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

Il ruolo dell'Italia sui reattori di quarta generazione

Mariano Tarantino

Cambiamenti Climatici e Transizione Energetica

28th March 2024

Nuclear Department (NUC)

Role of nuclear in the «energy transition»

Nuclear to be included in Delegated Act of EU taxonomy

21 April 2021

Share

The European Commission today announced its decision to include nuclear energy in a complementary Delegated Act of the EU Taxonomy Regulation. The decision follows the recent publication of the Joint Research Centre's report confirming nuclear is as sustainable as other taxonomy-compliant energy technologies.

The European Commission building in Brussels (image: Pixabay)

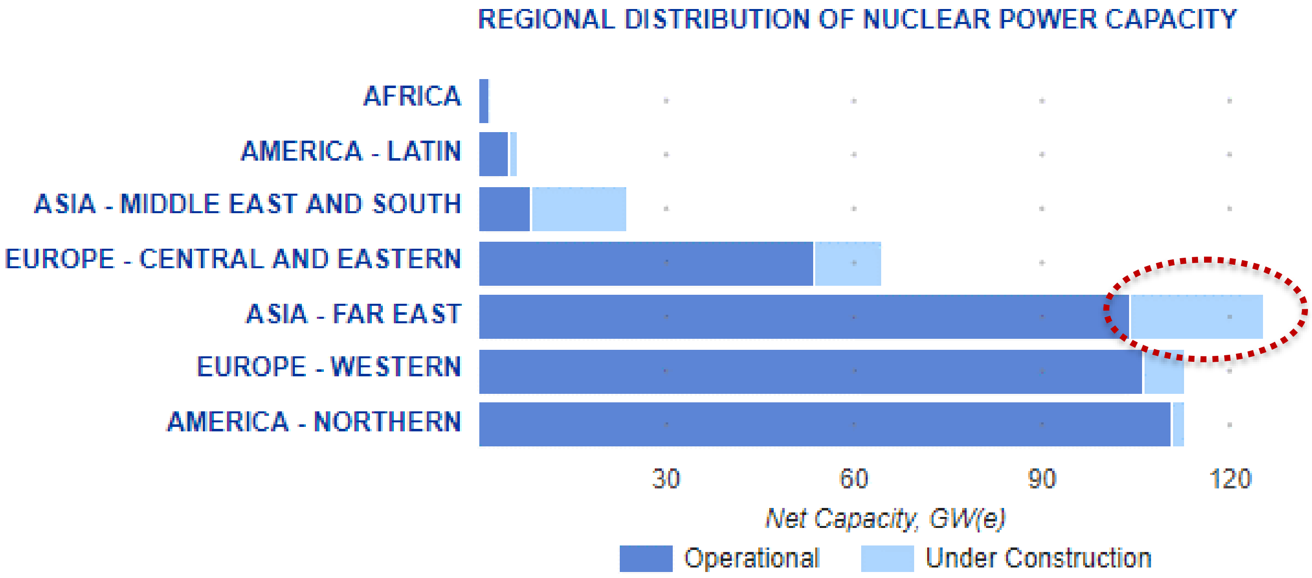
- **Nuclear energy is the largest (26.7% in 2019) single source of low-carbon energy in the EU**, ahead of hydro (12.3%), wind (13.3%), solar (4.4%) and other (0.5%).
- **Nuclear** energy contributes to **climate mitigation**.
- The technical expert group on Taxonomy concluded that there is clear evidence that **nuclear substantially** contributes to climate mitigation.

Ref.: World Nuclear News

https://world-nuclear-news.org/Articles/Nuclear-to-be-included-in-Delegated-Act-of-EU-taxo

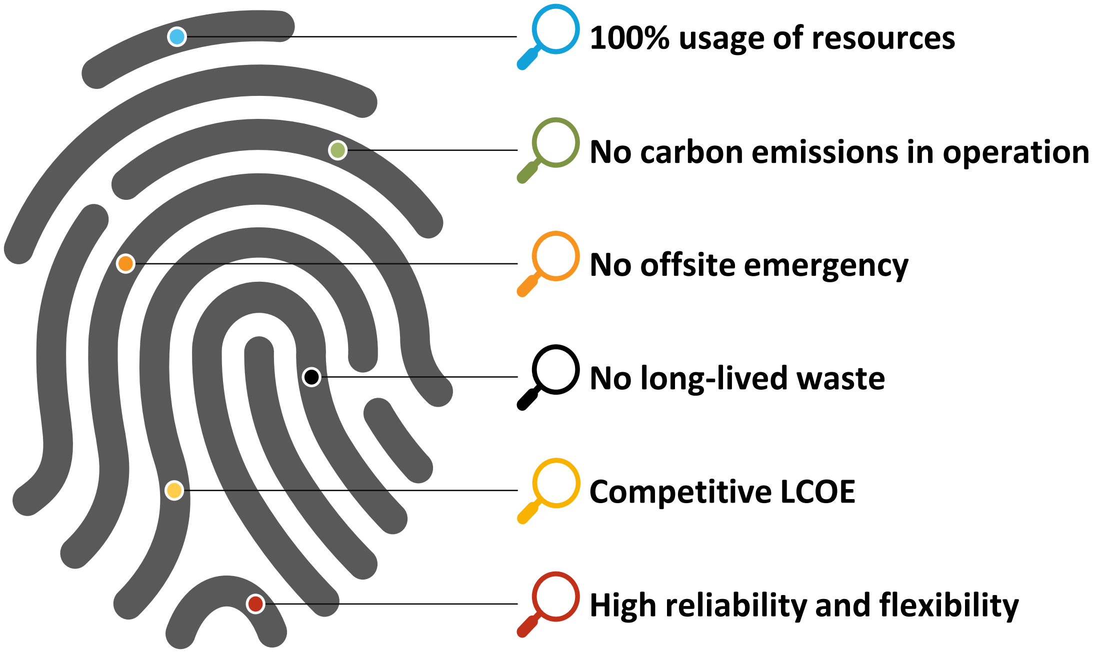
Current status

- 443 Nuclear Power Plants in operation
- Almost 19 000 reactor-years of opreation
- 52 Nuclear Power Plants under construction



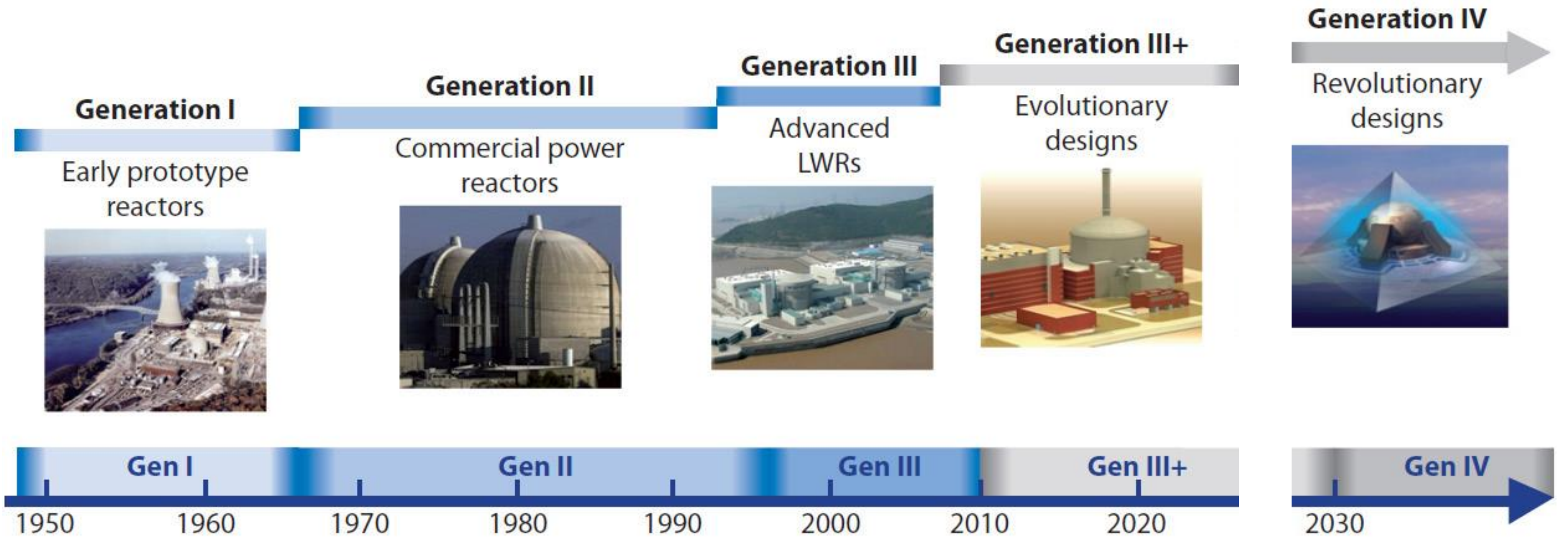
The «ideal» Nuclear Power Plant

Fission Nuclear Power Plants of a new type are being developed for a short-term deployment (beyond 2030) to replace the current fleet and better integrate future hybrid energy systems: smaller, more flexible, economically competitive, able to produce more than purely electricity.



