KEY MILESTONES OF *NEW*CLEO'S TH EXPERIMENTAL PROGRAMME: OTHELLO, CIRCE-NEXTRA and PRECURSOR Projects

IAEA Technical Meeting on Advances and Innovations in Fast Reactor Design and Technology

29 September – 3 October 2025

Track 6: Experimental facilities and databases

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Outline

*new*cleo's vision and roadmap

A new, innovative player in nuclear energy

REACTOR DESIGN:

Small Modular (SMR) + Lead-cooled Fast Reactors (LFR) = AMR

*new*cleo is working to design, build, and operate Gen-IV Advanced Modular Reactors (AMRs) cooled by liquid lead

FUEL MANUFACTURING:

Mixed Uranium Plutonium Oxide (MOX)

MOX and Fast Reactors allow the multi-recycling of nuclear waste into new fuel with no new mining for generations

INTRINSICALLY SAFE power production

COMPETITIVE energy cost

CIRCULAR nuclear waste recycling

€570 million of private funds
~€70 million revenues in 2024

French first **licensing stage completed** for the reactor in **Chinon** and the fuel production facility in **Nogent**

Selected by **France 2030** and the **European Industrial Alliance on SMRs**

1,100+ EMPLOYEES GLOBALLY	**30+** YEARS of leadership in Lead Technology	**24** PATENTS

Highly specialised EPCM capabilities

FUCINA ITALIA – A *newcleo* company
S.R.S. – A *newcleo* company
RÜTSCHI – A *newcleo* company

newcleo
Futurable Energy

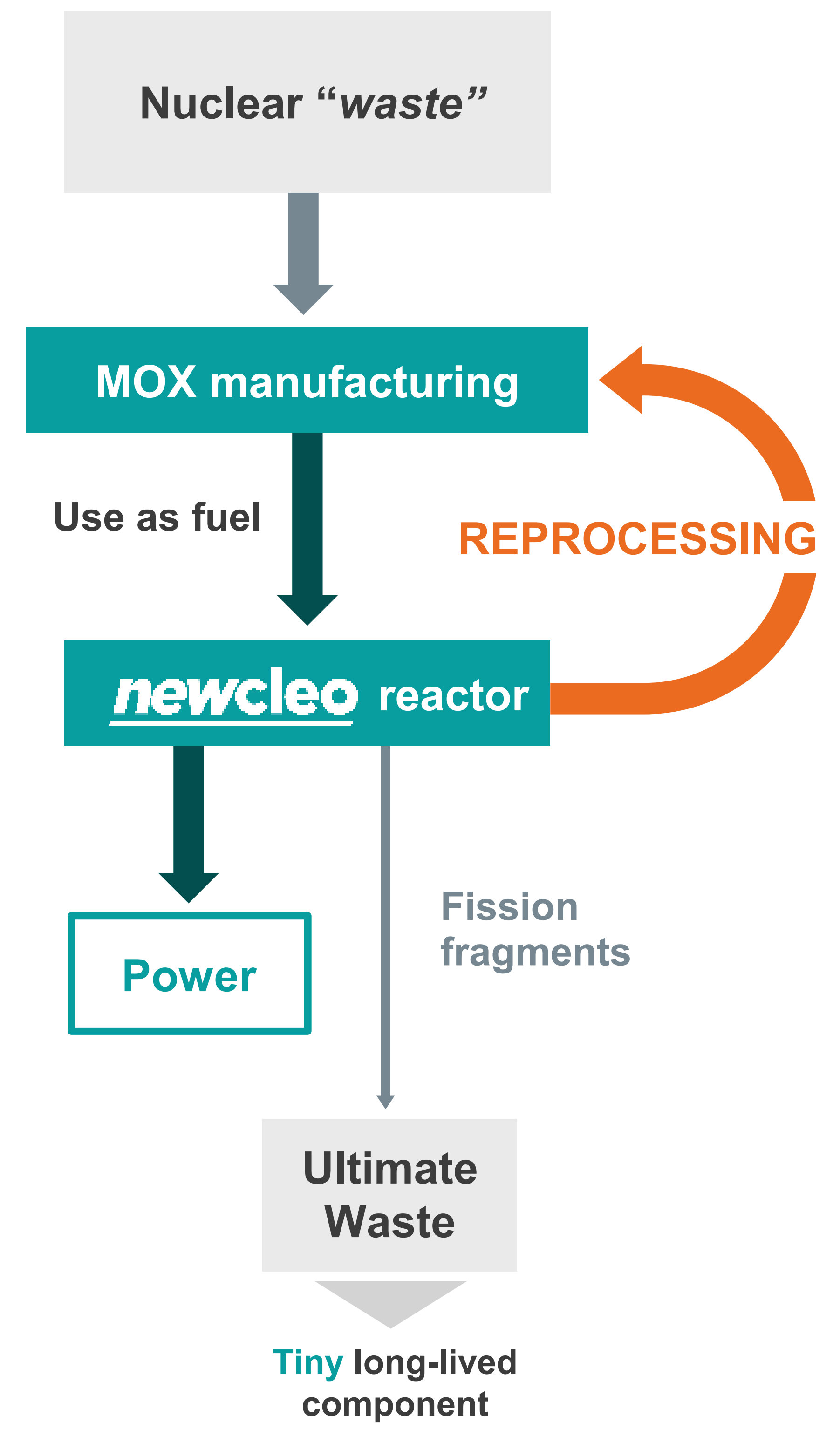
*new*cleo's long-term vision centred on safety, costs and sustainability

Reactor technology:
AMR: SMR + Gen-IV LFR

LEAD-COOLED		
High temperature	Compact and simple	Intrinsic safety

FAST NEUTRON SPECTRUM	
Low production of nuclear waste	Able to recycle reprocessed spent fuel

SMALL MODULAR REACTOR		
Faster construction	Site flexibility and industrial heat production	Further economies from series and modularisation



Fuel: MOX

- MOX is made of reprocessed spent fuel. A clean solution to the issue of costly and **long-lasting nuclear waste disposal,** but also a protection against future high, oscillating Uranium costs and availability
- The **long-term strategy** will eliminate the need to mine new uranium, enable **energy independence**, and reduce the volume headed to geological repository
- Spent fuel will be **reprocessed** multiple times. The unavoidable waste is less than **1t of fission fragments** (radioactive for 250y) from one year's generation by a 1GWe of *new*cleo LFRs vs. **200t** of nuclear waste from conventional reactors (radioactive for 250,000y)

Significant advantages of Lead-cooled Fast Reactors

Lead properties enable design simplification (hence **economic benefits**) and a high degree of inherent safety:

- Operating at atmospheric pressure, hence **thick forging not needed** as in traditional Pressurised Water Reactors (PWRs)
- No significant energy release in case of vessel failure, hence **high pressure-resistant containment not needed**
- Favourable chemical properties, hence **extra safety provisions can be avoided, no intermediate loop, possible use of low-cost water or air loops for Decay Heat Removal (DHR)**
- Coolant boiling practically eliminated, hence **safety injection systems not needed**
- Significant thermal inertia in case of a loss of cooling accident
- Lead fission product retention capability, gamma radiation shielding
- **High plant energy conversion efficiency (40-50%)**
- **High operating temperature enables non-electrical uses**

Unique properties for fast reactors design

Absorption cross-section	Boiling Point	Heat transfer properties	Density @400°C
Low	1737 °C	Good	10580 kg/m3
Large fuel pin lattice, low core pressure losses	No loss of core cooling	Reduced risk of fuel cladding overheating	No risk of core compaction

Critical properties that discouraged some designers were solved by *new*cleo

Density @400°C	Melting Point	Opacity	Compatibility with structural materials
10580 kg/m^3	327 °C	Yes	Corrosive at high temperature
Seismic response	Risk of freezing	Difficult operations inside	Need of new materials

80 effective reactor-years of Lead Bismuth Eutectic reactors

- Russia has operated 15 reactors across land-based facilities and submarines since the 1950s
- Russia also began construction of a new LFR in Jun-2021

A well-defined roadmap to achieve tangible development goals

2026 | 2030 | 2031 | 2033

REACTOR PROGRAMME

Qualification and R&D facility: Brasimone precursor

LFR-30 Programme: LFR-AS-30 design, licensing, and construction

Technology development

2026	2030	2031	2033
	MOX	AS-30	AS-200
R&D and Precursor	**MOX production**	**LFR-AS-30**	**LFR-AS-200**
Several R&D facilities, and a **10 MW** non-nuclear facility with turbo-generator	**FR-MOX production facility**, starting from available (separated) material in France	**30 MWe** nuclear irradiation reactor with core outlet at 430/440°	**200 MWe FOAK**, also for non-electrical uses (e.g. cogeneration and chemicals production)
Design, manufacturing and operation in progress	**Basic Design and pre-licensing in progress:** technical meetings with ASN and IRSN started in mid-2023		**Conceptual design in progress**

◇ Commercial operations date (COD)

LFR-AS design

*new*cleo LFR-AS (Amphora-Shaped) design

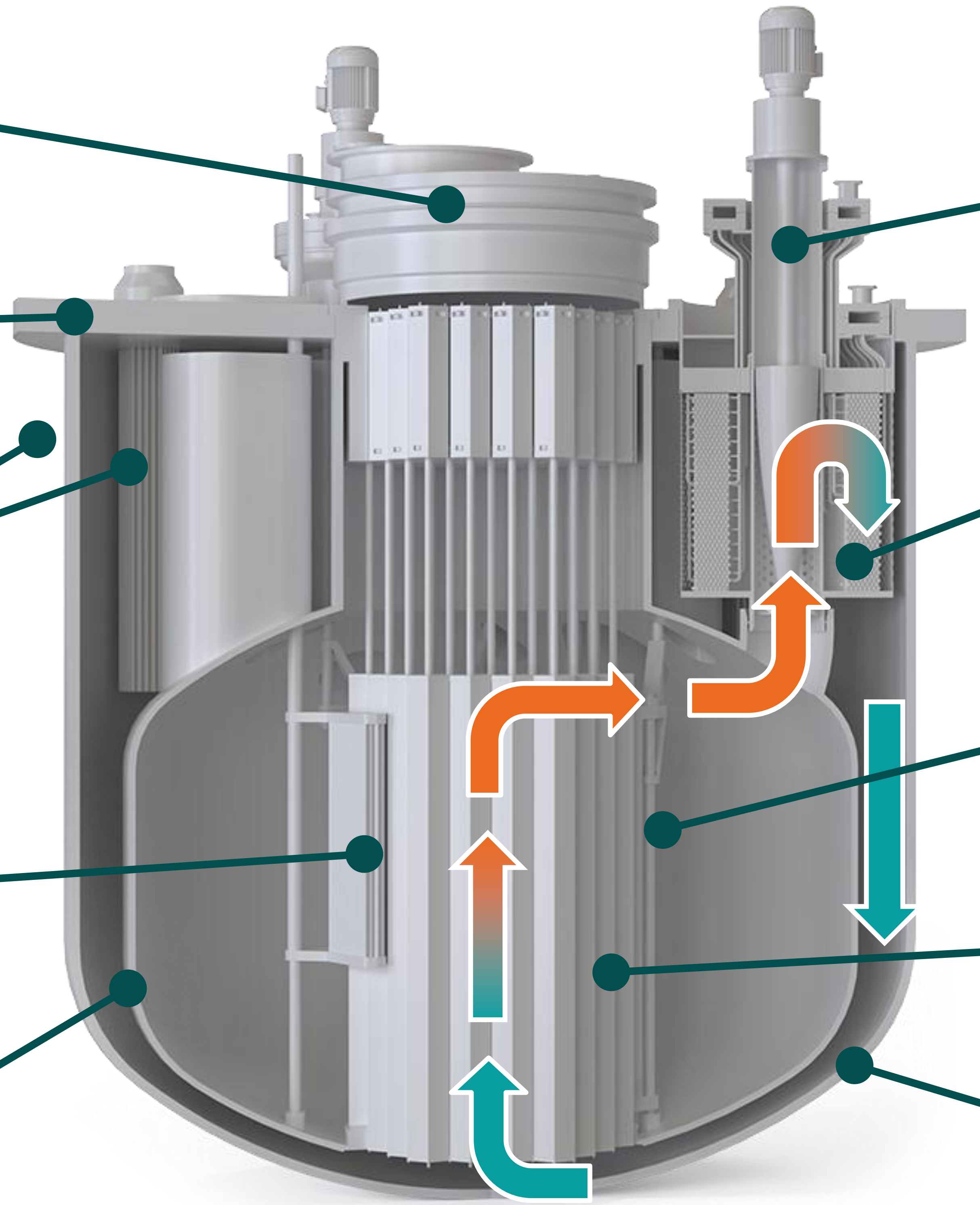
ROTATING PLUGS
Rotating arrangement used to provide access to the fuel assemblies to enable their removal and replacement

