*new*cleo's materials strategy for Gen-IV LFR research and development

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GIF LFR webinar
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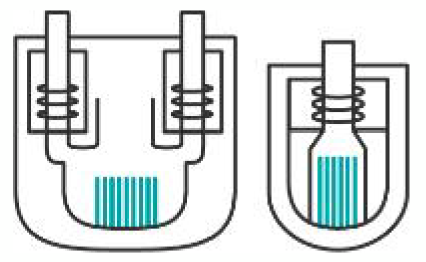
A *new*, innovative player in nuclear energy

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

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

INTRINSICALLY SAFE power production

COMPETITIVE energy cost

CIRCULAR nuclear waste recycling

Presence across **EUROPE**

Launched in **SEPTEMBER 2021**

- **€537 million** of private funds **~€50 million** turnover in 2024
- French **first licensing stage completed** for the first reactor and the fuel production facility
- Selected by **France 2030** and the **European Industrial Alliance on SMRs**

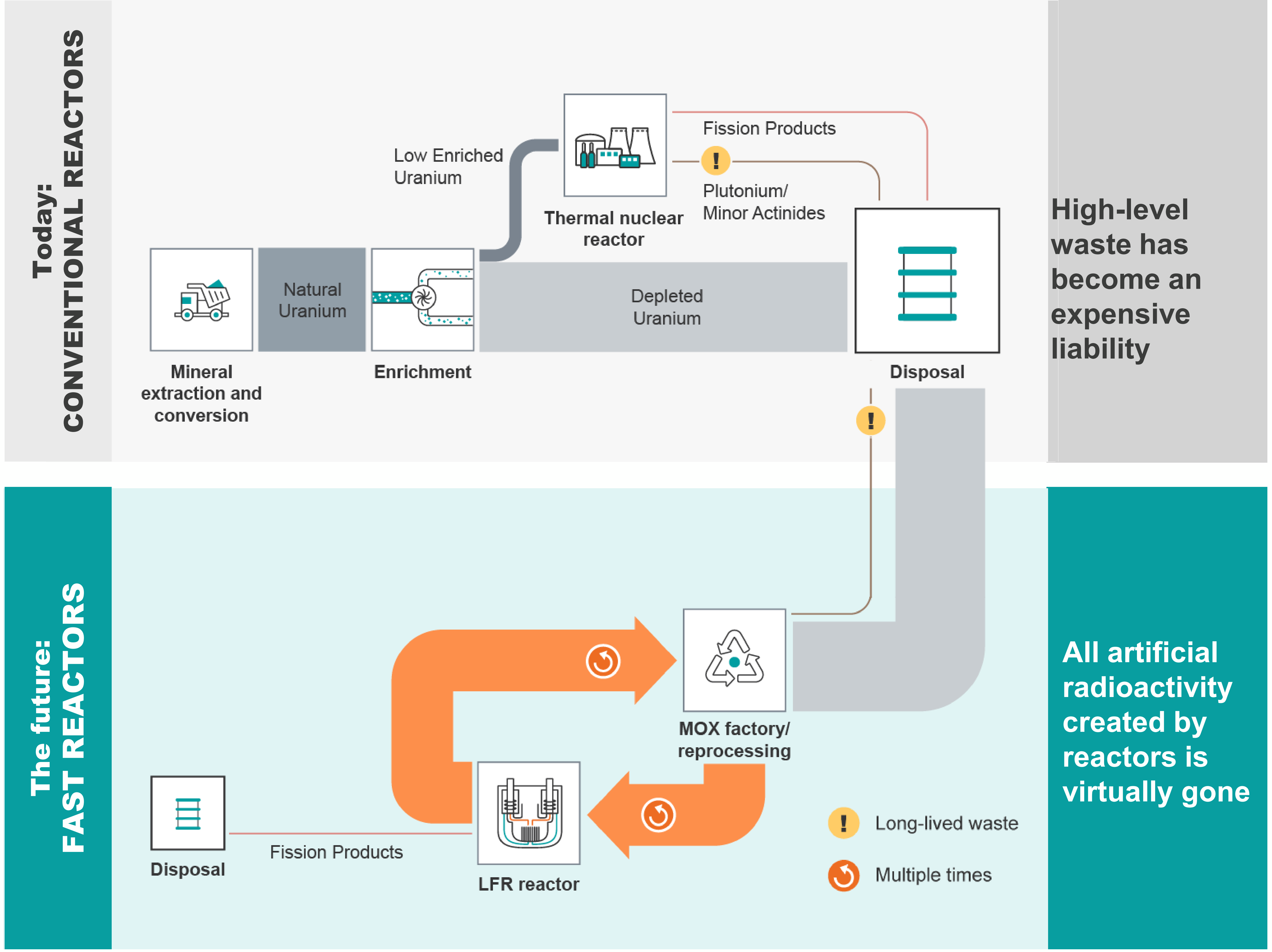
1,100+ EMPLOYEES GLOBALLY	**30+** YEARS OF R&D	**22** PATENTS

