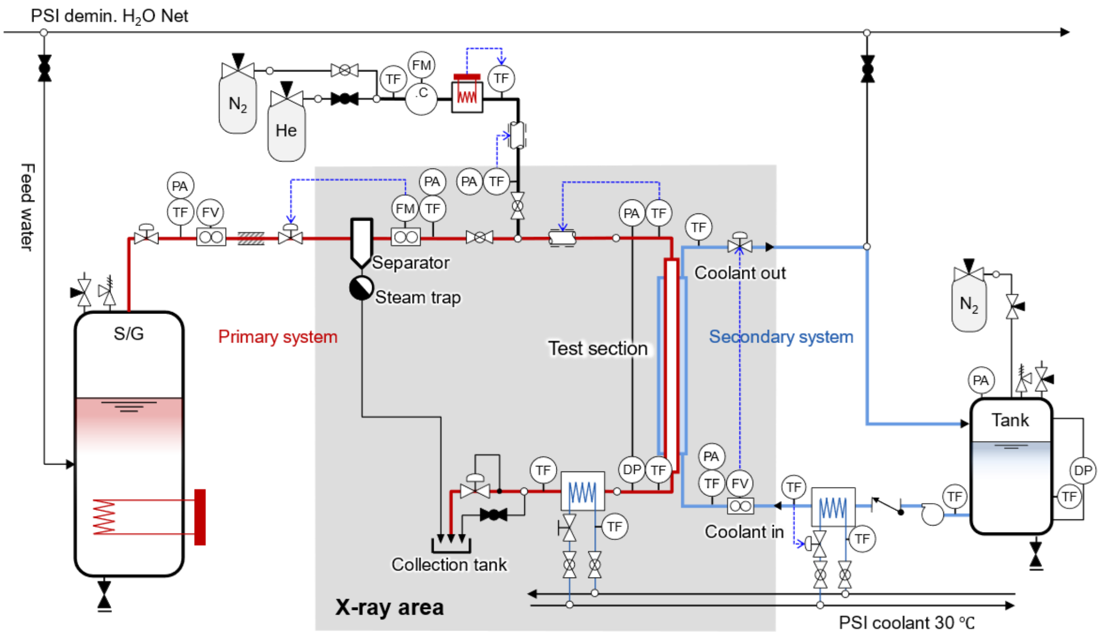

Figure 45 Schematic of PRECISE facility

7.7.2.2. Description of the test loop

PRECISE test facility consists of a primary loop for steam and NC gases and a secondary loop for cooling water as depicted in Figure 45. In the primary loop, steam generated by the steam generator passes through a separator to ensure high-quality steam. NC gases are properly heated using pre-heater before mixing with the steam to maintain in a saturated condition.

The upstream section of the test loop is well insulated, and the heat loss is compensated by a trace heater control to prevent premature condensation and film/mist generation. For upward flow tests, an additional inlet plenum is designed to collect the film that may flow backward. At the exit of the test section, steam and condensate are cooled by a heat exchanger. After passing through the back pressure regulator, the condensed water and NC gases are directed to a collection tank. The system pressure is controlled by the setpoint of the back pressure regulator.

In the PRECISE facility, the steam mass flow rate in the primary system is controlled by a pneumatic valve, while the mass flow rate of the NC gas is regulated using a mass flow controller. The coolant flow rate in the secondary system is also controlled by a pneumatic valve, and the inlet coolant temperature is adjusted by regulating the flow through a heat exchanger using another pneumatic valve.

Figure 46 illustrates the test section of PRECISE test. The inner diameter of the condensation tube will be finally determined in consultation with the KARLSTEIN COSAC experiments group. Local heat flux and condensation HTC will be measured at seven elevations. Test section is coaxially surrounded by a cooling jacket pipe having 1.5 m of effective cooling length and narrow gap of annulus channel (provisionally 4 mm). Countercurrent cooling water flow ensures fully-developed cooling water flow

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(hydraulic and thermally) in the test section upstream, thus reducing measurement uncertainty in condensation HTC. The narrow cooling channel gap ensures sufficiently high cooling heat transfer coefficient to prevent subcooled boiling and minimize undesired x-ray attenuation in the cooling channel. The inlet and outlet plenums of the cooling channel are designed to introduce an appropriate pressure drop to ensure uniform flow within the channel. In addition, if subcooling boiling cannot be avoided under high temperature steam test conditions, appropriate pressurization (up to 2 bars) of the cooling channel may be required.