REACTOR ROOF
Support structure for the components situated above the reactor

DECAY HEAT REMOVAL
(in- and ex- vessel)
Provide an additional source of cooling for the reactor when it is shut down and the steam generators are not operational. Also provide emergency cooling for the reactor during accident conditions

CONTROL ROD
Moveable neutron absorbers that can be raised or lowered to increase or reduce the number of neutrons and hence control criticality

AMPHORA-SHAPED INNER VESSEL
Support structure designed to direct hot lead from the core into the steam generators and colder lead from the steam generators back to the inlet of the core



PRIMARY PUMPS
Used to circulate the lead coolant around the reactor. These sit inside the steam generators

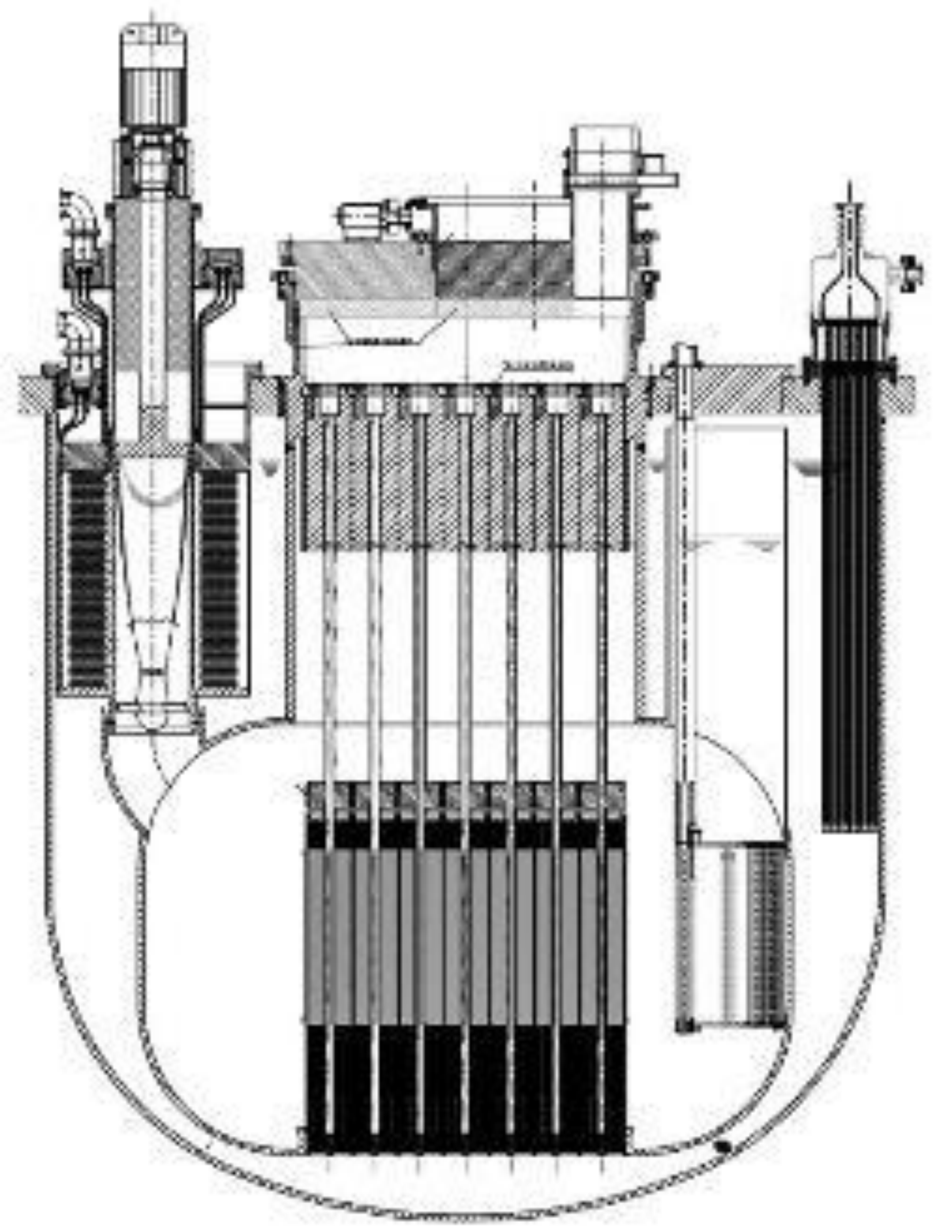
STEAM GENERATORS
Arrangement of several **spiral-shaped tubes** containing water. These take the heat from the lead and use it to boil the water, with the steam sent to the turbine to produce electricity

SHUTDOWN DEVICE
Additional neutron absorbers used to shutdown the reaction and prevent unintended restarts

CORE
MOX fuel pellets contained in multiple fuel assemblies, with openings to allow liquid lead to enter and the bottom and flow up through the top to remove heat. New spacer rings design (patented)

REACTOR VESSEL
Retains the lead coolant with the reactor

LFR-AS-30: 30MWe



- *new*cleo's irradiation machine used for materials R&D and other uses, offering unique irradiation services based on a hard and intense neutron spectrum
- The plant will have a single AS-30 unit and include hot cells and laboratories
- The reactor is designed to be **representative of the LFR-AS-200**, and will also be used to validate new components and solutions for our commercial reactors, to increase their operating temperatures and to expand production efficiency and performances
- Reactor conceptual design completed in March 2023, basic design in progress
- **First phase of technical meeting with ASN and IRSN completed in June 2024**

	1st phase Low temp. and power	2nd phase High temp. and full power
Power	**60MWth**	**90MWth**
Core coolant temperature	**inlet 370°C, outlet 440°C**	**inlet 420°C, outlet 530°C**
Steam at turbine inlet	**400°C, 150 bar**	**500°C, 150 bar**
Core coolant	**Pure lead**	
Layout	**Pool-type**	
Circulation	**Forced: 3 pumps**	
Spectrum	**Fast**	
Fuel form	**Extended-stem fuel assembly**	
Fuel	**MOX**	
Secondary side fluid	**Water**	
Steam generators	**3 spiral-tube SG**	
Design life	**60 years**	

Thermal-Hydraulics R&D needs and infrastructure

R&D is at the core of *new*cleo's DNA

In parallel to engineering activities, *new*cleo's R&D programme is progressing fast: findings are key in the completion of the reactors' design and licensing processes.

UNDERSTANDING

CHARACTERISATION

QUALIFICATION

VALIDATION (SETFs & ITFs)

ASSESSMENT

OPERATION AND SAFETY

DEMONSTRATION

- Structural materials and coatings
- Fuel and fuel integrity
- Primary coolant behaviour and chemistry
- Core integrity
- Primary system integrity
- Instrumentation and Control (I&C)
- Reactor physics / neutronics
- Components handling systems
- In-Service Inspection and Repair (ISI&R)
- Balance Of Plant (BOP)
- Plant operation and accident response

SIMULATION AND EXPERIMENTAL CAMPAIGNS

Close **partnership with ENEA**

Collaborations with labs and universities

Ongoing conversations with specialised companies

Large investments: **EUR90+ millions allocated**

*new*cleo: the world's largest R&D network for lead-cooling technology development

CORE
200 kW
CORE-1 operational in Apr 2024
CORE-2 installation in progress

Loop-type test facility for corrosion and erosion testing of structural materials in flowing lead

CHEMISTRY LAB
MATERIAL LAB

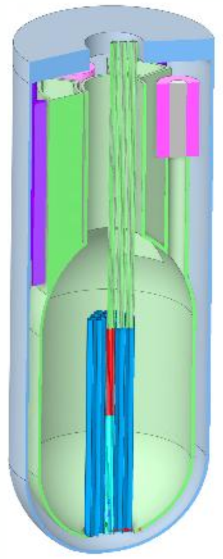
Chemical laboratory to evaluate mechanical properties in lead i.e., creep, long-term creep, slow strain rate tests, creep fatigue

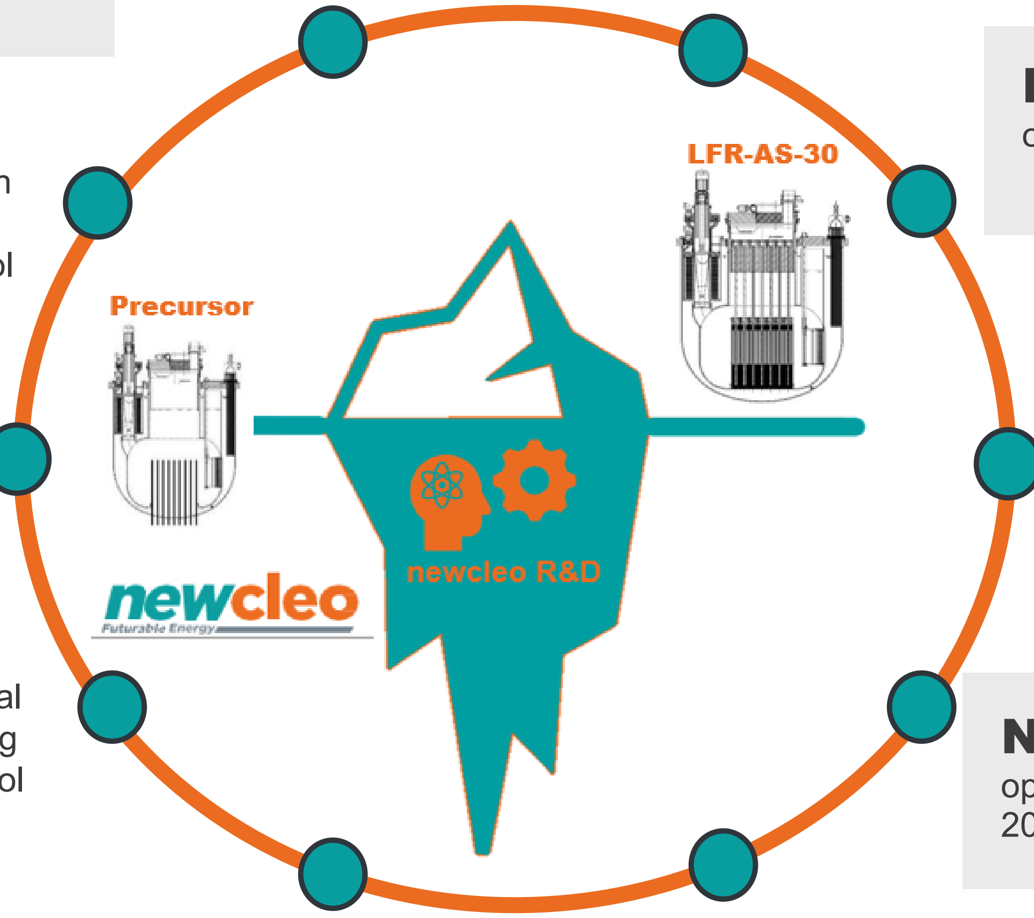
CAPSULE
operational Dec 2023

Several tanks filled with Lead and Argon with immersed specimens for corrosion tests in stagnant lead. Advanced temperature and oxygen control