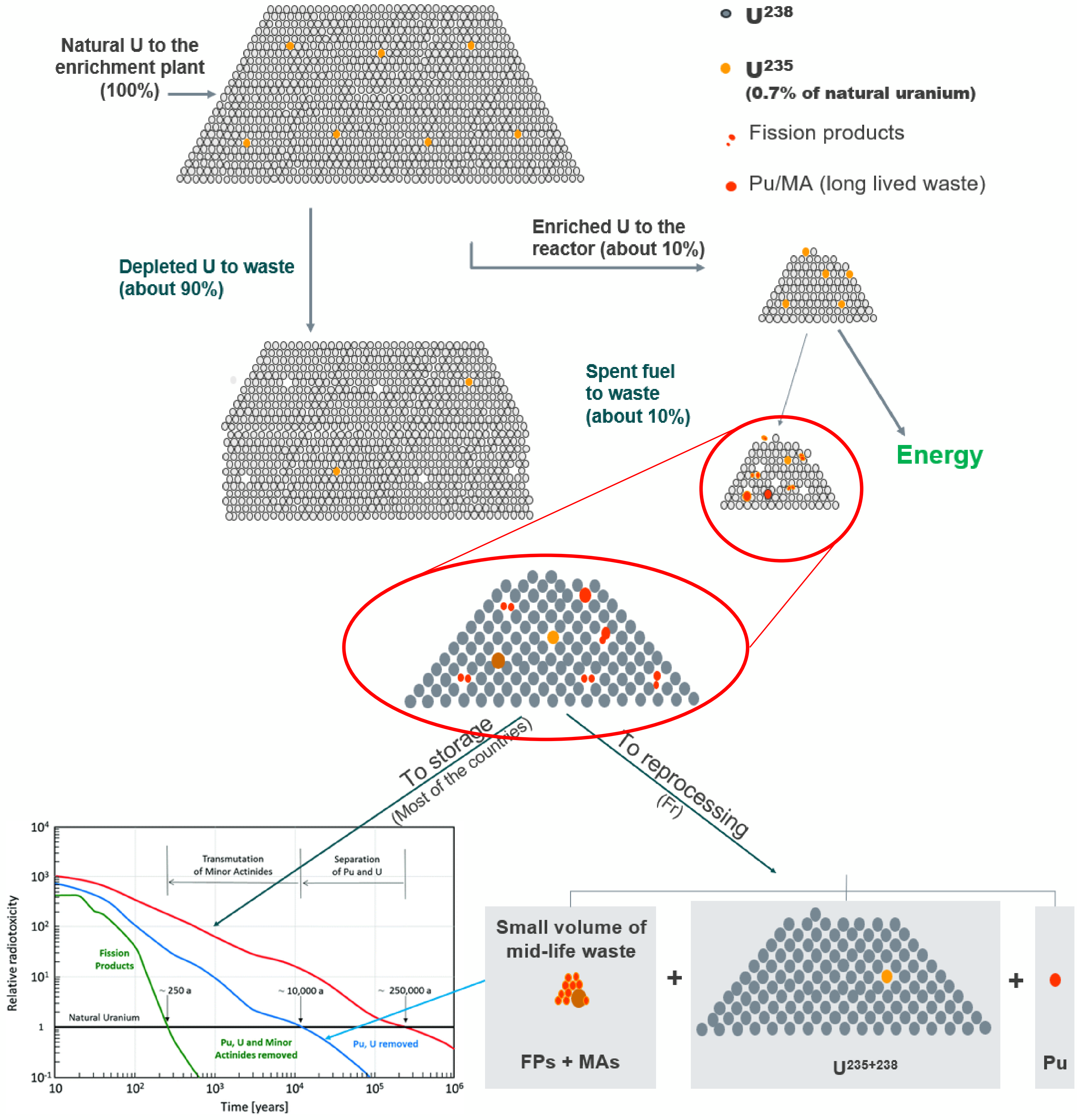
Highly specialised EPCM capabilities

FUCINA ITALIA – A *newcleo* company
S.R.S. – A *newcleo* company
RÜTSCHI – A *newcleo* company

