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

LFR R&D Programme

ENEA-INFN: collaborazioni in essere e sviluppi futuri

Bologna, 5th November 2024

Mariano Tarantino
Head od Nuclear Energy Systems Division, Nuclear Department

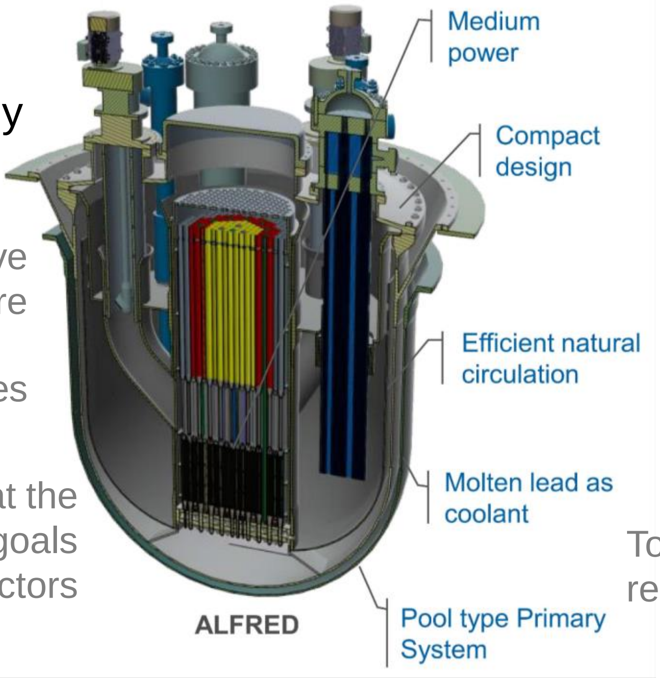
ALFRED and FALCON Consortium

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



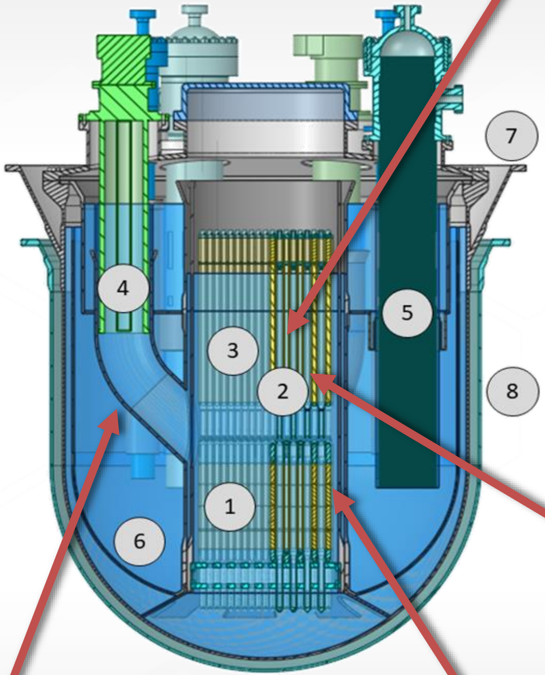
Developed by the FALCON consortium with European research organizations and industries.

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.*

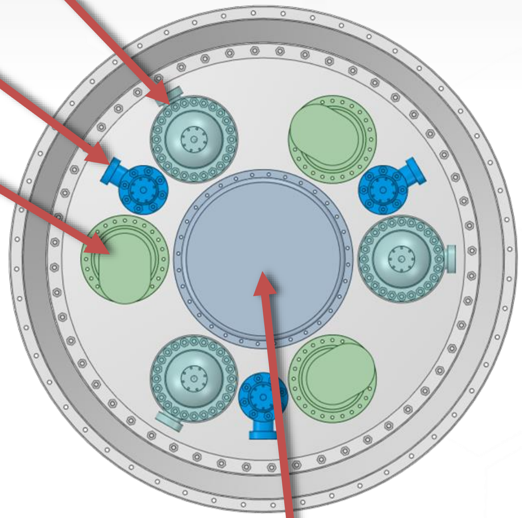
To bridge the final gap between conducted research and industrial application

