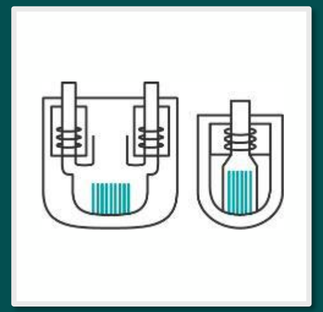
newcleo's R&D Programme in support of SM-LFR technology development and deployment

20 June 2024 – GIF talks with industry series #1

***Fabio* Moretti** – Head of R&D Thermal Hydraulics unit

The company

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

SAFE AND AFFORDABLE

CLEAN AND RELIABLE

CIRCULAR

Launched in **SEPTEMBER 2021**

Presence across **Europe**

ACQUISITIONS

FUCINA ITALIA
A *new*cleo company

S.R.S.
A *new*cleo company

RÜTSCHI
A *new*cleo company

700+ EMPLOYEES

25+ YEARS OF RESEARCH

14+ PATENTS

EUR400 MILLION of private funds
~EUR50 MILLION turnover in **2024**
Currently raising up to **EUR1 BILLION**

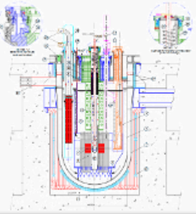
*new*cleo relies on 25+ years of international research efforts

The concept of the **Accelerator Driven System** was first introduced at **CERN** by Nobel Laureate and Director General Carlo Rubbia as 'Energy Amplifier'

1993

First contacts with Russian scientists who designed the Alpha class nuclear Pb-Bi **submarines**. V.Orlof presents at CERN the conceptual project of his BREST reactor (now under construction)

1995

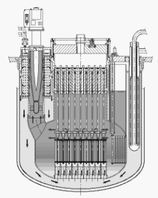


Italian Government funding an industrial project producing a reference configuration of the **ADS Experimental Facility** (XADS) with Luciano Cinotti as technical project manager

1999

Design and realisation of the large-scale liquid lead test facility CIRCE at ENEA-Brasimone, today the most relevant R&D infrastructure for LFR development

2002



Hydromine Nuclear Energy incorporated to design the **AS-200 and TL-X**, today part of the Gen-IV projects listed by the International Atomic Energy Agency (IAEA)

2013

1994

FEAT (First Energy Amplifier Test) run at CERN to demonstrate the ADS **feasibility** for energy production

1996

TARC (Test of Adiabatic Resonance Crossing) experiment at CERN to demonstrate **neutrons phenomenology in pure lead**

2000

LFR chosen as one of the **six leading technologies** developed by the **GIF** (Generation IV International Forum)

GEN IV International Forum
Expertise | Collaboration | Excellence

2003

The EU, through the **5th Framework Program**, launched a broad R&D program (~50 academic and industrial organisations) on lead-based ADS technologies

2021

***new*cleo** incorporation and acquisition of Hydromine Nuclear Energy with its set of international patents
Capital raise: **€100m**

A strong track record

Mar 2022

First AGM, launch of €300m equity raise

ENEA partnership

Jun 2022

Launch of our French subsidiary: **Lyon office**

Successful closing of **€300m equity raise**

Mar 2023

ENEL partnership

Second capital raise launch

Conceptual design AS-30 reactor completed

May 2023

Choose France summit

First technical meeting with **ASN and IRSN**

Jun 2023

Awarded **France 2030** call for projects

Jul 2023

Partnerships with **Fincantieri and RINA** for naval reactor

Oct 2023

Acquisition of **SRS-Fucina**, worldwide nuclear engineering leader

Cooperation and investment agreement with **Tosto Group**

Nov 2023

WNE participation

Partnerships with **Assystem, Ingérop, Onet**

Dec 2023

Acquisition of **Rütschi Group**, leader in pumps manufacturing

First experimental facility: **CAPSULE**

Jan 2024

Agreement with **MAIRE** for hydrogen and chemicals production

Contract with **Nuclear Transport Solutions (NTS)**

Apr 2024

Regulatory Justification submitted in the UK

CEA partnership

Second experimental facility: **CORE-1**

May 2024

Joined the European **Industrial Alliance on SMRs**

Increasing numbers of partners and suppliers

Creating a global strategy supporting our delivery

UK

TÜV SÜD · NIA · pillsbury · nexa · Freshfields Bruckhaus Deringer · DWD · National Nuclear Laboratory · Mott MacDonald · Frazer-Nash Consultancy · DM Dalcour Maclaren · wnti · dwf · TECNIMONT · mace · Nuclear AMRC · Jacobs · NTS · ATKINS · arabelle solutions · Hydrock · LSE The London School of Economics and Political Science

FRANCE

EDF · framatome · cea · afcen · ONET · assystem · naarea · orano · GEVELYS · Sifen · Nuclear Valley · KINGEROP · SFEN · SIEPS · THERMOCOAX

ITALY

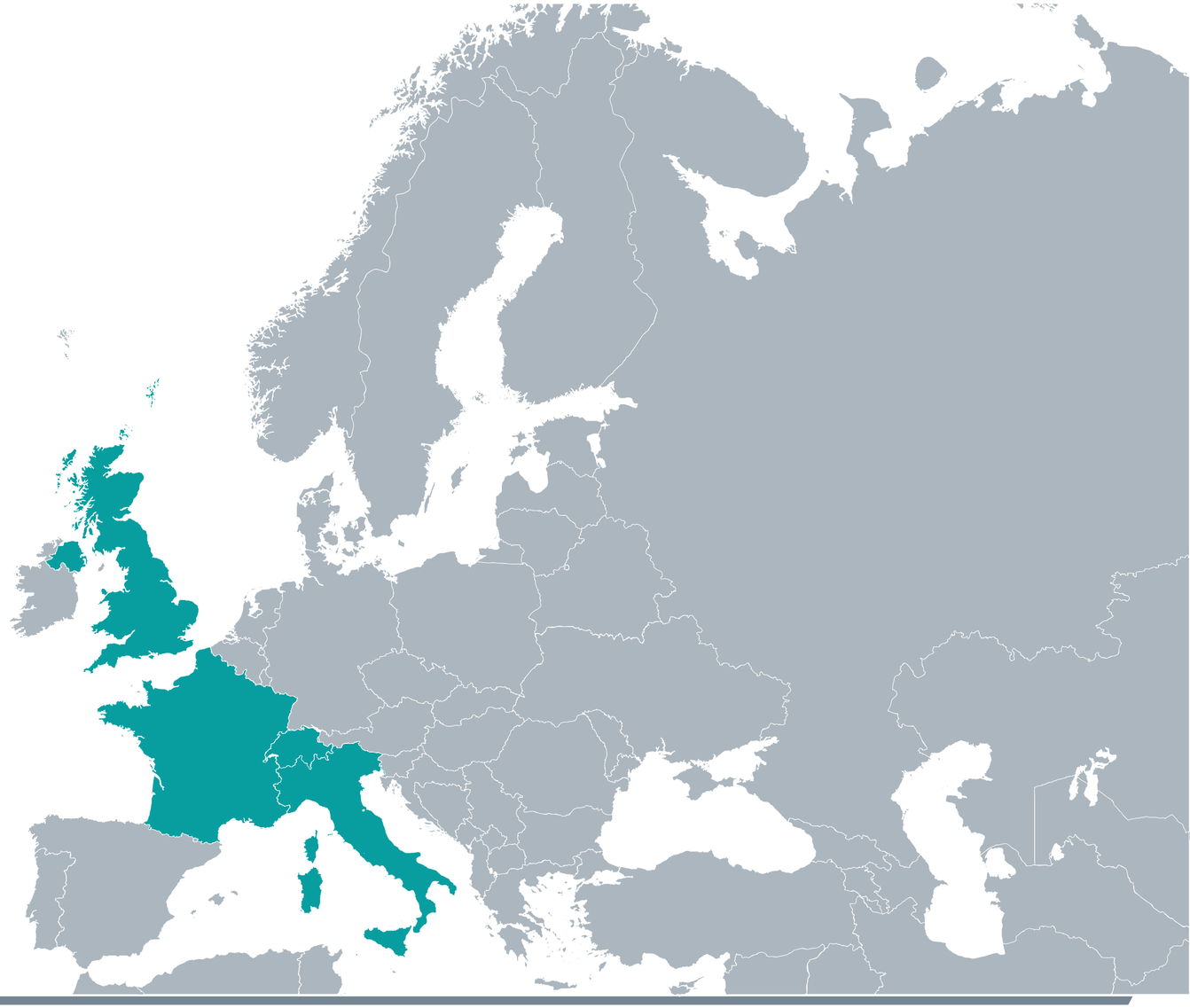
Torino iit Istituto Italiano di Tecnologia · Politecnico Milano 1863 · Politecnico di Torino · Sapienza Università di Roma · Alma Mater Studiorum Università di Bologna · tosto · AIN · Università di Pisa · UNIMORE · SIMIC S.p.A. · CARAGLIO · ENEA · RINA · FINCANTIERI · enel