ISO9001 and ISO19443 certification

Closing the fuel cycle with fast reactors via reprocessing



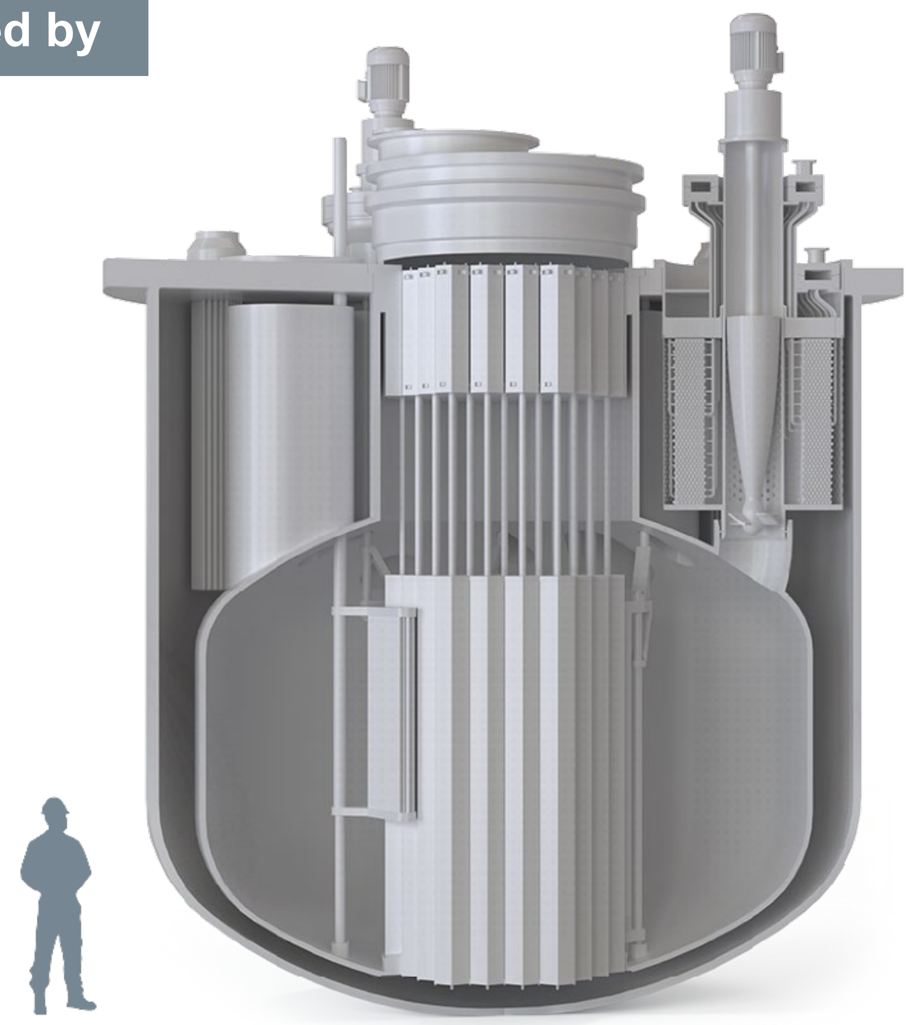


SMRs improve economics and flexibility in nuclear

Small Modular Reactors (**SMRs**) are designed for enhanced safety, flexibility, and reduced environmental impact, with competitive energy costs, lower capital investments, shorter construction times, and suitability for remote deployment.

ECONOMIES OF SCALE
Large reactors > 1GWe

replaced by



ECONOMIES OF SERIES
Small, standardised designs < 300MWe

Serial production
Reduced costs and risks of overrun

- Learning curve and economies of series
- Centralised factory production to limit onsite costs
- Transportable on site and faster construction

Modularisation