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



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

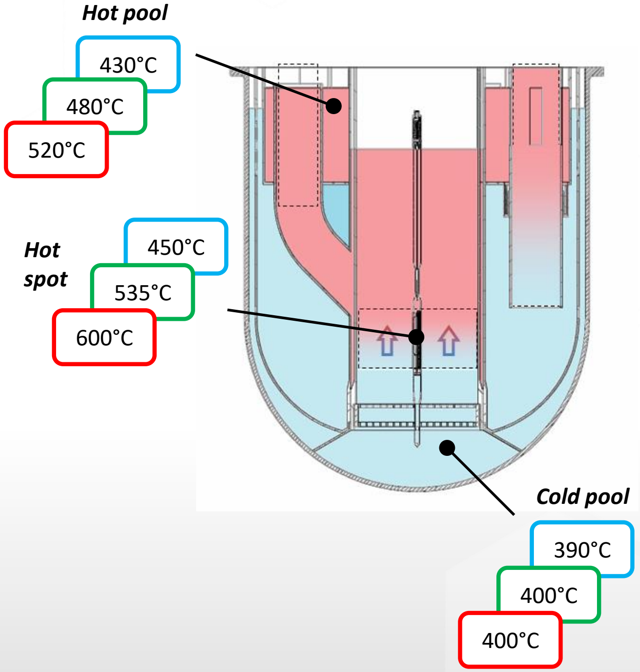
ALFRED Staged Approach

ALFRED

- ALFRED will facilitate licensing readiness and operational readiness for western LFR commercial reactors.

Increase in reactor coolant temperature

- **STAGE 1**
  - Proven technology, proven materials, oxygen control, low temperature
  - Aimed at in-core qualification of PLD Al_2O_3 coating for cladding
- **STAGE 2**
  - Need for FA replacement
  - Aimed at in-core qualification at higher temperature
- **STAGE 3**
  - Replacement of main components (SGs, PPs, dip coolers, ...)
  - Representative of FOAK conditions for LFR deployment



ALFRED Research-Infrastructure

FALCON

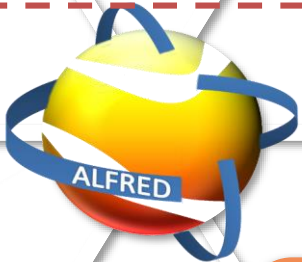
Under Construction (22 M€)

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

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€)

ATHENA

Advanced Thermo-Hydraulics Experiment for Nuclear Application

ATHENA is an **electrically heated 2.21 MW pool type multipurpose facility** representative of LFR systems aimed to investigate pool-TH

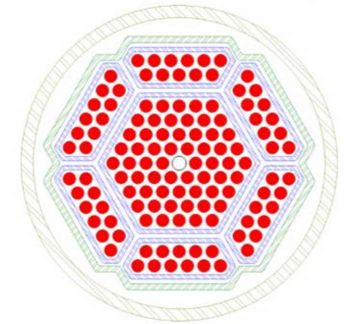
Large size vessel (**3.2 m diameter, 10 m in height**) which is capable to host and test single and coupled full scal components.