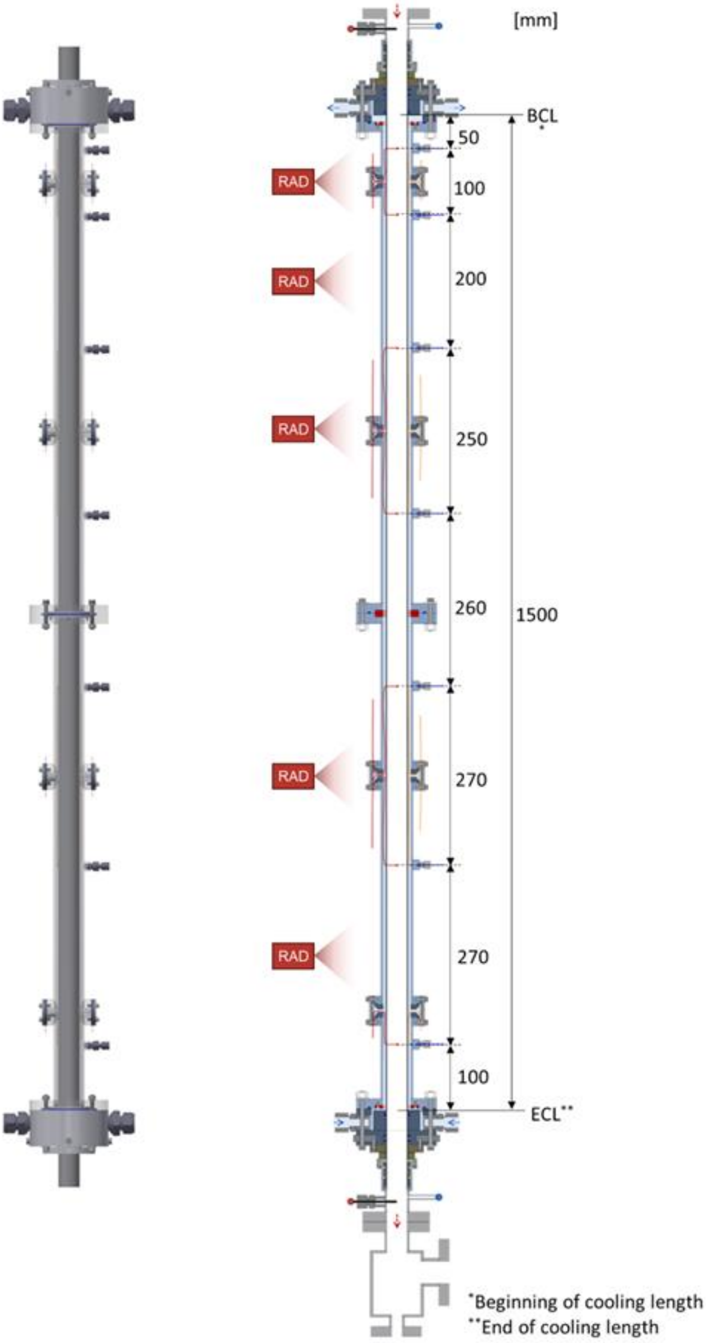

Figure 46 Detailed design of PRECISE test section

7.7.2.1. Instrumentation and range of thermo hydraulics parameters

Measurement parameters and instruments for thermo-hydraulic tests are listed in Table 17. For the primary system, the test boundary conditions involve steam and NC gas composition. These are determined based on the following values: pressure, temperature, and mass flow rate of each component. For the secondary system, the pressure, temperature, and mass flow rate will be measured to accurately estimate the heat removal rate from its enthalpy change.

In the test section, as described in previous section, thermocouples will be installed along the test section to measure the centerline temperature, outer wall temperature, and bulk temperature of the cooling water. These measurements will be used to calculate the axial distribution of the local heat flux and condensation HTC. The local heat flux is determined indirectly from the boundary conditions of cooling water side, while the condensation HTC will be calculated based on the wall heat flux and centerline fluid temperature. Additionally, the pressure, pressure drop and fluid temperature along the test loop and major components will be monitored to ensure safe operation of the experimental facility.

Furthermore, X-ray radiography will be utilized to investigate the film thickness and void fraction by measuring the attenuation according to two-phase distribution inside the condensation tube [7]. An X-ray tube and high-resolution detector will be mounted on a gantry to enable precise measurement of the desired location on the test section.

Table 17 Instrumentation and test range of PRECISE test

Parameters	Instruments	Range	Unit
Primary system			
Inlet pressure	Pressure transducer	1-10	bar(a)
fluid and wall temperature	K-type thermocouples	20- 180	°C
Power of primary steam generator	Powermeter	Max. 150	kW
Primary steam mass flux	Coriolis mass flowmeter	3 – 65	g/s
NC-gases mass flow rater	Gas mass flow controller	0 – 35 for He 0 – 7 for N_2	g/s
Secondary system			
Water pressure	Pressure transducer	1 – 2	bar(a)
Water temperature	K-type thermocouples	30 – 50	°C
Water mass flow rate	Vortex flowmeter	0 – 5	m^3/h

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7.7.2.1. Matrix data tests prevision

The test matrix includes the following inlet variables: primary pressure, steam mass flux, NC gas mass fraction, flow direction (upward or downward), coolant inlet temperature, and coolant mass flow rate. This experimental campaign aims to investigate the effects of steam conditions (pressure, mass flux, and flow direction) and NC gas composition (including nitrogen and helium) on the film condensation heat transfer coefficient and condensate film behavior. In addition, the effect of wall heat flux conditions will be investigated by changing the flow conditions of the cooling water. A summary of the experimental conditions is listed in Table 18. Detailed campaign will be determined based on the conditions of the KARLSTEIN COSAC experiments.

Table 18 Test matrix prevision for PRECISE test

Parameters	Range	Unit
Inlet pressure	1, 2, 3, 5, 10	bar (a)
Inlet steam mass flux	10 - 40	kg/m^{2}s
Inlet nitrogen mass fraction	0.1 - 40	%
Inlet helium mass fraction	0.1 - 5	%
Flow direction	vertical downward/upward	-
Cooling water inlet temp.	30, 40, 50	°C
Cooling water flow rate	0.5, 1, 1.5	kg/s

7.7.2.2. PRECISE activity schedule

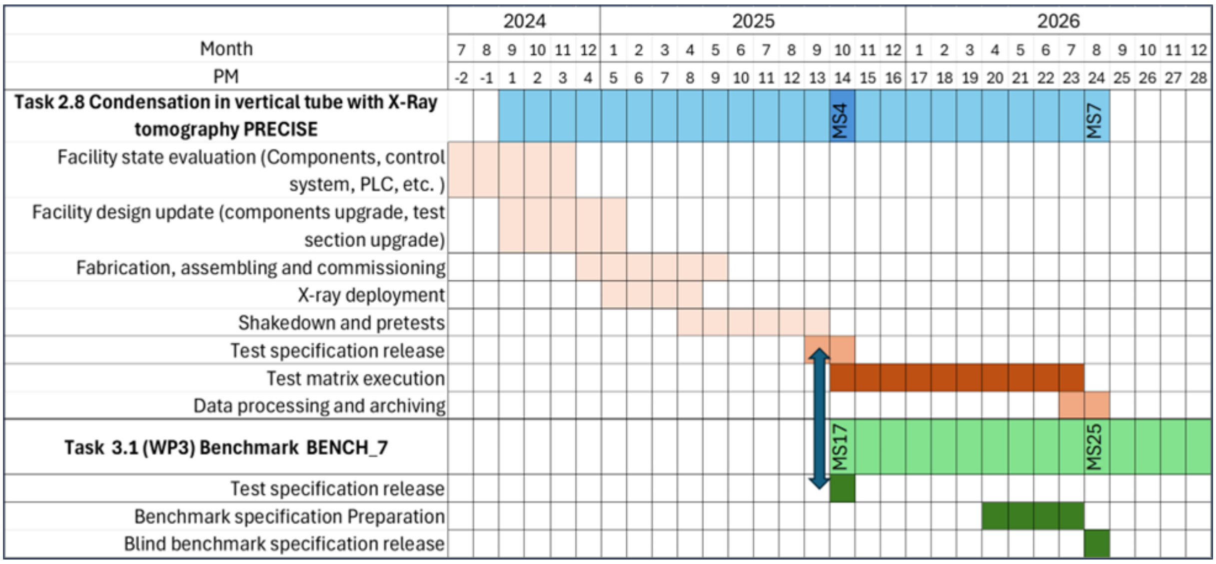

Figure 47 PRECISE activity schedule for first two years (until 2026)

