Italian National Agency for New Technologies, Energy and Sustainable Economic Development

SAUDI INTERNATIONAL CONFERENCE ON NUCLEAR POWER ENGINEERING

# Development of Lead-Cooled fast reactor technologies at ENEA Brasimone Research Centre

*SCOPE Conference13-15 Nov 2023 King Fahd Conference Center, KFUPM, Dhahran, KSA*


*Daniele MARTELLI*

**Fusion and Technology for Nuclear Safety and Security Department (FSN)**

# More energy… of a new type

**9.7** billion people by 2050
2/3 of the world's people living in urban areas

**25%** global energy increase by 2040
2 times faster electricity demand increase

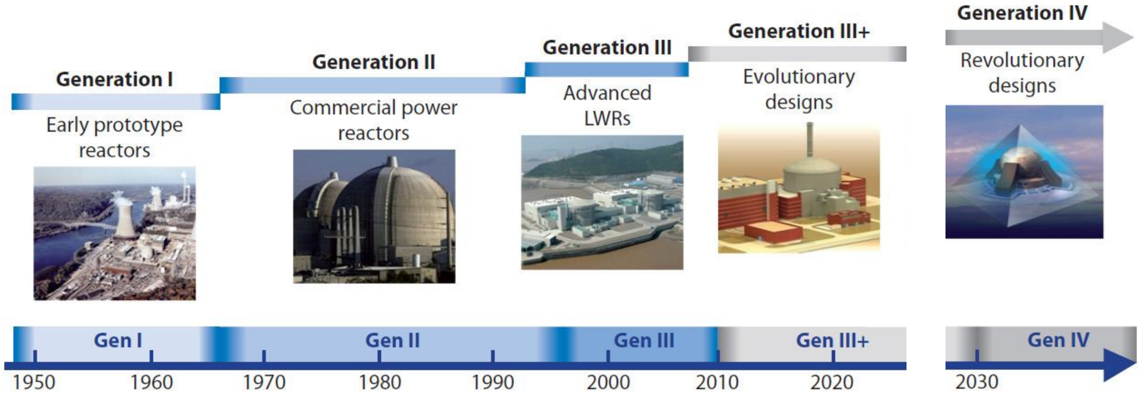
**1.7%** increase of $CO_2$ in 2018
70% higher than average increase since 2010

**2.8%** RES increase per year
RES will provide 31% of electricity generation by 2040

# New Technologies

New concepts: evolutionary…

**and revolutionary designs**




| *Generation IV Systems* | *Acronym* |
|---|---|
| Gas-Cooled Fast Reactor | GFR |
| Lead-Cooled Fast Reactor | LFR |
| Molten Salt Reactor | MSR |
| Sodium-Cooled Fast Reactor | SFR |
| Supercritical Water-Cooled Reactor | SCWR |
| Very-High-Temperature Reactor | VHTR |

# LFR .....the most promising GEN-IV system

- For heavy liquid metal coolants the stored thermal potential energy cannot be converted into kinetic energy.
- There is no significant release of energy and hydrogen in an events of coolant contacting with air, water, structural materials.
- There is no loss of core cooling in an event of tightness failure in the gas system of the primary circuit.
- LFR are reactor facilities with **the lowest stored potential energy**, where the inherent self-protection and passive safety properties are used to the maximal extent.

**Main advantages and main drawbacks of Lead**

| *Atomic mass* | *Absorption cross-section* | *Boiling Point (°C)* | *Chemical Reactivity (w/Air and Water)* | *Risk of Hydrogen formation* | *Heat transfer properties* | *Retention of fission products* | *Density ($Kg/m^3$) @400°C* | *Melting Point (°C)* | *Opacity* | *Compatibility with structural materials* |
|---|---|---|---|---|---|---|---|---|---|---|
| *207* | *Low* | *1737* | *Inert* | *No* | *Good* | *High* | *10580*<br>*10580* | *327* | *Yes* | *Corrosive* |