US

NEI Nuclear Energy Institute

GLOBAL

World Nuclear Association · SNETP



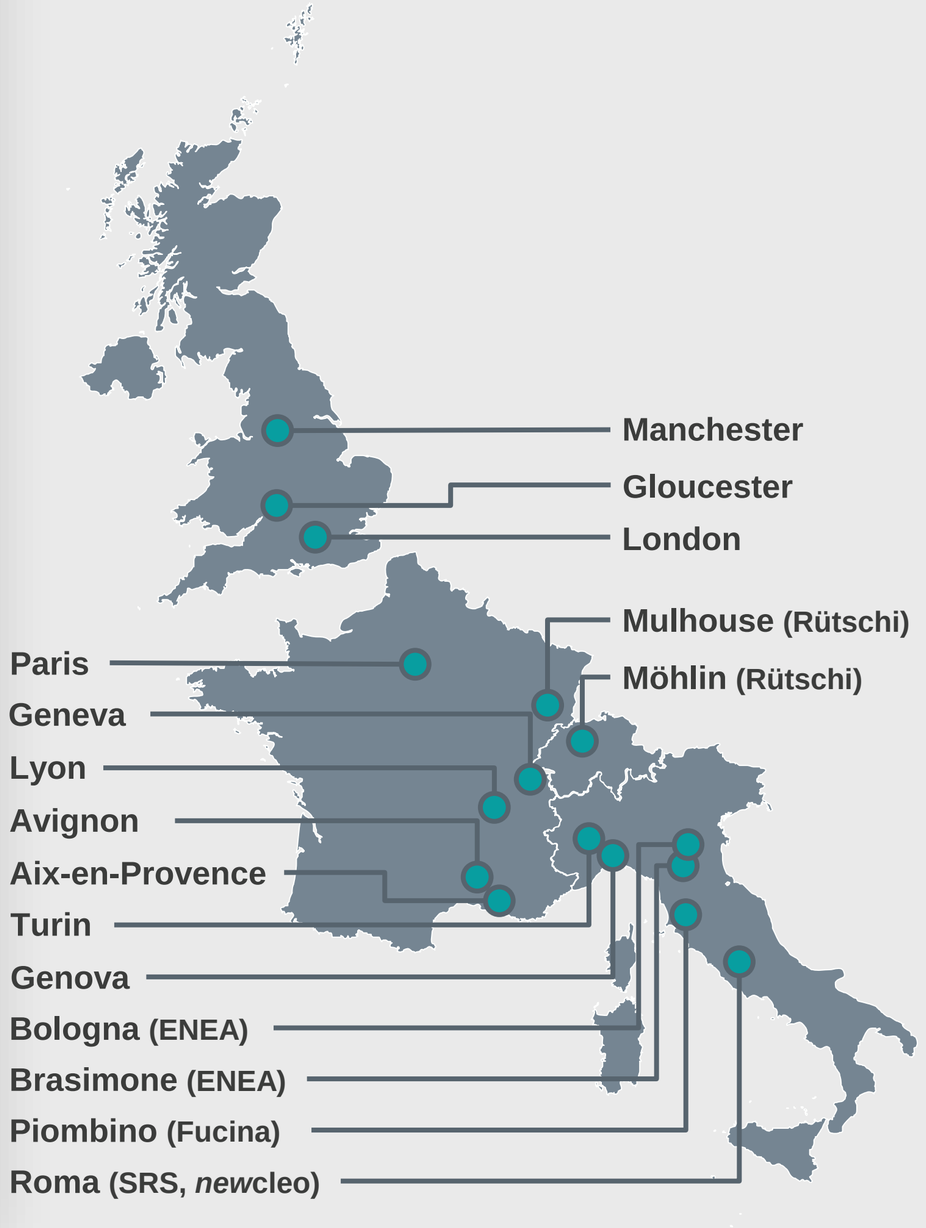
Presence across Europe

10+ locations and research centres



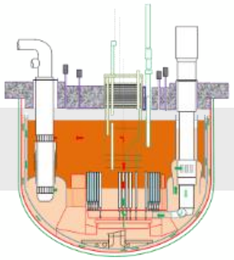


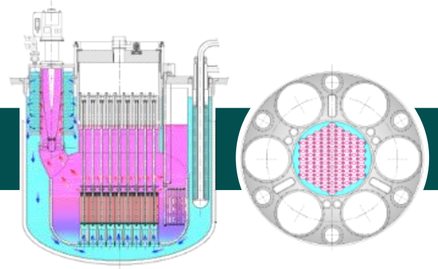


Products and plan-to-market

*new*cleo's design: simplification is key





CLASSICAL	*new*cleo
Pump in the **cold**	**hot** collector
Primary fluid inlet in the **upper**	**lower** part of the heat exchanger
Vertical	**Radial flow** of the primary coolant in the steam generator
Fuel element **fully immersed** in	with **heads out** of the primary coolant
Fuel element fixed at the **bottom**	**top**
Primary pumps **between**	**inside** the steam generators
Control rods **inside**	**outside** the core
Inner vessel larger at the **top**	**bottom**

INNOVATIVE COMPONENTS/SYSTEM

STEAM GENERATOR, REFUELLING SYSTEM, DHR SYSTEM, CONTROL RODS, FUEL ELEMENT

Compact and dense primary system

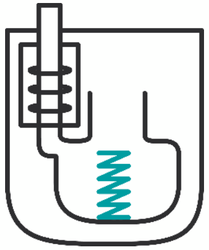
~4x less than Superphenix	Short reactor vessel: only 6.2 m

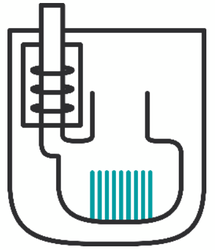
Compact reactor building

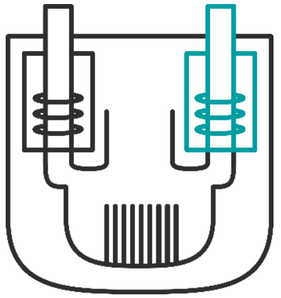
No intermediate loops	Compact primary system	No risk of LOCA

*new*cleo identified technical solutions to minimise the impact of lead's unfavourable characteristics and in some cases has also drawn design advantages. We innovate by reimagining the classical solution, resulting also in the elimination of several components no longer needed

newcleo's plan-to-market







2026

2030

2031

2033

R&D and Precursor

Several R&D facilities, and a **10 MW** non-nuclear facility with turbo-generator

MOX production

FR-MOX production facility, starting from available (separated) material in France

LFR-AS-30

30 MWe nuclear irradiation reactor with core outlet at 440° and later 530°C

LFR-AS-200

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

Our broad R&D programme

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

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 (ISI) and repair
- Balance of plant
- Plant operation and accident response

SIMULATION AND EXPERIMENTAL CAMPAIGNS

Close technological partnership with **ENEA** and notable contributions from **SRS** and **FUCINA**

Collaborations with labs and universities

Ongoing conversations with specialised companies

Large investments: **EUR90+ millions allocated**

ENEA partnership

A strong partnership on LFR technology

*new*cleo and ENEA signed a framework agreement on March 2022, a few months after the incorporation of the company

The scope of the collaboration spans over many aspects of Lead technology and deals with both the LFR design and the R&D programme.