HUSTLE
operational May 2025

Hot Ultra Sonic Testing Lead Experiment, two phases – one in hot air and the second in liquid lead



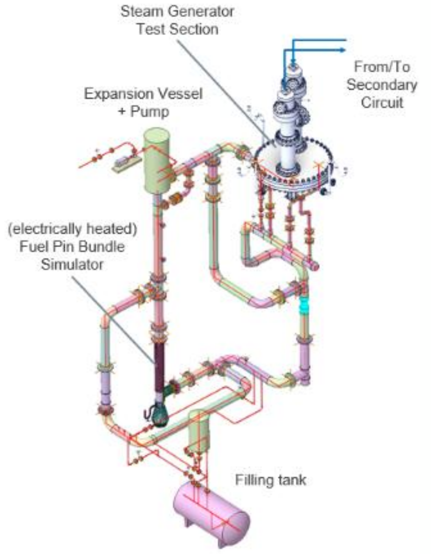


PRECURSOR
10 MW
operational in 2026

New pool-type large-scale test facility representative of the LFR-AS design for broad-scope investigations on LFR system transient behaviour, component testing/qualification, etc.

OTHELLO
2 MW
commissioning in 2026

Multipurpose thermal-hydraulics loop test facility for post-test analysis of components and thermal-hydraulic code validation



MANUT
dry and in-lead

Infrastructure to validate mechanical aspects of fuel assemblies including fuel/component handling and control rods. Two facilities: one in air and one in lead

NACIE-LHT
operational Jun 2024

*new*cleo's upgrade at existing ENEA NACIE loop facility. Aims to provide lead-side transverse heat transfer coefficient data

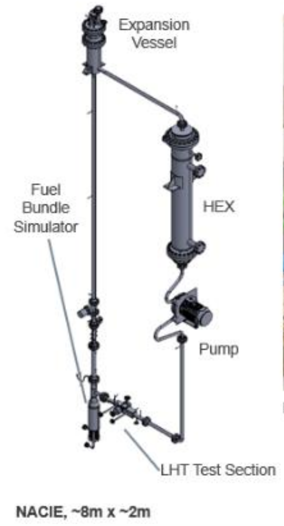
CIRCE-NEXTRA
Phase I – Pumps
Phase II - SGTR

To sit within existing CIRCE pool-type facility. Phase I: Primary pumps to study hydraulic performances, vibration dynamics, long-term endurance and mechanical loads

Phase II: Steam Generator Tube Rupture (SGTR) scenarios in LFR design

SOLEAD
operational 2023

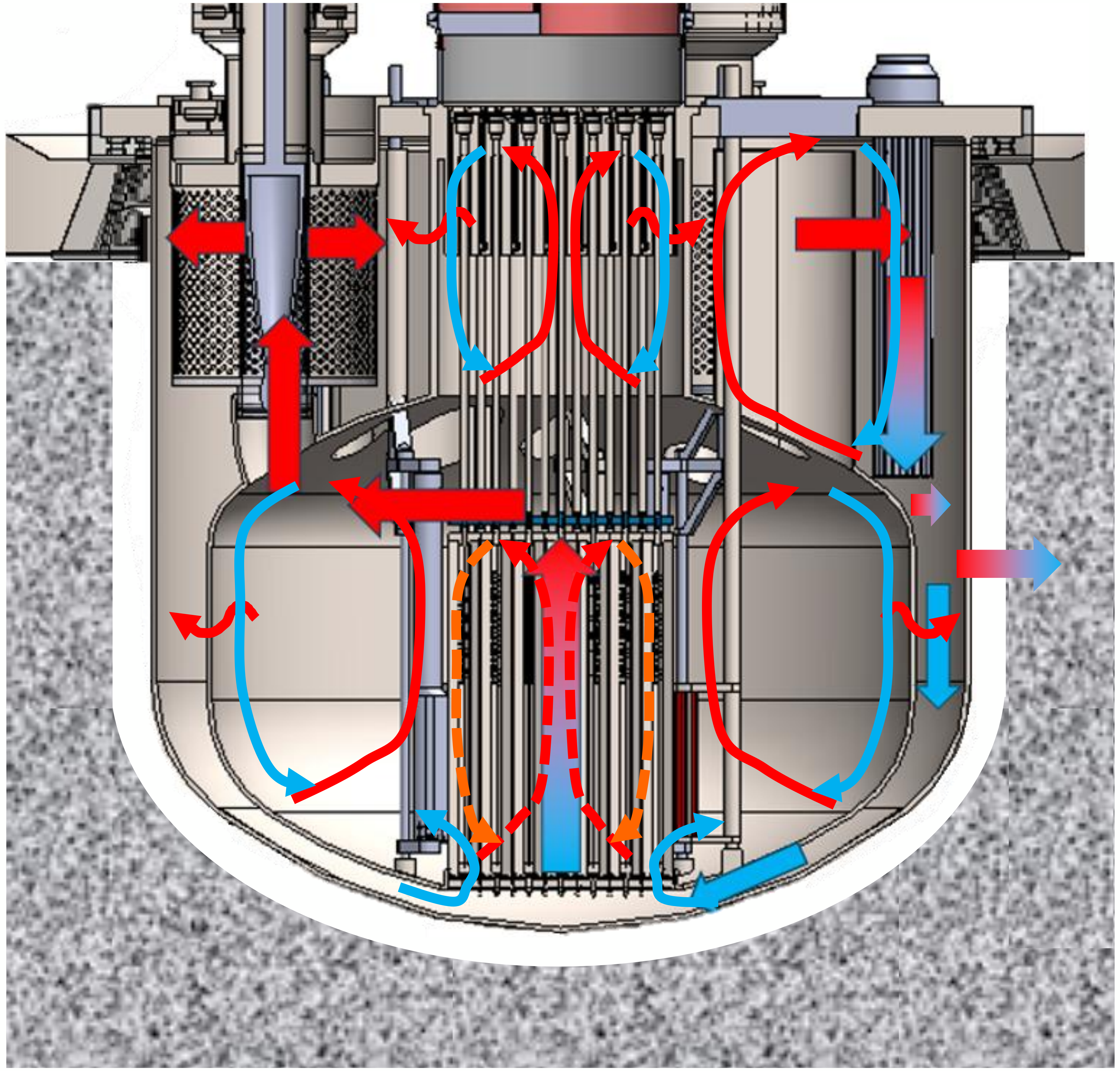
Lead coolant chemistry facility



LHT test section

LFR-AS principal thermal-hydraulic phenomena

- Main thermal-hydraulic phenomena identified through dedicated **PIRT panels** on selected relevant scenarios
- **Primary system**
  - Core flow and heat transfer (including bypass and inter-wrapper flow) under forced and natural circulation
  - Spiral-tubes Steam Generators flow and heat transfer
  - DHR bayonet-tube Dip-Coolers axial and cross flow
  - 3D pool behaviour
- **Secondary systems**
  - Spiral-tubes Steam Generators flow and heat transfer
  - DHR bayonet tubes behaviour
  - Thermal cycle with turbogenerator



Separate effect test facilities

(illustrative, non exhaustive list)

Component / Region	Facility/Test Section	Objectives / phenomena covered
Fuel assemblies	OTHELLO (fuel pin bundle simulator test section)	• Flow and heat transfer in FAs • Flow induced vibrations
Primary Coolant System	CIRCE-NEXTRA (Phase 2 – Steam generator tube rupture)	• Pressure-wave propagation • Multiple tube rupture propagation • Sloshing induced by SGTR
	EFESTO	• Sloshing and seismic dynamic loads
	HELENA	• Lead freezing phenomena
Primary pumps	CIRCE-NEXTRA (Phase 1)	• Primary pump behavior
	HELENA	
Steam Generators	OTHELLO (spiral tube steam generator test section)	• Primary and secondary side heat transfer • Secondary side flow distribution and stability • Flow induced vibrations
	NACIE-LHT	• Primary side heat transfer
Decay Heat Removal System	DCI	• Flow distribution among tubes and two-phase flow instability (secondary side)
	D-HEART 1	• DHR secondary side heat transfer