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7.8. ALCINA

7.8.1. Background to the ALCINA experimental facility

The operating principle of safety condenser (SACO) relies on a two-phase flow thermosiphon loop. It consists of a hot source (a steam generator) supplied by the residual power of the core and a cold source (a condenser) at the top, which transfers heat to a heat sink (e.g. a water tank). The system operates based on natural circulation, driven by the balance between resistive forces (pressure drops) and driving forces (buoyancy).

Pressure drops depend on the system's design (circuit components such as valves, pipe bends, etc.) and can change over time due to friction caused by the corrosion of the inner walls of the pipes. The buoyancy force, which sustains circulation, is proportional to the fluid's density difference between the hot and cold sources. This density difference is directly influenced by the efficiency of heat transfer at these sources but also the result of potentially complex flow regime transitions along the loop.

Accurately determining pressure drops and heat transfer is essential for modelling a natural circulation-based system. Variations in these parameters can lead to flow instabilities within the loop, directly impacting system performance and reliability. Over time, aging-related increases in pressure drop may further challenge the system's stability, potentially compromising its efficiency and safety.

To better understand these effects, the ALCINA experiment will use a new facility at ASNR to measure pressure drops and heat transfer in a large-scale loop. The findings from this study will contribute to improving the design and reliability of passive safety systems relying on natural circulation, which are crucial for the long-term safety of nuclear reactors.

7.8.2. Definition of the SET ALCINA

7.8.2.1. General description of the facility

ALCINA is a full-scale pressurized water loop. The residual power (hot source) is simulated by an electric heater with a maximum thermal power of 300 kW. Downstream of this source, two instrumented test sections will be implemented: one vertical and one horizontal. These sections will have a sufficient experimental length (more than 5 m) to ensure a representative flow. Each section will be interchangeable and will allow the study of various geometrical configurations such as pipe diameters and pipe roughness. The cold source (condenser), positioned approximately 10 m above the hot source, will operate either with a constant imposed power or with transient power variations to simulate a loss of performance of this heat exchanger. The other parts of the loop will integrate the "process" zones dedicated to the operation of the loop (e.g., valves, flowmeter...) and to achieving the thermal-hydraulic conditions. All components of the experimental loop will be thermally insulated.

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The thermal hydraulic loop ALCINA is modular. The range of possible values for each parameter (full/mid-scale, inclined test section, various diameters, etc.) enables a wide variety of SACO configurations to be simulated.

The first configuration, referred to as the **“reference configuration”** and illustrated in Figure 48, will be a full-scale rectangular loop with these parameters:

- Test section diameter: DN80;
- Cold leg diameter: DN50;
- Pipe roughness: standard supply (~3 µm);
- No inclination (rectangular loop);
- Sources orientation: vertical;
- Loop height and width: ~11m and ~8m.

This large-height configuration enables a wide range of Reynolds numbers to be explored.

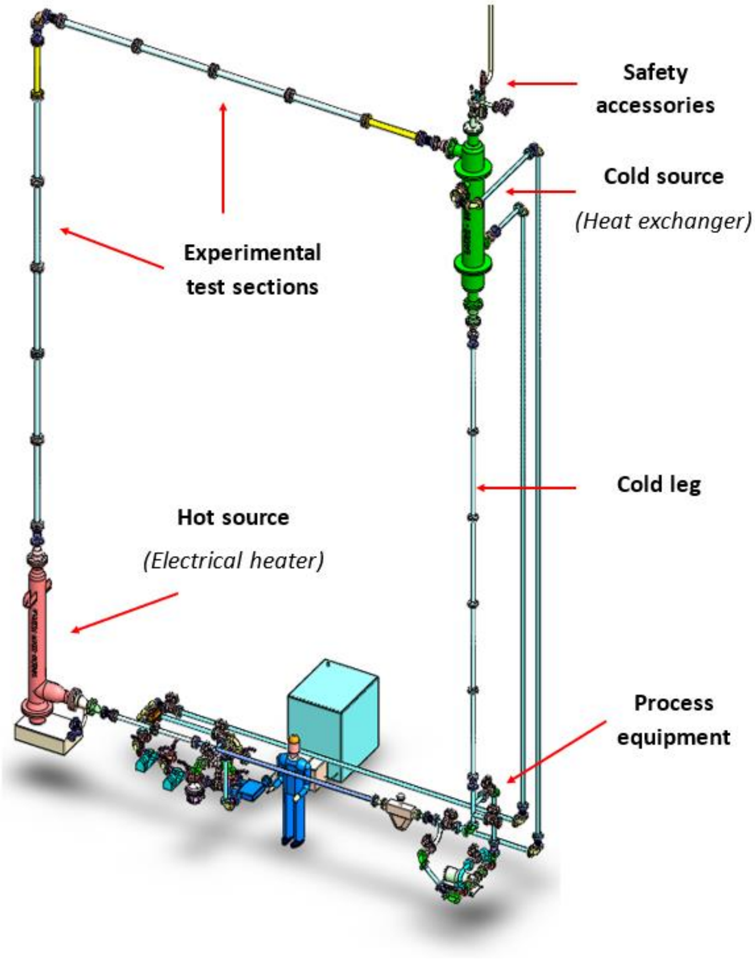

Figure 48: ALCINA reference geometry

7.8.2.2. Description of the test loop

The geometry details and parameter values will be described in the “Facility Description” technical deliverable. This section provides a general overview of the main components:

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- **Hot source:**

The hot source is positioned vertically at the bottom of the loop. The residual power is simulated by an electric heater, which is directly immersed in the fluid to maximise heat exchange and reduce heat losses. The power is generated by heating elements (rods) approximatively 1.2 m long, with a total thermal power of 300 kW. Liquid water from the cold leg circulates inside the heater, where it is vaporized to create a two-phase flow at the outlet. This equipment is controlled either by power or temperature regulation.