A close, crucial collaboration to fully exploit the skills on both sides and swiftly develop, design, install and operate non-nuclear experimental facilities.

At the ENEA-Brasimone centre *new*cleo is progressively restoring halls and installing new experimental facilities

SRS-Fucina expertise

A strong addition to our skillset

SRS focuses on the design and engineering of nuclear systems and in recent years has further built its track record on nuclear technology applications: decommissioning of power plants; nuclear waste management, including conditioning and storage; new power plants: fusion and Gen-IV; nuclear fuel cycle systems

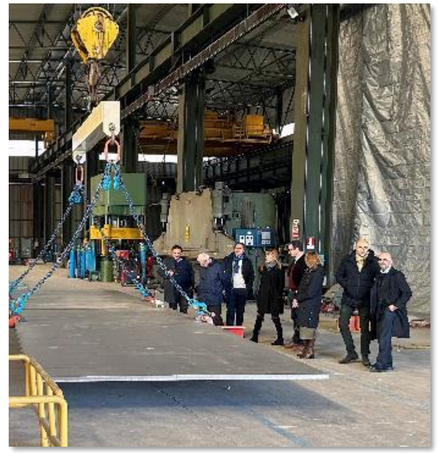
60
employees

Rome, Italy

Already involved in 24 LFR projects

Fucina has evolved from a high technology automation and steel and naval structures manufacturer to a leading company in the nuclear decommissioning, nuclear waste management and liquid lead systems.

A strong production platform benefitting from: 20,000 m2 production area, of which 9,000 m2 covered; 11,000 m2 additional available land, of which 6,000 m2 buildable land which will be a key production hub for newcleo



50
employees

Piombino (LI), Italy

Works closely with SRS

*new*cleo test facilities: Materials R&D infrastructure

*new*cleo's priority is to **validate materials** (structural and coatings) with respect to corrosion, erosion and embrittlement in liquid metal under our reactors conditions (high neutron flux, high temperatures, lead)

Starting from lead qualification of the materials listed in RCC-MRx/ ASME, to developing new materials in the long-term

CAPSULE module

FACILITIES and INFRASTRUCTURES

CAPSULE for corrosion tests in stagnant lead

CORE for corrosion and erosion tests in flowing lead

LEAD/CHEM LAB to evaluate mechanical properties in lead, including slow strain rate tests, creep, long-term creep, creep-fatigue

MATERIAL LAB to validate microstructure and mechanical performance

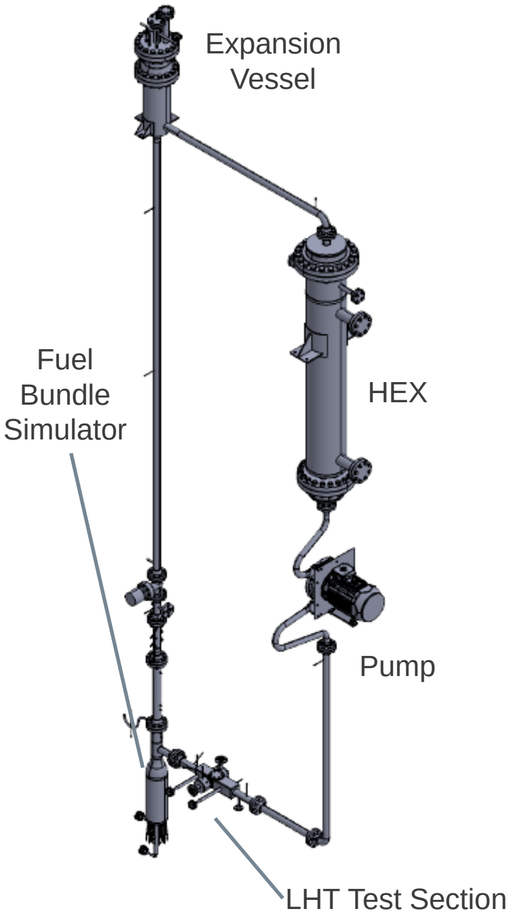
OTHELLO and **PRECURSOR** for post-test analysis of components


CORE - portion

*new*cleo test facilities: NACIE-LHT

Refurbishment of ENEA's Brasimone infrastructure

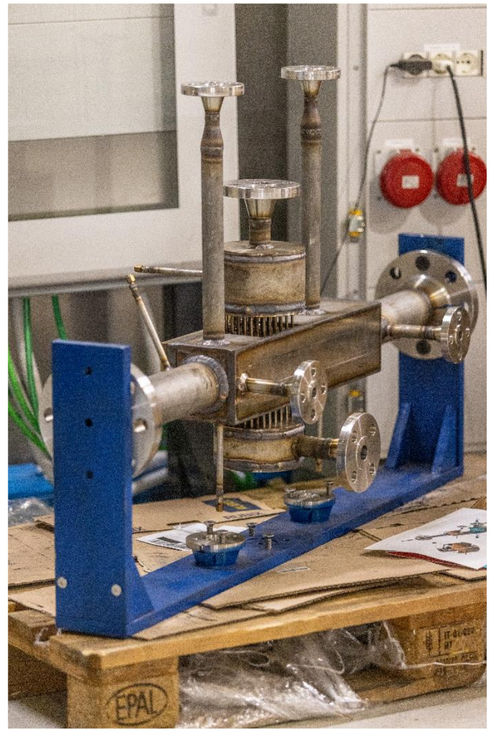
NACIE is an ENEA **loop-type** test facility dedicated to investigations on heavy liquid metal systems thermal-hydraulics (esp. heat transfer), component testing, chemistry control and corrosion protection.



NACIE, ~8m x ~2m

<u>The latest upgraded configuration</u> of this facility, NACIE-LHT (Lead Heat Transfer):

- uses liquid **lead** as working fluid (previously LBE)
- has been revamped to work up to **550°C**
- has been equipped with a new test section that partially reproduces the geometrical configuration of *new*cleo LFR steam generator and is properly instrumented to investigate on **lead-side heat transfer**



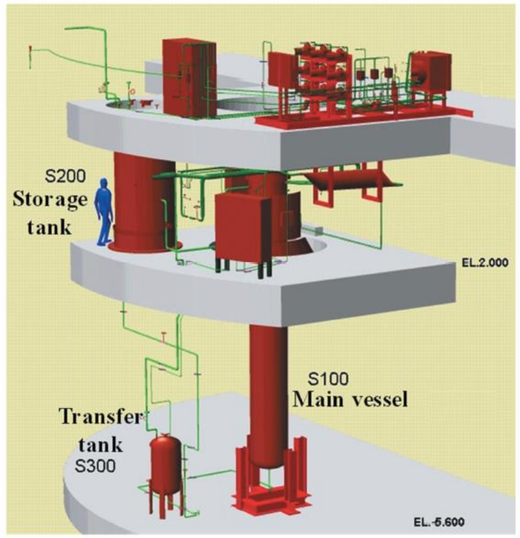
LHT test section

newcleo test facilities: 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:

- Long-duration endurance tests of **axial flow pump** operating with Heavy Liquid Metals (HLM).
- Thermal-hydraulic tests on **Decay Heat Removal (DHR)** component and system.
- **Steam Generator Tube Rupture (SGTR)** event investigation.