# Towards LFR…

## *A comprehensive R&D program is necessary because of:*

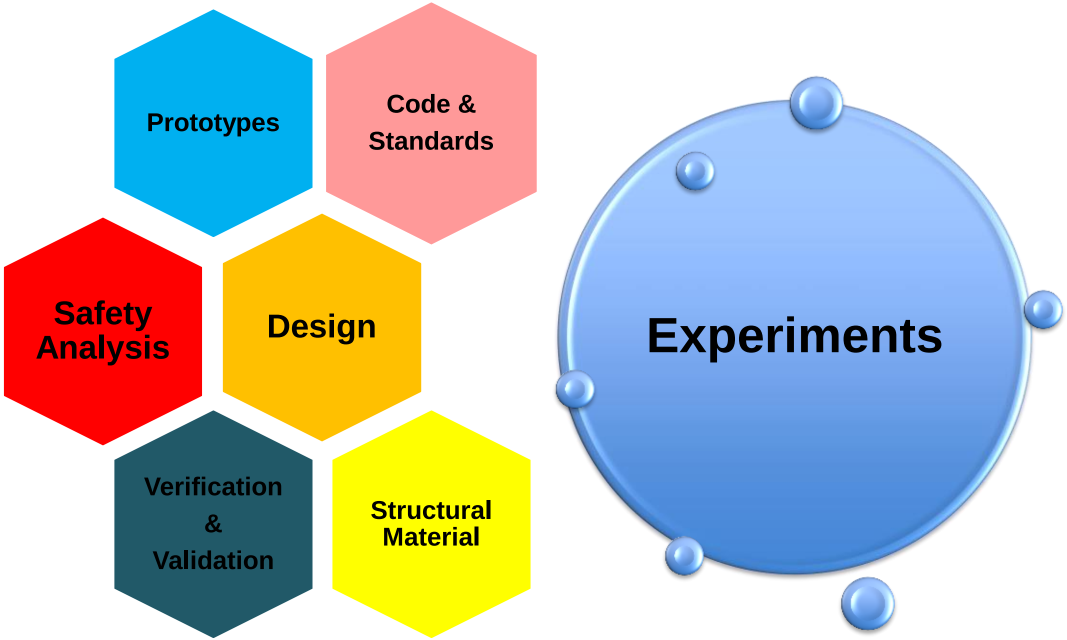
- **The use of a new coolant and associated technology, properties, neutronic characteristics, and compatibility with structural materials of the primary system and of the core.**

- **Innovations which require validation programs of new components and systems (the SG and its integration inside the reactor vessel, the extended stem fuel element, the dip coolers of the safety-related DHR system, pump, OCS, …)**

- **The use of advanced fuels (*at least in a further stage*).**

## *International Collaborations are set-up and continually strengthen*

# Role of Experiments in the R&D of LFR




- Integral test experiments
- Separate effect experiments
- Component qualification experiments

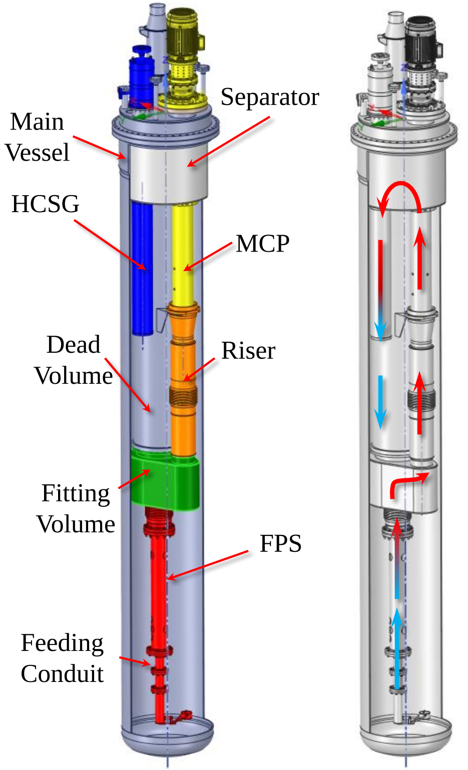
# Integral Test & component qualifications

## Test Section CIRCE-THETIS

*THETIS – Thermal-hydraulic HElical Tubes Innovative System*

The purpose of this integral test is to investigate transition from forced to natural circulation in and between four main operational modes and to qualify a prototypical helical coil steam generator and a mechanical pump

1. **With HCSG acting as DHR system.**
2. **With RVACS acting as DHR system for long term.**
3. **With HCSG and RVACS acting simultaneously as DHR system:**
4. **With RVACS active as DHR system**