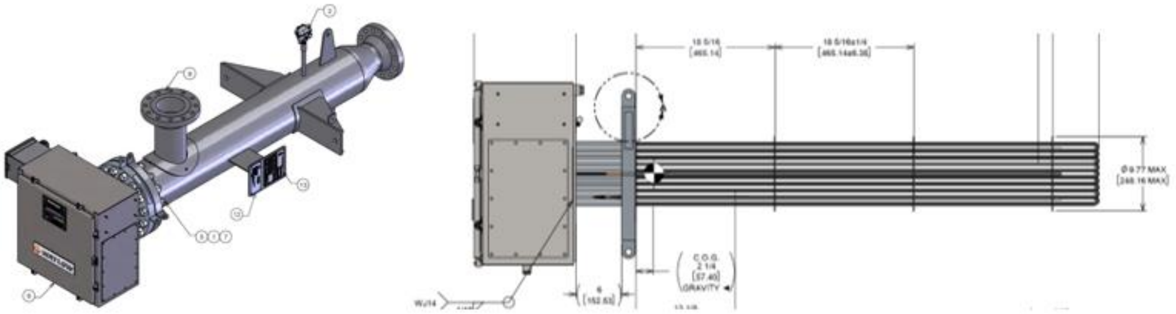

Figure 49: ALCINA electrical heater: pressure body (at left) and internal rods (at right)

- **Cold source:**

The cold source is positioned vertically at the top of the loop. The condenser comprises an inlet header, a set of straight vertical cylindrical tubes serving as a heat exchanger, and an outlet condensate header.

The fluid from the test section, in a two phase-flow state (liquid/steam), enters the upper part of the condenser through a lateral connection flange. It then flows downward into a tube bundle approximately 1.5 m long, which is cooled by a secondary circuit designed to extract the same thermal power (300 kW) as the heater. The condensed liquid is collected at the bottom and directed toward the cold leg.

The top of the condenser also includes an outlet flange used to connect:

- the emergency circuit, equipped with safety valve in case of overpressure inside the loop;
- the vent circuit, used to evacuate non-condensable gases (which can be either activated or deactivated).

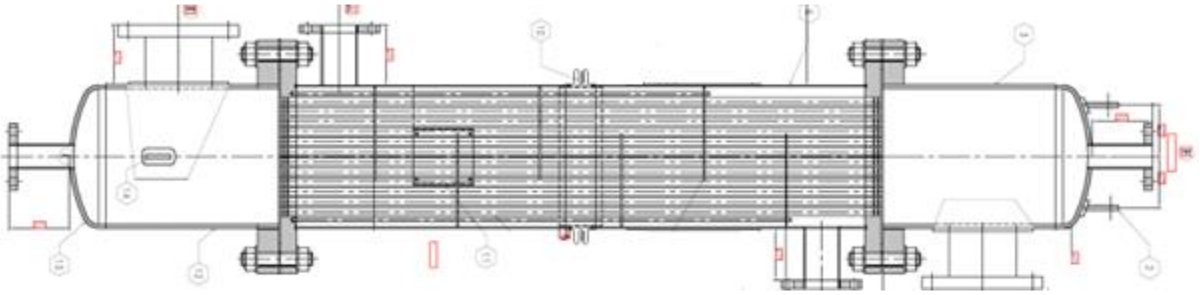

Figure 50: ALCINA condenser (bundle tube)

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- **Test sections:**

The test sections (vertical and horizontal) are made up of pipe sections approximately 1.4 m long and DN80 in stainless steel. Each section is flanged together seamlessly without gaps or changes to the internal diameter, to avoid any perturbation. An instrumented flange is integrated between each section to enable experimental measurements inside the fluid, such as thermocouples and pressure sensors. This component can be replaced by the Wire Mesh Sensor (WMS), at any location, without further modification, to create a cross-sectional map of void fraction.

At each end of the test section, the pipes are connected to the heater, the condenser, and the pipe bend (which links the vertical and horizontal test sections) by expansion bellows to compensate for thermal expansion.

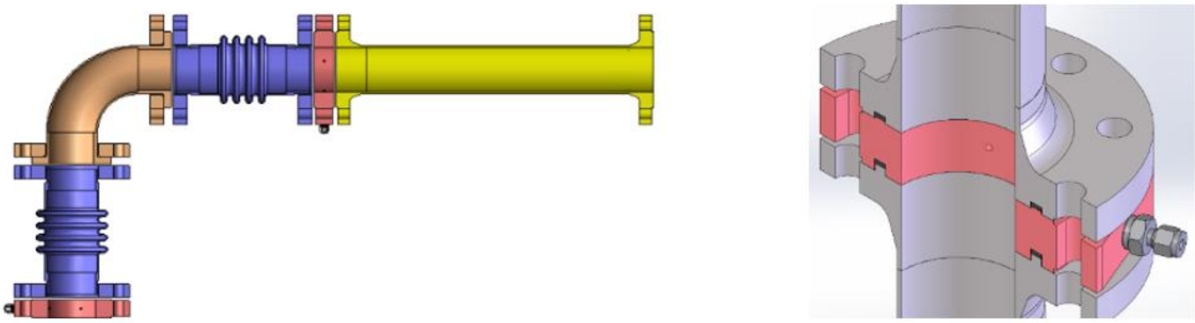

Figure 51: ALCINA instrumented test section

- **Cold leg:**

This circuit connects the condenser outlet with the heater inlet to close the loop. It is made up of process components to ensure the required thermal-hydraulic conditions. The main component is a DN50 diameter pipe, instrumented with a flowmeter and equipped with a regulated valve to adjust the pressure drops. Moreover, the cold leg is connected to various secondary circuits:

- A bypass line, incorporating a pump, used to carry out forced circulation tests;
- A pressure regulation system, based on water injection or extraction;
- A non-condensable gas line, which aims to inject nitrogen for specific tests;
- An expansion tank, which can be isolated by a valve.