New Technologies

New concepts: evolutionary… **and revolutionary designs**



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* *10580*	*327*	*Yes*	*Corrosive*

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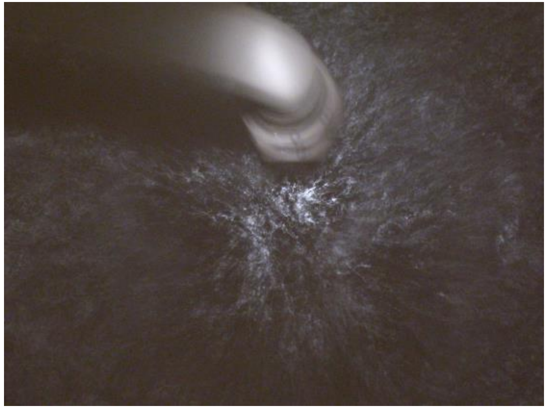
Towards LFR…

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.**

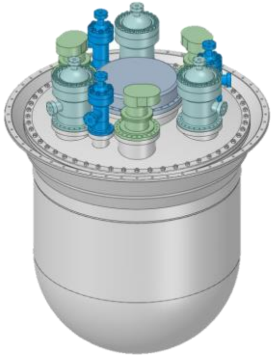
- **Innovations which require validation programs of new components and systems (the SG and its integration inside the reactor vessel, the extended stem fuel element, the dip coolers of the safety-related DHR system, pump, OCS, …)**

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

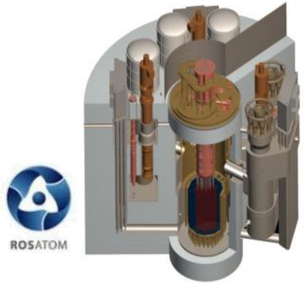


International Collaborations are set-up and continually strengthen

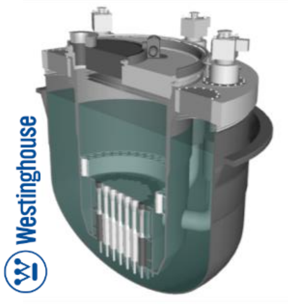
LFR International Framework



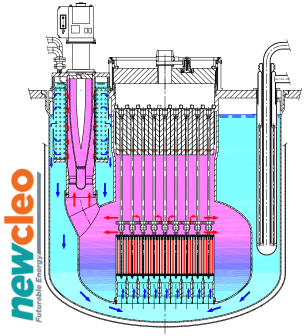
ALFRED
120 MWe, Romania - Italy
Under design



BREST-OD-300
300 MWe, Russia
Under construction

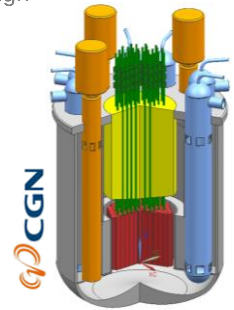


Westinghouse LFR
450 MWe, USA
Under design

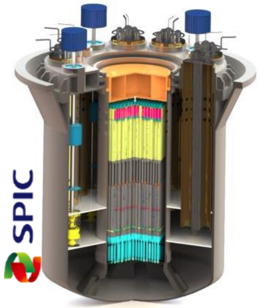


NewCleo AS-200
200 MWe, UK-ITALY
Under design

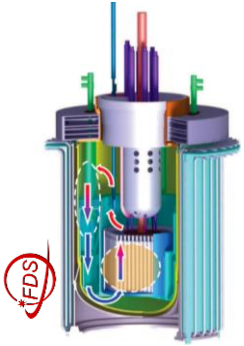
LeadCold SEALER
1-10 MWe, Sweden
Under design



CLFR-300 and CLFR-10
300/10 MWe, China
Under design



BLESS
100 MWe, China
Under design



CLEAR-1
10 MWth, China
Under design

Micro-Uranus
60 MWth, Korea
Under design

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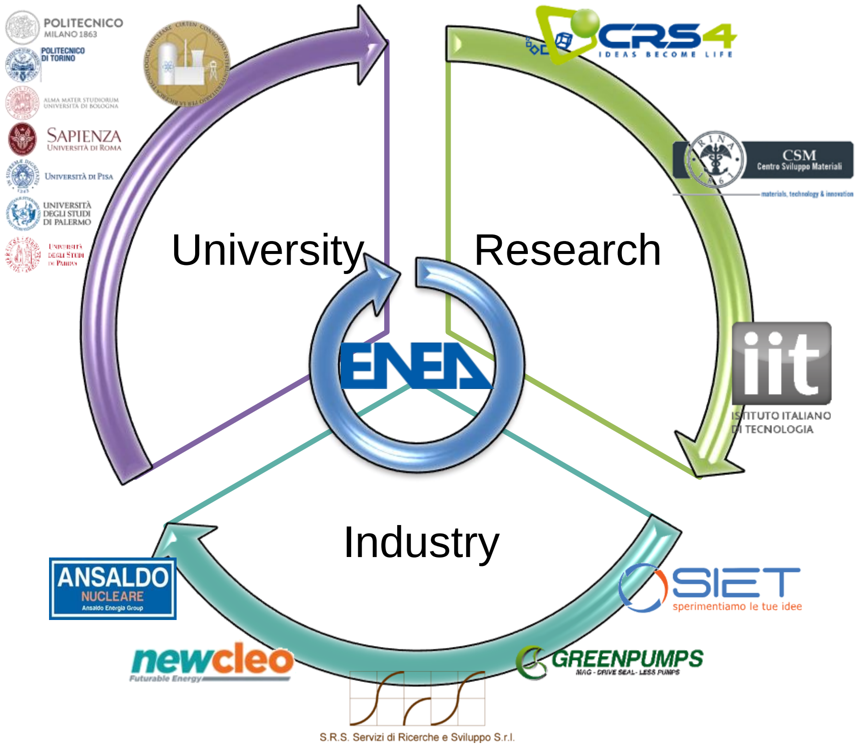
The Italian landscape

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



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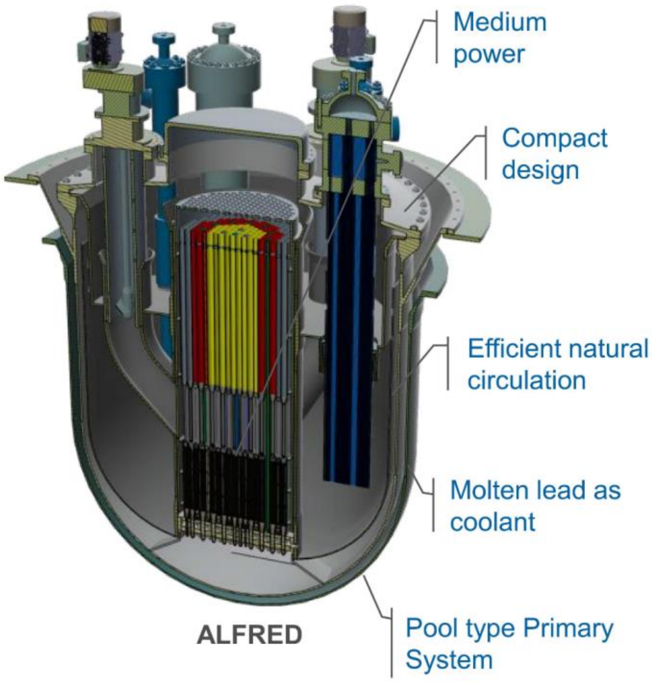
FALCON Consortium



- Deployment of a lead-cooled fast reactor demonstrator having
  - SMR-oriented features aimed at being a competitive option for the future Nuclear Power Plants (replacing the old generation NPPs facing retirement or conventional technologies based on fossil fuels), as well as
  - longer-term potentialities to demonstrate that the LFR technology can meet the goals set out by GIF for Generation-IV reactors

RATEN ICN PITEŞTI ansaldo nucleare ENEA

FALCON Consortium

POLITECNICO MILANO 1863

Università di Pisa

Sapienza Università di Roma

Università degli Studi di Palermo

Alma Mater Studiorum Università di Bologna

POLITECNICO MILANO 1863

CESINA

FALCON

ANSALDO NUCLEARE Ansaldo Energia Group

ENEA

RATEN ICN PITEŞTI

Supporting organizations (MOA)

walter tosto

NUCLEARELECTRICA

S.R.S. Servizi di Ricerche e Sviluppo S.r.l.