Shorter construction time

- Modular construction
- Multi-module deployment enabling “chain” financing of one module to the next

Simplification
Enhanced safety

In the case of *new*cleo’s LFR: reduced complexity enhancing overall safety, while limiting costs (e.g., passive safety) and reducing local permitting requirements

Limited capital intensity
Better affordability

- Lower upfront capital costs
- Higher profitability due to faster construction
- Limited financing risk, with greater access to private capital

Smaller footprint
Greater site flexibility

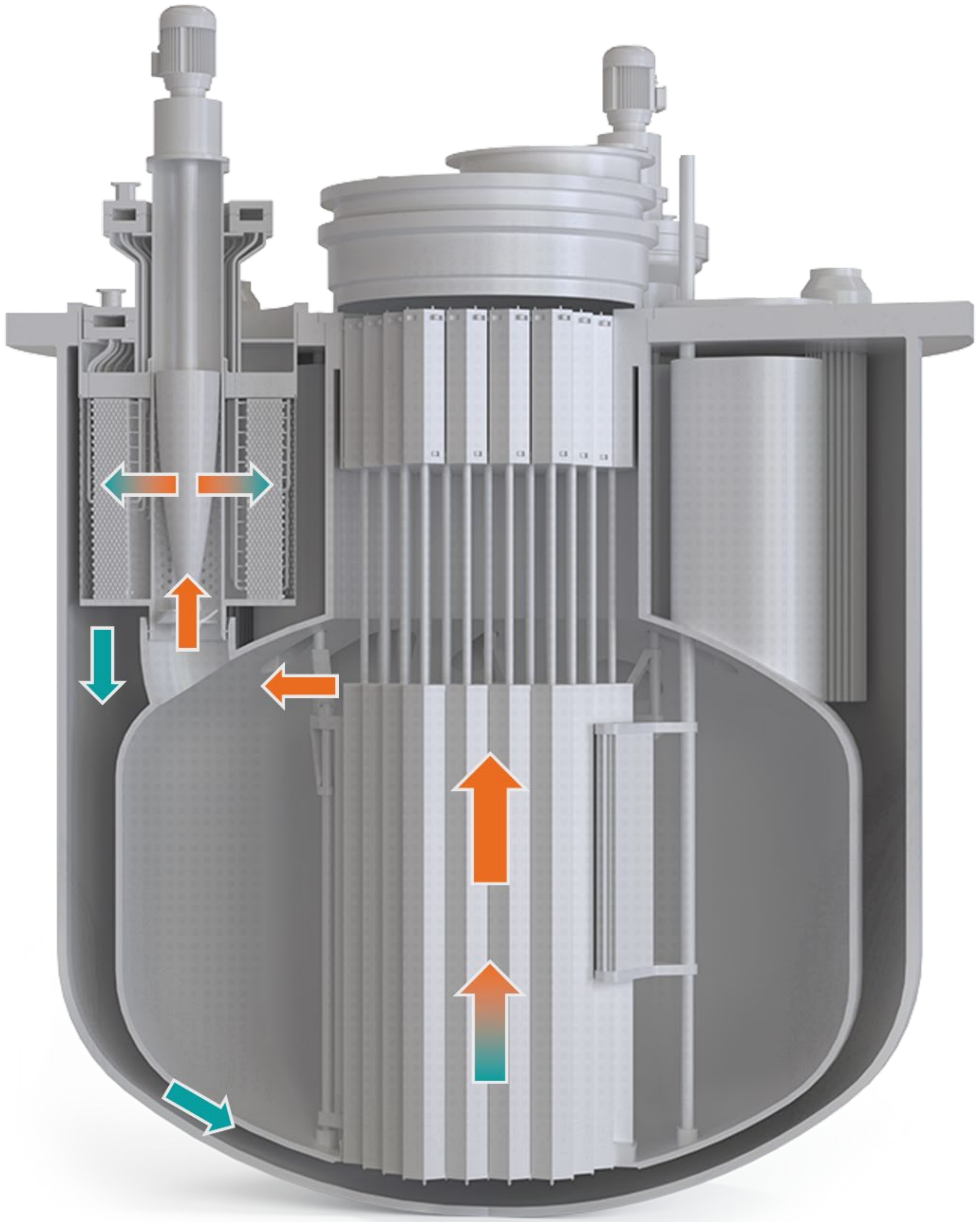
- Reduced site size
- Suitable to decarbonise industrial production or Data Centres
- In the case of *new*cleo’s LFR: reduced emergency planning zone