CIRCE test facility overview
(courtesy of ENEA)

CIRCE-MAXSIMA test section overview
(courtesy of ENEA)

CIRCE facility is the main European pool-type facility operating with HLM:

- main vessel of 8.5m height and diameter of 1.2m
- Up to ~90 tons of molten LBE
- includes argon cover gas and recirculation system, LBE heating and cooling systems, secondary loop to supply water up to ~180 bar and 335°C, LBE storage and transfer tanks, data acquisition system

newcleo test facilities: CIRCE-NEXTRA

Refurbishment of ENEA's Brasimone infrastructure

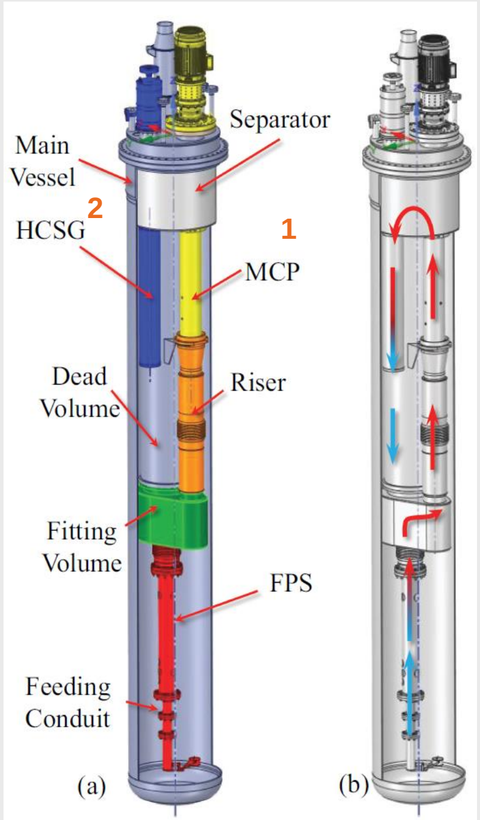
Phase 1 – components refurbishment

Pump:

- Refurbishment of the pump[1] instrumentation in view of endurance tests
- Mechanical monitoring and long-term reliability as main purposes

DHR:

- Replacement of CIRCE-THETIS steam generator[2] with a bayonet tube heat exchanger representative of LFR DHR-1 system
- Thermal-hydraulic characterization (heat transfer, Δp)
- DHR secondary side investigation
- Start-up, shut-down transients



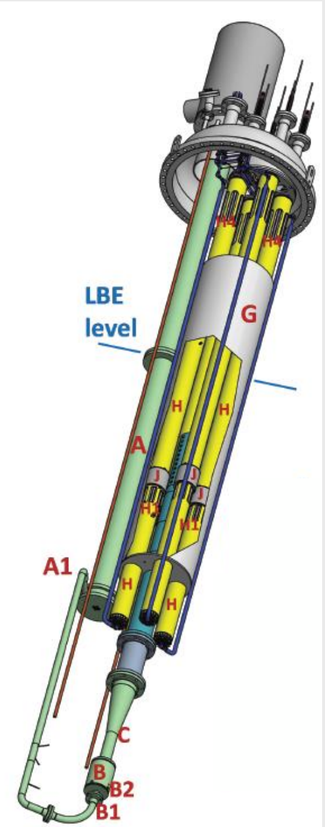
CIRCE-THETIS overview
(Courtesy of ENEA)

Phase 2 – SGTR: new test section installation

- SGTR event consist of a secondary circuit (pressurised water/steam) **discharge** into the primary system (low-pressure molten lead pool) caused by a steam generator tube leakage/break
- Very **complex phenomenology** (e.g., pressure-wave propagation, sloshing, gas entrainment)
- **New test section** designed and installed in CIRCE main vessel to investigate the SGTR in conditions relevant to LFR-AS-30 (like CIRCE-MAXSIMA campaign)

Features:

- Pump to reproduce primary system, secondary system under circulation, internal heating system, **real rupture** induced, **multiple rupture events** tested



MAXSIMA TS
(Courtesy of ENEA)

newcleo test facilities: OTHELLO

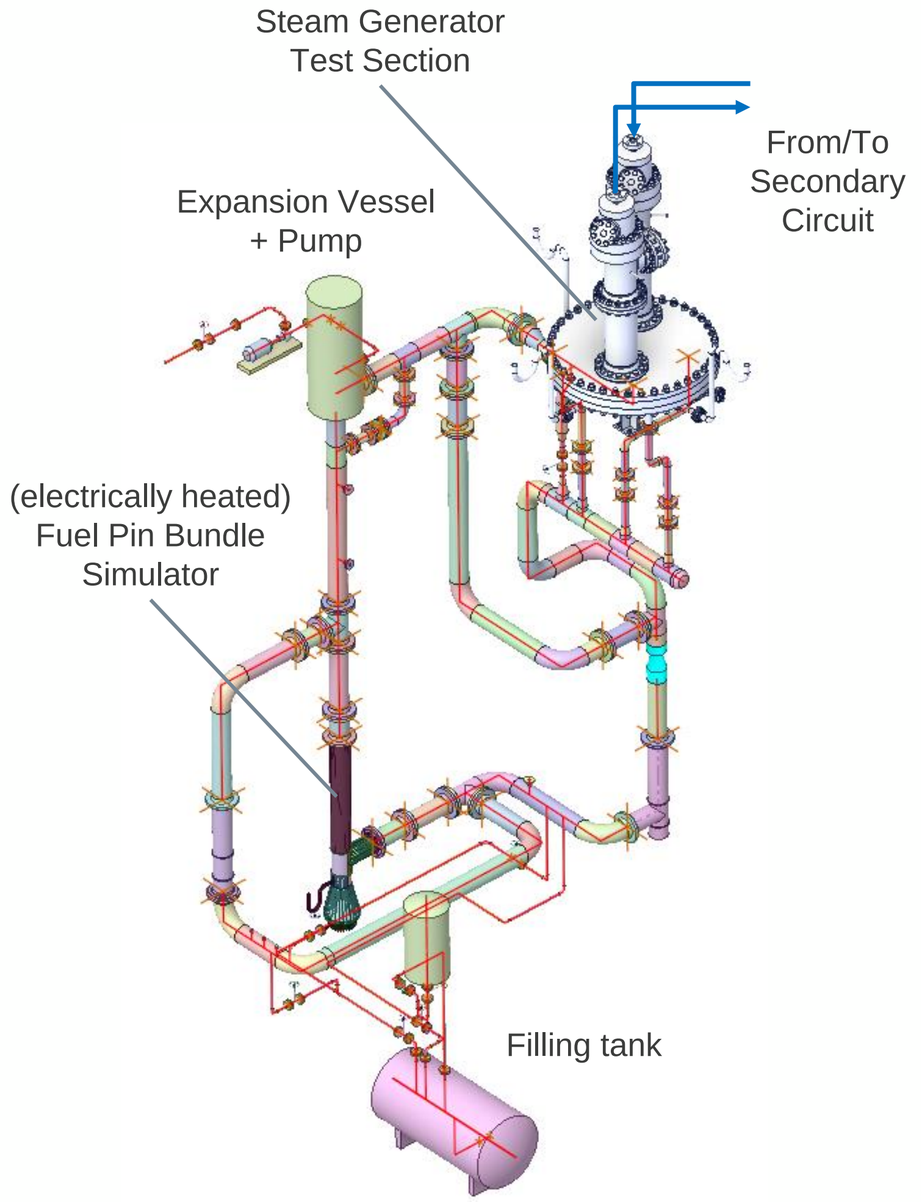
Oxygen controlled Thermal Hydraulic Experimental Lead Loop

