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

Generation IV
Lead-cooled Fast Reactor

Roma, 28th May 2024

Mariano Tarantino, Nuclear Department (NUC)

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

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)

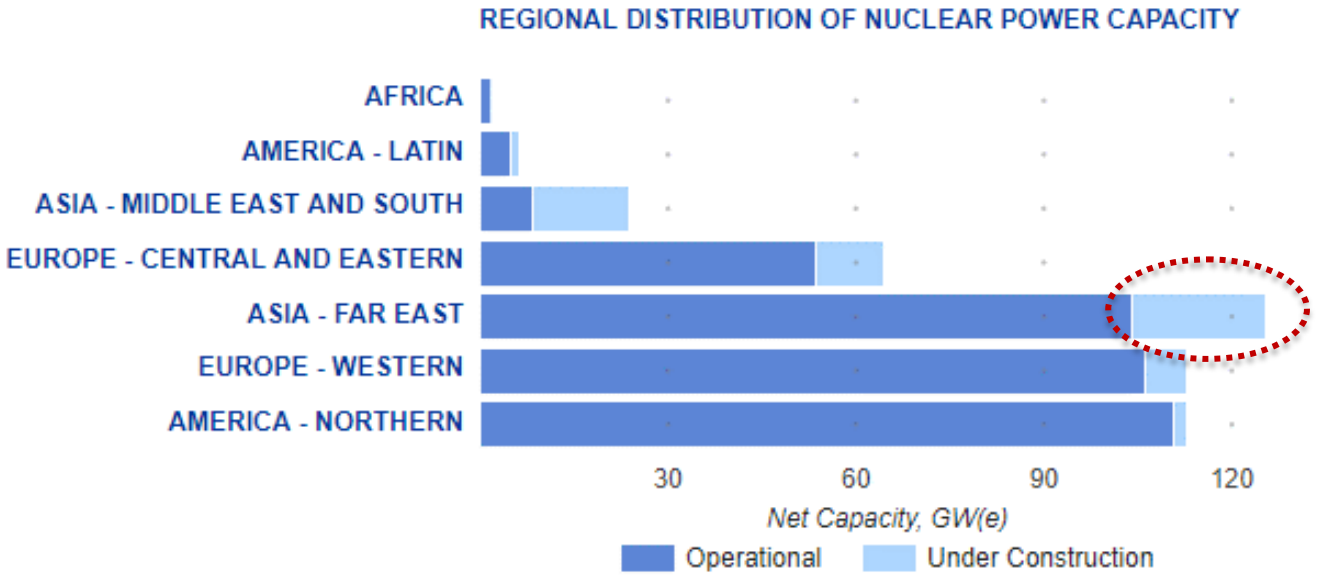
- **Nuclear energy is the largest (26.7% in 2019) single source of low-carbon energy in the EU**, ahead of hydro (12.3%), wind (13.3%), solar (4.4%) and other (0.5%).
- **Nuclear** energy contributes to **climate mitigation**.
- The technical expert group on Taxonomy concluded that there is clear evidence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

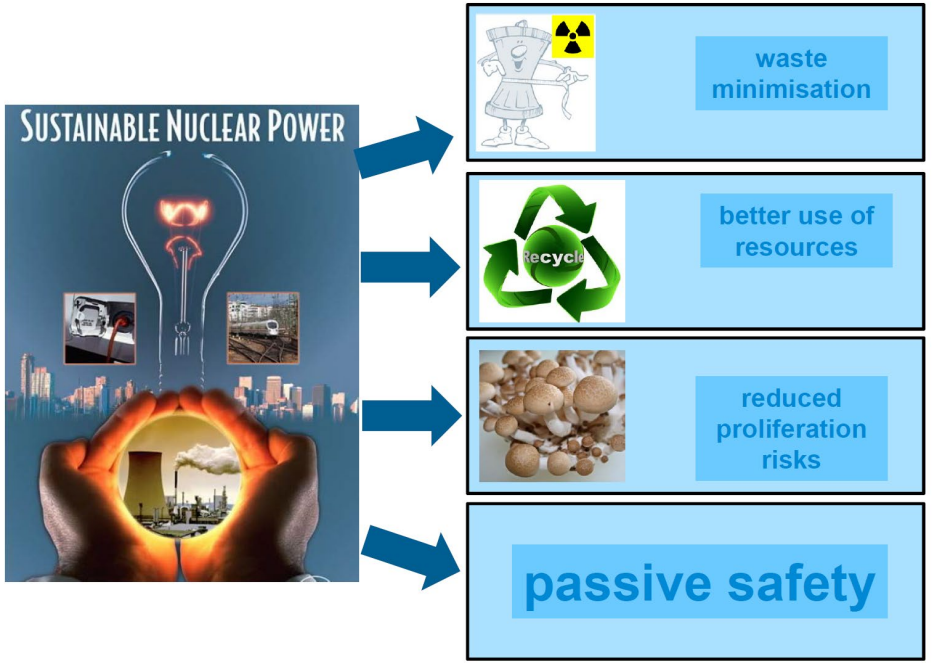
- 443 Nuclear Power Plants in operation
- Almost 19 000 reactor-years of opreation
- 52 Nuclear Power Plants under construction