OTHELLO

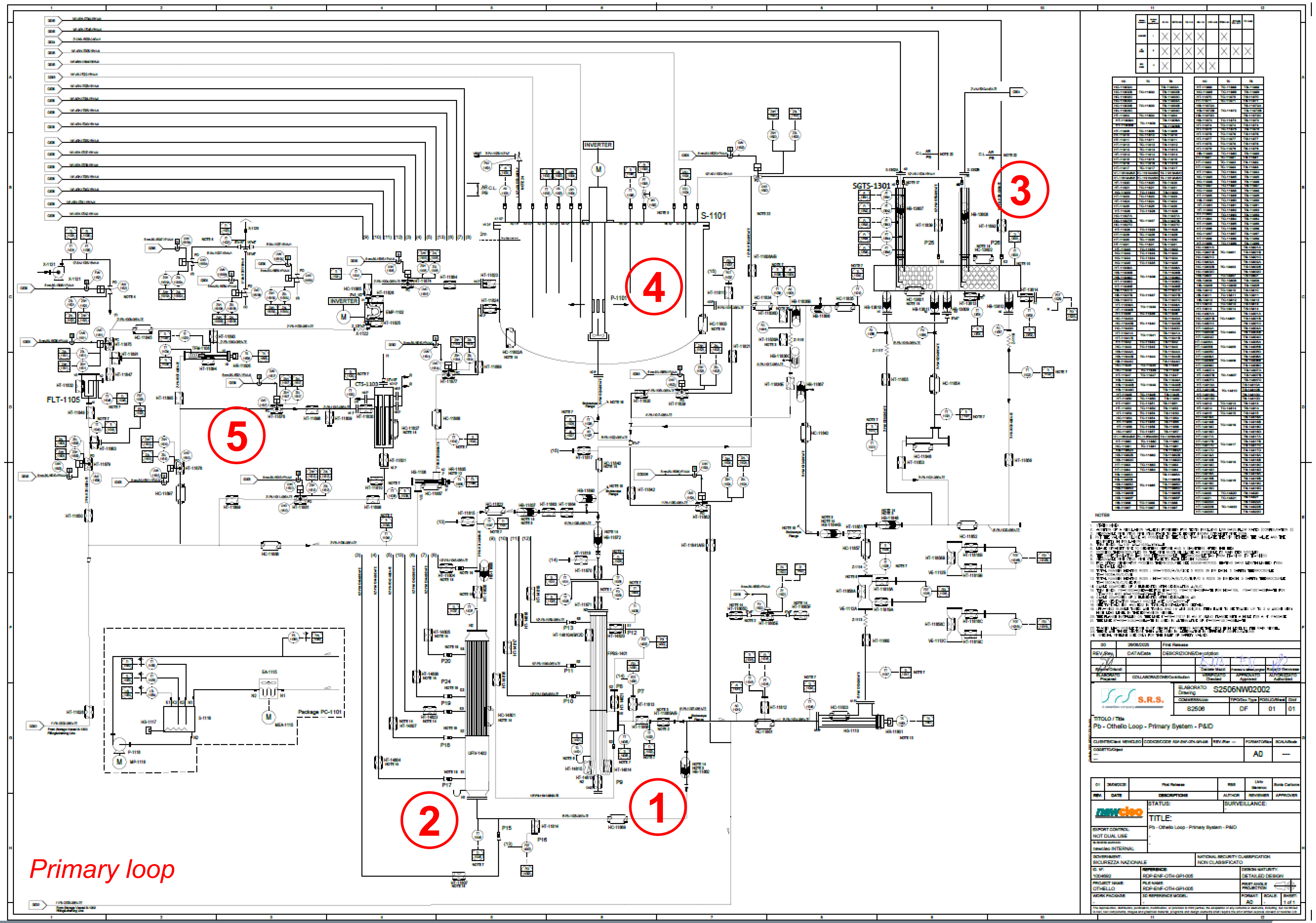
General info

- Oxygen-controlled Thermal-Hydraulic Experimental Lead Loop
- Component-scale testing: performance characterization; code validation; etc.
- Joint effort of *new*cleo (including SRS) and ENEA
- Largest and most complex test facility in *new*cleo's R&D programme. Plant (primary and secondary loop; heat sink; ancillary systems; …) spread over multiple compartments of PEC building at ENEA-Brasimone Research Centre
- Installation in progress; completion due by 2026-Q1 (then commissioning)

OTHELLO

Primary system key components

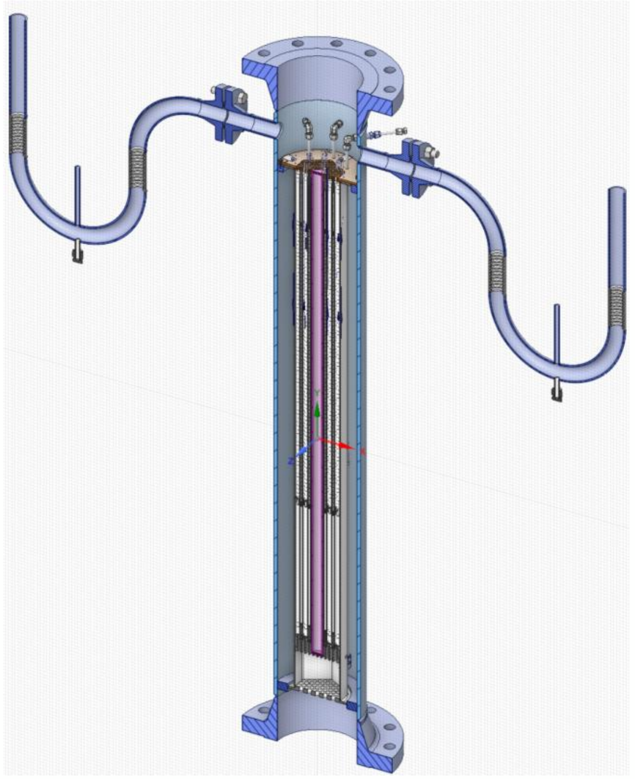
1. Electrically heated Fuel Pin Bundle Simulator (FPBS)
   - 2 MW; individual rod power control
   - FA hydraulics and heat transfer performance testing
2. Unheated Fuel Pin Bundle Simulator for FIV testing (U-FIV)
   - Fluid-induced vibrations; pressure losses
3. Spiral-tube Steam Generator Test Section (SGTS)
   - 5 spiral tubes from LFR-AS-30 SG (1:1)
   - Heat transfer performance; SG dynamic behaviour; FIV; …
4. Expansion vessel & axial flow pump
   - Technology of lead pumps
5. Ancillary circuits for testing of cold traps, filters, etc.