NRG

CRS4 IDEAS BECOME LIFE

GREENPUMPS MAG - DRIVE SEAL- LESS PUMPS (*)

EMPRESARIOS AGRUPADOS

iit ISTITUTO ITALIANO DI TECNOLOGIA (*)

CHALMERS UNIVERSITY OF TECHNOLOGY

(*) Bilateral agreeement with ENEA

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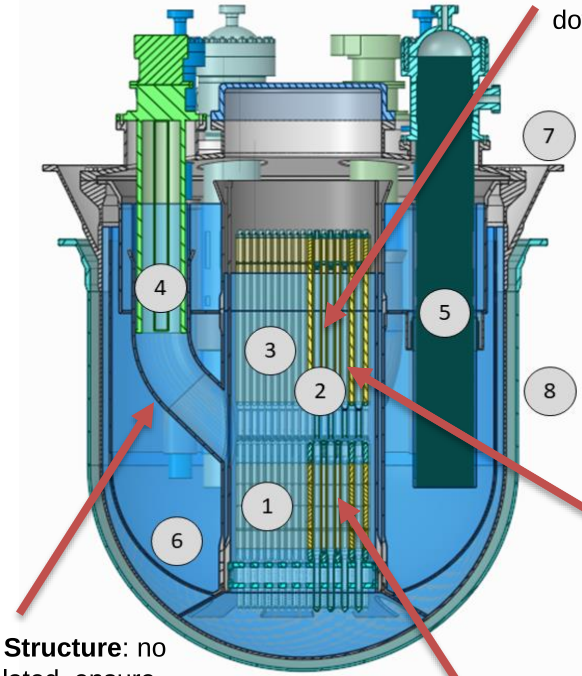
ALFRED Layout

Reactivity control: Two diverse and redundant systems, control and shut-down rods

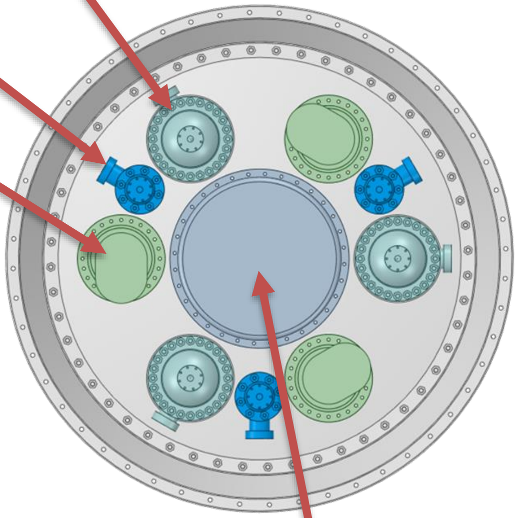


1. Core
2. Sub-Assemblies
3. Inner Vessel
4. Reactor Coolant Pump
5. Steam Generator
6. Internal Structure
7. Reactor Vessel
8. Safety Vessel

Steam Generator

Dip-cooler

Pump



Fuel assemblies: MOX fuel, grid-spaced, hexagonal, wrapped, extended stem

Design to ensure FA handling under lead during refueling operations

Internal Structure: no safety related, ensure pools separation and flow recirculation

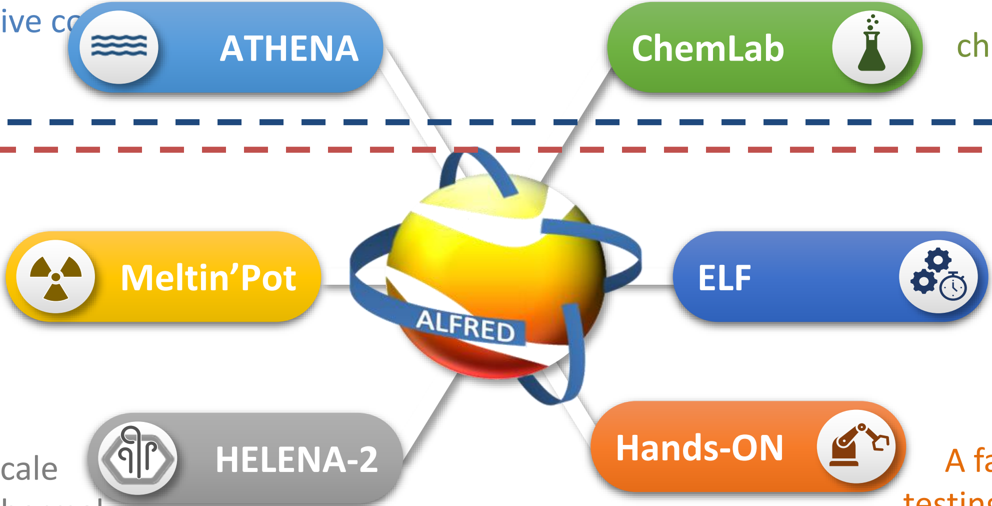
Inner Vessel: safety-related, removable for out-of-vessel inspection

A world-class Research Infrastructure

Under Construction (22 M€)

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

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



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

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

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

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

Funding secured (> 100 M€)

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ATHENA installation almost completed

the first step of ALFRED experimental infrastructure

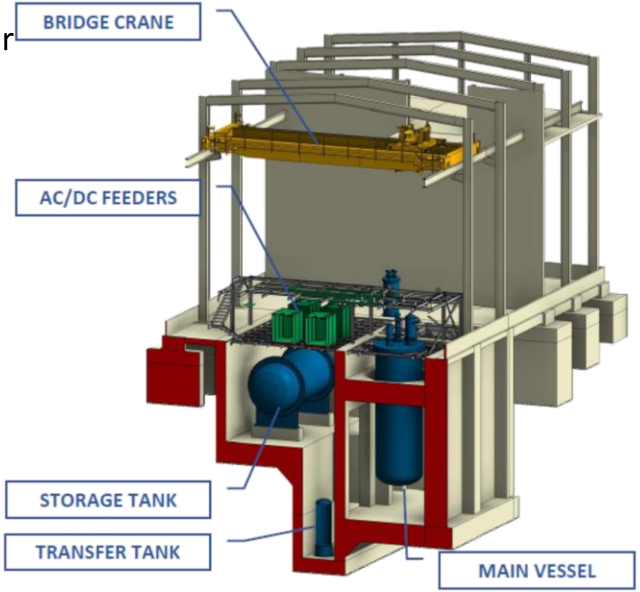
- 2.21 MW Core simulator
- Full height bayonet tube heat exchanger
- Main Vessel hosting 800 tons of lead

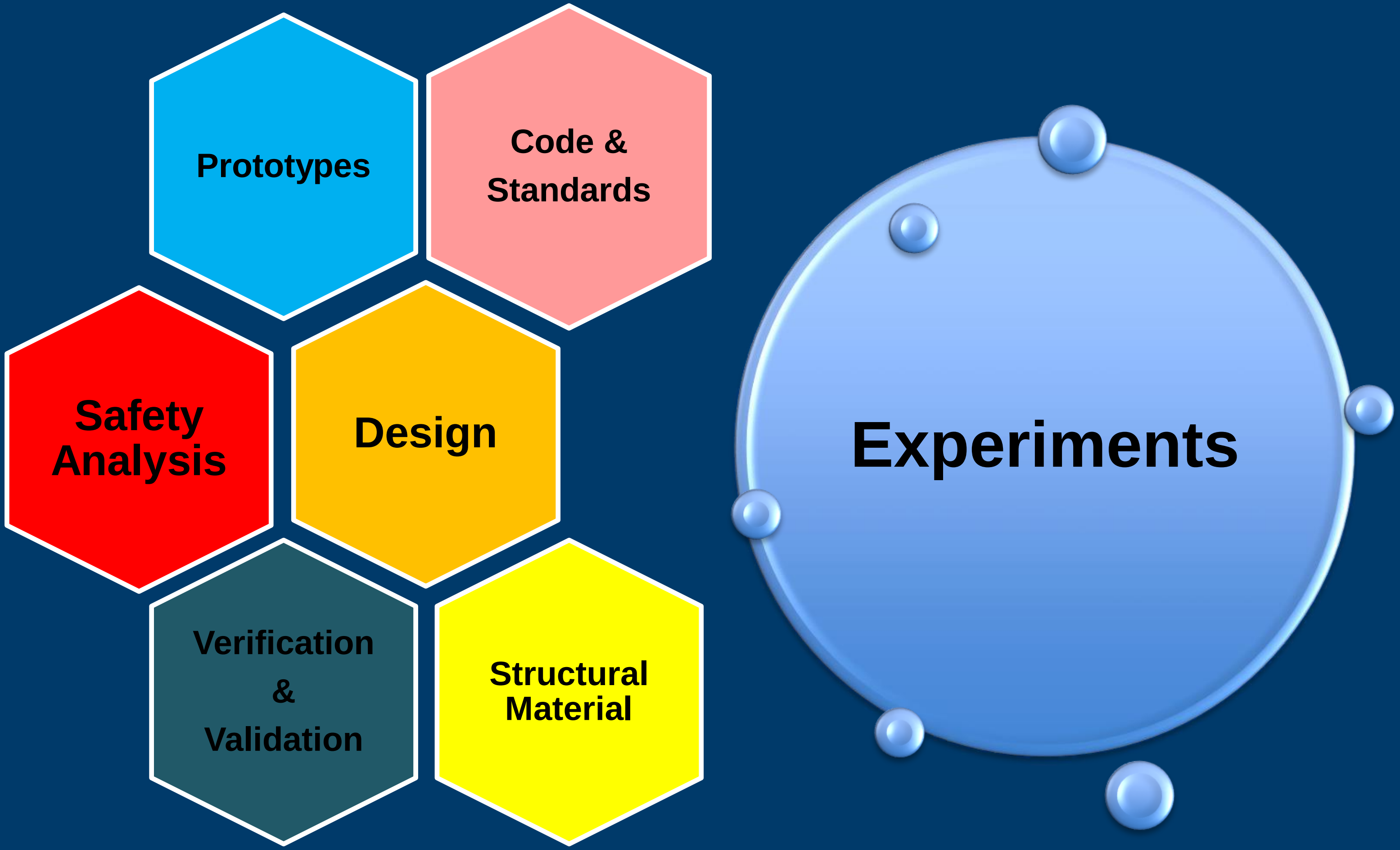
Status:

- Auxiliary building is ready
- Main equipment are on site
- Civil works progressing steady

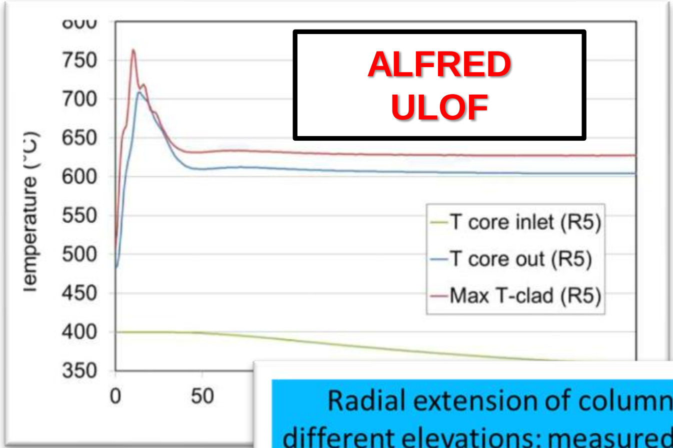
Experiments to be performed:

- Fuel assembly performance
- Chemistry control in large pools
- SGTR

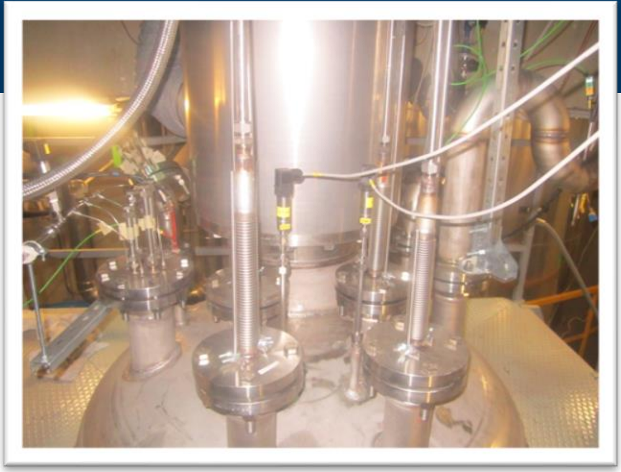



Prototypes
Code & Standards
Safety Analysis
Design
Verification & Validation
Structural Material
Experiments

Safety Analysis

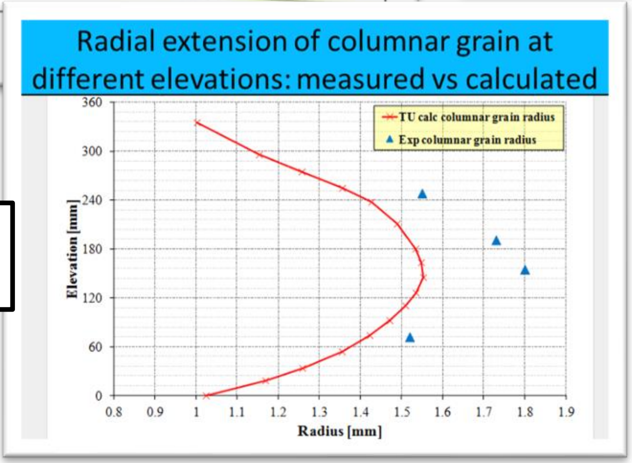


ALFRED
ULOF

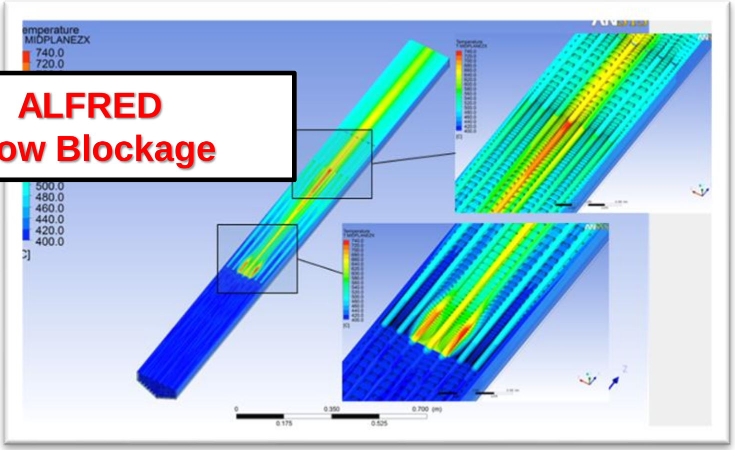


MYRRHA
SGTR

Fuel
Safety

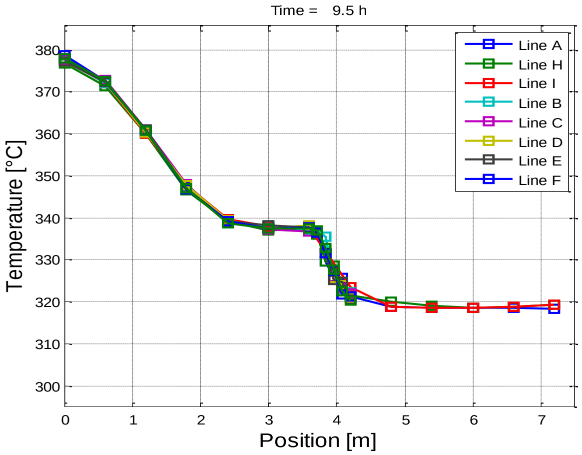


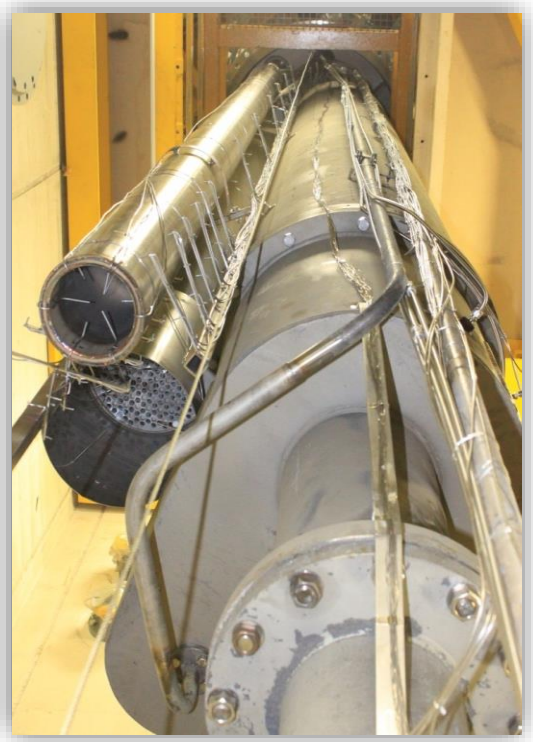
ALFRED
Flow Blockage

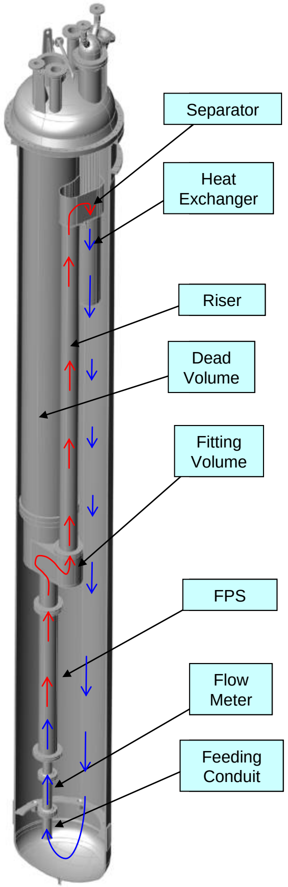


Integral Test & Component Qualification

- **Integral Experiments (@ 1 MW)**
- **OCS testing in large pool**
- **Component qualification**
- **SGTR Experiments**
- **SG & Pump Unit Test**