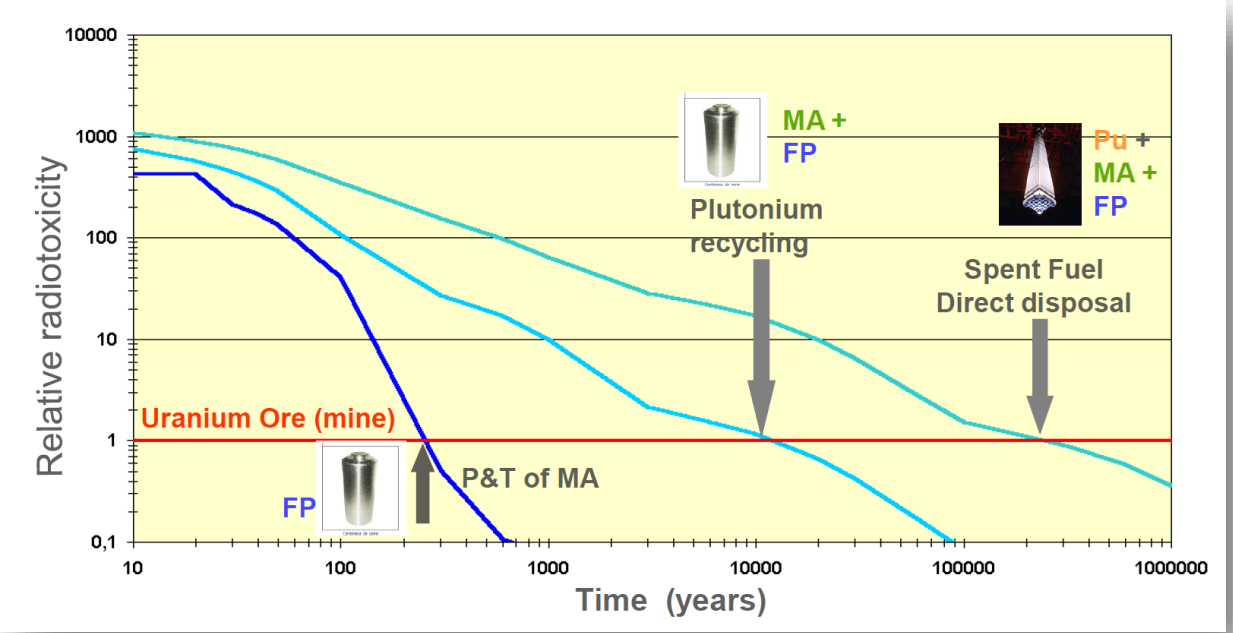
Ref: IAEA, Power Reactor Information System (2021)
https://www.iaea.org/pris/

Nuclear Open Issues

- Nuclear Energy
  good but not good enough
- Improvement Safety
- Waste
  - Too much of it
  - Too long lived
- Economy
  Once through strata
  uses less than 0,5% of the fuel



Waste Minimization & Economy



Recycle of all actinides in spent LWR fuel in fast reactors provides a significant reduction in the time required for radiotoxicity to decrease to that of the original natural uranium ore used for the LWR fuel (i.e., man-made impact is eliminated). From 250,000 years down to about 400 years with 0.1% actinide loss to wastes

Safety Improvement

Severe Nuclear Accidents. During the historically short period several low probability NPP accidents occurred with significant radioactivity release into environment and considerable economical losses