# Integral Test & component qualifications

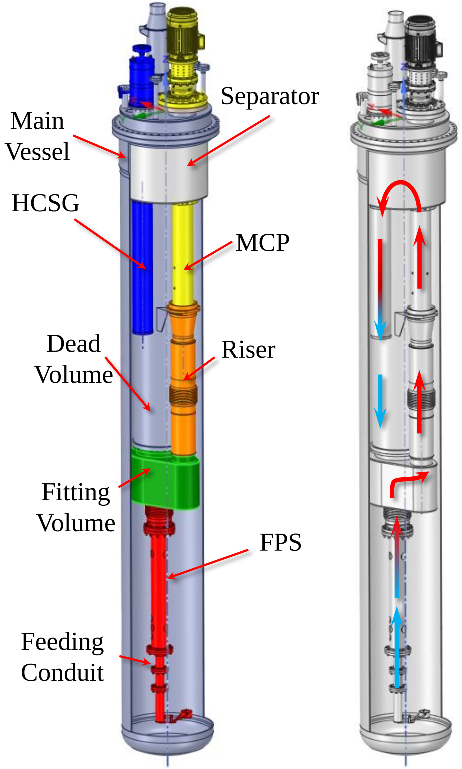
*PRO*

- *Compact geometry*
- *High heat transfer surface*
- *High robustness*
- *High flexibility*

*CONS*

- *Complex geometry*
- *Novel concept for HLM systems*
- *Lack of operational experience*
- *Lack of database for code validation*

| PUMP PARAMETERS | |
|---|---|
| **Type: mixed axial pump** | |
| **Working fluids: LBE/LLE** | |
| **Nominal FR [m³/h]** | 23 |
| **Min/Max FR [m³/h]** | 10/30 |
| **Pump head [bar]** | 1.5 |
| **Design T [°C]** | 500 |
| **LBE nominal FR [kg/s]** | 64.8 |

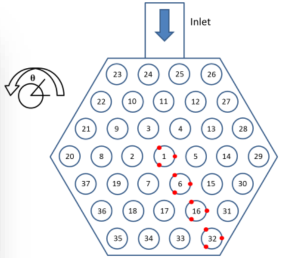


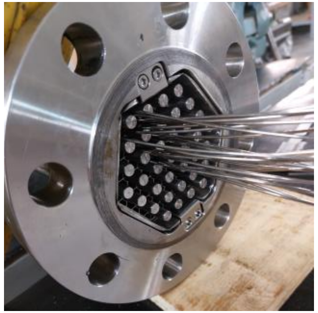
# FIV Experiments - HELENA loop

- HELENA is a pure lead loop and it consists mainly in a rectangular loop 5m height and 8m large

- The loop, designed by ENEA, is with 2 1/2” AISI304 pipe and it is designed for 550°C and 10 bar.

- The loop has a **prototypical mechanical centrifugal pump** (110 kW) which allows to reach 50 kg/s with 4 bar pressure head. The pump will be tested both as component and for impeller corrosion