Flexible applications
Wider range of users

- Remote locations and small grids, suitable for fossil plant replacement
- Non-electrical applications (e.g. industrial heat, desalination)
- Marine based (floating, propulsion) applications and Data Centres

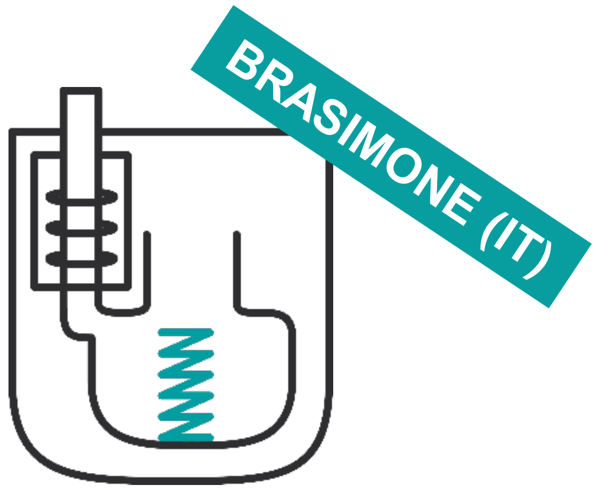
*new*cleo's design: simplification as an enabler for AMRs

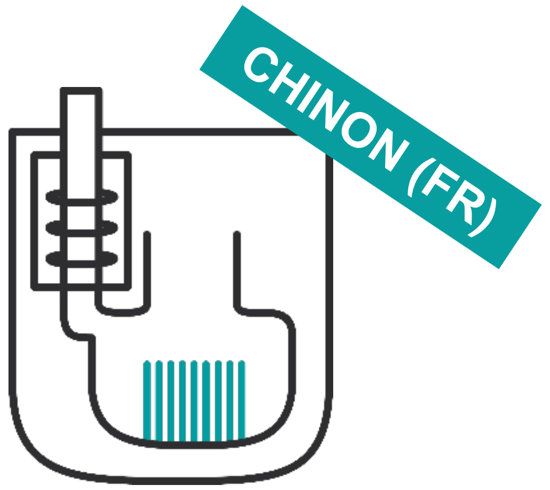
CLASSICAL SFR	***new*cleo LFR**
With **intermediate loops**	**without** intermediate loops
Fuel element **fully immersed**	with **heads out** of the primary coolant
Fuel element fixed at the **bottom**	**top**
Inner vessel larger at the **top**	**bottom**
Primary pumps **between**	**inside** the steam generators
Pump in the **cold**	**hot** collector
Primary fluid inlet in the **upper**	**lower** part of the heat exchanger
Vertical	**radial flow** in the steam generator