Design P→ 2.0 MPa

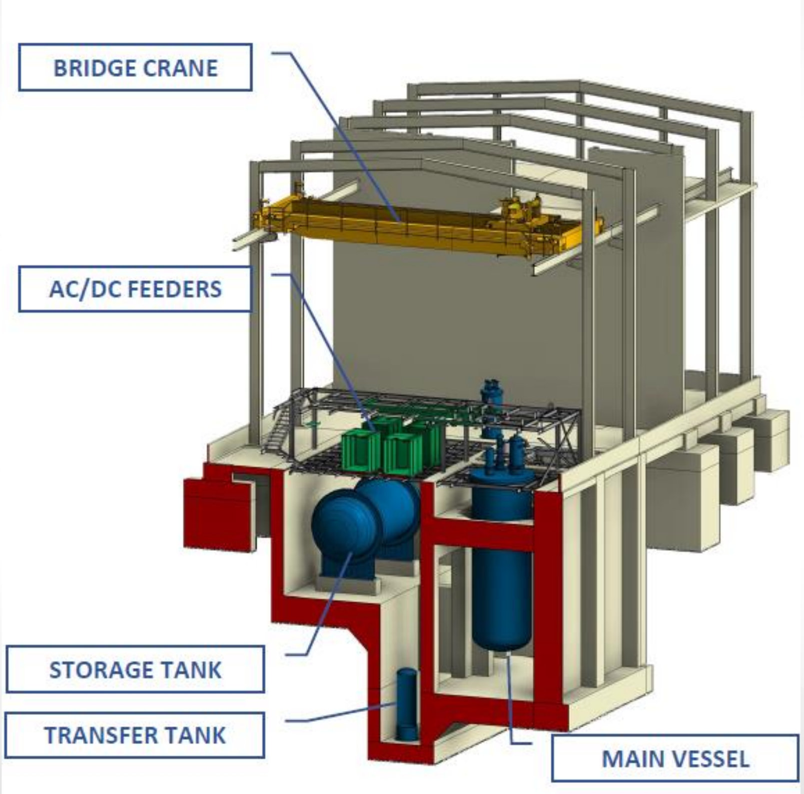
Design T → 450°C

Flow Rate → 130 kg/s

Pb Inventory → 800 tons



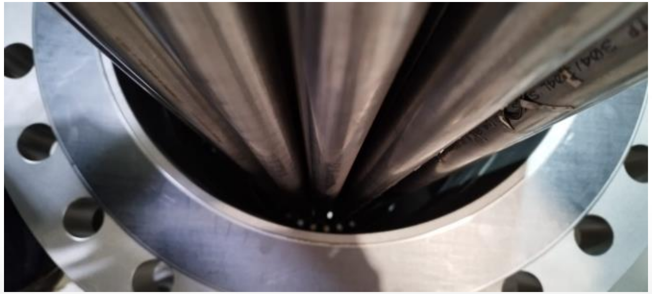
CORE Simulator
2.21 MW



ATHENA

Installed

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



ATHENA

Enlarging the collaboration at European level

FALCON

Italy

- Investing in LFR research since the 2000s.
- Discontinued national research program in 2018.
- But continued to support industrial research and Euratom projects.
- Now showing renewed interest in nuclear technologies.
- Very open to international collaboration.

ansaldo nucleare

ENEA
Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

Romania

- RATEN-ICN center involved in European projects on LFR since about 2010.
- Declared interest in hosting the first LFR demonstrator (ALFRED) in 2011.
- Joined the FALCON consortium led by Ansaldo Nucleare in 2013.
- Eembedded ALFRED and the associated research infrastructure in multiple national strategy documents.
- Financing the largest and most powerful experimental lead infrastructure in Europe (ATHENA).
- Allocated an additional €100 million over the next 4-5 years.

RATEN
REGIA AUTONOMĂ
TEHNOLOGII pentru ENERGIA NUCLEARĂ

Belgium

- Traditionally focused on ADS to LBE solutions.
- In 2022, an analysis of SMR solutions was launched, concluding that LFR is the technology that best meets national targets.
- Allocated an investment of 100 M€ over 4 years.
- SCK CEN is in charge of the research and demonstration activities.
- Experience in licensing process with FANC/Bel-V.
- Managing a fleet of experimental HLM-based infrastructures (including a subcritical reactor).

sck cen
Belgian Nuclear Research Centre

SMR Industrial Alliance

- Meet decarbonization targets through high temperature heat
- Advanced technology for the closure of fuel cycle
- Proven passive safety features
- Adaptability to wide range of customers
- Competitive economics

Reference design

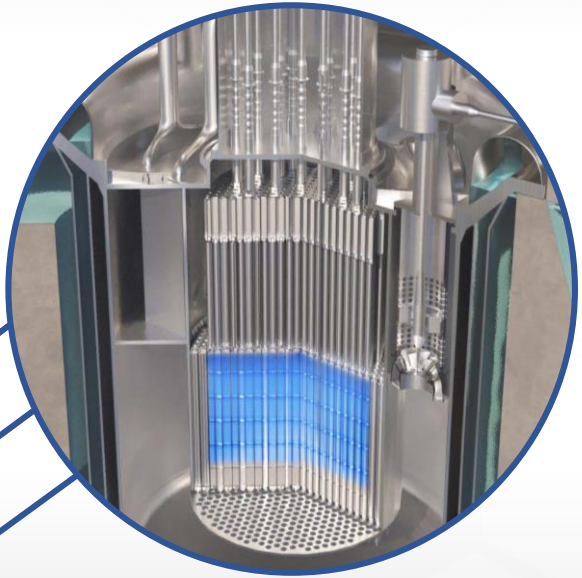
Simplified, robust, modular

Candidate sites

Mol-Belgium and Pitesti-Romania

Shared roadmap

Commercial deployment by 2040



A *new*, innovative player in nuclear energy

REACTOR DESIGN:

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

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

FUEL MANUFACTURING:

Mixed Uranium Plutonium Oxide (MOX)

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

INTRINSICALLY SAFE

COMPETITIVE ENERGY COST

CIRCULAR NUCLEAR WASTE RECYCLING

Presence across **EUROPE**

Launched in **SEPTEMBER 2021**

€500+ million of private funds

~€50 million expected turnover in **2024**

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

800+ EMPLOYEES

30+ YEARS OF R&D

14+ PATENTS

HIGHLY SPECIALISED EPC CAPABILITIES

FUCINA ITALIA – A newcleo company

S.R.S. – A newcleo company

RÜTSCHI – A newcleo company

A long-term vision centred on safety and sustainability

Reactor technology:
AMR: SMR - LFR

LEAD-COOLED

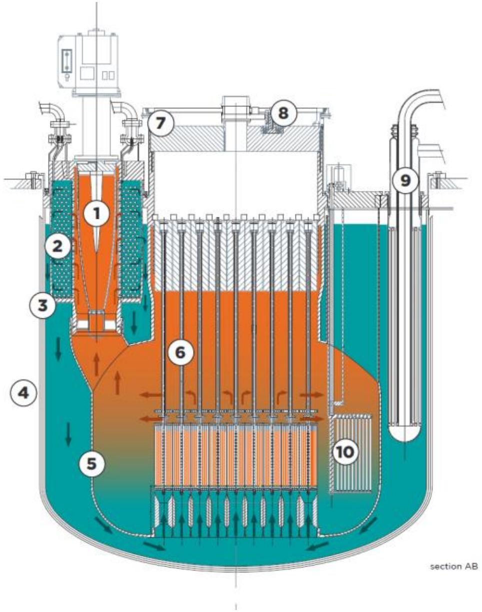
High performance	Compact and simple	Intrinsic safety