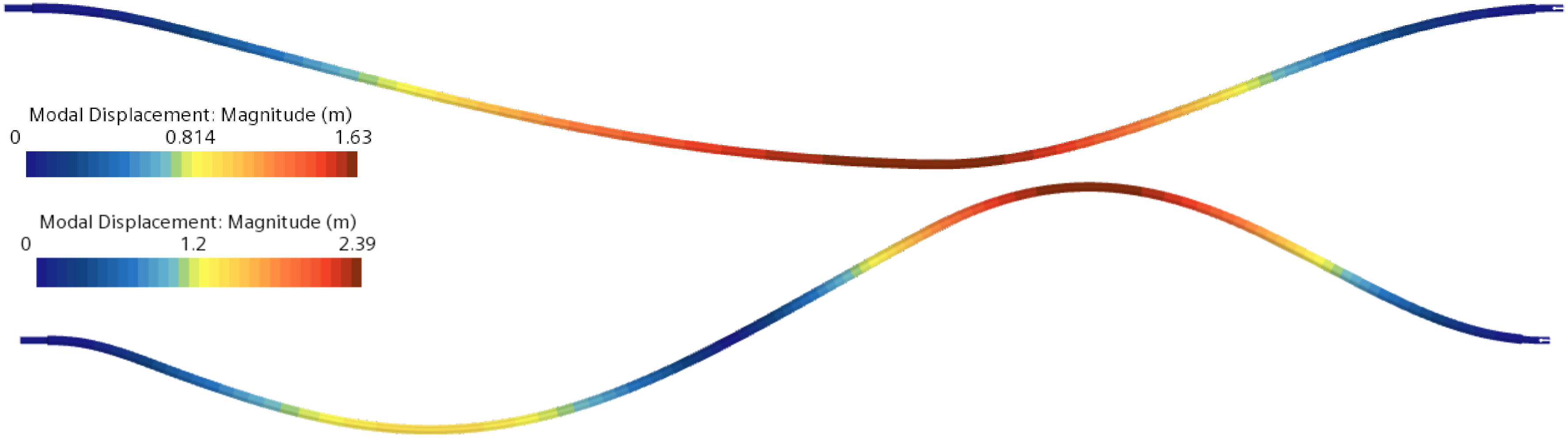


# FIV Experiments - HELENA loop

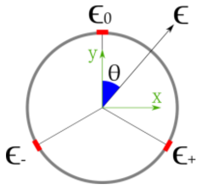
- Single pin – modal analysis

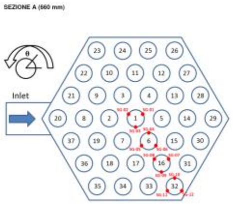
| Mode | Axial location of maximum displacement [m] | Location adjusted for start pin (+0.061 m) [m] |
|---|---|---|
| 1 | 0.622 | 0.683 |
| 2 | 0.628 | 0.689 |
| 3 | 0.445 | 0.506 |
| 4 | 0.454 | 0.515 |



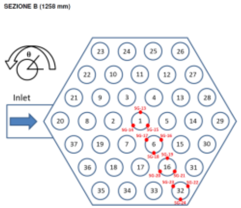
# FIV Experiments - HELENA loop

In each monitoring point will be installed with 3 SG at 120°




Z=660 mm
(first mode)




Z=1258 mm
(third mode)

The local curvature is approximated by an arc of a circle of radius R, d is the diameter of the pin

It can be shown that

$$R = \frac{d}{2\epsilon} = \frac{3\sqrt{2}}{4}\frac{d}{\sqrt{\epsilon_{eff}^2}}$$

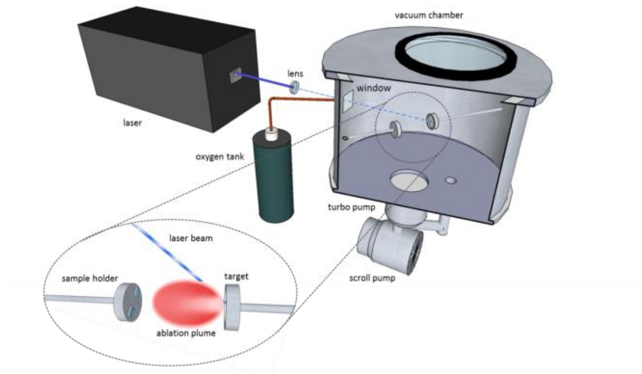
where $\epsilon_{eff}^2 = (\epsilon_0 - \epsilon_+)^2 + (\epsilon_0 - \epsilon_-)^2 + (\epsilon_+ - \epsilon_-)^2$ is a function of the deformation measured by the 3 strain gauges

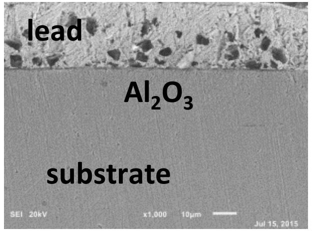
$$pin(z)_{k_1,k_3} = k_1 \cdot \left(M_1(z)\right) + k_3 \cdot \left(M_3(z)\right)$$

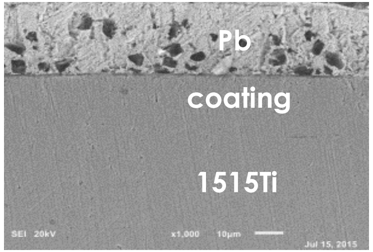
# Coatings developments

## Pulsed Laser Deposition Nanoceramic Coatings (IIT & ENEA)

1 μm Al2O3 coating
no buffer layer



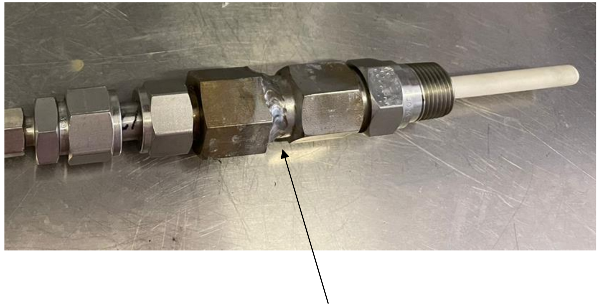




- ✓ high quality coatings
- ✓ custom process: bottom-up approach
- ✓ process at room temperature