Separate-effect test facility aimed at

- assessing performance of key components of LFR primary system
- at supporting validation of thermal-hydraulic codes
- testing instrumentation and chemistry control systems
- investigating on specific TH phenomena

Key test sections

- Electrically heated **Fuel Pin Bundle Simulator**:
  - Largely representative of LFR fuel assembly
  - To characterize convective heat transfer over a range of TH operating conditions and circulation regimes
- Unheated **Fuel Pin Bundle Simulators**:
  - Largely representative of LFR fuel assembly
  - To investigate on FA pressure losses, effect of pin spacers, fluid-induced vibrations in FA, etc.



newcleo test facilities: OTHELLO

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- assessing performance of key components of LFR primary system
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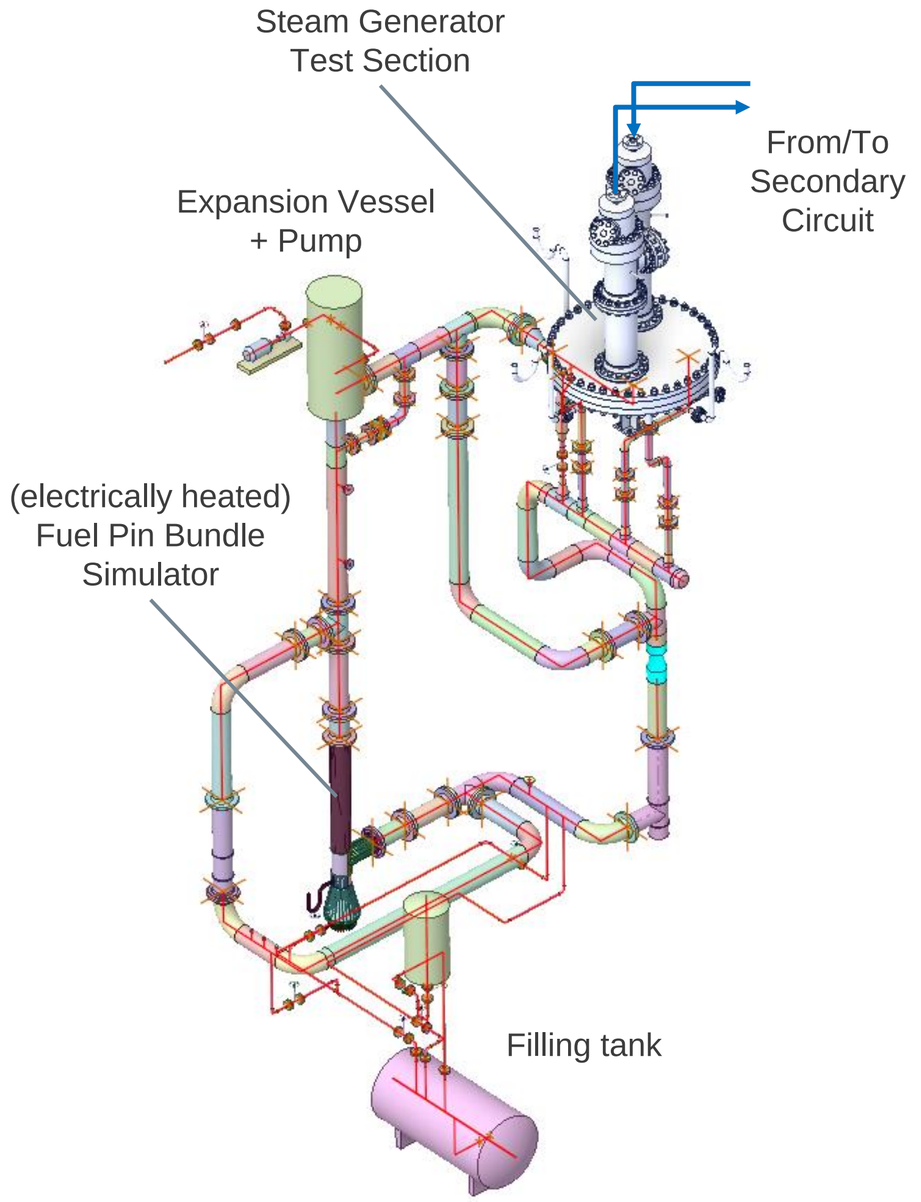
- testing instrumentation and chemistry control systems
- investigating on specific TH phenomena

Key test sections (cont'd)

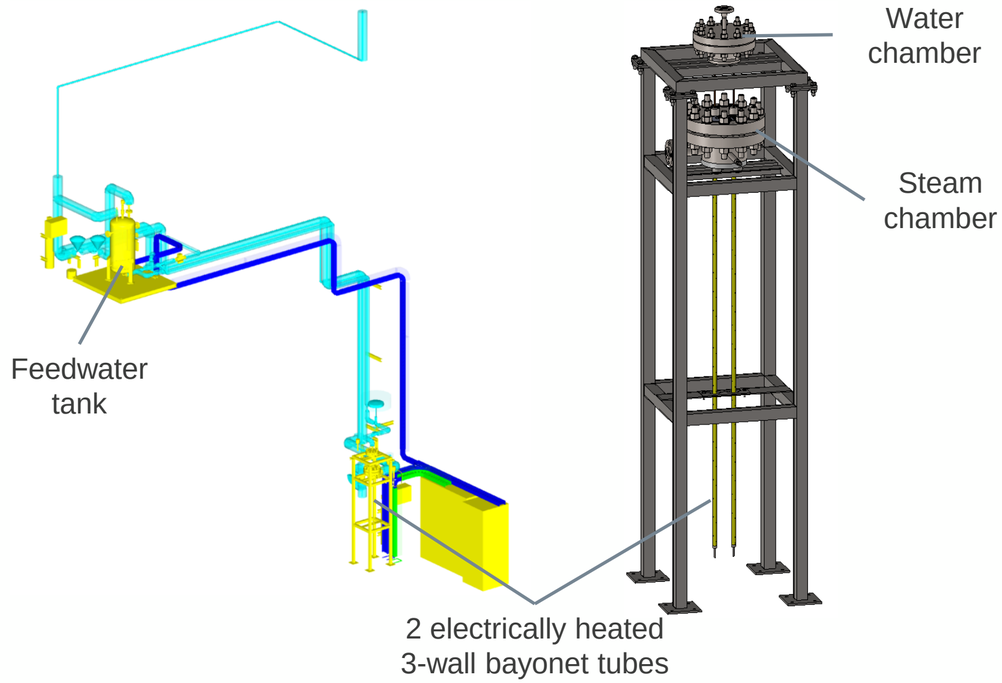
- **Steam Generator Test Section**:
  - Largely representative of LFR steam generator (full-length spiral tubes, prototypical TH conditions)
  - To characterise SG thermal performance in various operating conditions
  - To investigate on flow maldistributions, SG transient TH behaviour, SG thermomechanical behaviour, etc.
- **Freezing and Remelting Test Section**:
  - Fundamental investigation on solidification and successive re-melting of Lead in SG-relevant geometrical configuration



newcleo test facilities: DCI

Dip Cooler Instability Test Section

- Experimental loop to investigate thermal-hydraulic aspects of dip cooler operation, particularly start-up transient and water flow rate instabilities (relevant to DHR system)
- To be installed and operated at the Polytechnic of Turin
- Test section
  - Composed by two full-length bayonet tubes, connected to a water header and a steam header
  - Fed by a water tank positioned several meters above
  - Equipped with electrical heaters to achieve uniform outer wall temperature
  - Water flows downward in the inner tube, boils in the annular gap between inner and intermediate tube, and exits in the form of superheated steam
  - Helium fills the annular gap between the intermediate tube and outer tube
- The system is designed to enable tests in different conditions
  - pressure
  - temperature
  - flow rates
  - open- and closed-loop configurations



newcleo test facilities: PRECURSOR

Integral-effect test facility representative of LFR-AS-30

The facility aims to assess the thermal-hydraulic behaviour of the reactor, with particular focus on:

- Thermal-hydraulic performance in stationary design operating conditions, normal startup/shutdown transient and accidental transient (proof of concept of the overall system performance during the above-mentioned operating scenarios, transition from forced to natural circulation, DHR systems performance assessment).
- BOP transients/instability and interactions with the Primary System.
- Each of the reactor main component (e.g., core, steam generators, pumps, DHR) properly designed to reproduce the overall system performance, without the aim of component qualification campaign.

It will also serve plant accident response: set-points for safety system actuation, transient Figure of Merits, accident response procedures, validation of thermal-hydraulic codes. The accident matrix to be investigated will encompass scenarios such as partial/total loss of primary flow, loss of DHR systems during shutdown states (normal/accidental shutdowns), loss of off-site power, turbine trip, loss of feedwater, loss of preheaters.

POOL-TYPE

10 MWth

NON-NUCLEAR

COUPLED WITH THE BOP

STATIONARY AND TRANSIENT CONDITIONS

PLANT ACCIDENT RESPONSE

newcleo test facilities: PRECURSOR

Integral-effect test facility representative of LFR-AS-30

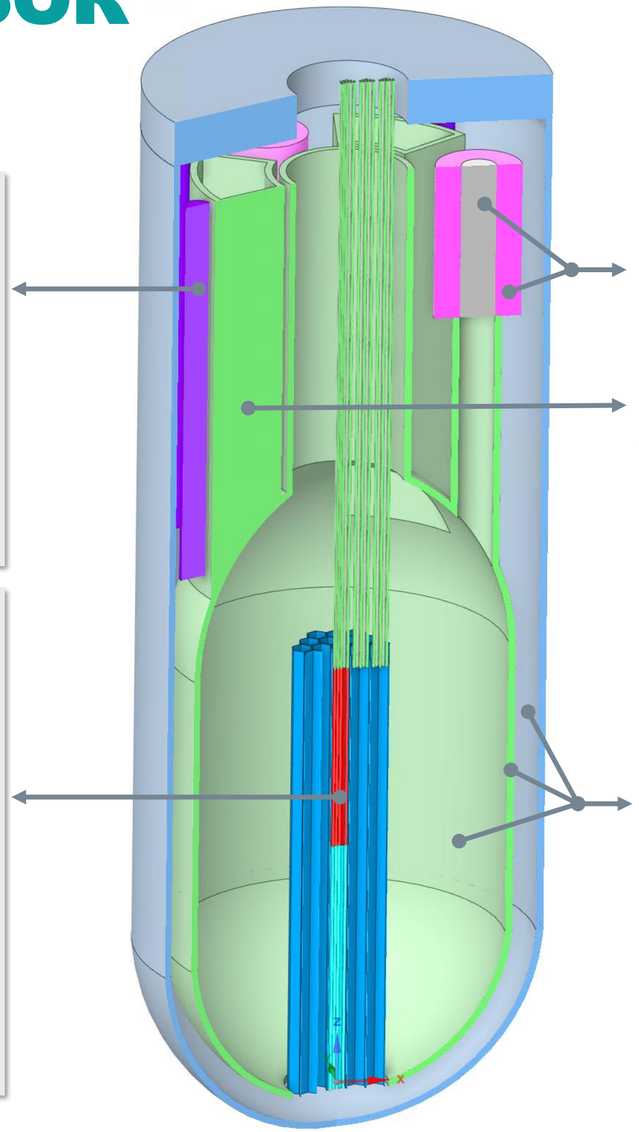
- PRECURSOR facility conceptual design phase currently ongoing
- Challenge to find the best tradeoff between **representativeness** (both at system and components level), **cost-effectiveness** and other **side constraints** (e.g., time, space)
- Consolidated **Power-to-Volume (P2V) scaling method** and **phenomena-driven approach** adopted to drive the facility design activities

DHR:

- With respect to reactor component, PRECURSOR DHR obtained by reducing the number of tubes while **preserving their length**. Solution to **minimise thermal-hydraulic distortions** (especially linked to DHR secondary circuit)

eCore:

- designed to **comply with P2V** while ensuring primary flow shaping (19 fuel assemblies) and minimising the number of heating rods
- Electric supply from **above**
- Ongoing activities to design a system to cool down the rods in their unheated sections **(parasite power generation due to Joule's effect)**



PRECURSOR facility, notional sketch

Pump and SG:

- SG designed to **minimise its radial footprint** (due to P2V constraints) while ensuring representative operating conditions of primary and secondary circuit
- Axial flow pump inside the SG as in LFR-AS-30

Control rods housing:

- Control rods penetrations included in order to **preserve ratio between hot and cold lead volumes**

Pools and ASIV:

- PRECURSOR vessel and Amphora-shaped Inner vessel (ASIV) dimensions such that hot and cold pool volumes are properly scaled down (according to P2V)
- **Preserved** components and overall system **length** to aim at a time-preserving approach

*new*cleo test facilities: MANUT (Dry/in-Lead)

for Fuel / Component Handling and Control rod actuation

MANUT will validate design choices on fuel assemblies (mechanical aspects), fuel handling operation and equipment, and primary system's components handling.

The main areas of interest related to fuel handling are:

- Fuel assembly mechanical design and functional tests on handling procedure and equipment;
- Rotating Plug System, which allow the connection between the Fuel Handling Machine and the reactor while maintaining primary confinement function;
- Fuel Handling Machine

Dry tests at the beginning, followed by tests in lead that will be carried out in close collaboration with ENEA.

A similar approach is envisaged for tests on component handling procedures and related components (counter flange / handling flask mechanism and leak tightness).

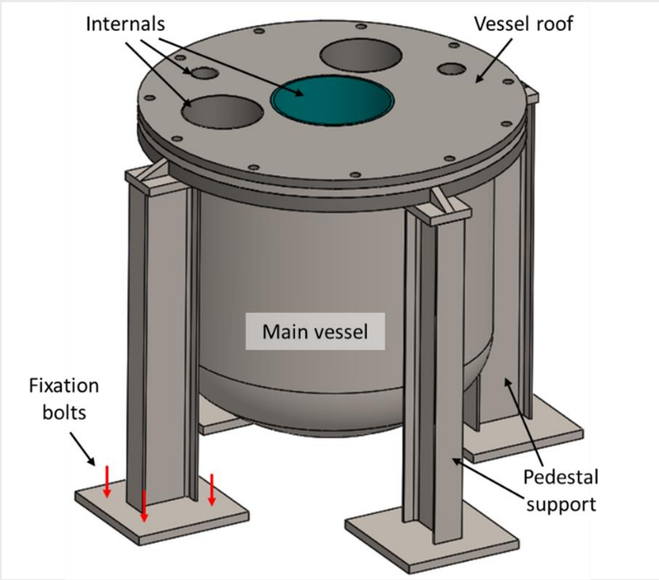
Testing activities are also foreseen on *new*cleo's control rods mechanisms