All these circuits are equipped with instruments for measuring fluid characteristics (pressure, temperature, and flowrate).

7.8.2.3. Instrumentation and range of thermal-hydraulics parameters

In terms of instrumentation, thermal-hydraulic parameters (absolute pressure, differential pressures, temperatures and flow rates) will be measured locally at different positions along the loop in order to determine the pressure drops for different flow regimes, including single-phase and two-phase flows. Flow regimes will also be characterized within the test sections using WMS to map the void fraction across an entire pipe section to identify the flow regime. Flow rates inside the loop will be measured using a Coriolis mass flowmeter, providing good accuracy and measurements in both directions to detect flow oscillations due to instabilities. Fluid parameters in the secondary circuit of the heat exchanger will also be measured (using accurate sensors, such as PT100 for temperature) to assess the heat flux evacuated.

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The preliminary instrumentation plan is shown on the Figure 52.

Symbol	Measurements	Sensors
TE-F	Fluid temperature	PT100
TC-F	Fluid temperature	Thermocouple
TC-P	External pipe temperature	Thermocouple
TC-E	External insulation temperature	Thermocouple
TC-AMB	Room temperature	Thermocouple
DP	Differential pressure	Pressure sensor
PR	Relative pressure	Pressure sensor
OD	Oxygen dissolved	Oxygen probe
CD	Conductivity	Conductivity probe
WMS	Void fraction	Wire mesh sensor
DE	Flowmeter	Coriolis (mass flowmeter)

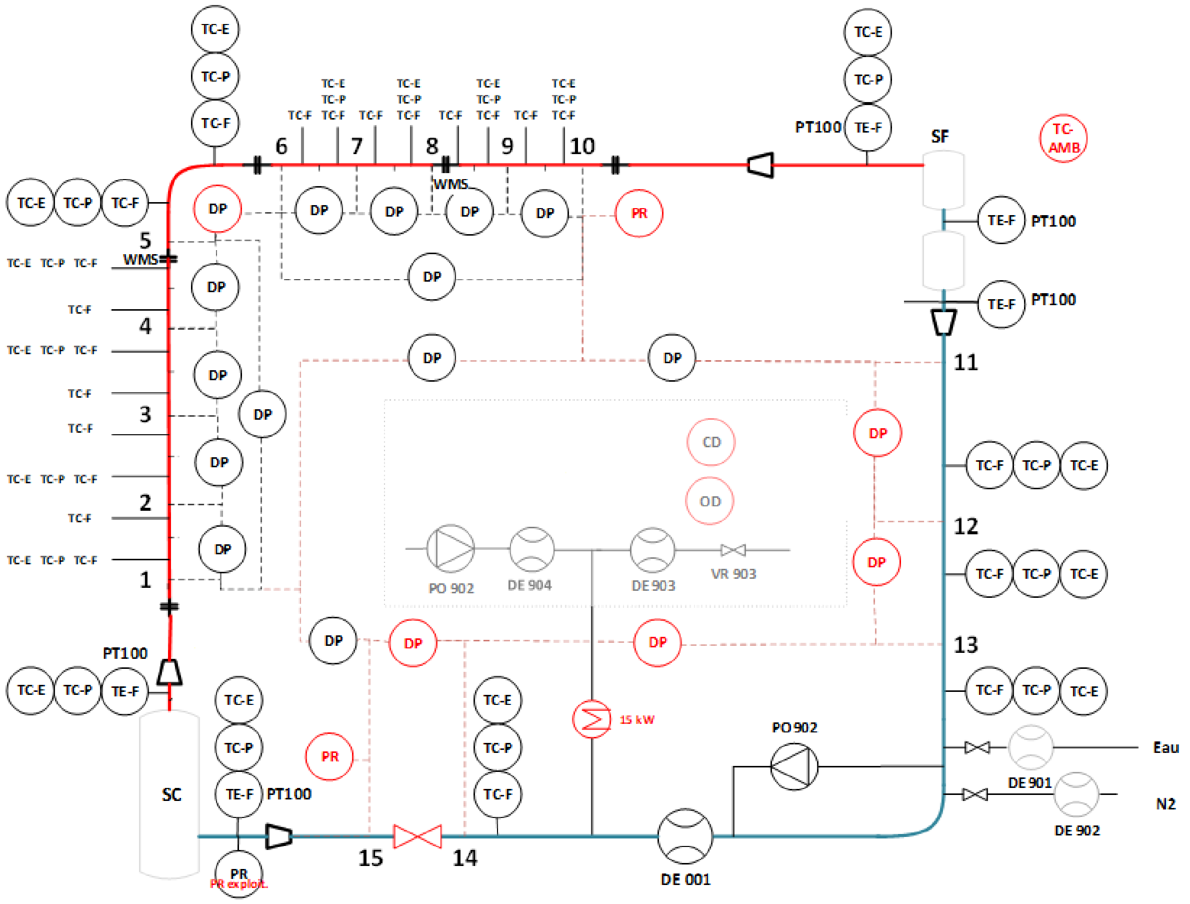

Figure 52: ALCINA loop preliminary instrumentation plan

The operating conditions of the loop could be adjusted to simulate different situations. The main thermal-hydraulic parameters are:

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- **Fluid conditions:**
    - forced or natural circulation;
    - single-phase or two-phase flow;
    - amount of non-condensable gas.
- **Thermal-hydraulic conditions:**
    - power exchange: up to 300 kW;
    - pressure: up to 20 bar;
    - temperature: up to 220°C;
    - filing ratio: up to 100%.

7.8.2.4. Matrix data tests prevision

The first test campaign will focus on steady state experiments with the primary goal of obtaining precise estimates of the flow characteristics along the loop for a specific set of control parameters (thermal-hydraulic conditions) and a predefined geometry ("**reference configuration**"). The key variables of interest are the flowrate and the pressure drops across the different sections of the loop. Additional data will be gathered to characterize the two-phase flow regime at various points in the system.

These tests will be performed without the introduction of non-condensable gas. Other thermal-hydraulic conditions will be defined within the range of interest, by variation the following parameters:

- Filing rate;
- Pressure drop;
- Pressure;
- Power.