FAST

Efficient use of uranium resources	Able to recycle reprocessed spent fuel

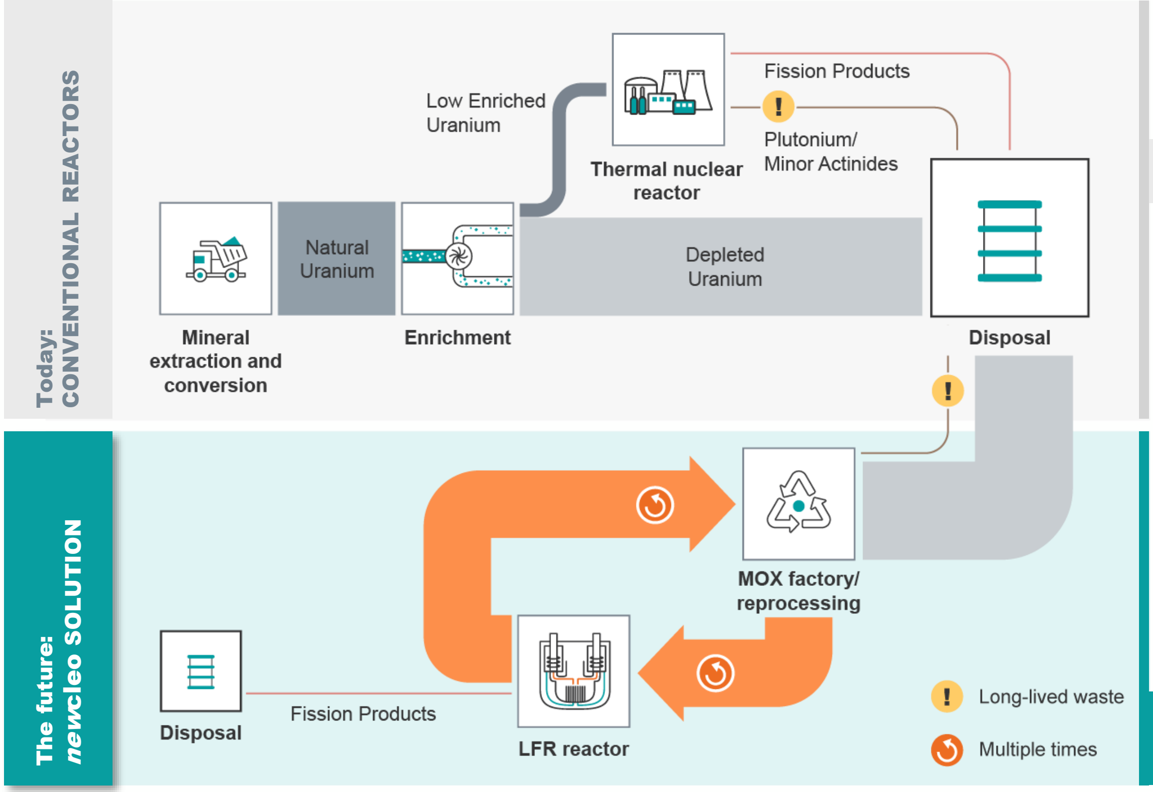
SMALL MODULAR REACTOR

Plant manufactured	Site flexibility	Modularisation and economies of learning



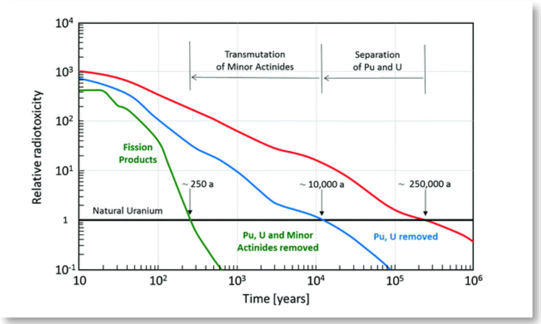
1. Primary pumps (6)
2. Spiral-tube steam generators (6)
3. Reactor vessel
4. Safety vessel
5. Amphora-shaped inner vessel (ASIV)
6. Extended stem fuel assemblies
7. Large rotating plug
8. Small rotating plug
9. Heat exchanger of the lead-water DHR
10. Flag-type control rods (3)
11. Lead-lead heat exchanger of the lead-air DHR (3)
12. Gravity actuated shut down rods (3)
13. Buoyancy actuated shut down rods (3)

Closing the fuel cycle: MOX



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

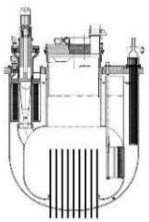
High-level waste has become an expensive liability



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

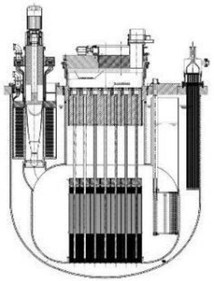


2026

Precursor

10 MW electrically heated/non-nuclear facility with turbogenerator

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



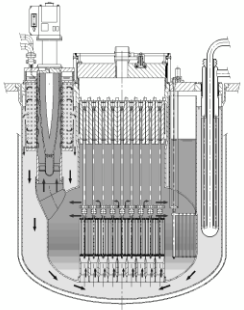
AS-30

2030

LFR-AS-30

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

Demonstrator and test reactor



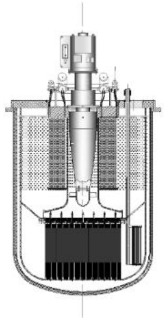
AS-200

2032

LFR-AS-200

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

First-Of-A-Kind (FOAK) reactor



TL-30

2032

LFR-TL-30

30 MWe mini nuclear reactor for industrial and maritime applications

Working as a closed reactor, with infrequent refuelling (10y +)

R&D needs and experimental infrastructures

Large-scope experimental program to support the development of LFR-AS series technology up to the **full demonstration**