Other *new*cleo test facilities

EFESTO

Experimental FSI for Earthquake and Sloshing Test Observation

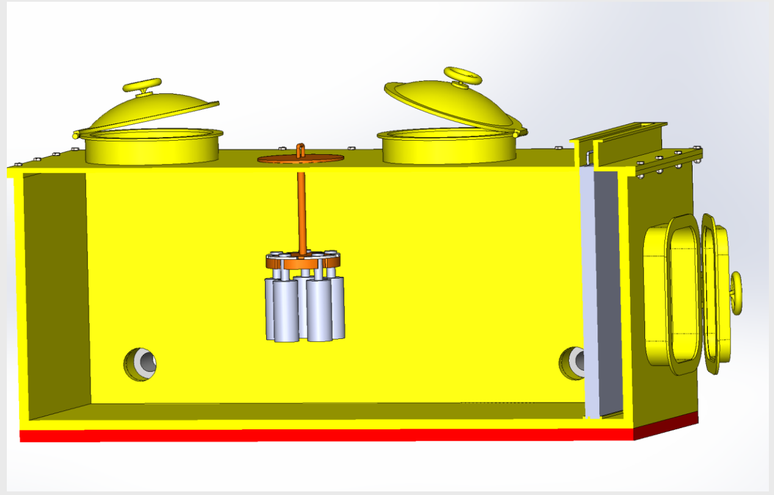
Small Lead pool, to be installed on a shaking table at ENEA Casaccia research lab



HUSTLE

Hot UltraSonic Testing Lead Experiment

To develop, test and calibrate various ultrasonic and visual inspection techniques for LFR vessel ISI purposes



*new*cleo's R&D programme summary

To broaden and complement this programme, **further collaborations** with nuclear companies, universities, laboratories and institutes **are being established and actively pursued by *new*cleo** to leverage existing infrastructure and accelerate R&D programmes

LFR Technical Domain / Experimental Facility	CORE1 & CORE2	CAPSULE	LEAD/CHEM LAB (BRA)	MAT LAB (TO)	MANUT in-lead	MANUT dry	EFESTO	NACIE-LHT	DCI	CIRCE-NEXTRA	OTHELLO	PRECURSOR
Structural materials and coatings	■	■	■	■								
Core, fuel and control/shutdown rods					■	■					■	
Coolant chemistry and auxiliary systems	■	■									■	■
Primary system integrity and component studies							■	■	■	■	■	■
Fuel and component handling					■	■						
Plant operation & accident response												■
Balance of plant integrity studies												■

The current planning of most R&D infrastructures foresees the completion of exp. campaigns within 2026 → **submission of the DAC file (French Safety Authority Licensing Dossier file) for the construction of LFR-AS-30/200 reactors** for low temperature operations

*new*cleo's R&D programme: further considerations

- A **Steering Committee** oversees the *new*cleo R&D programme and starts new R&D initiatives as needed to meet LFR projects needs
- The R&D programme is closely linked to *new*cleo **equipment qualification** and **computer code validation** programmes
- Actively pursuing opportunities for **testing of materials under neutron irradiation**
  - Having conversations with JAEA JOYO; JRC Petten HFR; CVR LVR-15
- *new*cleo R&D programme is also connected with **international research projects and initiatives**
  - EC-funded projects (see below)
  - CEN Workshop 064 Phase 3 PG 2 "Mechanics GEN IV and innovative reactors"

Project title	Call reference	Coordinator	Duration
LESTO - *LEad fast reactor Safety design and TOols*	*HORIZON-EURATOM-2023-NRT-01*	ENEA	48M *from November 2024*
CONNECT-NM - Coordination of the European Research Community on Nuclear Materials for Energy Innovation	*HORIZON-EURATOM-2023-NRT-01*	CIEMAT	60M *from October 2024*

newcleo: a compelling proposition

NUCLEAR FISSION OFFERS A SOLUTION TO DECARBONISATION AND ENERGY SECURITY
Abundant carbon-free, dispatchable baseload energy to achieve our 2050 objectives

SMALL MODULAR REACTORS AND GENERATION IV
To ensure affordability, fast deployment, safety, and high performance

MOX FUEL MANUFACTURING
Using nuclear byproducts as fuel provides a circular and sustainable solution

***newcleo* IS CONSTANTLY GROWING**
Led by a highly experienced management and engineering team

***newcleo* IS NOT ONLY ESG-ENABLED VALUE PROPOSITION, BUT ALSO ESG INVESTED**

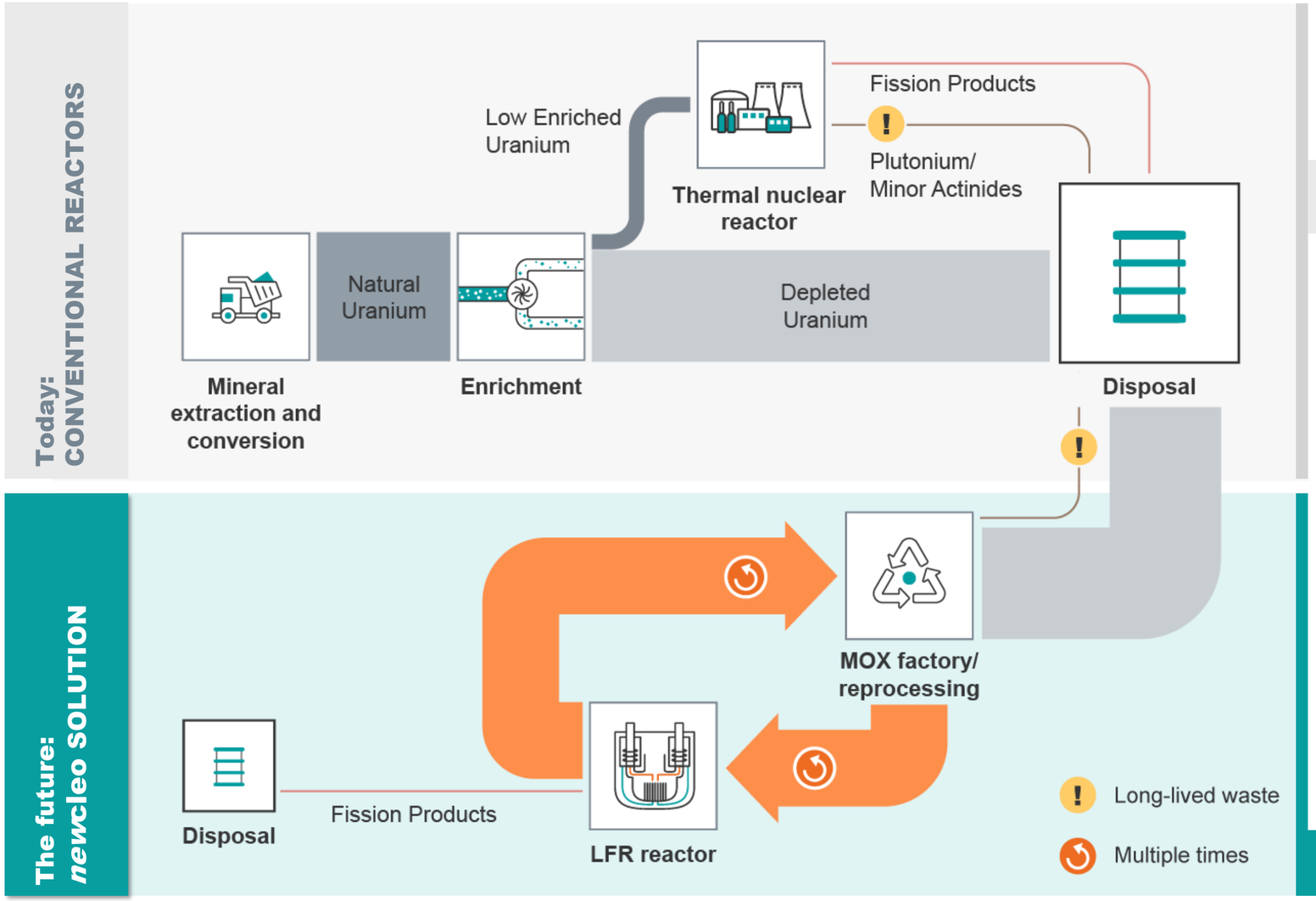
The future belongs to those who have the energy to imagine it. And build it.