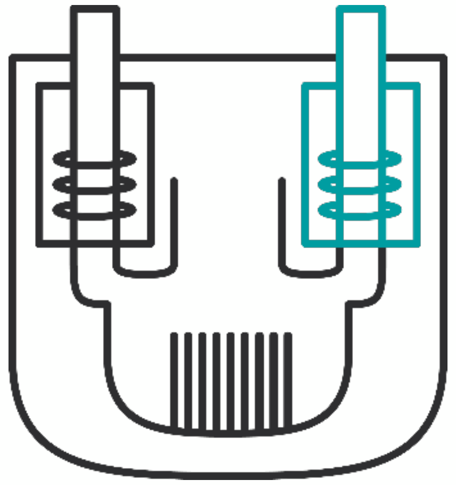


newcleo
Futurable Energy

*new*cleo’s plan-to-market







R&D and Precursor	MOX production	LFR-AS-30	LFR-AS-200
2026 Several R&D and qualification facilities, and a **10 MW non-nuclear reactor** with turbo-generator (Precursor) built in ENEA-Brasimone	**2030** **FR-MOX production facility**, starting from available (separated) material in France; 20→40→120 t/year – DOS submitted to ASN	**2031** **30 MWe** irradiation reactor licensing step 1: familiarisation of ASN done ‘23-’24; phase 2 WIP: pre-instruction ‘25-’26; phase 3: ‘26 instruction ‘26+	**2033** **200 MWe FOAK**, also for non-electrical uses (e.g. cogeneration and chemicals production)
Design, manufacturing and operation in progress	**Basic Design** in progress **Licensing** in progress for both facilities		**Basic design** in progress **UK Licensing** started in 2024

Ongoing M&A programme

newcleo
Futurable Energy

Brasimone: the world's largest centre for lead-cooling technology development

R&D and PRECURSOR	MOX PRODUCTION	LFR-AS-30	LFR-AS-200

Facility	Description
CAPSULE operational Dec 2023	Corrosion tests in stagnant lead, with advanced temperature and oxygen control
CORE 200 kW CORE-1 operational in June 25 CORE-2 commissioning WIP	Two loop-type test facilities for corrosion and erosion testing of structural materials in flowing lead, with filtering section and cold trap
OTHELLO 2 MW commissioning in 2025	Multipurpose thermal-hydraulics loop test facility for thermal-hydraulic code validation and post-test analysis of components
PRECURSOR 10 MW 2026	Pool-type large-scale test facility representative of the LFR-AS design for broad-scope investigations on LFR system transient behaviour, component testing/qualification, etc.
MANUT dry and in-lead	Infrastructure to validate mechanical aspects including handling of fuel assemblies, components, and control rods
CHEMISTRY LAB operational in 2025	Chemical laboratory to evaluate mechanical properties in lead i.e., creep, long-term creep, slow strain rate tests, creep fatigue
SOLEAD operational 2023	Lead coolant chemistry facility

Facility	Description
NACIE-LHT operational Jun 2024	Within existing ENEA NACIE loop facility. Aims to provide lead-side transverse heat transfer coefficient data
CIRCE-NEXTRA Phase I – Pumps, DHR Phase II - SGTR	Within existing ENEA CIRCE pool-type facility Phase I: primary pumps and DHR to study hydraulic performances, vibration dynamics, long-term endurance and mechanical loads Phase II: Steam Generator Tube Rupture (SGTR)
HUSTLE commissioning in progress	Hot Ultra Sonic Testing Lead Experiment, two phases – in hot air and in liquid lead
DCI operational in Mar 2025 at PoliTO	Dip Cooler Instability test facility with two Decay Heat Removal systems, in- and ex- vessel, designed to ensure safe reactor temperatures
MATERIALS LAB	Advanced materials characterization & metallurgy equipment
EFESTO at ENEA-Casaccia	Earthquake and Sloshing Test Observation. Pool-type test facility filled with liquid lead that reproduces LFR-AS-30 behavior under seismic events