- ✓ CREEP & SSRT test in lead a@550°C in very low Oxygen content environment (10^-8)

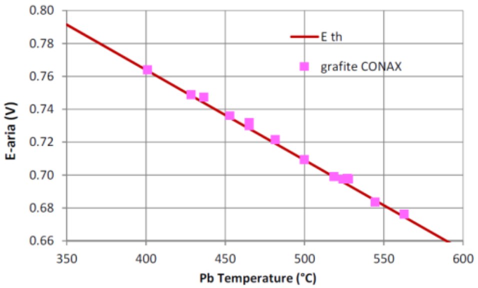
**Corrosion tests in static Pb:**
**550°C -1000 h - $10^{-8}/10^{-9}$ wt.% O**
**1 μm Al2O3 coating**

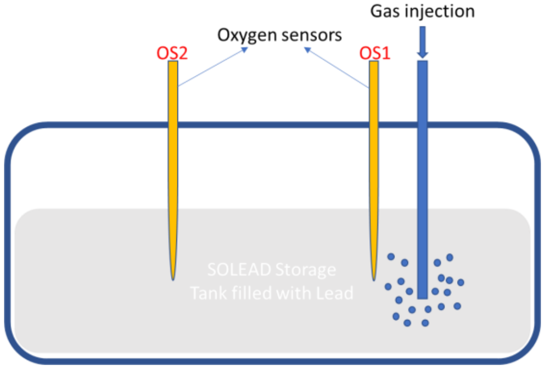
# Coolant chemistry

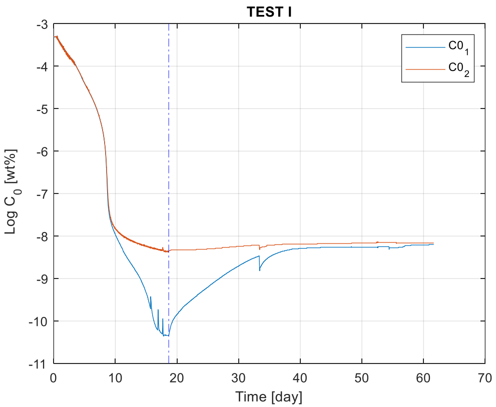


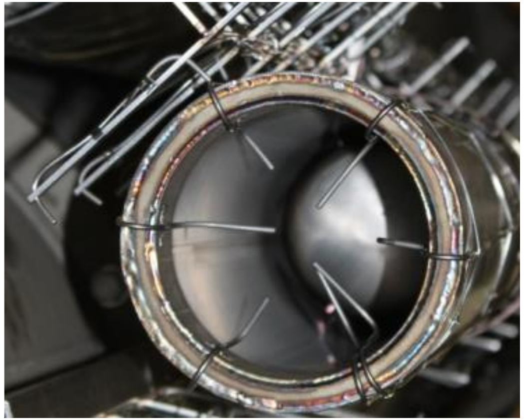
lead resistant weld

- Calibration test