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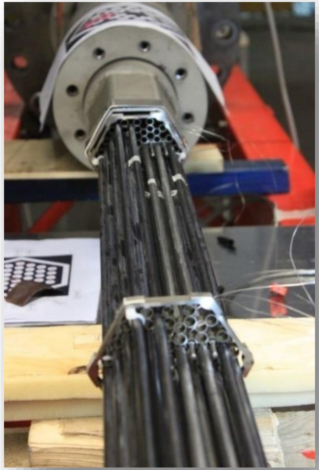
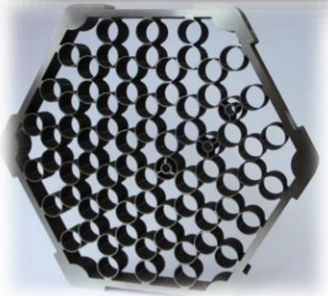
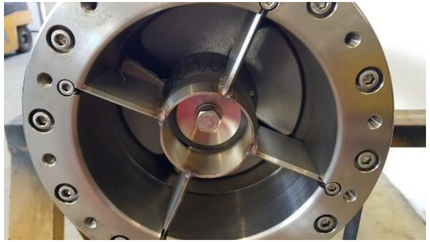
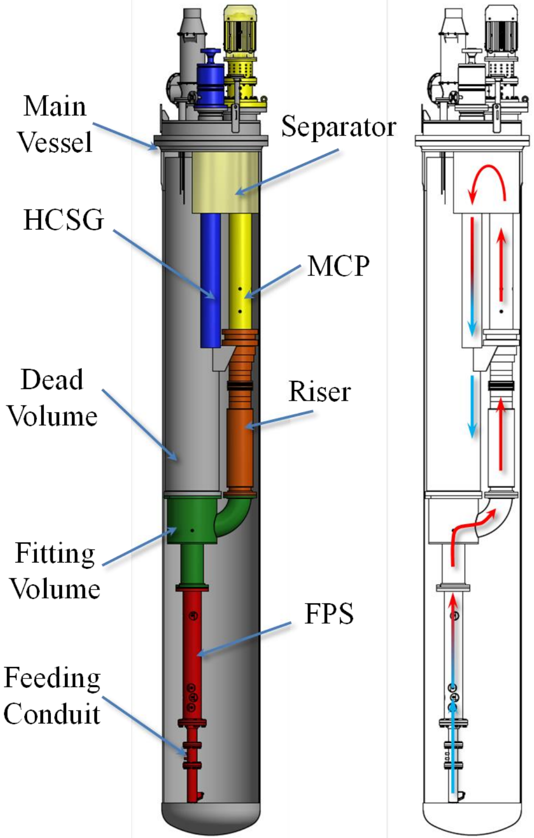
Integral Test & Component Qualification



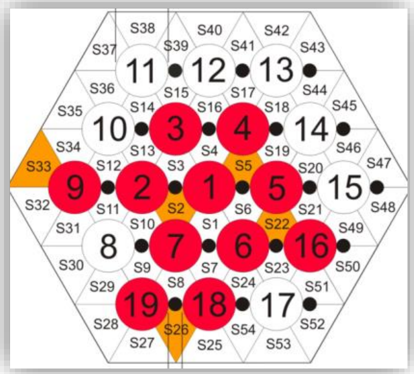






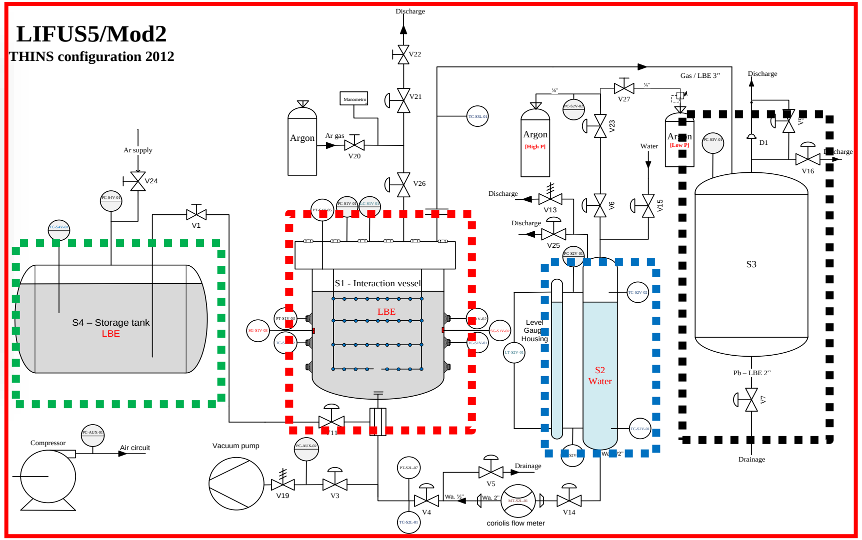
Fuel Pin Bundle

- Experiments @ 250 kW
- OCS testing in loop
- Component qualification
- Instrumentation Test



Separate Effect Experiments

- HLM-water interaction
- Component qualification



- ❑ Experimental facility for **HLM/water interaction** investigations (i.e. PbLi, LBE, Pb)
- ❑ Designed to operate in a wide range of conditions: **up to 200 bar and 500 °C**
- ❑ Suitable for code validation, models development, safety analysis studies, testing engineering solutions, …

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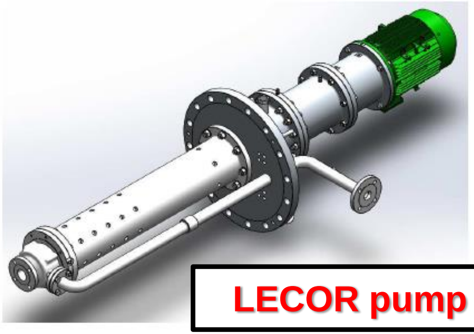
Material Characterization

- Corrosion test in flowing lead
- OCS testing in loop
- Component qualification
- Instrumentation Test
- Pump Unit Test


LECOR loop


HELENA pump impeller

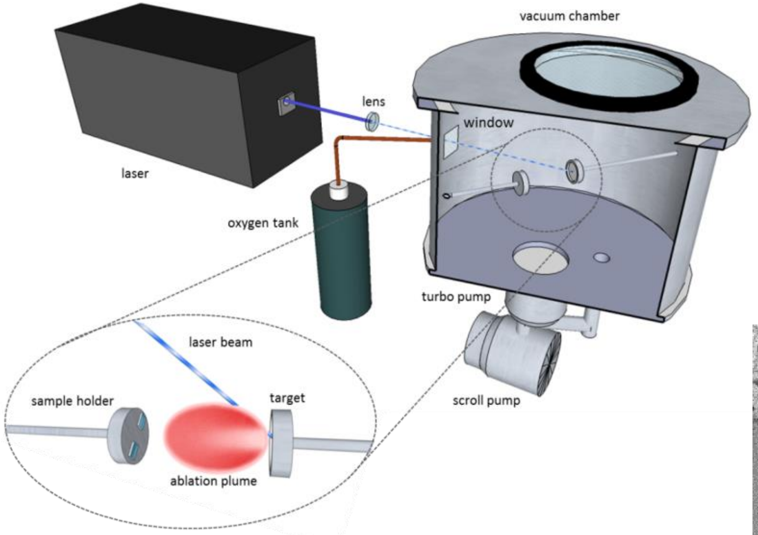

LECOR pump


HELENA pump

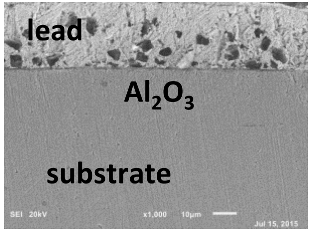

HELENA loop

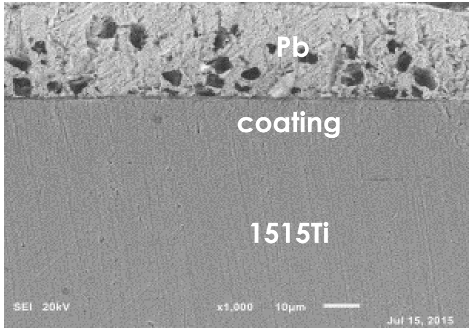
Coating Development

Pulsed Laser Deposition Nanoceramic Coatings (IIT & ENEA)



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



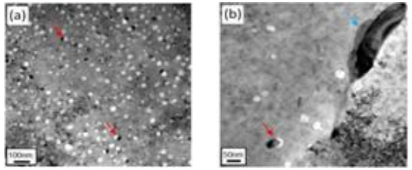


1 µm Al2O3 coating
no buffer layer

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

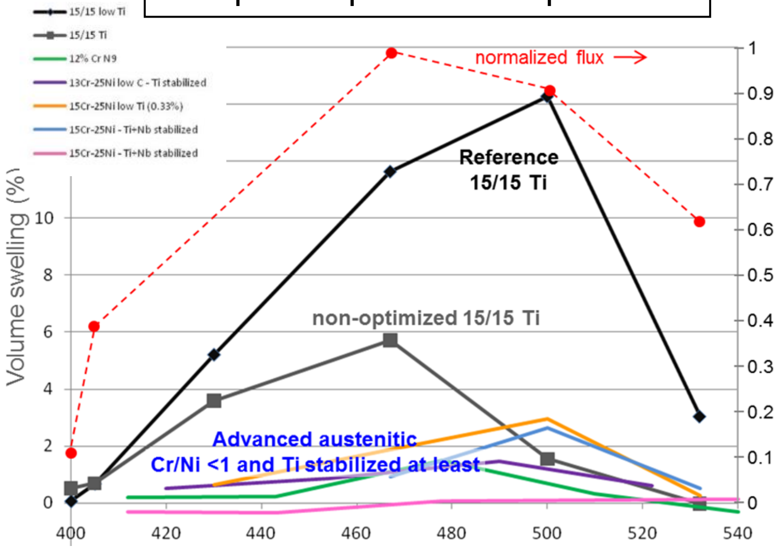
Structural Materials Development

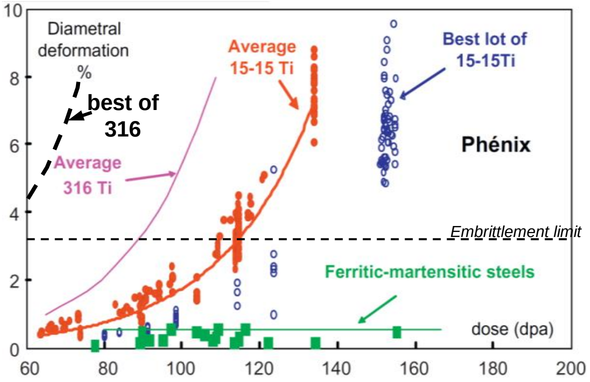
alloy	Evaluation (from * poor to *** excellent)
15-15 std	*
DS3 (15-15)	No data
DS4 (15-25)	***
DS5 (15-25)	**



Low amount of cavities in the advanced austenitic stainless steel (b) if compared to the non-optimized 15-15 Ti (a)

89 dpa «Supernova» experiment



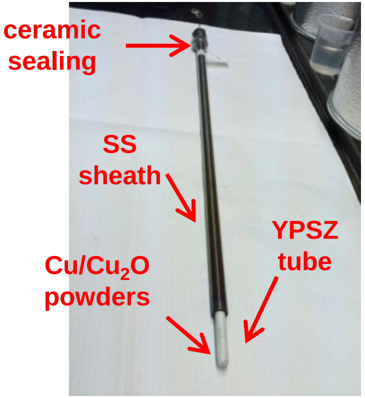


[Séran et al.]