CAPSULE module


CORE-1

Partnership signed with ENEA in March 2022: unique global know-how and 30 *new*cleo engineers, with EUR 90 million investment for about 10 years. Renovation works started in June 2022

At ENEA-Brasimone | Located elsewhere

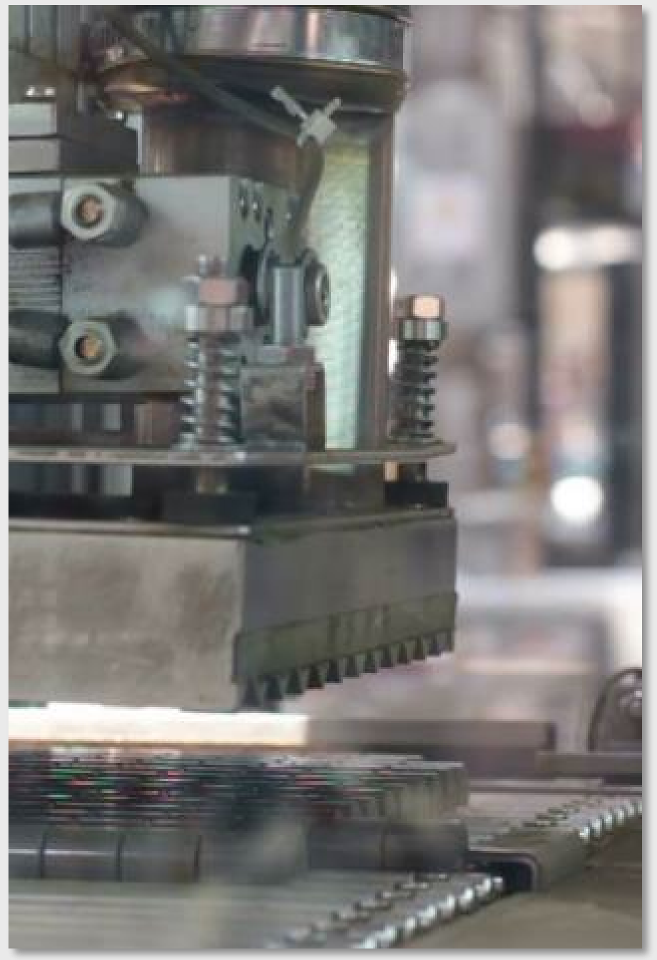
Our fuel cycle programme

R&D and PRECURSOR	**MOX PRODUCTION**	LFR-AS-30	LFR-AS-200

Powders

- Uranium Oxide
- Plutonium Oxide

Powder preparation → Pellet fabrication → Rod fabrication → Assembly fabrication → Shipping and loading



*new*cleo to manufacture MOX fuel

- from powders to assemblies to fuel our LFR demonstrator and fleet
- starting from already available (separated) material
- in synergy with the in-country environment, establishing deep industrial collaborations with the sector's leading actors

Design and licensing in progress

An advanced and modular facility concept to gradually increase capacity: first production line of 20 t/year (rapidly increasing to 40 t/year), with the possibility to add other production lines up to 120t/year.