- To address technological aspects related to the use of a **molten Lead** as coolant
- To test and validate **novel components and systems**

CORROSION CAPSULES	Several tanks filled with O2-controlled lead and Argon, and with immersed specimens: corrosion of structural materials in molten lead
CORE 200 kW	New loop-type test facility for corrosion/erosion testing of structural materials in molten lead
OTHELLO 2 MW	New thermal-hydraulics loop test facility: components performance testing, validation experiments
PRECURSOR 10 MW	New pool-type large-scale test facility: broad-scope investigations on LFR system transient behavior, component testing/qualification, etc.
MANUT dry test	Mechanical-type test facility: fuel handling systems and mechanisms in air
MANUT in-Lead	Mechanical-type test facility: fuel handling systems and mechanisms in Lead
HUSTLE	ISI&R facility
COOLANT CHEMISTY & MATERIAL TESTING IN LEAD	Chemical laboratory to support lead technology related investigations
NACIE-LHT	Test section at existing ENEA NACIE loop facility: lead cross flow heat transfer
CIRCE-NEXTRA	Multiple refurbishments of the existing ENEA-CIRCE pool facility for Components Testing and Steam Generator Tube Rupture (SGTR)
DIP COOLER at PoliTo	New test facility investigating dip cooler based DHR system: TH performance and start-up issues
POOL TEST FACILITY	Potential campaigns at existing pool-type test facilities: thermal-hydraulics, lead chemistry control in large pools, SGTR tests with full-length tubes
MATERIALS LAB Environmental Park Turin	Material laboratory, mechanical testing on structural materials
EFESTO	Fluid-Structures interaction (seism)

newcleo Futurable Energy

Material Infrastructure

APPLICATIONS

steels and superalloys
316L, 316L(N), 1515Ti, AIM1, 800

surface modifications
weld-overlay, spraying, cladding, PVD, CVD

new materials
AFA and SFA alloys, ODS, refractories, HEA, MAX

INFRASTRUCTURE

- chemistry
- corrosion
- metallurgy
- mechanics
- coatings
- characterisations

SITES

Brasimone

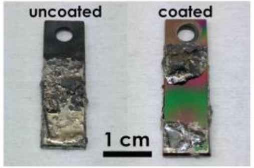
Turin – Energy Center

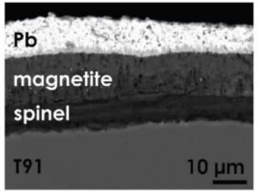
Turin – Environment Park

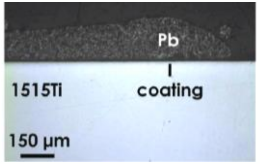
Corrosion lab @ENEA Brasimone (Q4’24)

Static corrosion capsules

- **CAPSULES**: 6 skids of 3 capsules; 108 samples
- Active control of [O] and T (400-750°C)

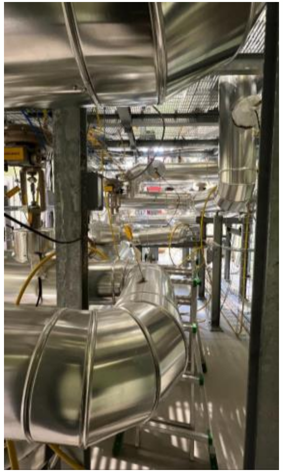


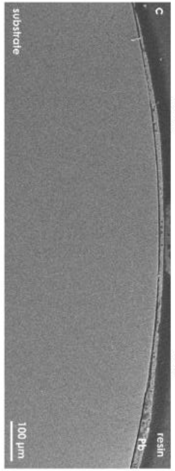




Flowing Pb loops

- **CORE-1**: 32x corrosion (1 m/s, T<650°C) + 3x erosion (10 m/s, T<520°C) + cold-trap and mechanical filters
- **CORE-2**: 120 corrosion samples (1 m/s, T<650°C)