The results from these tests will be used to establish the benchmark for WP3.

The second test campaign will focus on investigating the effect of one of the geometric parameters. These tests will be conducted under the same thermal-hydraulic conditions as the first campaign, but in a new geometric configuration, likely by modifying either the pipe diameter or the test section inclination. The findings from these tests will not be used as part of the benchmark for WP3.

7.8.2.5. ALCINA activity schedule

ALCINA is a new facility under construction, the main activities accomplished or planned for the next few years are:

- The final design study of the facility was completed in 2024;
- All components are currently in production, with some already supplied, and the remaining ones will be delivered in the second half of 2025;
- Facility assembly will begin at the end of 2025 and continue until mid-2026;
- Commissioning tests will be performed in the second half of 2026;
- The experimental tests campaign will be take place in first months of 2027.

All previous information and important documents delivery from WP2 ALCINA tests are summarized in the following graphical representation.

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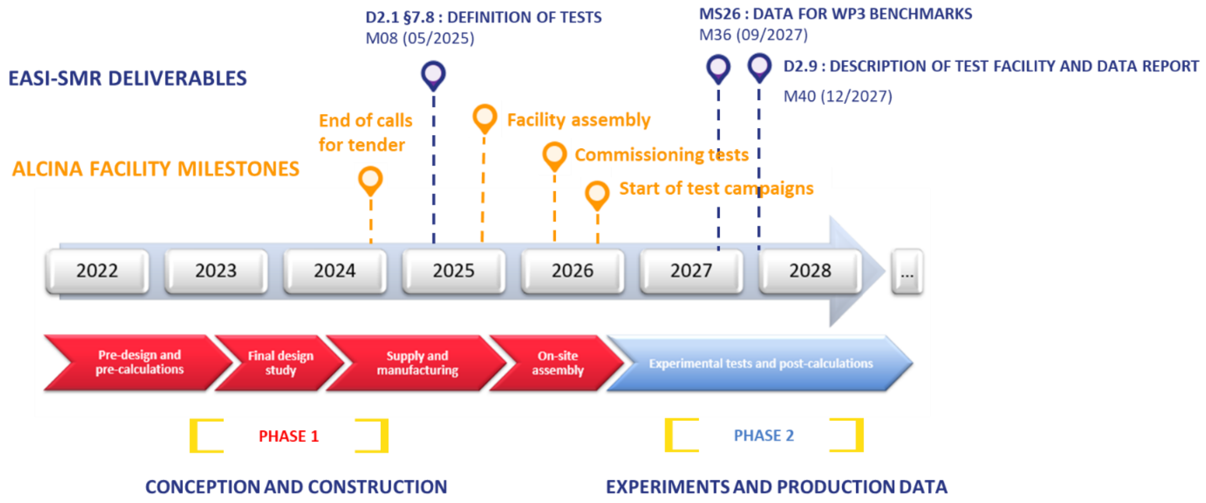

Figure 53: Overall schedule of ALCINA experimental tests program

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7.9. ECRINS

7.9.1.Background to the ECRINS experimental facility

Efficient heat removal components have an important place in the design of new nuclear reactor concepts. In particular, heat exchangers with a minichannel geometry are very interesting when spatial clutter is an issue: they can take the form of compact components while enabling a fair amount of heat removing.

In water-cooled reactor concepts, such heat exchangers have to remove the heat from the primary circuit in two different situations:

- In normal conditions with the primary side of the heat exchangers being only liquid;
- In accidental conditions where the primary side of the heat exchangers could be a mix between liquid, vapor and some noncondensable gases.

In the latter situation, the capacity of the heat exchangers to remove the heat via condensation of the vapor is key to ensure the reactor’s safety. Thus, a more fundamental understanding of condensation-related phenomena in minichannel geometries is mandatory to be able to predict accurately the behavior of such components in accidental situations.

Although minichannel geometries are widely studied and used in several industrial fields, data on water condensation is lacking because other refrigerants such as R134a or R410A are preferred.

To fill the gap concerning water condensation, the Thermal-hydraulics and Fluid Mechanics section at CEA is currently developing a novel experimental apparatus to study the characteristics of condensation heat transfer in minichannels. The installation is named ECRINS, standing for, in French, "Expériences de Condensation en Réacteur Intégré pour les échangeurs Normaux et de Sûreté".

7.9.2. Definition of the SET ECRINS

7.9.2.1. General description of the facility

ECRINS is a separate effect test facility focusing on vapor condensation in a minichannel geometry, with or without noncondensable gas.

The test section is a single 1-meter high vertical minichannel with a fluid cross-section of dimension 2mm x 10mm. The fluid enters at the top (slightly overheated vapor and noncondensable gas in controlled proportions and controlled flowrates). The test section is surrounded with a cooling jacket containing thermal oil. The installation is designed to work in forced or natural convection conditions.

The main objectives are:

- The analysis of pure vapor heat transfer coefficients for different pressures, flowrates and coolant temperatures;
- The analysis of the noncondensable gas influence on the heat transfer coefficients (noncondensable gas plugging, dissolution, etc.).

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7.9.2.2. *Description of the test loop*

The ECRINS project is currently in the detailed design study phase and some slight changes may occur. A schematics of the experimental installation is presented in Fig. 1.

Forced convection

In the forced convection loop, the vapor is produced in an evaporator vessel (with controlled pressure and temperature). The vapor flows through an upper horizontal heated vapor line towards the test section (named as "condenser"). The vapor enters the condenser where vapor to liquid phase change will occur thanks to a cooling jacket surrounding the condenser. At the condenser's exit, the liquid line is divided into two streams:

- A small liquid sample goes towards a spectrometer that will evaluate the dissolved gases in the liquid phase;
- The majority of liquid goes through a postcondenser that ensures a complete condensation in the case of partial condensation in the upper condenser.

The liquid exits the post-condenser towards a liquid recipient in the lower part, which has its pressure and temperature controlled, similarly to the upper vessel. A pump is used to provide liquid flow from the lower vessel back to the upper evaporator, closing the loop in forced convection mode. In this working mode, the lower vessel cools down the incoming liquid before sending it to the pump to avoid cavitation.