DS4 Hot rolling of the ingot (Pre-heating -1200°C)

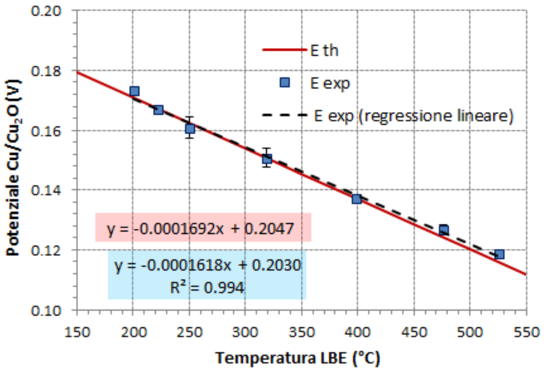
Coolant Chemistry

Oxygen sensors construction and calibration for HLM loop

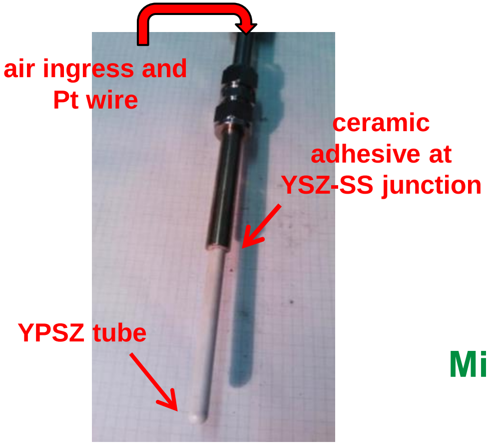


Cu/Cu_2O sensor
L= 600 mm
T=200-400°C

Min. reading T ≈ 200°C

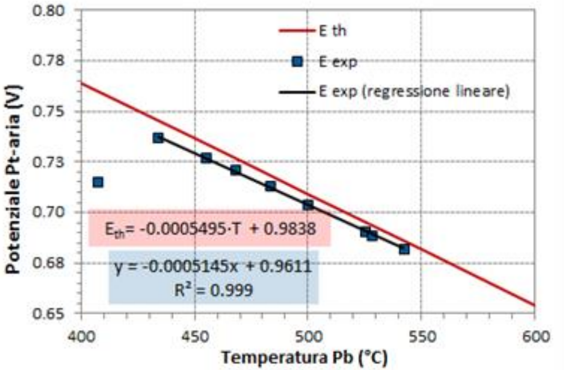


oxygen-saturated LBE



Pt-air sensor
L= 850 mm
T=400-550°C

Min. reading T ≈ 430°C



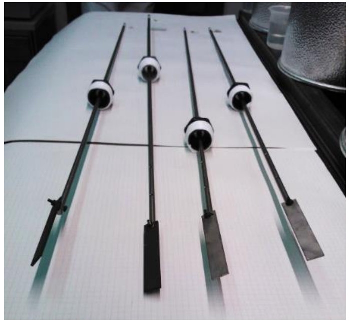
oxygen-saturated Pb

Coolant Chemistry

capsules (small & large)

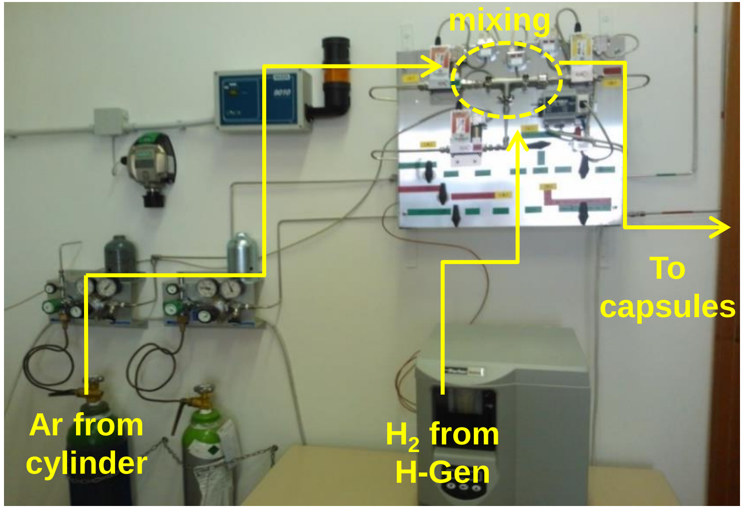
Stagnant Test up to 750°C

capsules for HLM chemistry (oxygen sensor testing, deoxygenation with gas) & corrosion tests of materials in Pb alloys



specimen

gas control system (Ar-H_2 injection)



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Coolant Chemistry

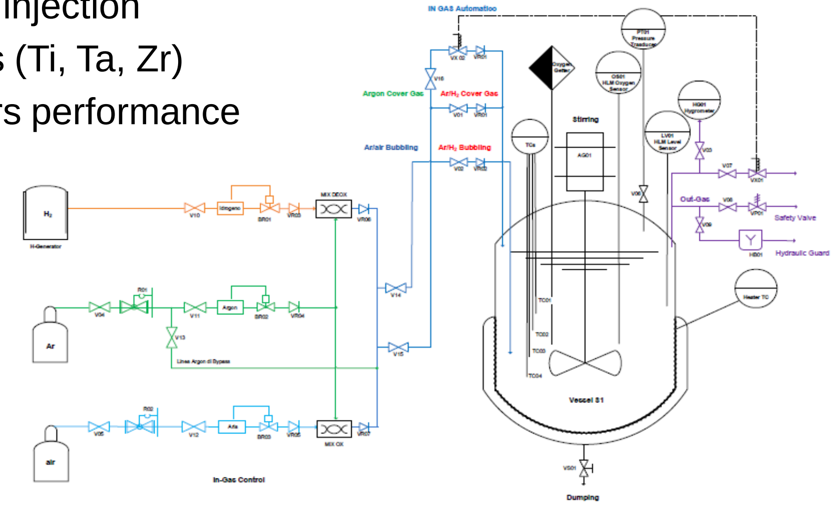
BID-ONE (Brasimone gas-Injection Device 1)

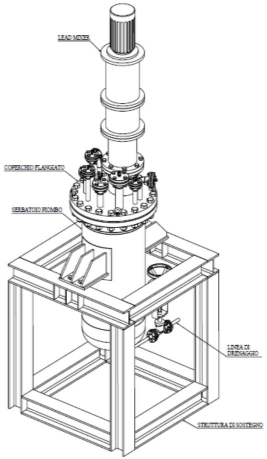
Pb small pool (150 L) to test oxygen control methods:

- H_2 and O_2(air) injection
- oxygen getters (Ti, Ta, Zr)
- oxygen sensors performance

cartridge for OGs

Gas Control System with Ar-H_2 + Ar-O_2 injection

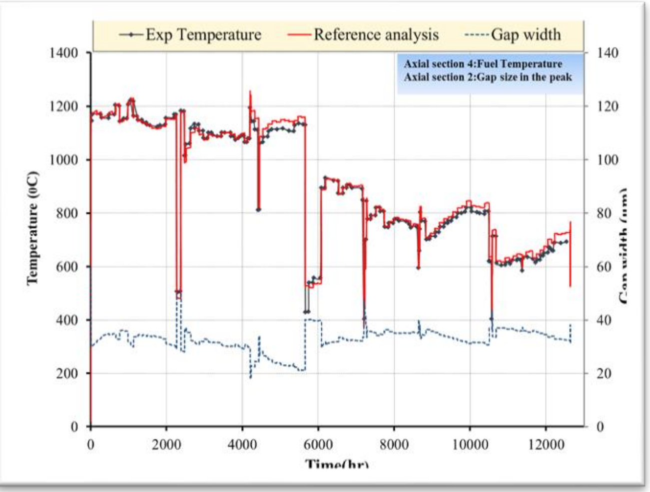




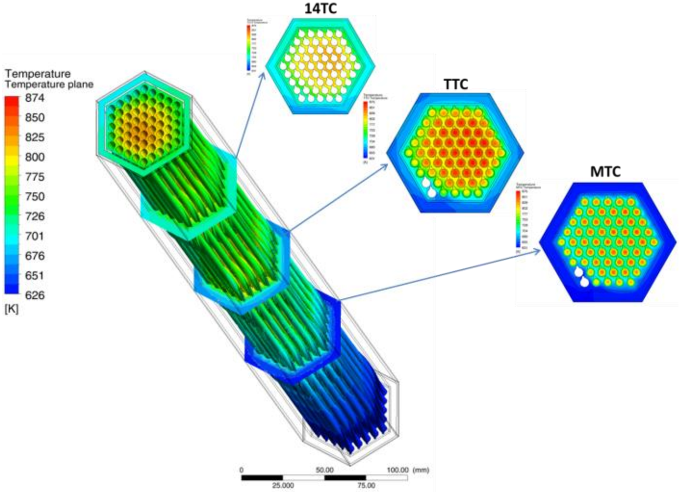
HLM mixer to study the effect of fluid-dynamic conditions on oxygen control