Three Mile Island-2
(PWR)
1979

Chernobyl-4
(RBMK)
1986

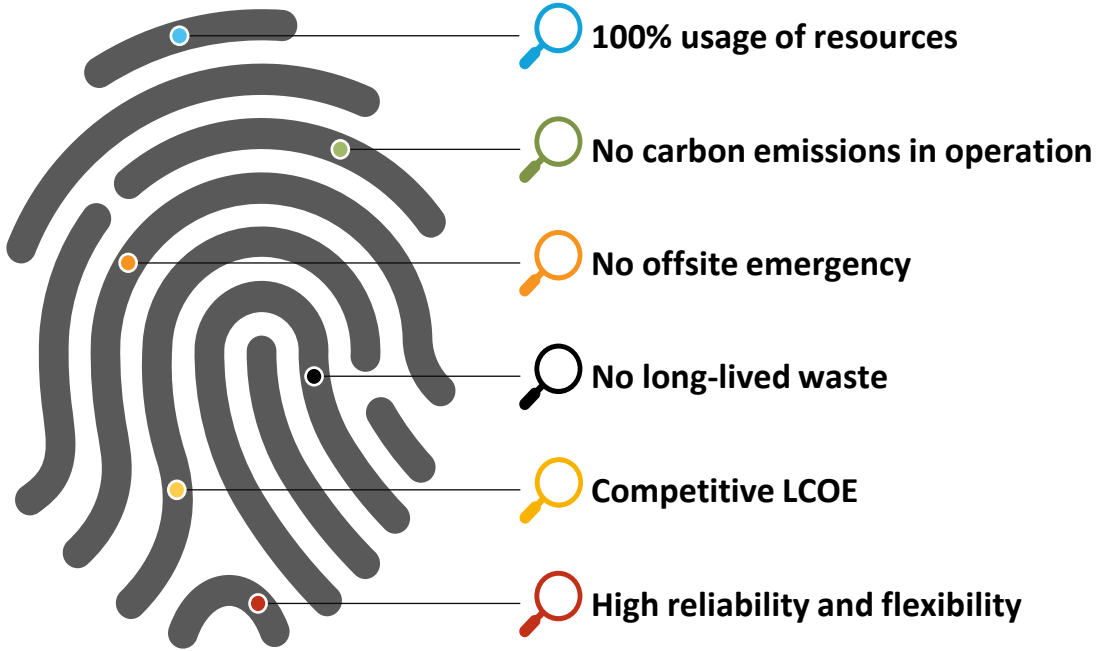
Fukushima-1
(BWR)
2011

The initial events for these accidents are of extremely low probability

technical failure **human error** **extreme external impact**

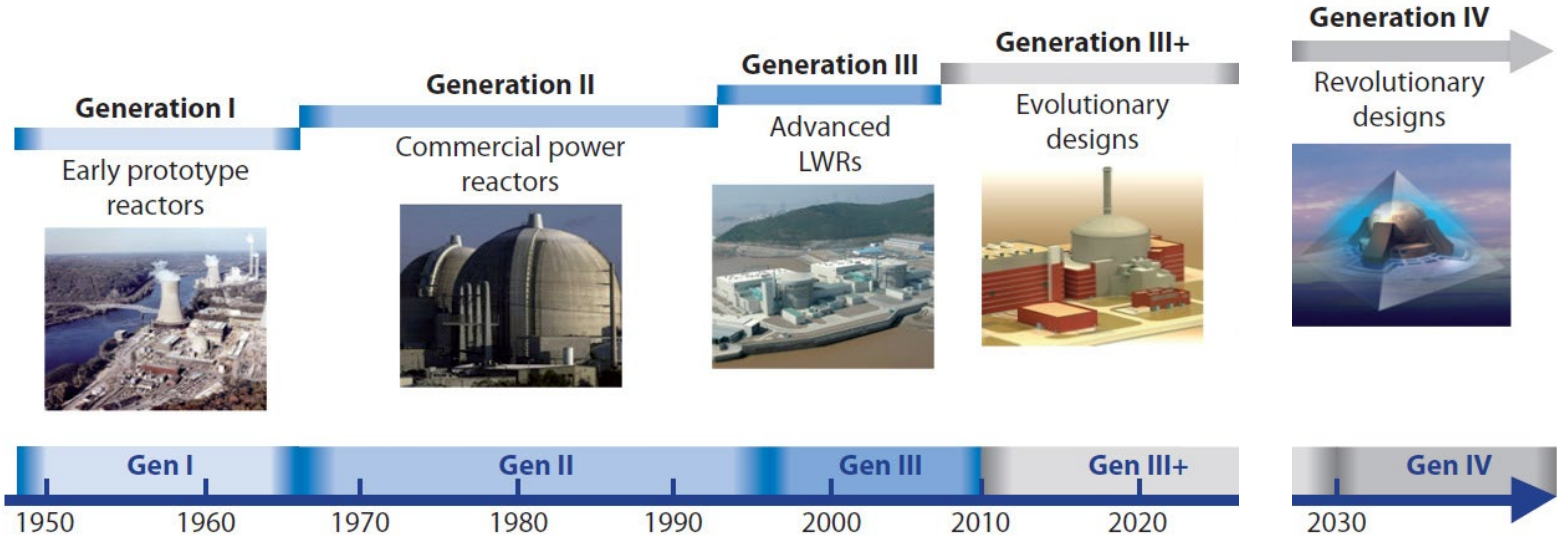
The «ideal» Nuclear Power Plant

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.

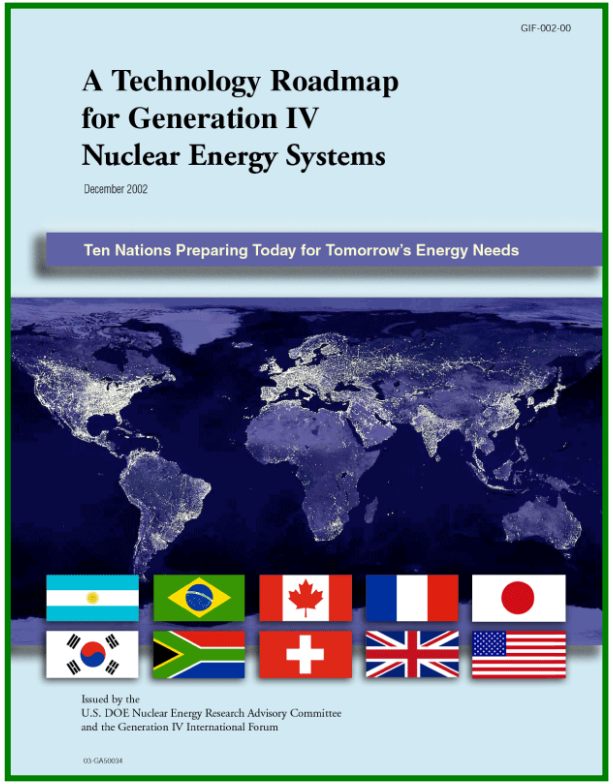


New Technologies

New concepts: evolutionary… and revolutionary designs



Generation IV



The path from current nuclear systems to Generation IV systems is described in a 2002 Roadmap Report entitled "***A technology Roadmap for Generation IV Nuclear Energy Systems"*** which:

defines challenging technology goals for Generation IV nuclear energy systems in four areas:

- ✓ **sustainability,**
- ✓ **economics,**
- ✓ **safety and reliability, and**
- ✓ **proliferation resistance and physical protection.**

identifies six systems known as Generation IV to enhance the future role of nuclear energy**;**

defines and plans the necessary R&D

Generation IV

Generation IV Systems	*Acronym*
Gas-Cooled **F**ast **R**eactor	**GFR**
Lead-Cooled **F**ast **R**eactor	**LFR**
Molten **S**alt **R**eactor	**MSR**
Sodium-Cooled **F**ast **R**eactor	**SFR**
Super**c**ritical **W**ater-Cooled **R**eactor	**SCWR**
Very-**H**igh-**T**emperature **R**eactor	**VHTR**

Because the capability of fast reactors to meet the sustainability goal and hence to re-position nuclear energy from the present transition-energy role into an inexhaustible source of clean energy

- three out of the six systems selected by GIF (GFR, LFR and SFR) are fast reactors and
- for two systems (MSR and SCWR) studies have been carried out recently to explore the possibility of them to become fast reactors.

Lead cooled Fast Reactor

- For heavy liquid metal coolants (lead-bismuth alloy, lead) 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.
- The way to improve the NPP safety and economic performance is to implement reactor facilities with **the lowest stored potential energy**, where the inherent self-protection and passive safety properties are used to the maximal extent.

Lead cooled Fast Reactor

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

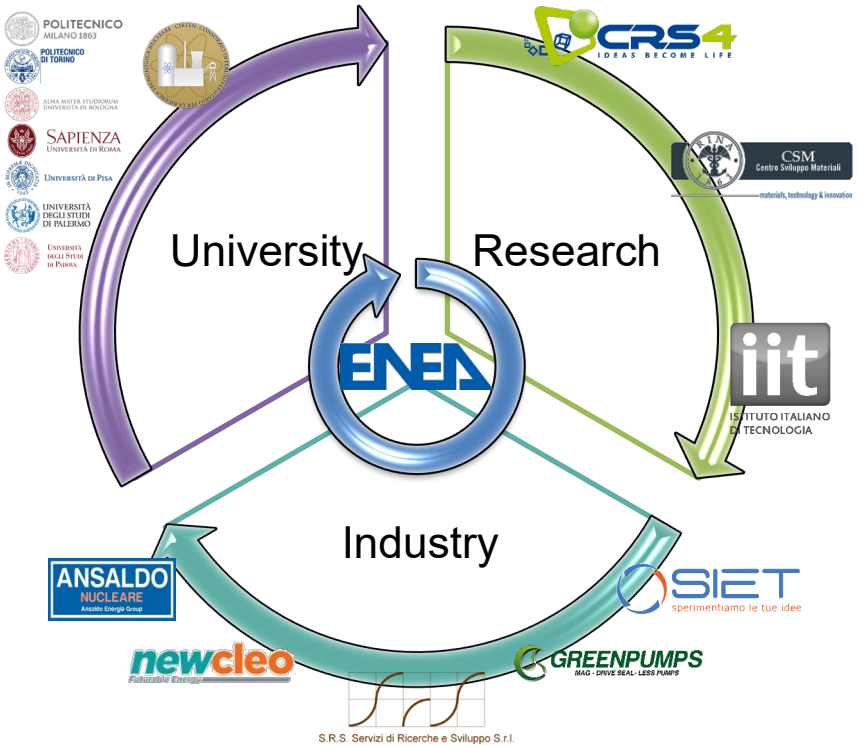
Lead cooled Fast Reactor

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*).**

The Italian landscape

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



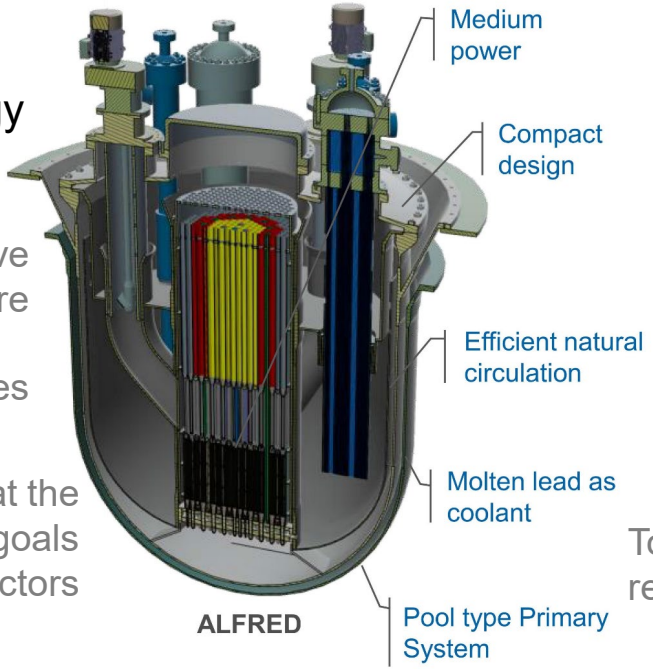
ALFRED Design and FALCON Consortium

ALFRED *(**A**dvanced **L**ead **F**ast **R**eactor **E**uropean **D**emonstrator)*:
Lead-based SMR technology

Provided with a comprehensive research infrastructure

SMR-oriented features

Potentialities to demonstrate that the LFR technology can meet the goals set out by GIF for Gen-IV reactors



Developed by the FALCON consortium with European research organizations and industries.