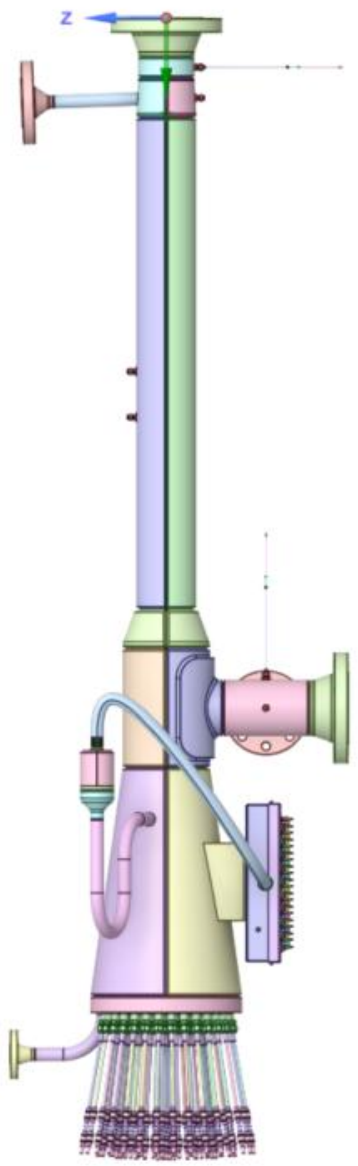
OTHELLO

Primary system key components

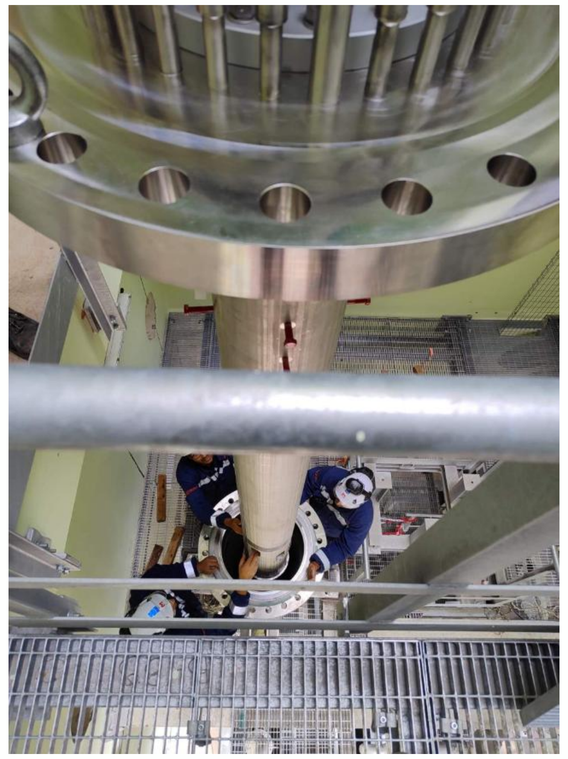
FPBS assembly



U-FIV 3D model

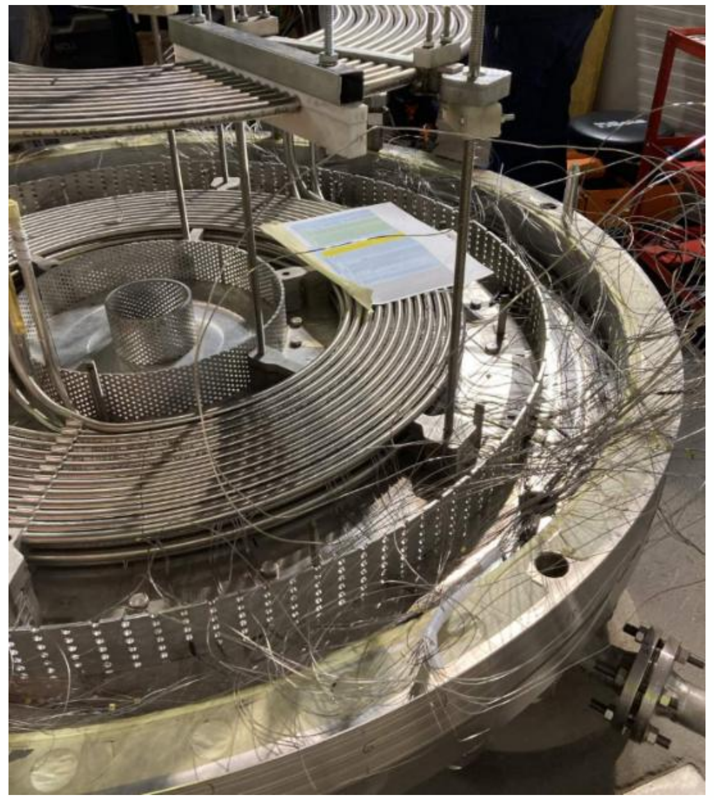


FPBS 3D model



Axial flow pump installation

SGTS 3D model

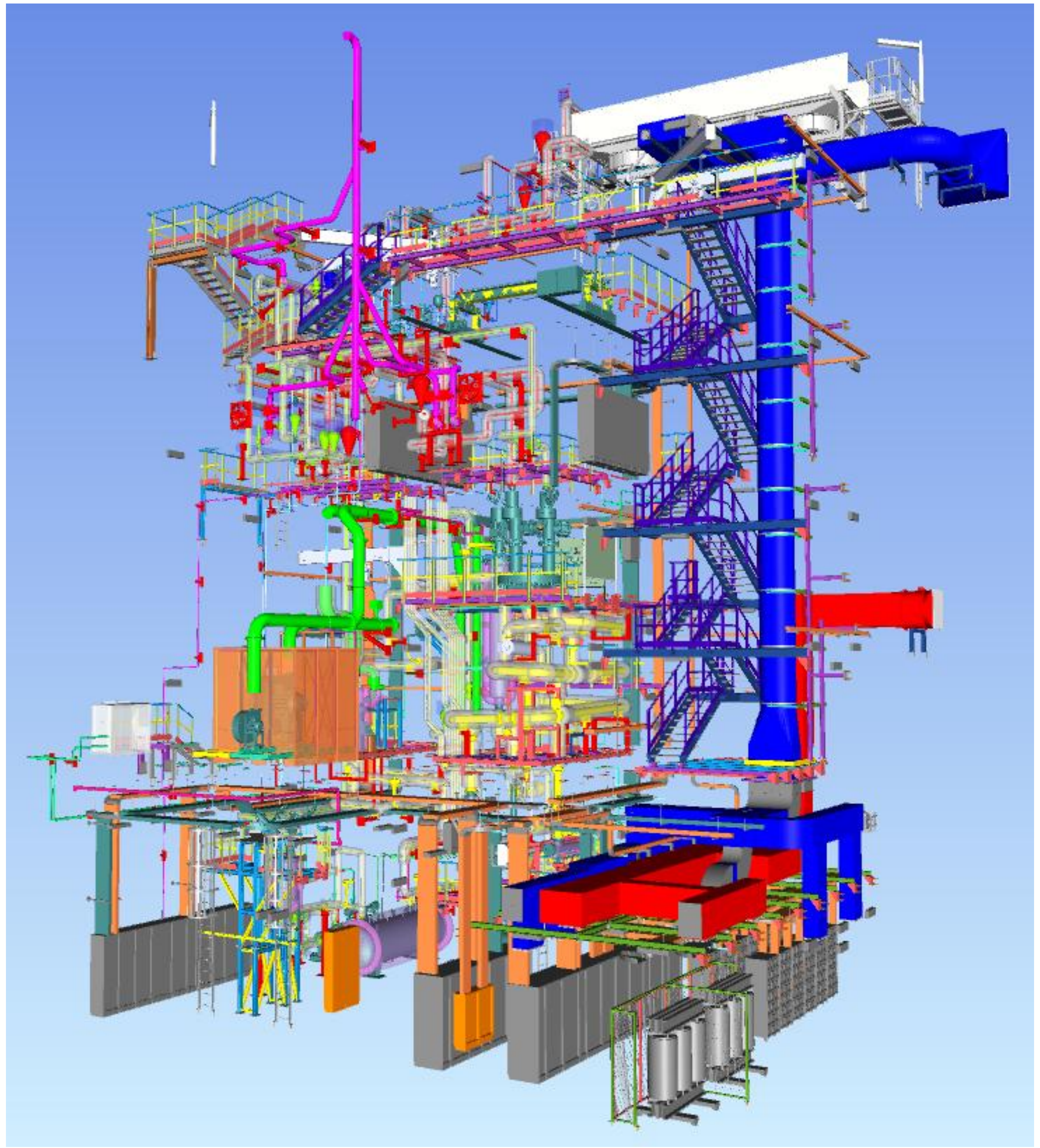


SGTS assembly

SGTS spiral-tube bank
(test operations before assembly)

OTHELLO

Layout



PRECURSOR

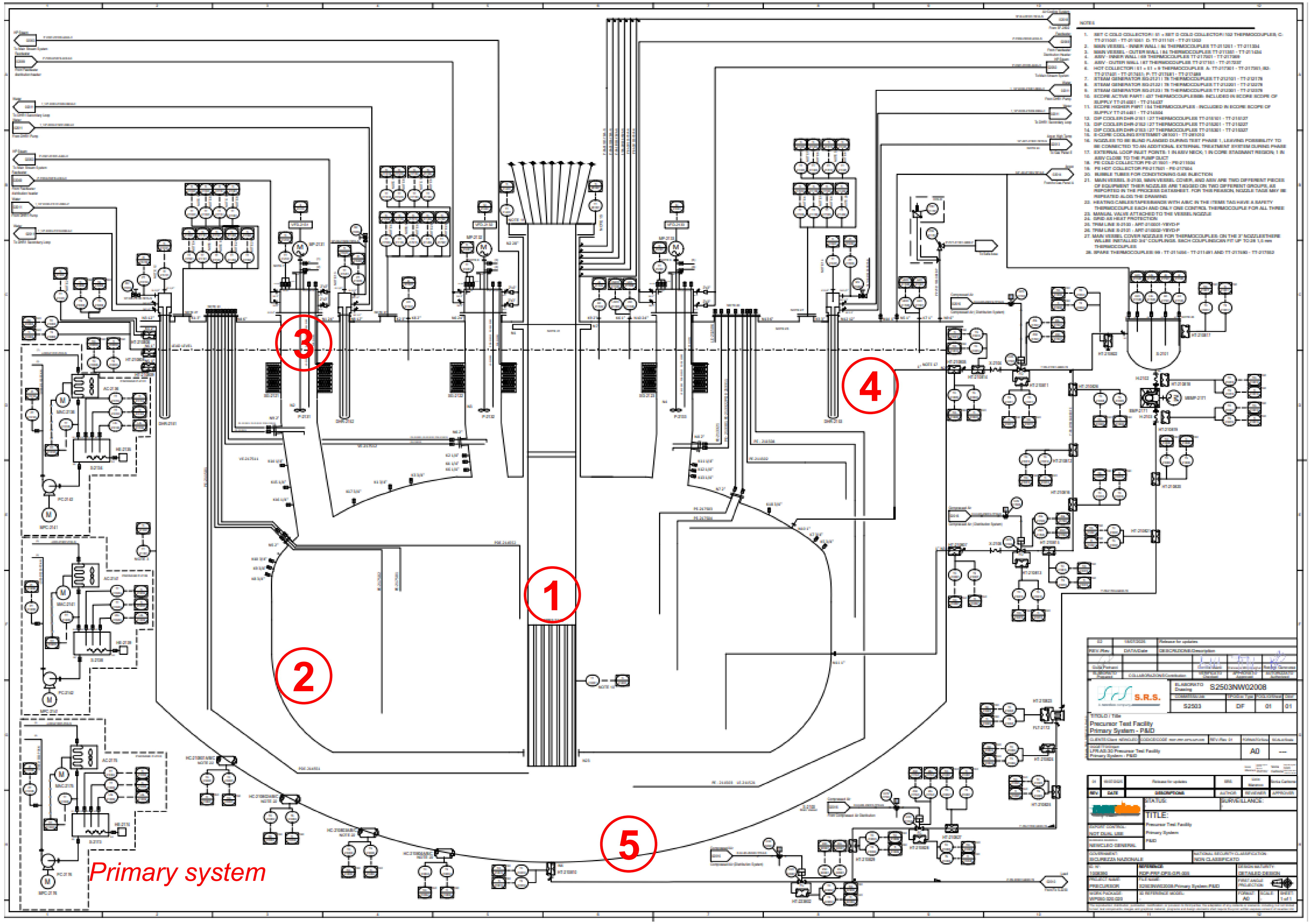
General info

- Molten lead pool-type down-scaled integral test facility
- Largely representative of LFR-AS-30:
  - Primary system; Steam cycle with turbine; DHR system; ancillary systems; …
- 1:9 power-to-volume scaling, with adaptions (→ 10 MW, from electrical heating)
- Scope:
  - Investigation on pool thermal-hydraulics (to improve understanding, and gather data to support modelling and code qualification)
  - System-scale testing of plant operation in a wide range of normal and off-normal operating conditions (also accidental transient, to limited extent)
  - Testing ancillary systems (lead handling; oxygen control; lead quality control; cover gas; …)
- Joint effort of *new*cleo (including SRS) and ENEA
- Detail design and procurement in progress; completion of installation due by 2026-Q4

PRECURSOR

Primary system key components

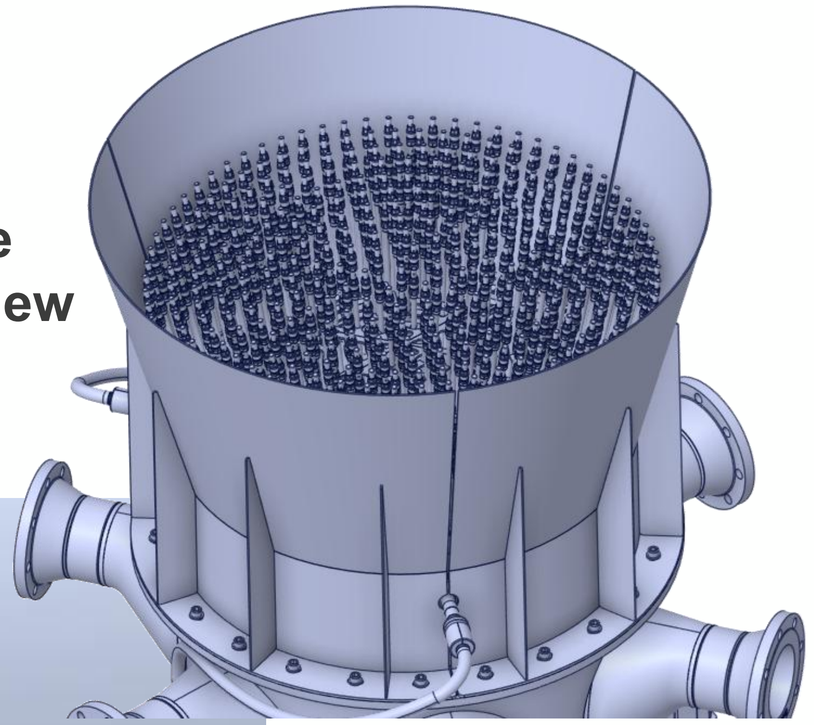
1. Electrically heated core simulator (eCore)
   - 10 MW (max 14); individual FA power control (x 19)
   - Core-wise shaping of power and flow
   - Non representative FA thermal-hydraulics
2. Amphora-shaped Inner Vessel (ASIV)
   - Prototypical topology; preserving cold/hot volume ratio
3. 3 x Spiral-tube Steam Generators + axial flow pumps
   - “Weak” scaling of SG
4. 3 x Bayonet-tube Dip Coolers
   - DHR
5. Main Vessel