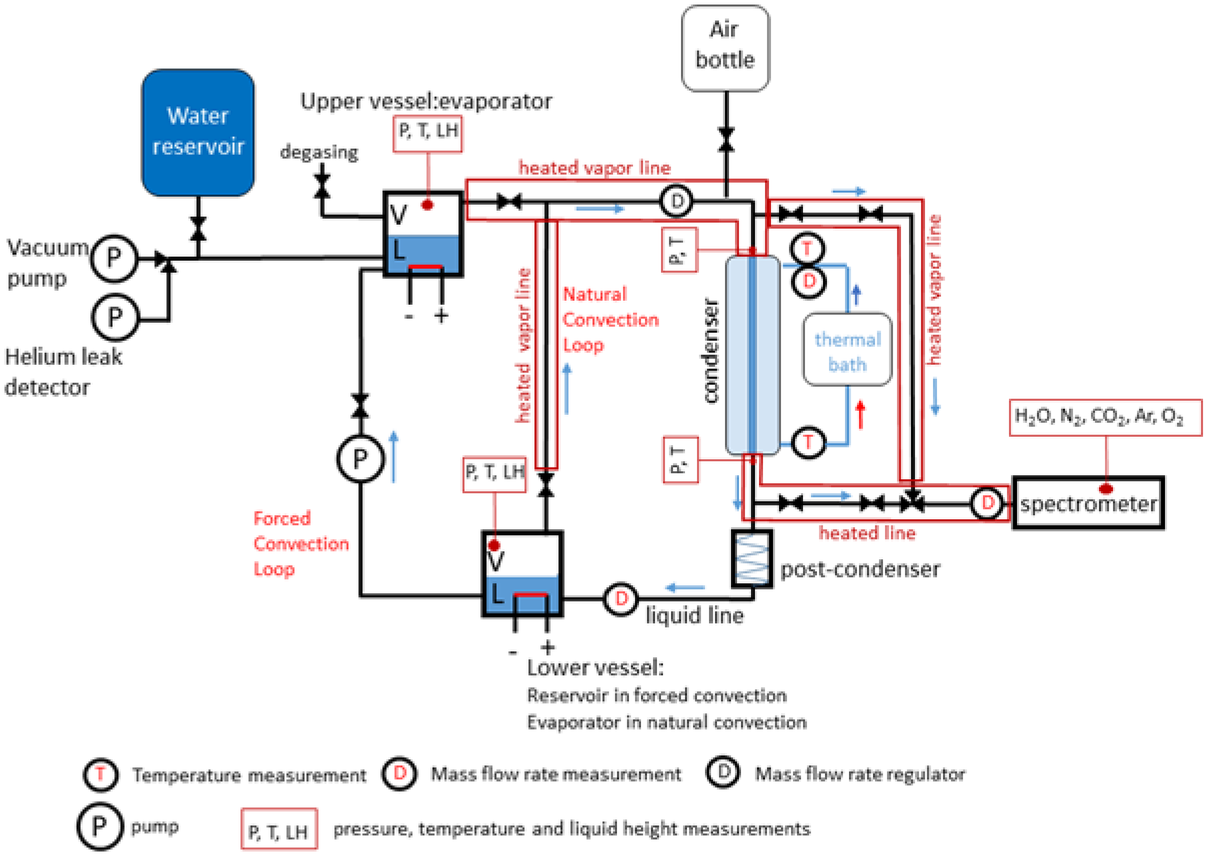

Figure 54: Schematics of the experimental setup.

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The forced convection is meant to allow a more controlled experiment in terms of variables that can be set by the operator. The pressure drop in the circuit in forced convection is imposed
by the temperatures in the upper evaporator and in the lower cooling. The mass flow rate can be regulated by a valve in the horizontal vapor line. Therefore, pressure and mass flow rate in the condenser are both controlled.

Thanks to a vacuum pump and a degassing procedure, experiments can be first conducted with a negligible amount of noncondensable gases inside the loop. A bottle of synthetic air is connected to the horizontal vapor line to inject a controlled amount of incondensables at the entrance of the test section. The impact of these gases on the condensation heat transfer phenomena can then be determined. In particular, the novelty of this installation is that one can evaluate the effect of dissolved gases in the liquid phase thanks to the mass spectrometer analysis, located at the exit of the test section.

Natural convection
In the natural convection loop, the upper evaporator is by-passed by connecting a vertical vapor line between the lower vessel and the upper horizontal vapor line. The lower vessel works now as an evaporator producing the vapor that flows-up through the vertical vapor line, reaching the upper vapor line and then the condenser. In natural convection, the system works similarly as a pressurized thermosyphon. In this configuration, the post-condenser is turned-off.
Contrary to the forced convection loop, in natural convection, the system's pressure is auto-regulated depending on the input power in the lower evaporator and the heat removal capacity in the condenser. The vapor flow rate is not regulated in this case. The mass flow rate regulator in the upper horizontal vapor line is then fully opened.

7.9.2.3. Instrumentation and range of thermal hydraulics parameters

The following table sums up the range of the main thermal hydraulics parameters:

Table 19– ECRINS: Range of the main thermal hydraulics parameters

Test section's pressure (bar)	Inlet temperature (°C)	Inlet flowrate (g/s)	Temperature difference between the test section and the refrigerant (°C)	Inlet noncondensable gas mass fraction
1 - 15	Tsat (100 – 200)	0,01 – 0,5	25 - 50	0 – 0,05

There is an uncertainty on the noncondensable gas mass fraction range because their influence on the condensation efficiency is not known yet. A significant degradation of the condensation could occur at very small noncondensable gas mass fractions so a quite small range is expected. A very fine control of the mass fraction is necessary.

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Instrumentation

The required parameters to be measured at the inlet, outlet and along the condenser are shown here in table 2 along with the proposed instrumentation.

At the inlet and outlet of the condenser, pressure sensors and thermocouples or resistance thermal detectors (RTD) will be used to measure pressure and temperature, respectively. A Coriolis mass flow rate measures the inlet flow rate in the test section. The mass spectrometer will measure the amount of dissolved gases in the liquid phase.