FALCON (international consortium "**F**ostering **AL**FRED **Con**struction) *was established in 2013 by Italian Ansaldo Nucleare and ENEA, along with the Romanian RATEN-ICN.*

To bridge the final gap between conducted research and industrial application

ansaldo nucleare ENEA RATEN ICN PITEŞTI

Supporting ALFRED Research Infrastracture

FALCON

Under Construction (22 M€)

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

ATHENA

ChemLab

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

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

Meltin'Pot

ELF

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

HELENA-2

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

Hands-ON

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

Funding secured (> 100 M€)

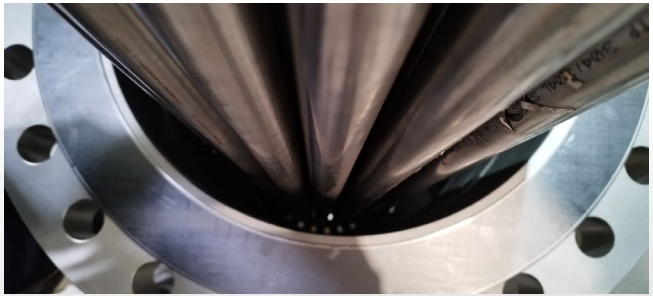
Supporting ATHENA design and construction

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

Experiments to be performed:

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



ENEA – *new*cleo Agreement

16 March 2022

*new*cleo signs agreement with ENEA to develop safe and innovative nuclear systems

Press releases

Download

*new*cleo's Generation-IV reactors to be built outside of Italy.
*new*cleo, the clean and safe nuclear technology company developing innovative reactors, signed today an agreement for the development of safe and innovative Generation-IV nuclear systems with ENEA, the Italian national agency for new technologies, energy and sustainable economic development.

DATA STAMPA — la Repubblica BOLOGNA — 17-MAR-2022
www.datastampa.it — Dir. Resp.: Maurizio Molinari — Tiratura: N.D. Diffusione: 16061 Lettori: 137000 (0001581) — 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.

Objective of the Agreement: PRECURSOR (electric LFR prototype) at the ENEA Brasimone Research Centre

ENEA-Brasimone non-nuclear experimental facilities

CAPSULE
operational since December 2023

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.

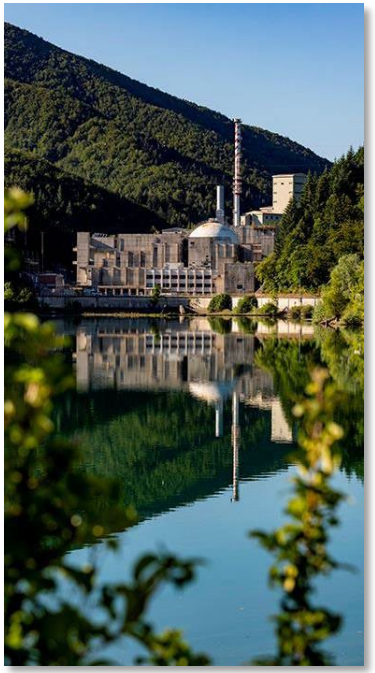
Also, to test the behaviour, both lead side and water/steam side, of the Steam Generator

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 behaviour 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 refuelling campaign. This facility is just at a first conceptual draft.



newcleo/ENEA/SRS: quick growth in R&D

- **CAPSULES**
  operational since December 2023

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**
  operational in March 2024