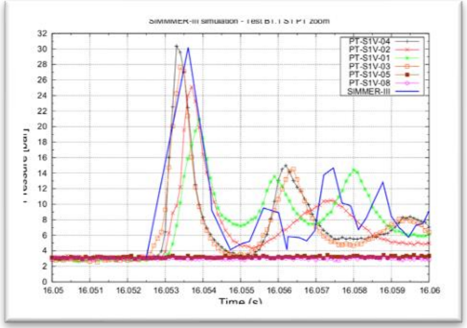
Modelling & Simulations

Fuel Pin Mechanic Code (TRANSURANUS)

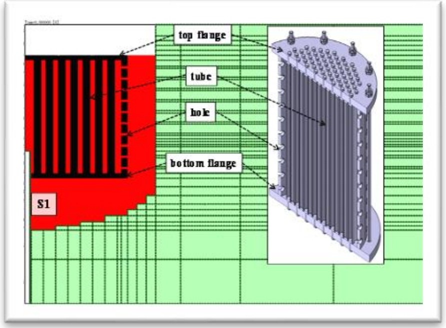


CFD (ANSYS FLUENT)

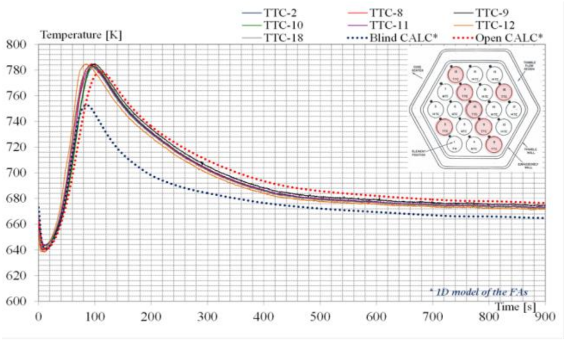




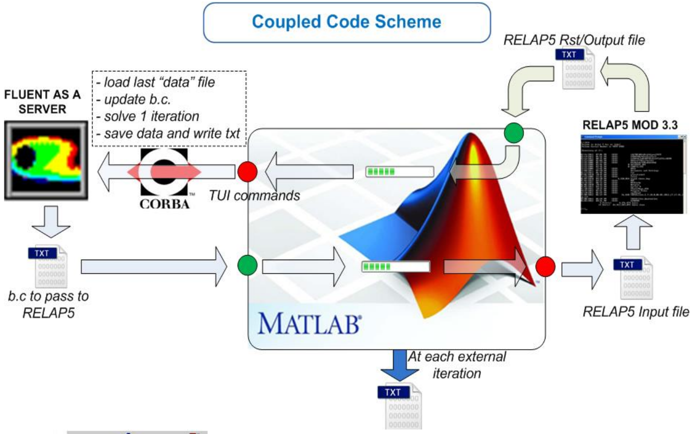
Coarse Mesh CFD (SIMMER)

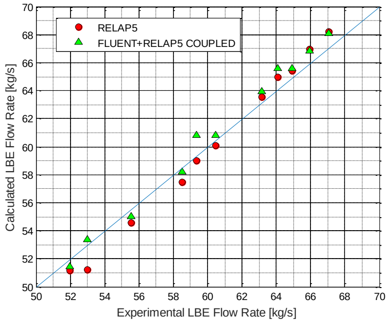


Modelling & Simulations



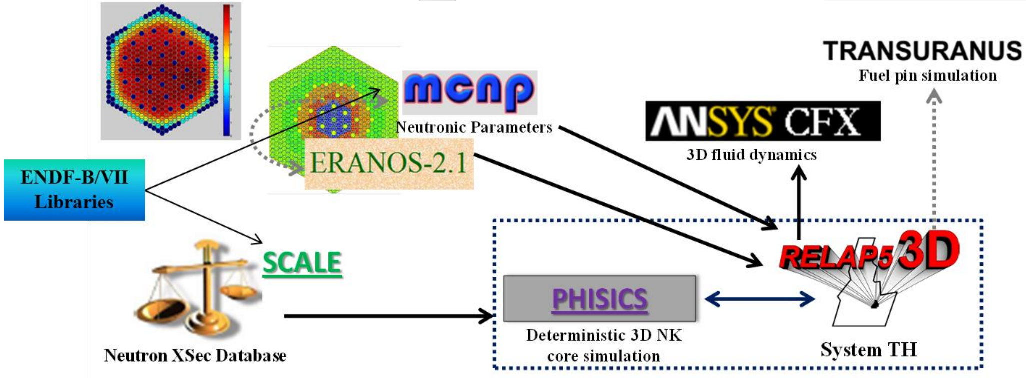
SYSTEM CODE (RELAP5)



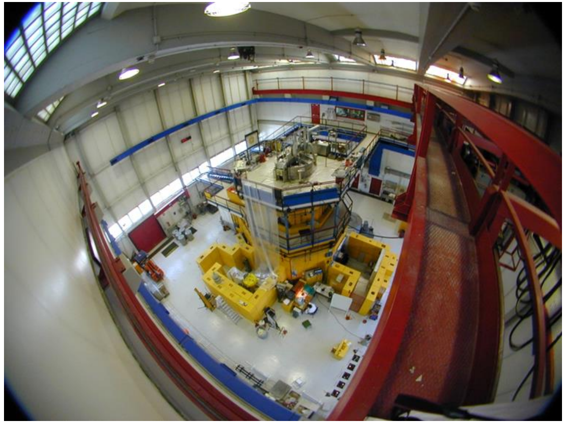


System Code + CFD coupling

Multi-physics



ENEA Research Reactors



TRIGA RC-1: 1 MW power, $2.7 \cdot 10^{13}$ n cm^{-2} s^{-1} thermal neutron flux nuclear research reactor

- ✓ **Neutron Activation Analysis**
- ✓ **Radioisotopes for Medical Applications**
- ✓ Production of gamma emitters
- ✓ **Neutron irradiation damage**: support to Italian and European Space Agencies
- ✓ Neutron Diffraction

RSV TAPIRO: 5 kW power, $4 \cdot 10^{12}$ n cm^{-2} s^{-1} fast neutron flux nuclear research reactor

- ✓ Radiation effects damage on functional material
- ✓ **Innovative detectors** calibration and performances
- ✓ **Minor Actinides** capture cross sections integral measurements (AOSTA; NEA-CEA-ENEA)

ENEA

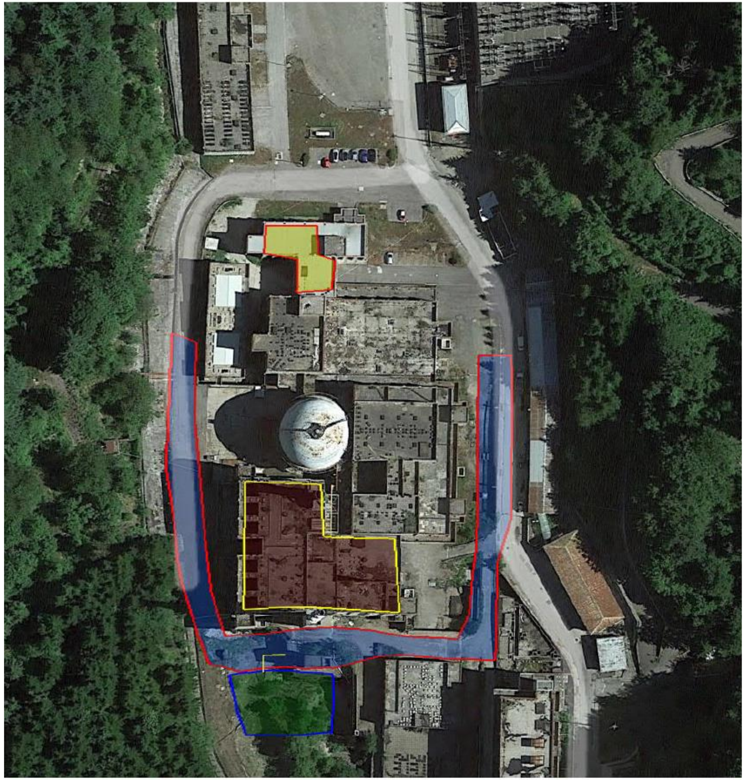
FDS Team (CASHIPS – China)

FDS Team (CASHIPS – China)

- **CLEAR-S Pool**
  - LBE pool (300°C – 400°C)
  - MCP @ 220 kg/s , 2,5 bar
  - CS (7 FPS) @ 2,5 MW
  - DWBT HX @ 100 bar