Along the condenser, transparent optical windows will be installed to allow visualization of the condensation flow pattern inside the minichannel. Along the test section, pressure sensors and thermocouples/RTD's will measure pressure drop and temperature profiles, respectively. The liquid film thickness will be measured by white light interferometry and or confocal sensor. This instrumentation will allow local evaluation of the heat transfer performance. Additionally, the cooling jacket that surrounds the condenser will allow the measurement of the coolant oil flow rate and its inlet and outlet temperature for a global energy balance.

Table 20: Required and proposed instrumentation.

Position	required measurement	proposed technique
Inlet and outlet of the condenser	pressure	pressure sensor
	mass flow rate	Coriolis mass flow rate
	temperature	resistance thermal detector (RTD) or thermocouple
	non-condensables	mass spectroscopy
along the condenser	pressure	pressure sensor
	internal wall temperature	RTD, thermocouple, optical fiber or IR thermography
	external wall temperature	RTD or thermocouple
	liquid film thickness	interferometry and/or confocal sensor
	flow pattern	shadowgraphy

7.9.2.4. *Matrix data tests prevision*

Tests matrix

General chronology principles:

- For a given pressure, a given secondary temperature and a given condenser inlet flowrate: increase little by little the inlet non-condensable mass fraction.
- Prioritize the tests with no liquid at the inlet (gaseous phase only) to focus on the liquid film formation on a dry wall.
- Prioritize the high-pressure tests to facilitate the study of dissolution phenomena.
- For a given pressure, prioritize the conditions leading to high heat transfers (high flowrate, low refrigerant temperature) to focus on the influence of the non-condensable gas on the heat transfer coefficient.

The following table gives an idea of a tests matrix (still to be adapted accordingly to possible design evolutions):

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Test section's pressure (bar)	Temperature difference between the test section and the refrigerant (°C)	Inlet mass flowrate (g/s)	Non-condensable mass fraction	Inlet void fraction
15	50	0.5	[0 – 0.05], increasing step- by-step	1
		0.4		
		0.3		
		0.2		
		0.1		
		0.05		
		0.01		
	25	0.5		
		0.4		
		0.3		
		0.2		
		0.1		
		0.05		
		0.01		
7	50	0.5	[0 – 0.05], increasing step- by-step	1
		0.4		
		0.3		
		0.2		
		0.1		
		0.05		
		0.01		
	25	0.5		
		0.4		
		0.3		
		0.2		
		0.1		
		0.05		
		0.01		
1	50	0.5	[0 – 0.05], increasing step- by-step	1
		0.4		
		0.3		
		0.2		
		0.1		
		0.05		
		0.01		
	25	0.5		
		0.4		
		0.3		
		0.2		
		0.1		
		0.05		
		0.01		

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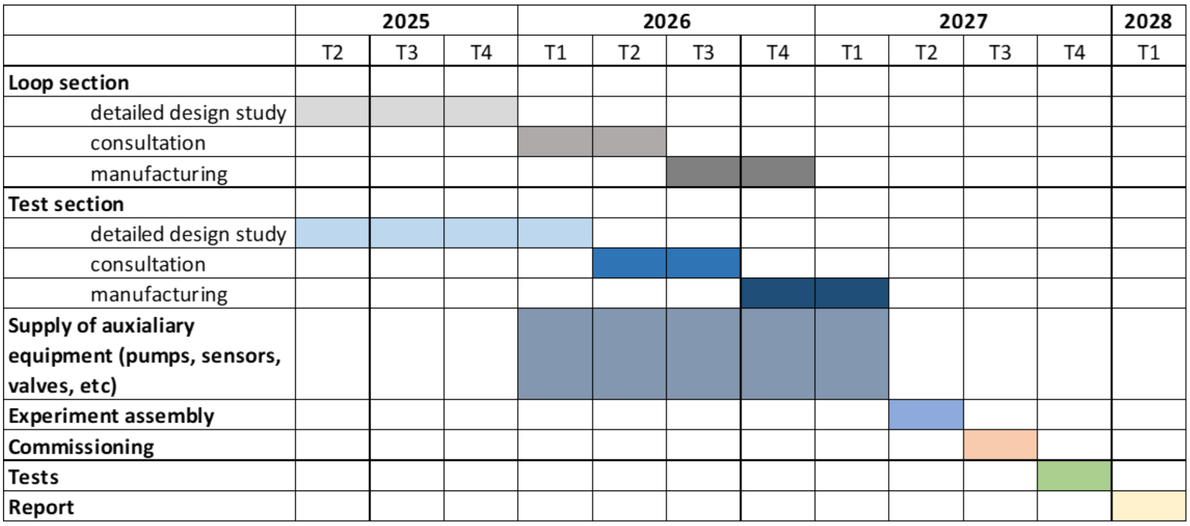
Table 21: ECRINS: Draft version of a tests matrix

7.9.2.5. *ECRINS activity schedule*

Global planning

The global planning is presented in table 3. It is divided in two parallel work lines: the development of the loop and the test sections. The project is currently in the detailed design study. The planning takes into account the major delays expected throughout the project. The commissioning is expected to occur in the third semester of 2027.

Table 22: Planning of the project by trimesters



	2025			2026				2027				2028
	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1
Loop section												
detailed design study	▨	▨	▨									
consultation				▨	▨							
manufacturing						▨	▨					
Test section												
detailed design study	▨	▨	▨	▨								
consultation					▨	▨						
manufacturing							▨	▨				
Supply of auxialiary equipment (pumps, sensors, valves, etc)				▨	▨	▨	▨	▨				
Experiment assembly									▨			
Commissioning										▨		
Tests											▨	
Report												▨

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8. Conclusion

This document corresponds to the first deliverable of WP2 Experimental tests, which summarizes the definition studies for the various experimental tests to be carried out during the EASI SMR project. It is the result of several technical meetings, as well as meetings with the people in charge of WP3 code benchmarks, who will reproduce most of the experimental tests carried out in this WP2. Following this document, several internal memos will be issued to the people involved in the benchmarks, including the facility description, to describe in greater detail each experimental installation, tests configuration, test matrices and final instrumentation. At the same time, documents from WP3 will also be issued to prepare for the benchmarks' implementation. Finally, a final deliverable will be produced for each experimental test, covering all experimental campaigns and results obtained.

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