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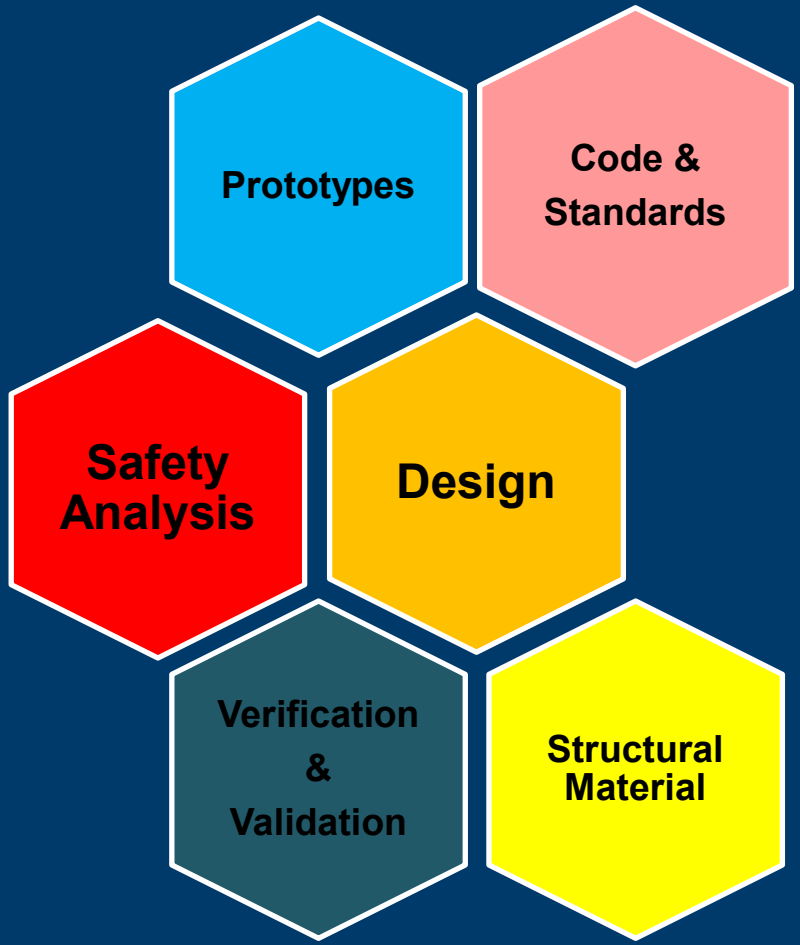
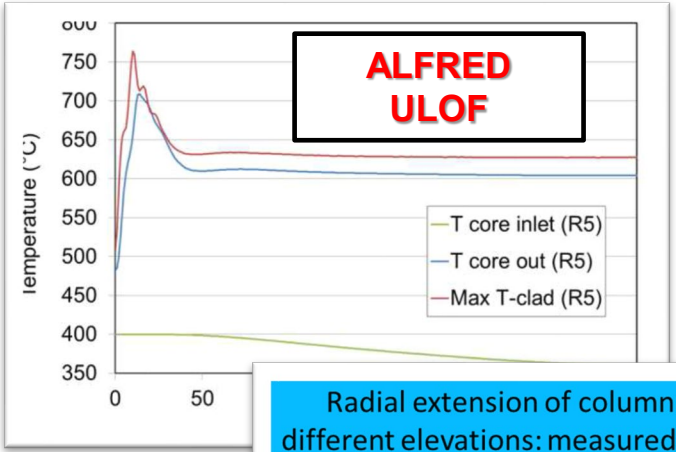
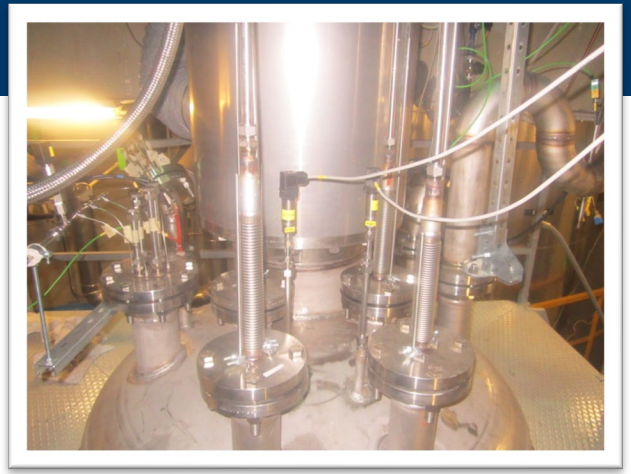