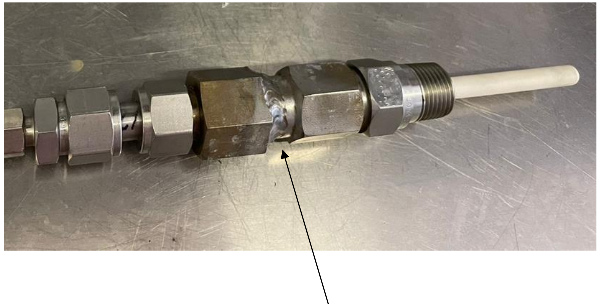


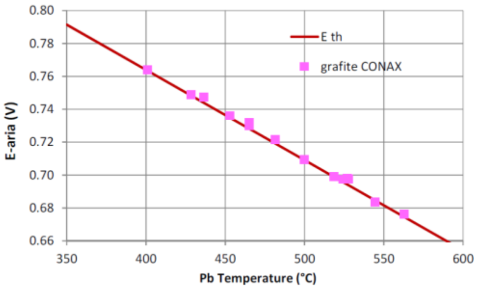



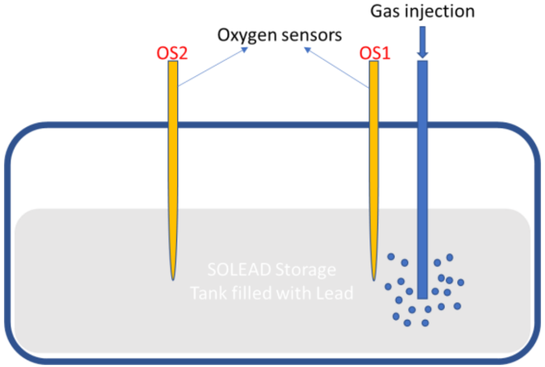



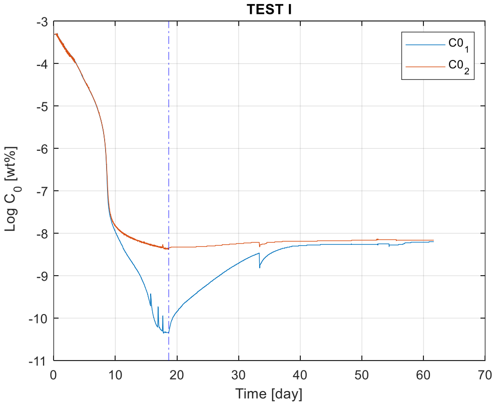
# Coolant chemistry




- Calibration test

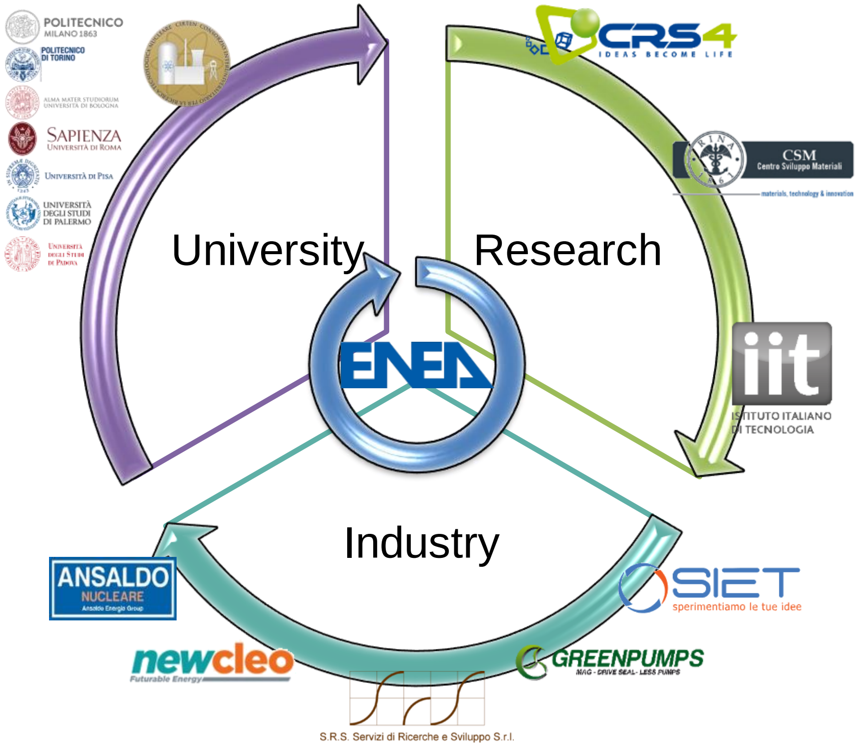



# The Italian landscape

**In the Italian framework, ENEA serves as coordinator for all LFR R&D projects involving universities, research organizations and industrial companies.**