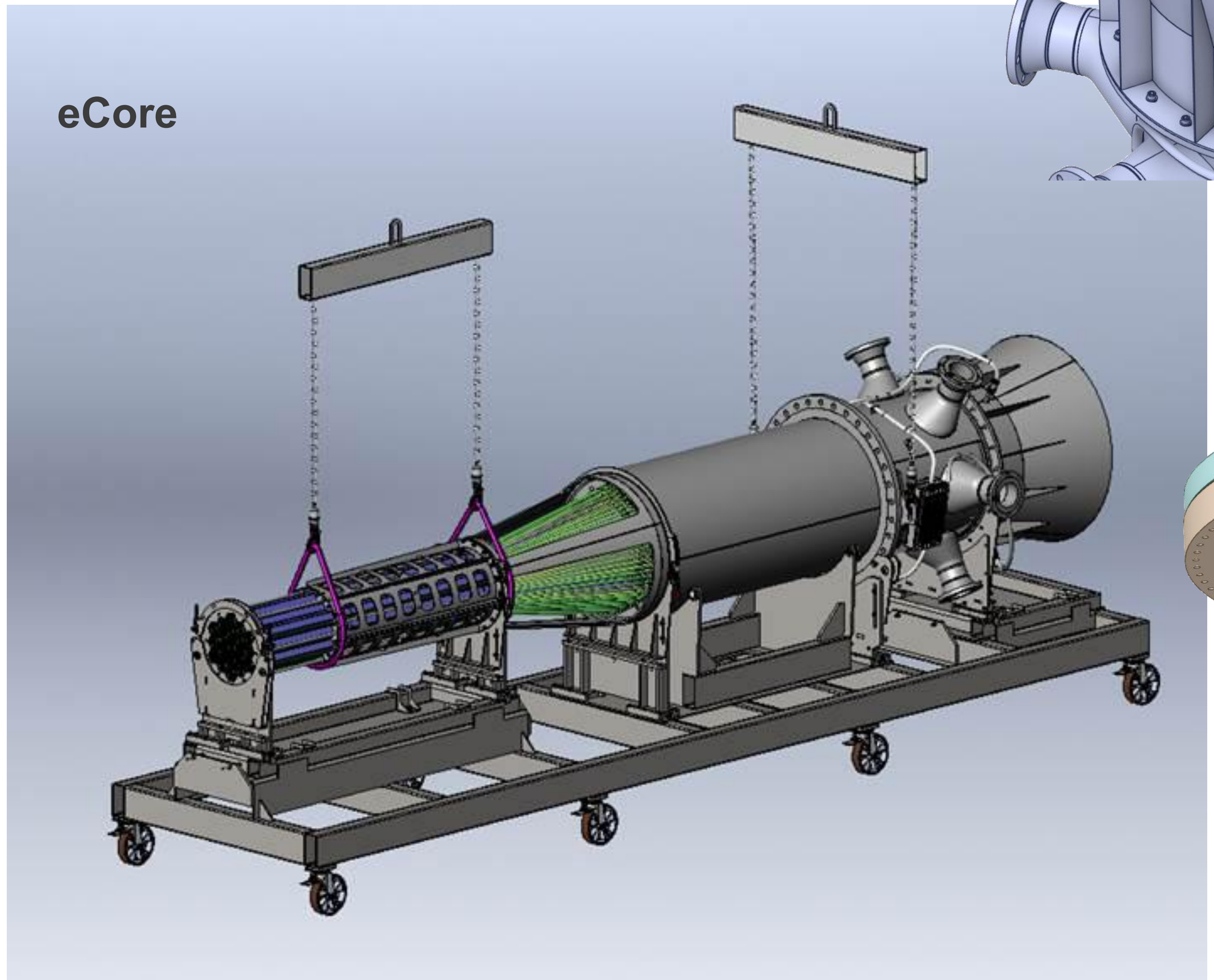


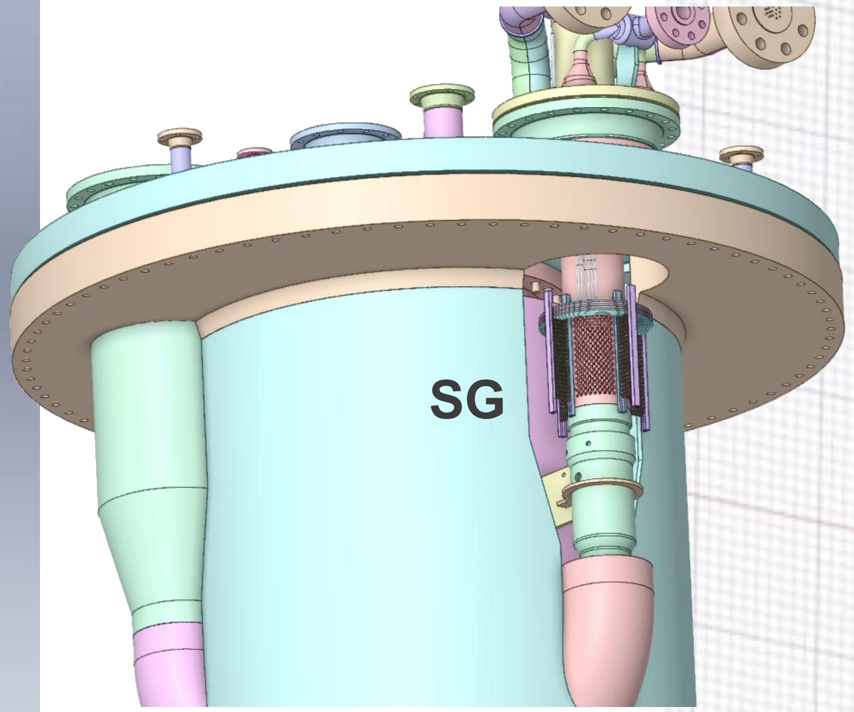
PRECURSOR

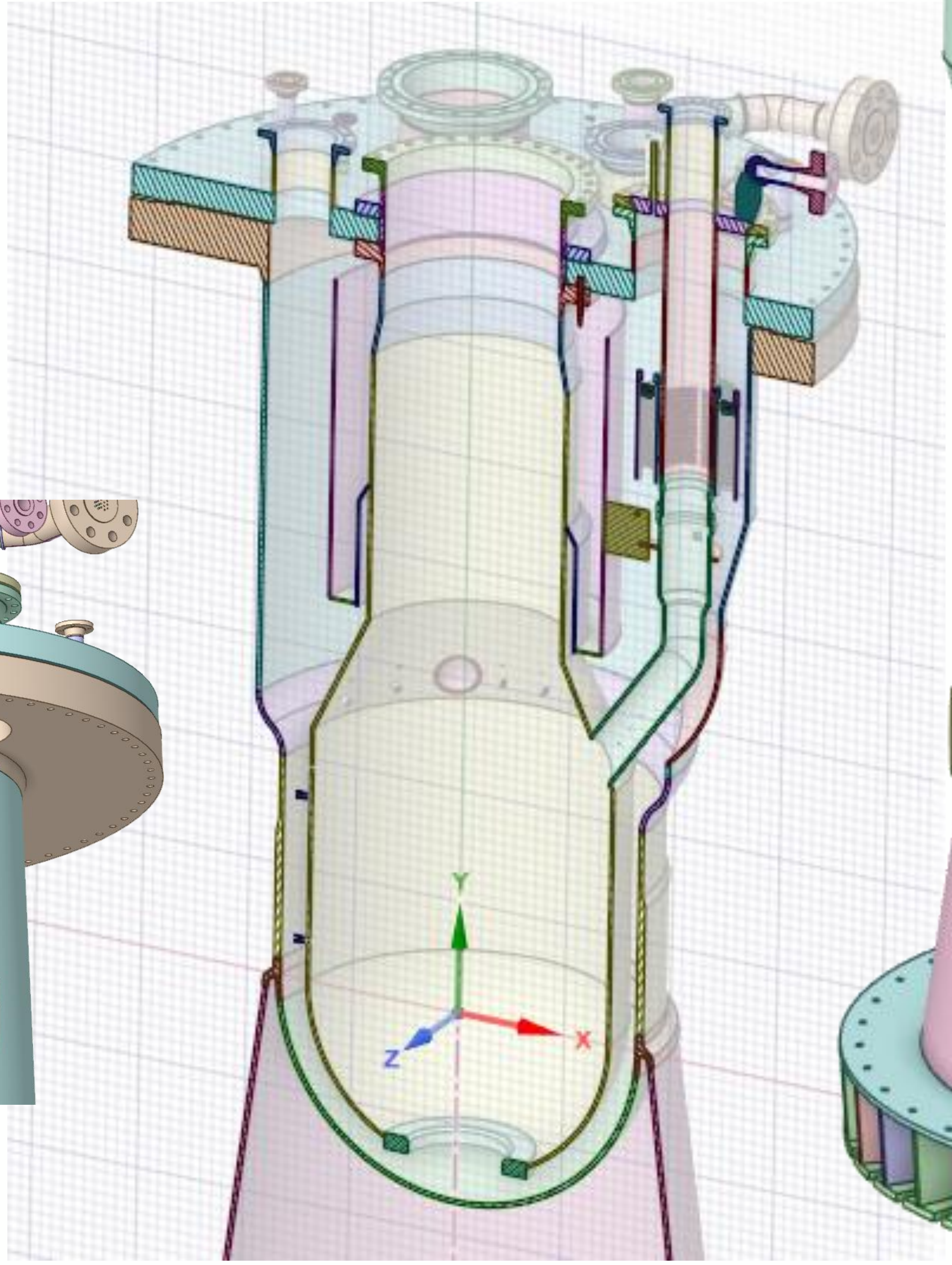
Primary system key components

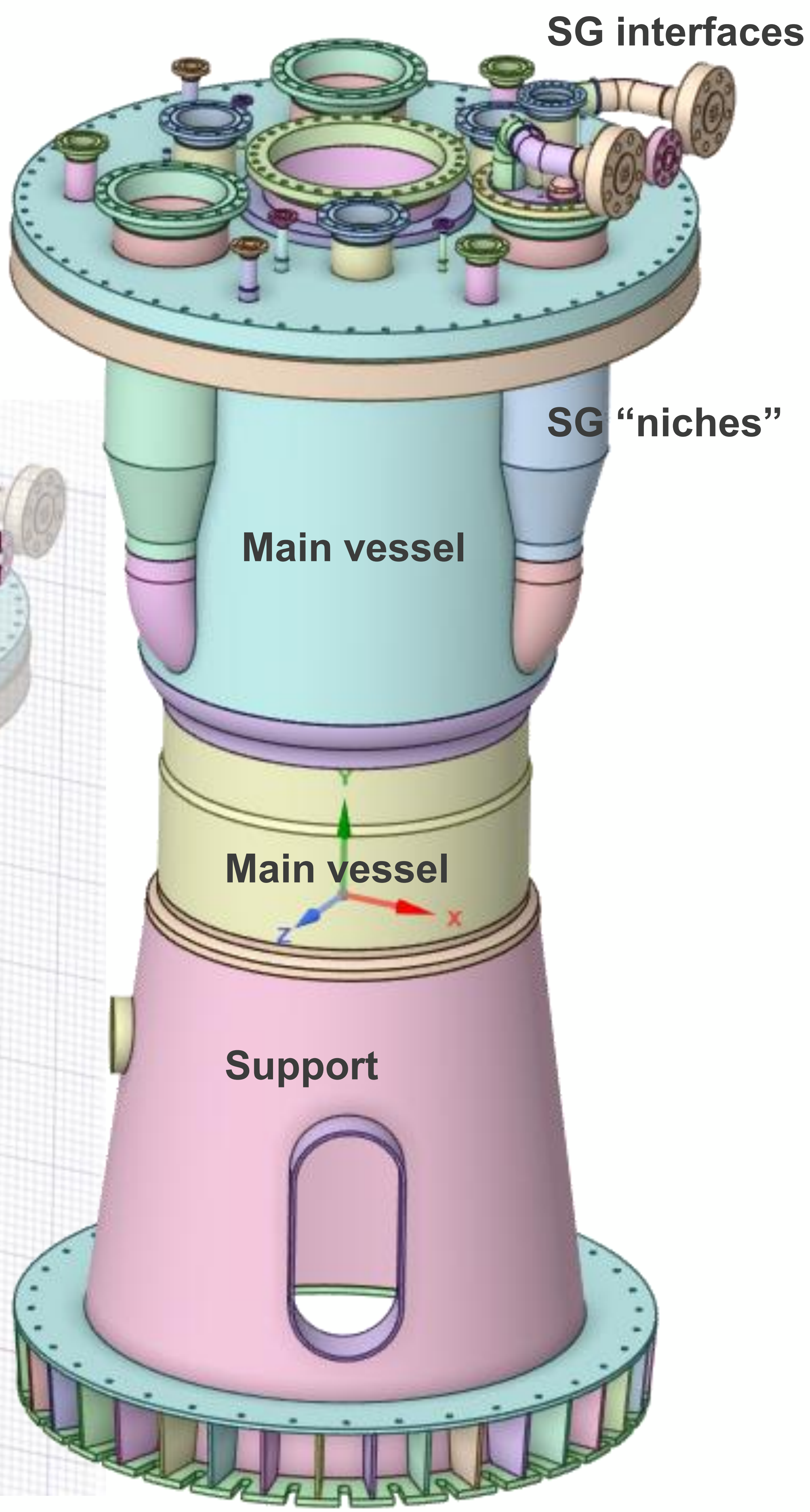
eCore
top view











CIRCE-NEXTRA

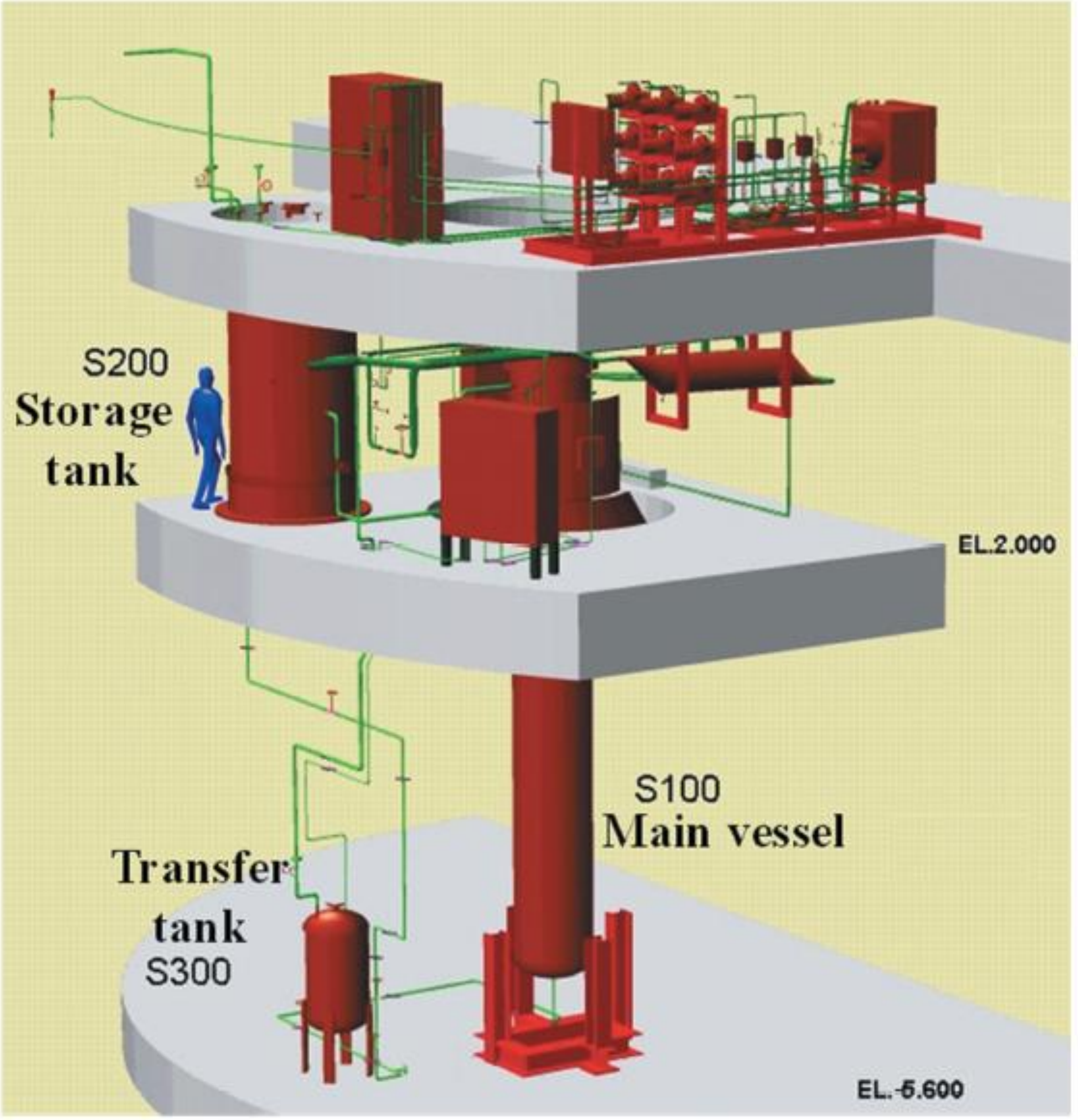
Refurbishment of ENEA's Brasimone infrastructure

CIRCE-NEXTRA (Newcleo rEvamped eXperiments, Testing and steam generator tube Rupture Analysis) is a stepwise refurbishment programme of the CIRCE facility, devoted to:

- **NEXTRA-I**: Long-duration endurance tests of **axial flow pump** operating with Heavy Liquid Metals (HLM)
- **NEXTRA-II: Steam Generator Tube Rupture (SGTR)** event investigation

CIRCE-NEXTRA-II general info:

- The design of a new SGTR Test Section, to be coupled with CIRCE facility main vessel (S100), is currently ongoing (similarities with CIRCE-MAXSIMA project).
- Main objectives of the experimental campaign:
    - Investigate the occurrence and the extent of the SGTR-related phenomenology in conditions as representative as possible of the LFR-AS-30 (real ruptures induced).
    - Provide experimental data to perform code development and validation.



CIRCE test facility

NEXTRA-II SGTR-Test Section (TS)

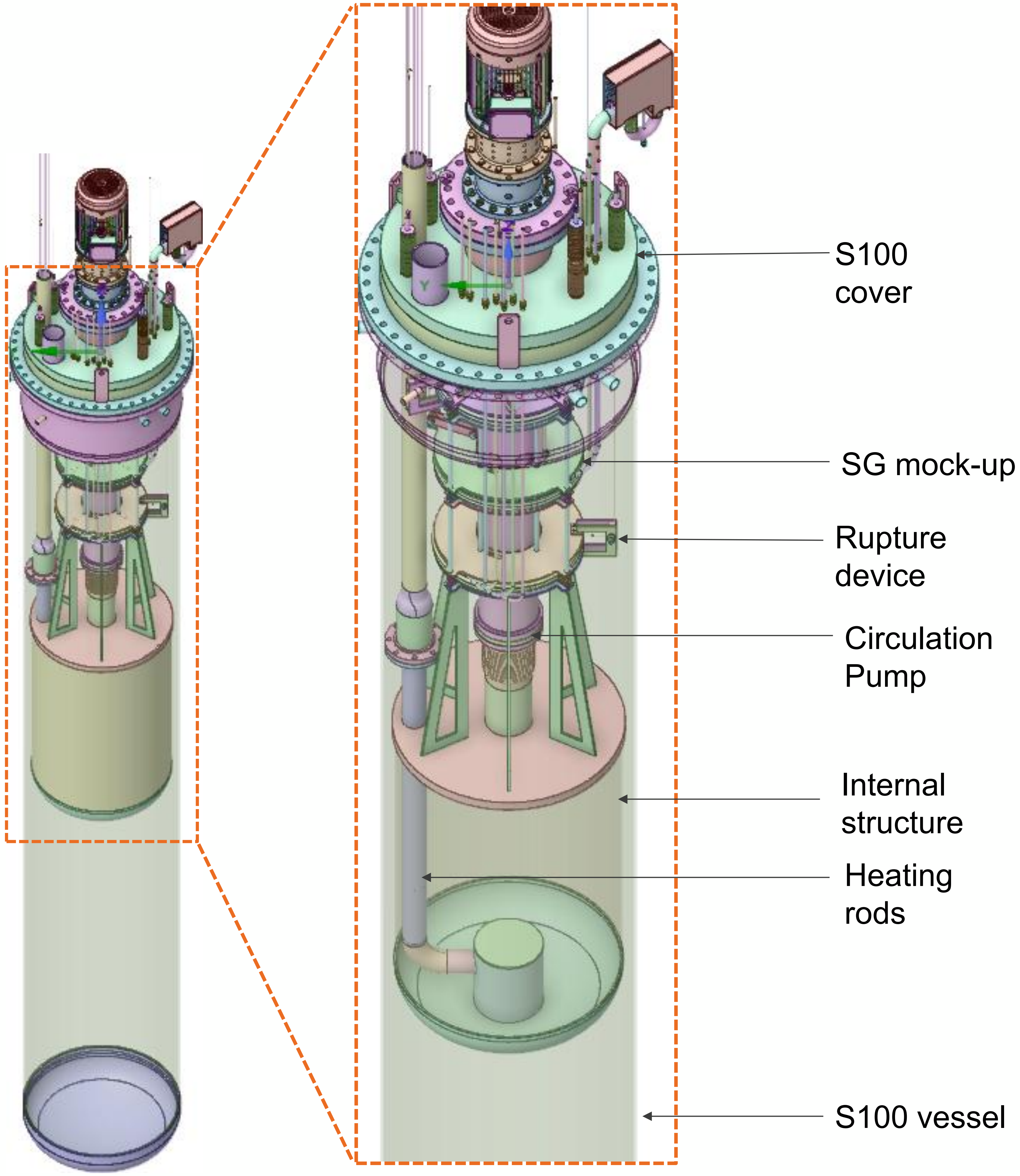
Main concepts and components

The SGTR-TS shall be coupled with CIRCE facility main vessel (Dint = 1170mm, H ~8500mm)

The SGTR-TS is preassembled and installed as a single component on the main vessel, therefore all the TS components are anchored to the S100 cover.