Experiments

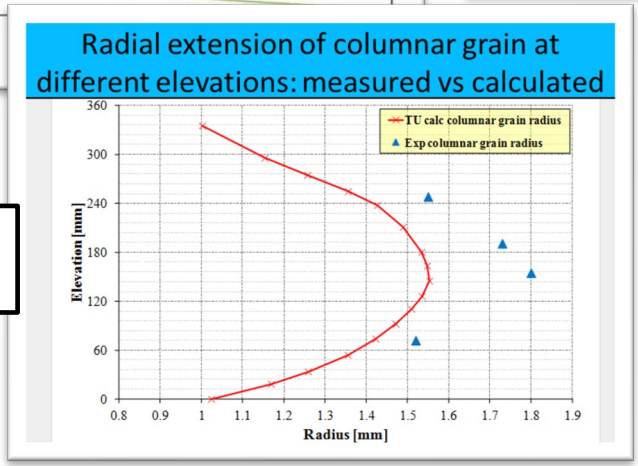
Safety Analysis



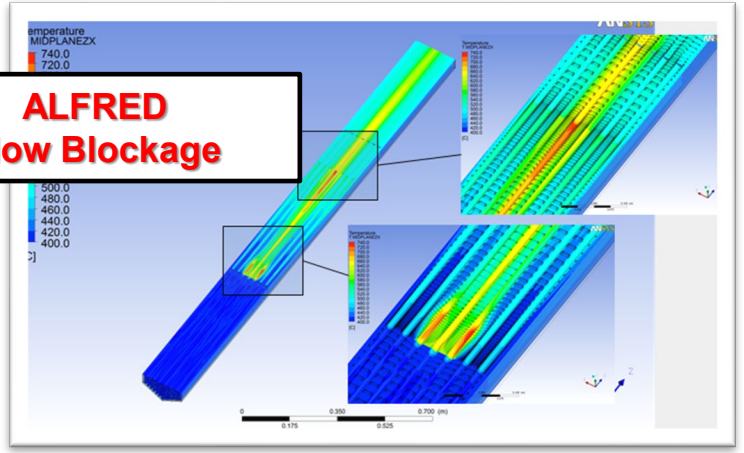


MYRRHA
SGTR

Fuel
Safety

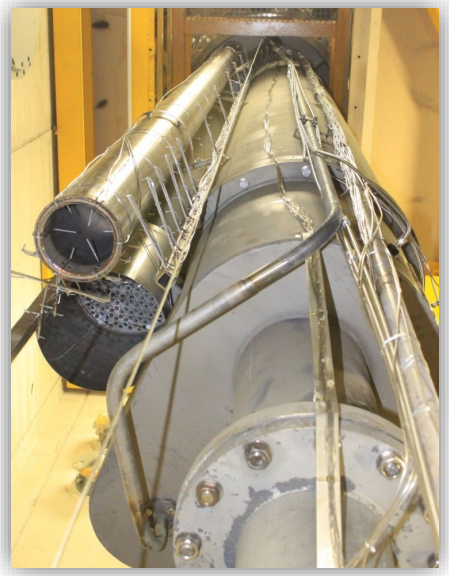


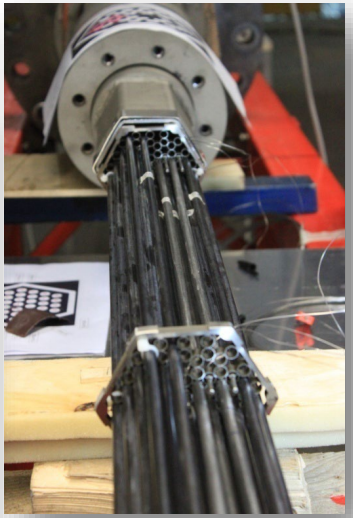
ALFRED
Flow Blockage

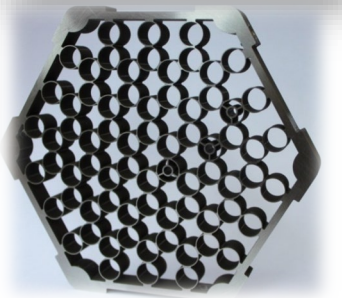


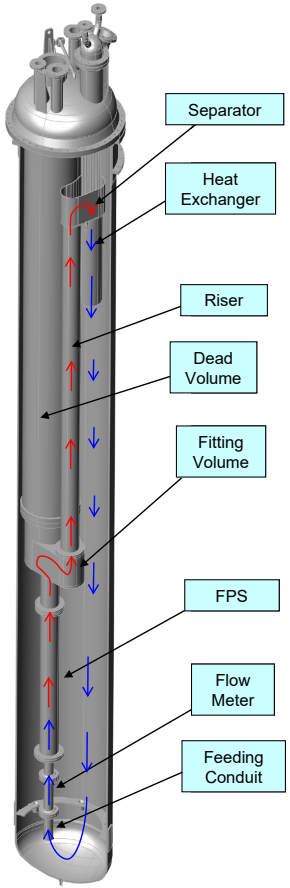
Integral Test & Component Qualification

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



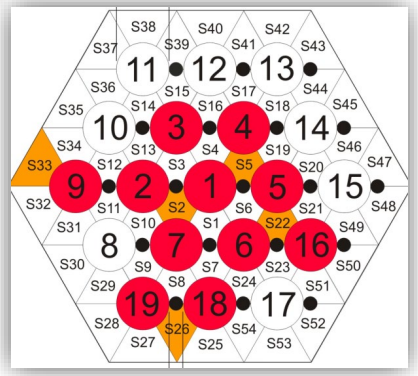




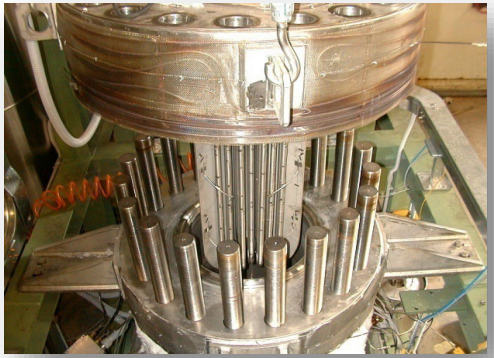


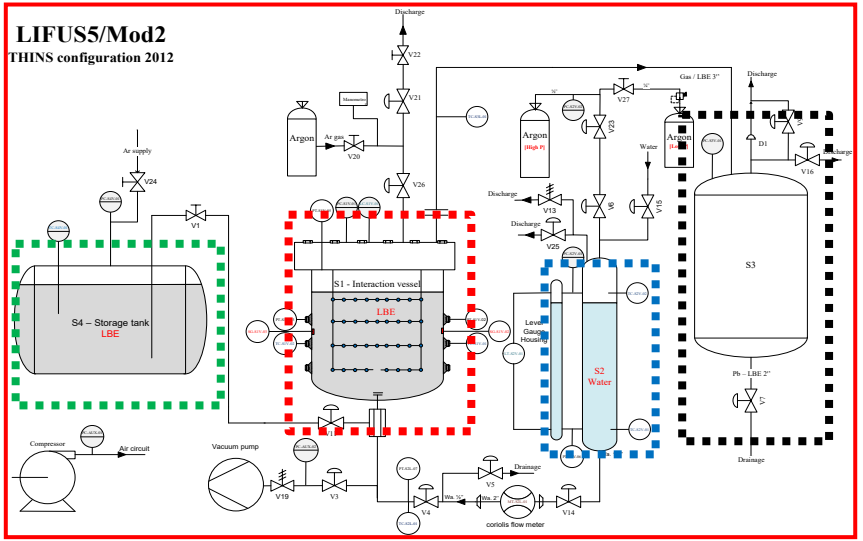
Fuel Pin Bundle

- 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, …

Material Characterization

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

LECOR loop

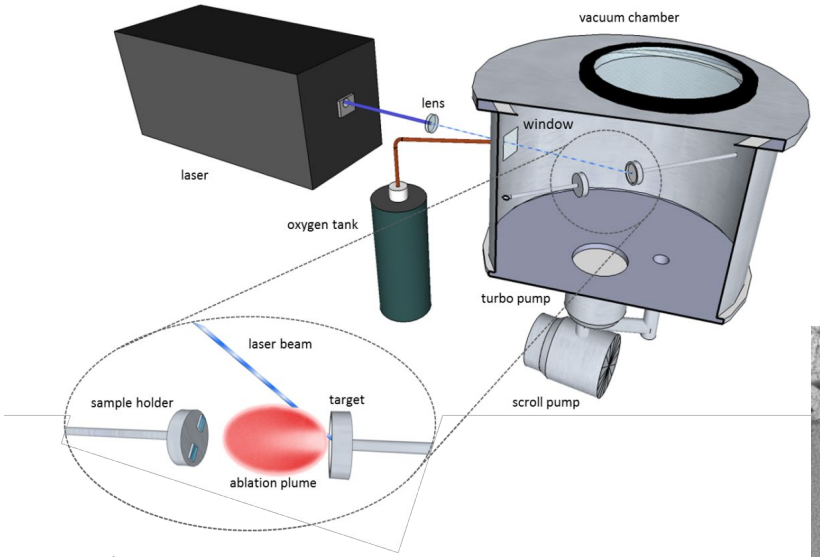