Mechanical tests in Pb

- 20x creep + 2x fracture mechanics frames
- 1 tensile test/SSRT frame

ATS

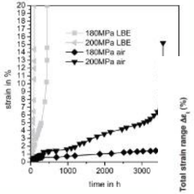
20x creep tester

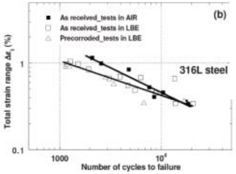
Instron

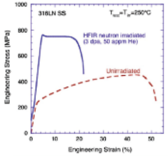
1x servohydraulic tester

Instron

5x tensile







Perform corrosion exposure experiments on steels, surface treatments and new materials, in static and flowing conditions and under mechanical stress

Corrosion lab @ENEA Brasimone (Q4'24)

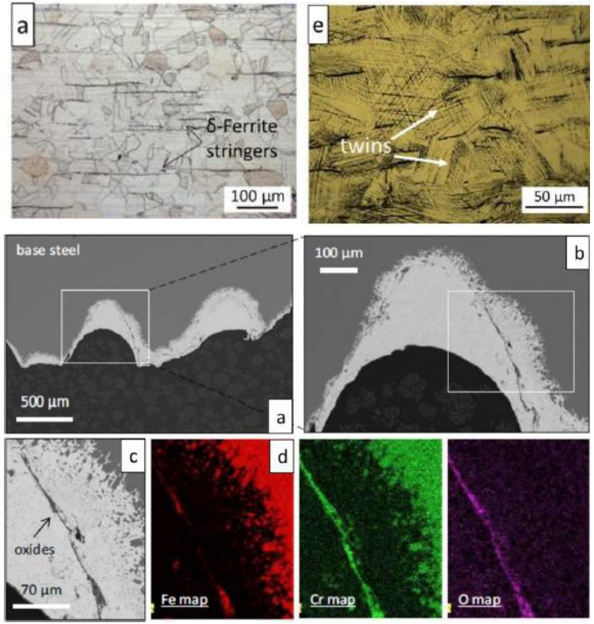
Metallography and Microscopy

Struers
cutting and polishing equipment

Zeiss Discovery V8
stereoscope

Zeiss Smartzoom 5
digital microscope

Zeiss Sigma 360
FEG SEM w/EDX (Oxford)



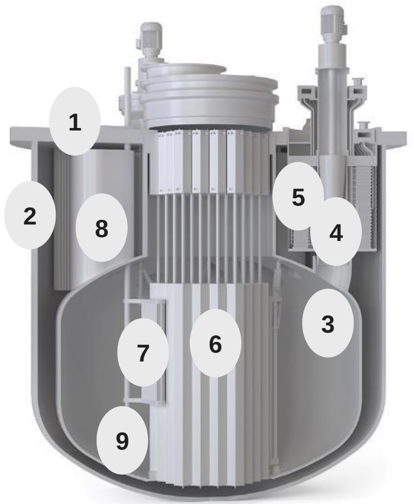
study metals, corrosion layer thickness, morphology and chemical composition

Metrology

Zeiss O-Inspect
tactile and optical metrology

dimensional measurements w/µm precision

materials strategy



Component	Phase I (≤ 480°C)	Phase II (≤ 600°C)	Phase III (> 600°C)

NOT REPLACEABLE

1. Roof structure — standard steels
2. Reactor vessel — standard steels
3. Amphora-shaped inner vessel — surface modifications/new materials

REPLACEABLE

4. Primary pump
5. Steam generator tubes
6. Fuel assemblies
7. Control rods
8. Decay heat removal tubes
9. Other internals

Phase I (≤ 480°C)	Phase II (≤ 600°C)	Phase III (> 600°C)
surf. modif./new m...ls sta... Materials R&D programme I	surface... Materials R&D programme II	ne... Materials R&D programme III

chemistry and irradiations

- In SFR nuclear codes and not operating in Pb → limited R&D needed
- In SFR nuclear codes but operating in Pb → qualification in Pb needed
- Operating in Pb, not in codes → substantial R&D required

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Futurable Energy

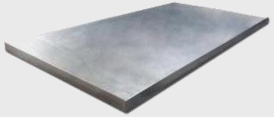
R&D programme 1 – standard steels

1

316L

2

316L(N)