Thank you

Appendix

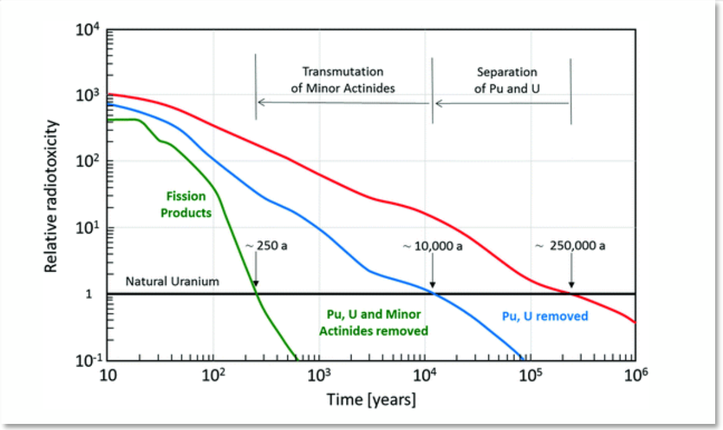
Closing the fuel cycle: MOX

Including MOX (Mixed Pu-U Oxides) for cost effective, cleaner, and virtually inexhaustible production of nuclear energy, with no need of mining



Thermal fission reactors use a very small portion of the extracted uranium: an average 1GWe LWR uses every year 200t of mined uranium of which only 1t is fissioned (Fission Products), the rest is not used

High-level waste has become an expensive liability



Today MOX for thermal reactors is used in a few countries, in a mono-recycling scheme. **Fast Reactors and fuel reprocessing** can extract energy from existing material and at the same time reduce radiotoxicity of residual waste to dispose: Fission Products return to value of the natural uranium ores after ~250 years

All artificial radioactivity created by reactors is virtually gone

International patents for our Gen-IV SMR designs

Patent 1
Spiral-tube Steam Generator — 1

Patent 2 and **Patent 3**
Pump/heat exchanger assembly — 2 3

Patent 4
Extended stem FA — 4

Patent 5
Self-supporting core — 5

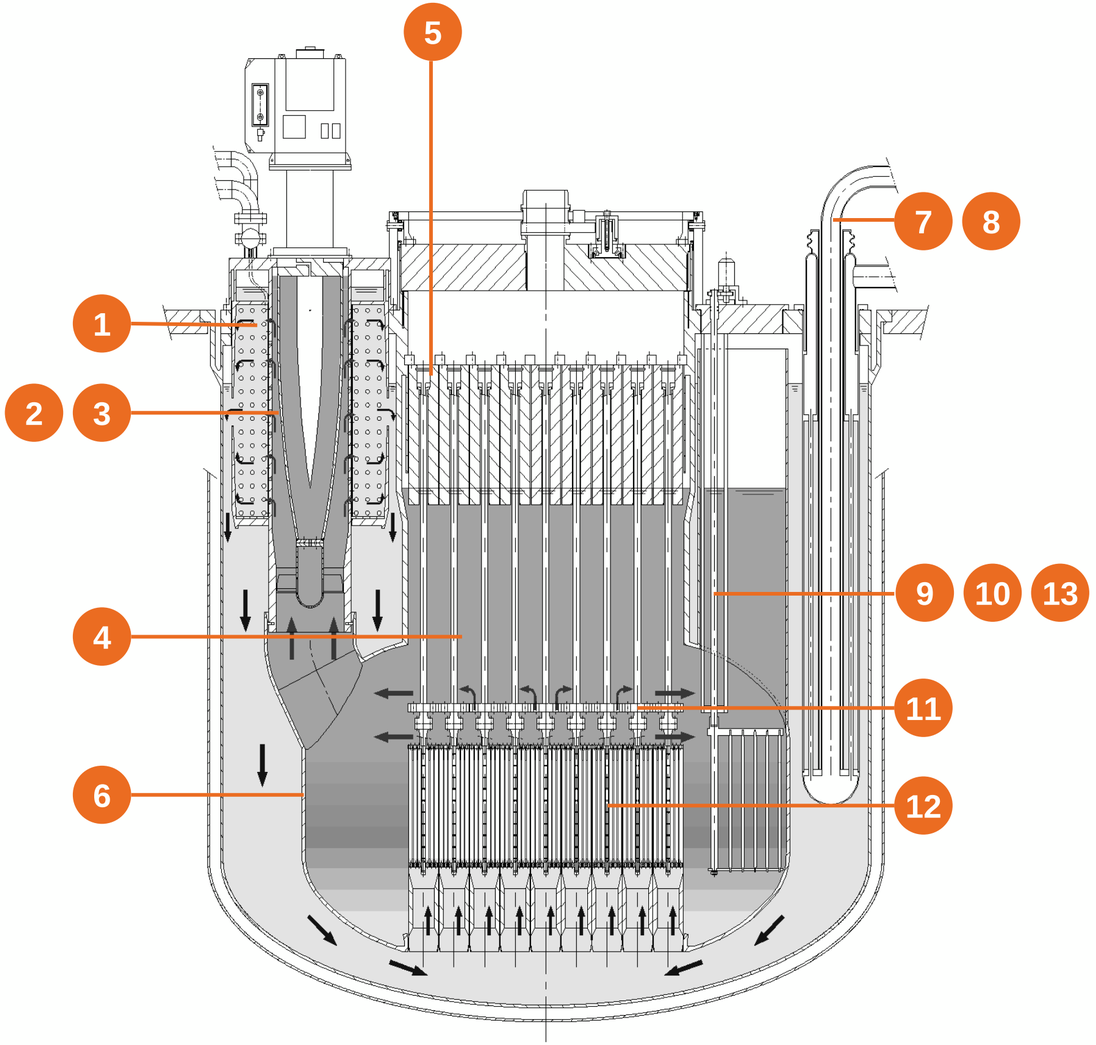
Patent 6
Amphora Shaped Inner Vessel — 6

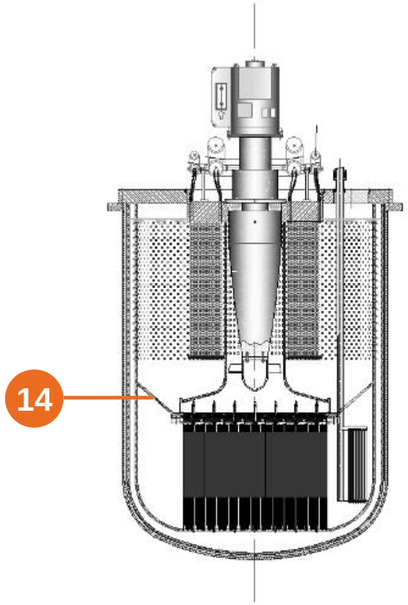
Patent 7 and **Patent 8**
DHR passive systems — 7 8

Patent 9, **10** and **13**
Control and shut down rods — 9 10 13

Patent 11
Expanders — 11

Patent 12
FA with cooling ducts — 12





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Patent 14
Support system of the core of a nuclear reactor
Filed 13-06-2022

Five additional patents filed in 2023