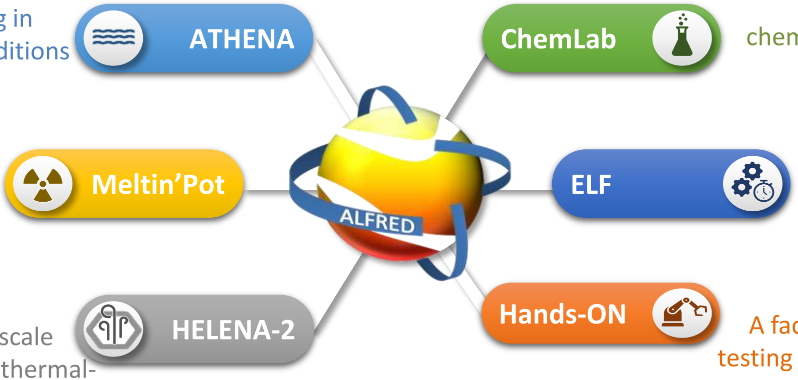


# ALFRED Advanced LFR European Demonstrator

The largest pool facility in the world, for large-scale components testing in representative conditions

A hot facility to characterize radioisotopes behavior in Lead under accident conditions

A loop facility for full-scale testing and complete thermal-hydraulic characterization of fuel and absorber assemblies

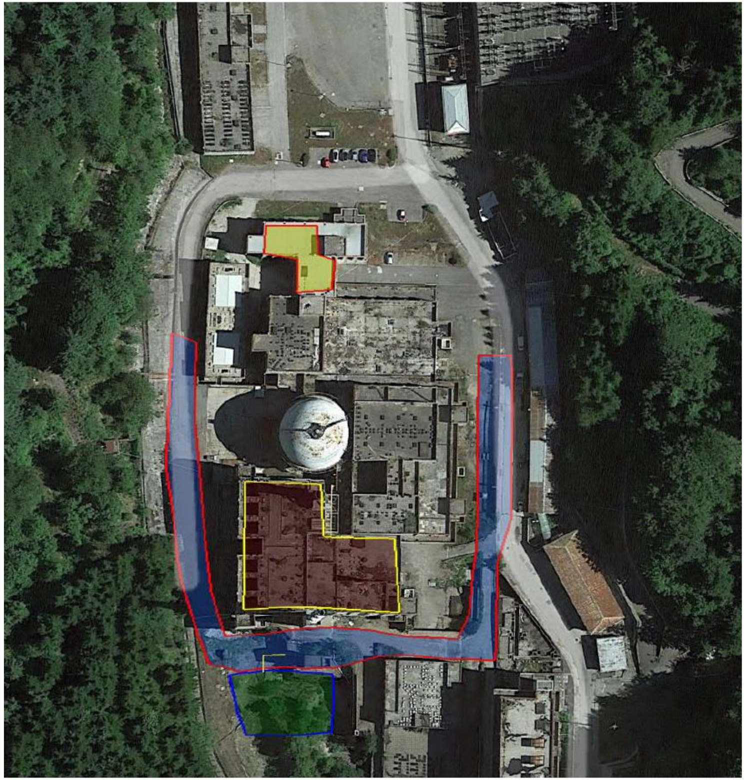



A broad-scope laboratory on the chemistry of HLMs and materials science

A pool facility for long-term experiments, to characterize the components and systems

A facility devoted to the testing and qualification of systems and procedures for the handling of core elements

# ENEA – NEWCLEO Agreement



DATA STAMPA
www.datastampa.it

la Repubblica BOLOGNA
Dir. Resp.: Maurizio Molinari
Tiratura: N.D. Diffusione: 16061 Lettori: 137000 (0001581)

17-MAR-2022
da pag. 2 /
foglio 1
Superficie 16 %

*Accordo Enea-Newcleo per studiare i nuovi reattori di quarta generazione*

## Nucleare, 50 milioni al Brasimone

*di* **Marco Bettazzi**

Nuova linfa al Brasimone. Grazie a un accordo annunciato ieri tra Enea e la società Newcleo con sede a Londra, sulle sponde del lago sull'Appennino bolognese si studieranno nuovi reattori nucleari di quarta generazione che poi verranno realizzati fuori dall'Italia. Un investimento da 50 milioni che porterà all'assunzione di 25-30 ingegneri.

Ed è un'altra boccata d'ossigeno per la montagna, dopo la conclusione felice della vertenza Saga Coffee, il rilancio delle Terme di Porretta e gli investimenti legati al Pnrr. Questa volta si parla di energia nucleare, ovvero quello di cui si occupava il centro Enea prima del referendum del 1987. Da allora il Brasimone, dove lavorano una settantina di persone, si è specializzato in altri ambiti di ricerca come la fusione nucleare e lo studio dei metalli fluidi. Newcleo invece è una start up che fa ricerca sull'energia costituita nel 2021 da Stefano Buono, imprenditore e fisico italiano che ha lavorato per 10 anni col premio Nobel Carlo Rubbia al Cern e ha poi creato un'altra start up, venduta nel 2018 a Novartis per 3,9 miliardi di dollari.