ENEA

ENEA – *newcleo* Agreement



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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

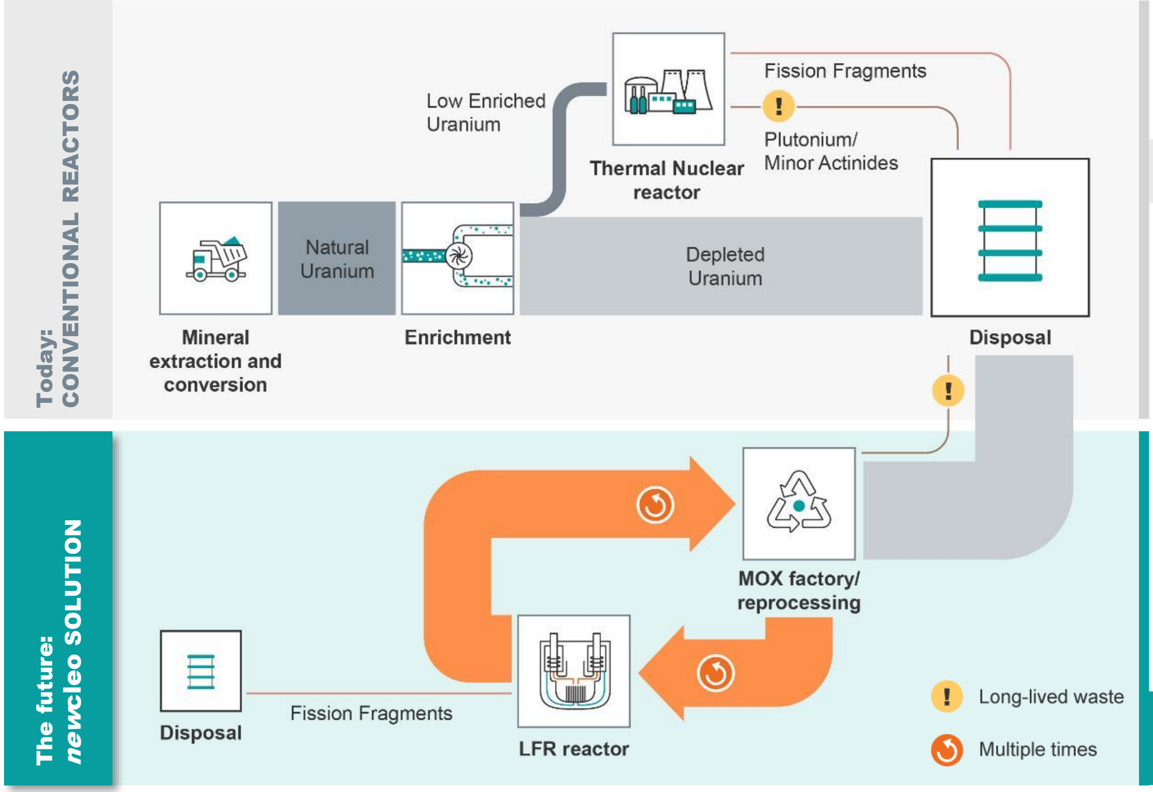
In base all'accordo Enea e Newcleo investiranno al Brasimone, che tra i comuni di Camugnano e Castiglione dei Pepoli conta 400 ettari di superficie e 17 diversi edifici. Verranno rinnovati impianti e laboratori per realizzare un prototipo elettrico di reattore raffreddato al piombo, senza l'uso di materiali 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.

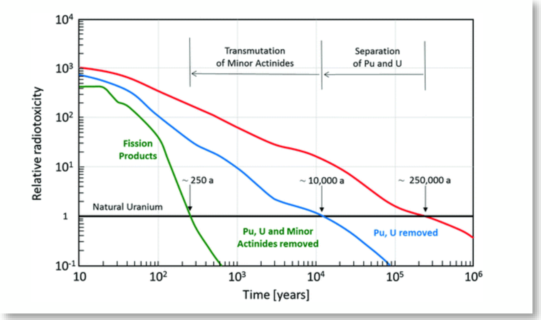
Closing the fuel cycle: MOX

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 "*waste*"

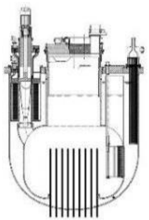
High-level waste has become an expensive liability

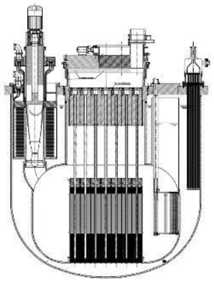


Fast Reactors and fuel reprocessing can extract energy from existing material and at the same time reduce radiotoxicity of residual waste to dispose: Fission Products return to value of the natural uranium ores after ~250 years

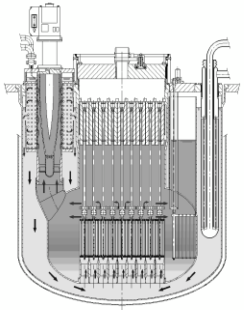
All artificial radioactivity created by reactors is virtually gone

*new*cleo's plan-to-market

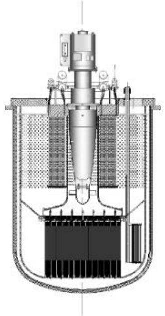




AS-30



AS-200



TL-30

2026 | **2030** | **2032** | **2032**

Precursor

10 MW electrically heated/non-nuclear facility with turbogenerator

It reproduces scaled or full-scale components of the LFR-AS-30

LFR-AS-30

30 MWe nuclear module with core outlet at 430/440° (later 530°), using MOX as fuel

Demonstrator and test reactor

LFR-AS-200

200 MWe nuclear SMR, for stand-alone or multi-module configuration, using MOX as fuel

First-Of-A-Kind (FOAK) reactor

LFR-TL-30

30 MWe mini nuclear reactor for industrial and maritime applications

Working as a nuclear battery, with infrequent refuelling (10y +)

ENEA-Brasimone non-nuclear experimental facilities

CAPSULE
operational in February 2024

Facility to test various kinds of steel, bare and coated, in stagnant lead under oxygen-controlled concentration, essentially between 10^{-8} - 10^{-6} wt %; temperatures span between 450 - 750 °C

CORE
200 kW
operational in March 2024

Loop-type facility to test various kinds of steel, bare and coated, in fluent lead under oxygen-controlled concentration, essentially between 10^{-8} and 10^{-6} wt %; temperature in the corrosion test section 650 °C and velocity 1 m/s; in the erosion test section the temperature is 520 °C and the velocity 10 m/s.

It will also be used to test the effectiveness of cold traps and mechanical filters

OTHELLO
2 MW
operational in 2025

Loop-type facility with a Fuel Pin Bundle Simulator and a mock-up of *new*cleo Steam Generator with three full length tubes. It will be used to test a Fuel Pin Bundle Simulator to validate thermal-hydraulic computer codes, to appreciate the consequences of partial inter-pins obstructions, to check the risk of fluid induced vibrations.

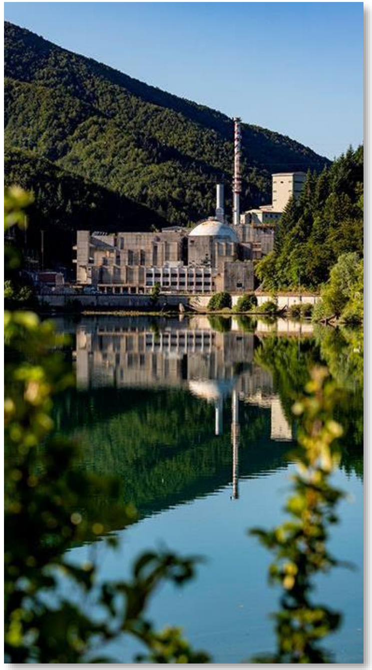
Also, to test the behaviour, both lead side and water/steam side, of the Steam Generator

PRECURSOR
10 MW
operational in 2026

Pool-type integral test facility with an electrical resistors bundle, and three Steam Generators at a thermal reduced scale, and the associated turbine-generator set. It will be used to test the global behavior of the plant in stationary and transient mode, the inset of lead flow both in hot and cold plenum and of possible stagnant zones, the effectiveness of the DHR system, test various mechanisms as the control rods

MANUT
conceptual phase

It is a "cold" facility to test the fuel hanging and handling systems as well as the rotating plugs operation during refueling campaign. This facility is just at a first conceptual draft.



ENEA-Brasimone centre

HELENA facility

Partnership signed in March 2022: ENEA unique global know-how and *new*cleo 25-30 engineers and EUR50+ million for about 10 years. Renovation works started in June 2022

- LFR research program in Italy was set-up by ENEA, involving all the Italian stakeholders (e.g. industries, universities, research bodies), committed on:
  - Design
  - Safety Assessment
  - Numerical Code V&V
  - Structural Material & Coolant Chemistry
  - Thermal-Hydraulic
- The research is supported by a **large experimental program based on a very comprehensive fleet of experimental facilities**, almost unique worldwide.

- A strong synergy with the European framework is achieved, on which ENEA is one of the most important and skilled player on LFRs development.

- **ENEA plays an important role in the international framework of innovative nuclear system (Gen. IV LFRs) design, research, development and demonstration.**

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