The SGTR-TS consists of the following key components:

- Steam Generator (SG) mock-up with secondary system under circulation before the rupture
- Circulation pump coaxial with the SG mock-up → primary system under circulation
- LBE pool heating system
- Internal structures
- Devices to induce tube rupture
- Overpressure Protection System (OPS)
- Instrumentation

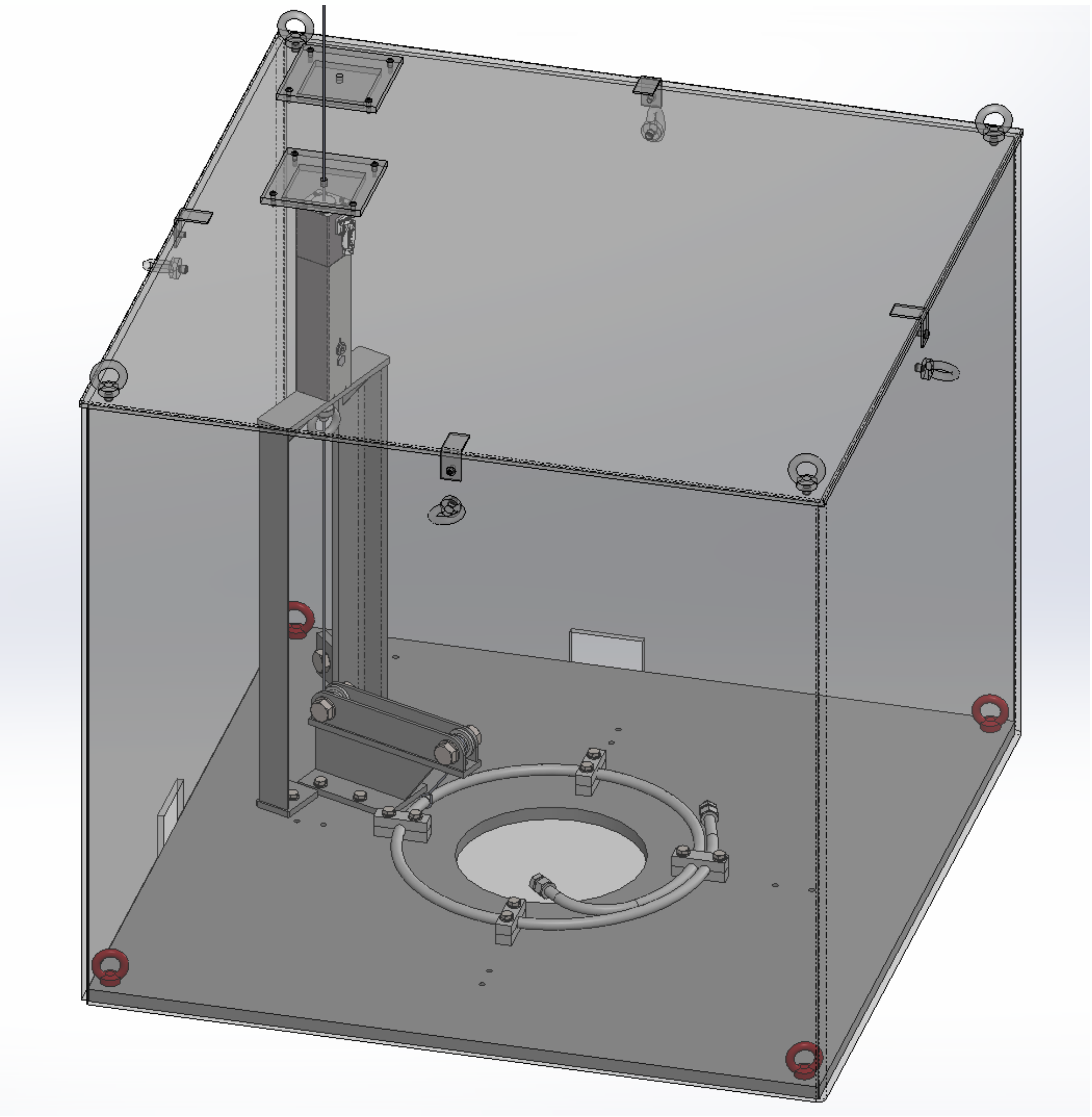


newcleo Futurable Energy

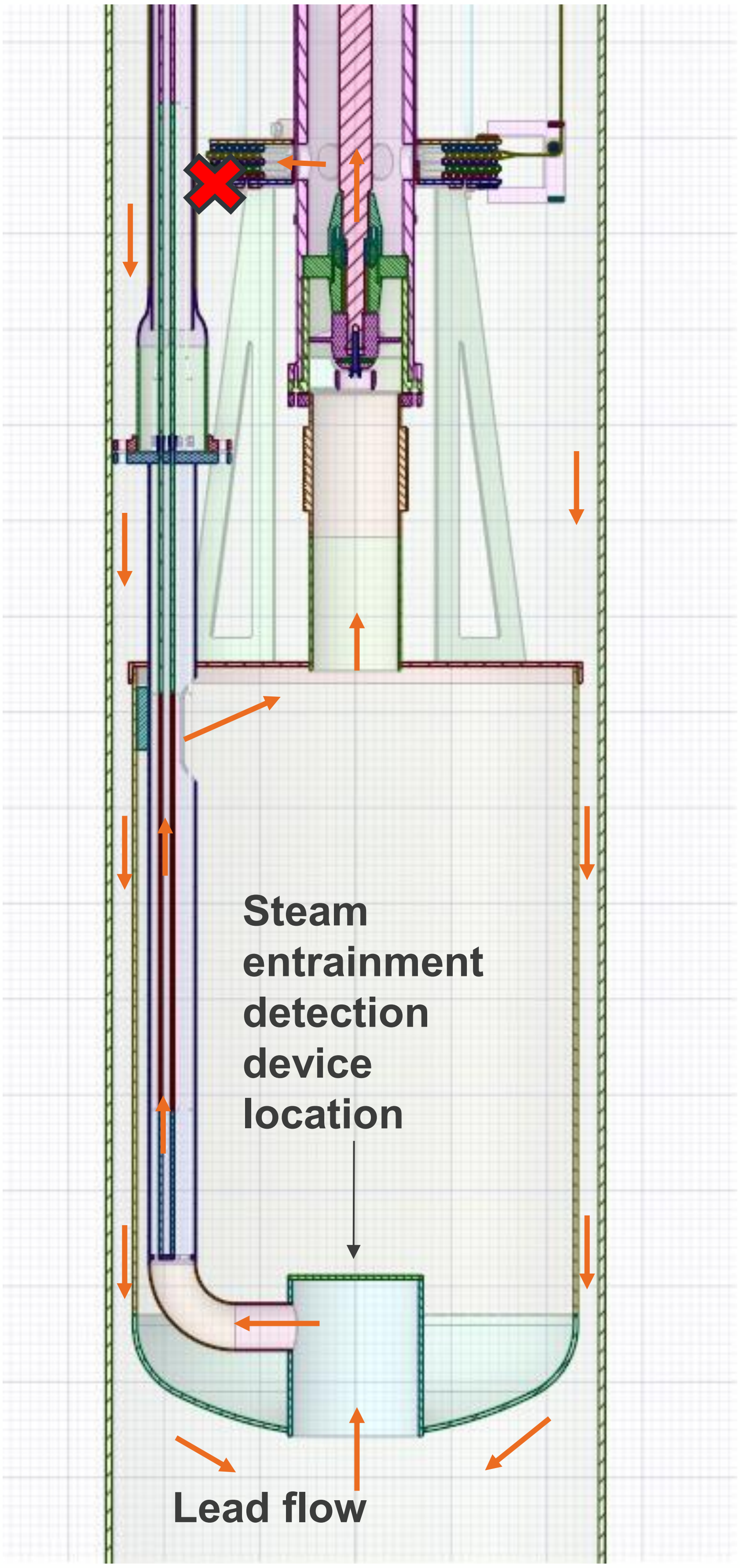
NEXTRA-II SGTR-TS

Focus on ruptures and steam entrainment detection

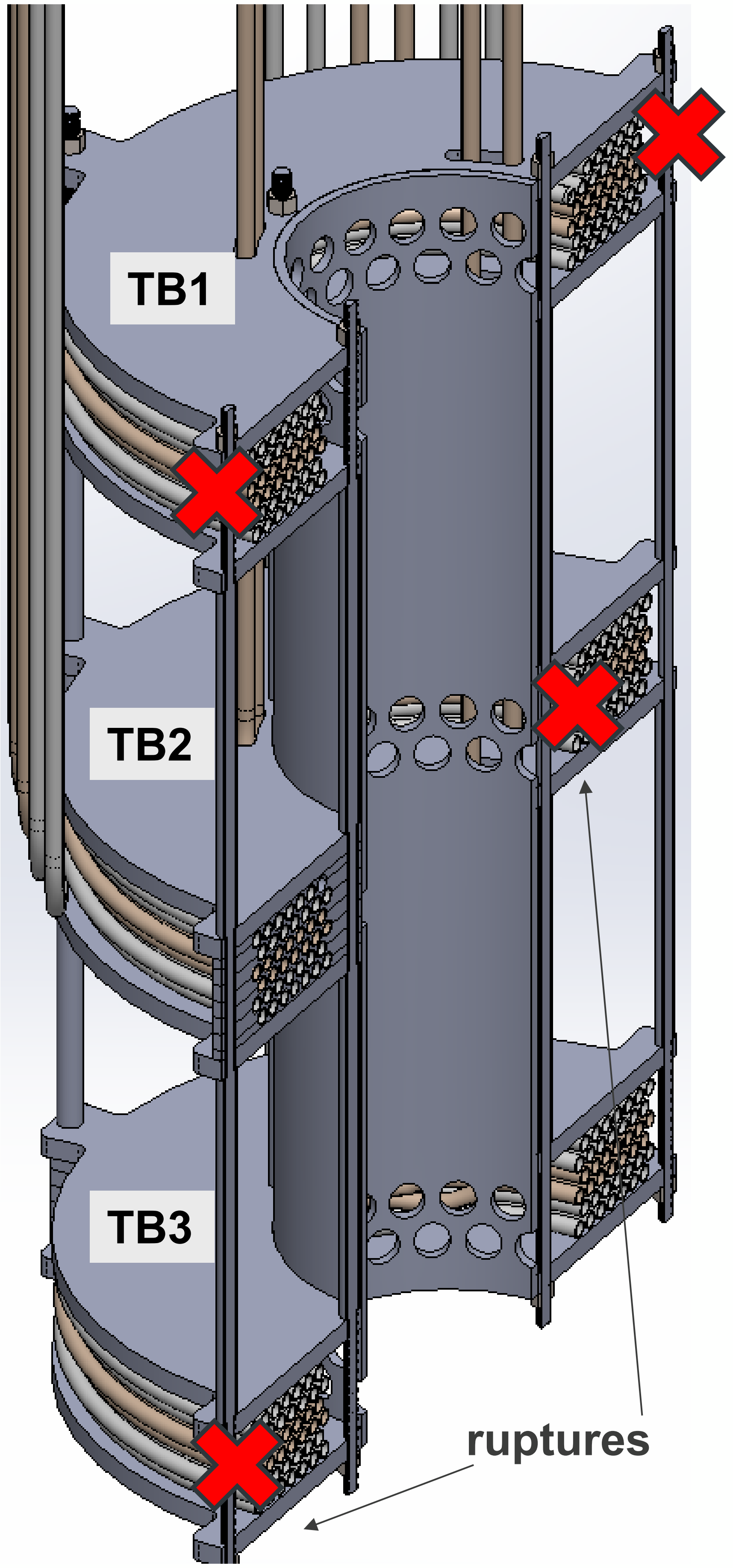
- SG mock-up consisting of three tube bundles (TBs), having strong representativity of LFR reactor spiral tube Steam Generator (SG).
- Real ruptures induced through a dedicated rupture device, which is going to be priorly tested in a dedicated test bench (already designed – see related image).
- It is under development an instrument to detect and possibly measure steam eventually reaching a location representative of the LFR reactor core inlet.



Rupture device test bench



Steam Entrainment detection device



SG mock-up

Conclusions

- *new*cleo is implementing a challenging roadmap to deploy its LFRs
- R&D on various disciplines and specifically on Thermal-Hydraulics is essential to:
  - Support design
  - Support licensing
  - Produce data for code V&V
- The design of TH facilities is in turn supported by SYS-TH and CFD simulations; then, extensive pre- and post-test simulation campaigns envisaged
- Interesting opportunity for international cooperation

Thank you!