HELENA pump impeller

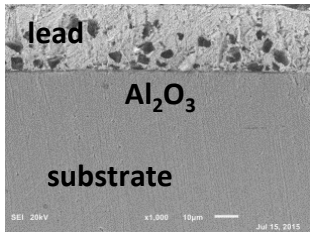
HELENA pump

HELENA loop

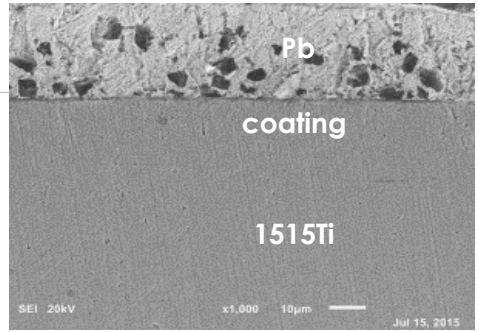
Coating Development

Pulsed Laser Deposition Nanoceramic Coatings (IIT & ENEA)





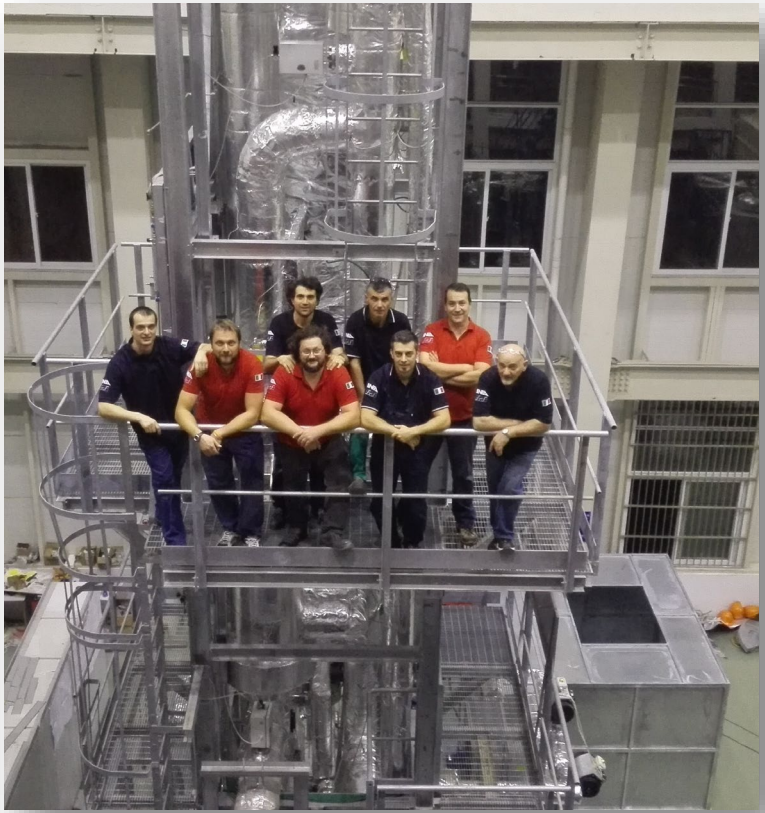
1 µm Al2O3 coating
no buffer layer



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

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

International Collaborations



International Collaborations

- **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

- LFR research program ongoing in Italy, **led by ENEA**, involves all the Italian stakeholders (e.g. industries, universities, research bodies), and involves:
  - 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.**