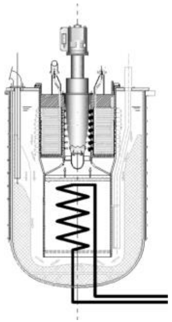
La centrale del Brasimone

In base all'accordo Enea e Newcleo investiranno al Brasimone, che tra i comuni di Camugnano e Castiglione dei Pepoli conta 400 ettari di superficie e 17 diversi edifici. Verranno rinnovati impianti e laboratori per realizzare un prototipo elettrico di reattore raffreddato al piombo, senza l'uso di materiali radioattivi o combustibile nucleare. Per 50 milioni di investimenti, appunto, e un team di 25-30 ingegneri che lavoreranno "in pianta stabile per circa 10 anni", spiegano Enea e Newcleo.

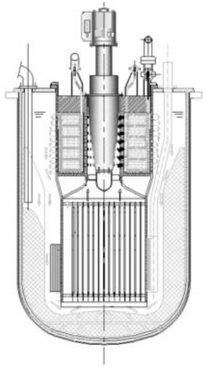
«Collaboreremo per garantire la produzione di energia elettrica in sicurezza e a lungo termine in impianti da realizzarsi all'estero – spiega Gilberto Dialuce, presidente di Enea – ma con ricadute rilevanti di investimenti e occupazione a livello locale».

«Lavorando insieme a Enea e investendo nelle strutture del Brasimone – spiega invece Buono – contribuiremo all'avanzamento della ricerca in Italia». Esultano le istituzioni locali. «È la più grande operazione di rilancio di un sito strategico per il Paese», conclude l'assessore regionale Vincenzo Colla.

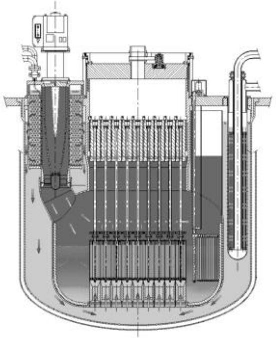
# *new*cleo's LFR-SMRs – Reactor development goals



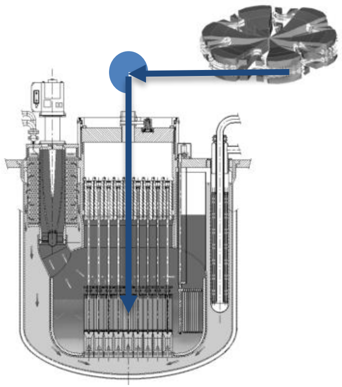
Ø ≅ 2.5 mt ≅ 3.2 mt



Ø ≅ 3.5 mt ≅ 5 mt



Ø ≅ 6 mt ≅ 6.2 mt



| 5 years | 7/10 years | 10/12 years | 13/15 years |
|---|---|---|---|
| **Precursor** | **Mini LFR-SMR (30 MWe)** | **LFR-SMR (200 MWe)** | **ADS LFR-SMR** |
| Electrically heated facility **10MWth**, with turbogenerator.<br><br>It reproduces scaled or full-scale components of the Mini LFR | Power: **30 MWe**<br>Fuel: MOX<br><br>***new*cleo's present activity is focused on the 30MWe LFR** | Power: **200 MWe**<br>Fuel: MOX + MA<br><br>Terrestrial plant to burn existing nuclear waste | Power: TBD<br>Fuel: MOX + MA, U free fuels, Thorium<br><br>The future Accelerator-Driven reactor |

# Remarks

- Nuclear energy will play a relevant role in the forthcoming energy transition scenario. Revolutionary design of fission technologies, ready to market in the frame 2030-2035, will sustain the transition.
- **Lead cooled Fast Reactors** seems to be among the most promising! Many initiatives are supporting such approach and, among the others
- On LFR, international context is every day more positive.
- ENEA is working to strength the international collaboration to target the industrial goal of the LFR on the market by 2030-2035.
- ENEA has developed large international collaborations on the most innovative and promising nuclear technologies, involving research bodies and industries

Daniele Martelli
martelli.daniele@enea.it



ENEA