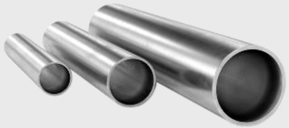


3

316Ti

4

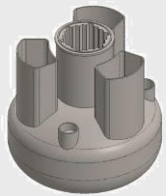
AIM1 and 1515Ti



R&D programme 2 – surface modifications

1

Out of core:
industrial methods

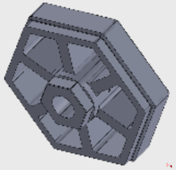


2

Core – simple geometry:
PVD and metallurgy methods

3

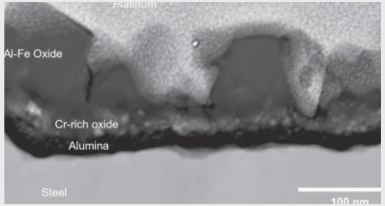
Core – complex geometry:
CVD and electrochemical methods



R&D programme 3 – new materials

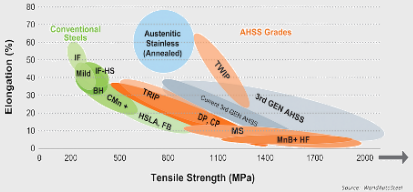
1

Alumina- and silica-forming alloys



2

AHSS
(Advanced High Strength Steel)

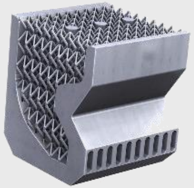


3

Other materials

4

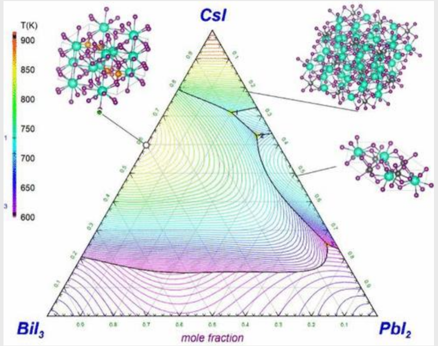
Advanced manufacturing



R&D programme 4 – chemistry

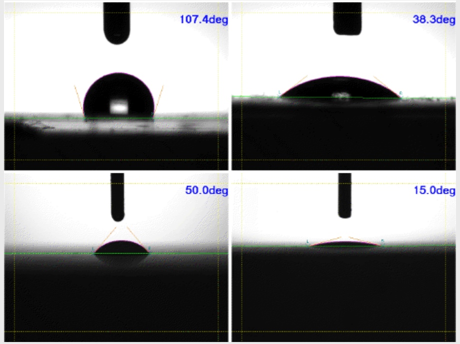
1

Impurities:
oxygen, corrosion products and fission products



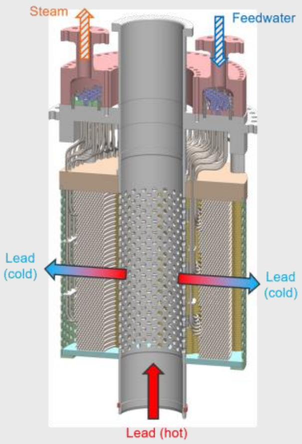
2

Wettability



3

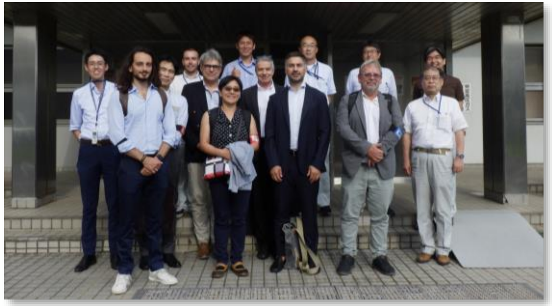
Aqueous corrosion



R&D programme 5 – irradiations

	Programme I	Programme II	Programme III
ion irradiations		initial iterations: radiation effects on microstructure and mechanical properties	
corrosion tests on ion irradiated materials		explore functionality	
neutron irradiations		test actual radiation effects	
corrosion tests on neutron irradiated mater.	effect of radiation damage on corrosion behavior		
neutron irradiations in lead	test for synergistic effect		

ions			neutrons			
CEA Jannus	Uni Manchester	HZDR/NCBJ/JRC	HFR, NRG	Joyo, JAEA	LVR, CVRez	CEA



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