Licensing status: submitted our **Safety Options Dossier (DOS)** to **ASN**

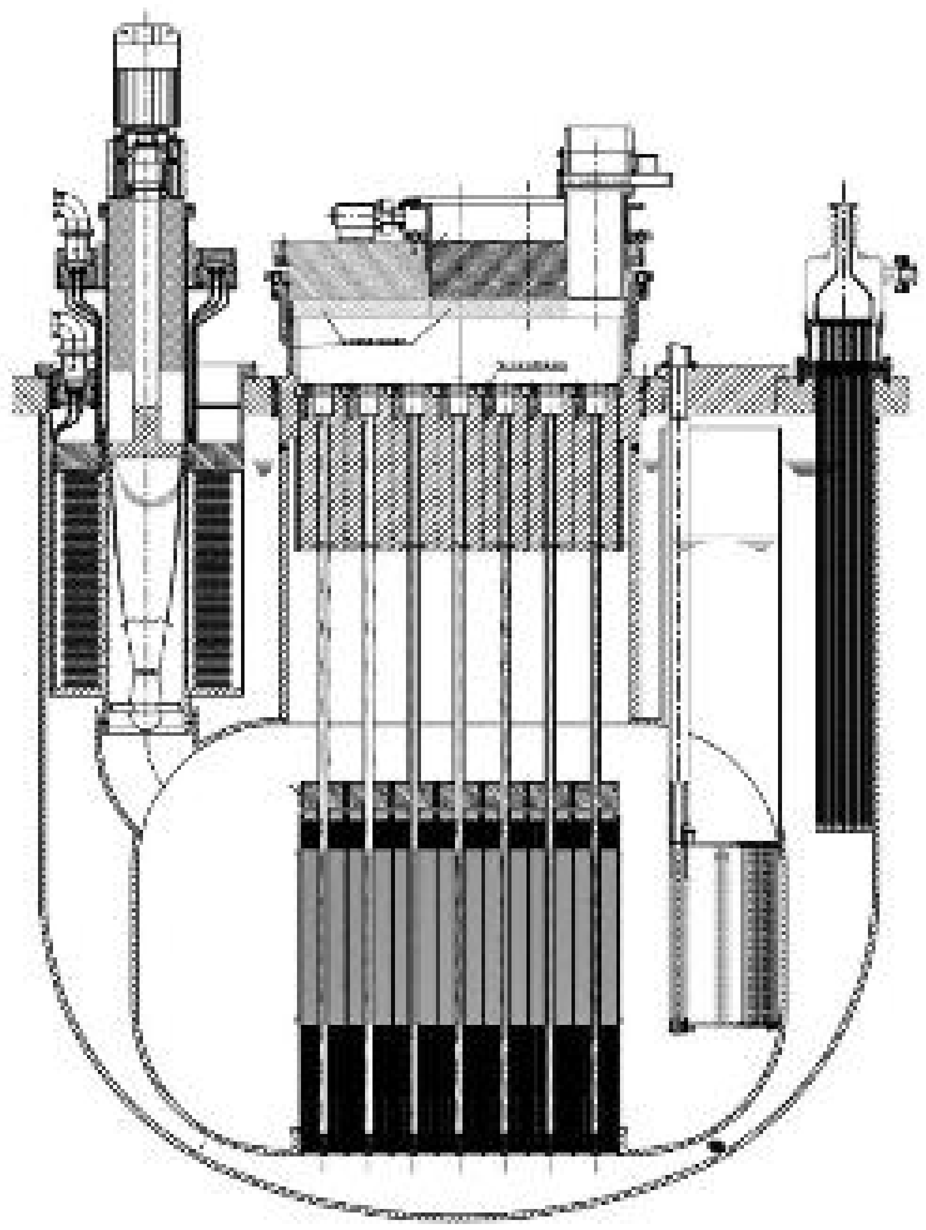
Progressive implementation of long-term fuel cycle programme

*new*cleo's long-term fuel cycle programme will be realised one step at a time in an agile and flexible way: taking rapid steps to make progress in a way that will not preclude future options or a change of approach

- Fuel *new*cleo's demonstrator and first commercial unit
- Fuel *new*cleo's fleet
- Exploit reprocessing
- Deliver services internationally
- Achieve fully sustainable nuclear

LFR-AS-30: Amphora Shaped, 30MWe

R&D and PRECURSOR	MOX PRODUCTION	**LFR-AS-30**	LFR-AS-200

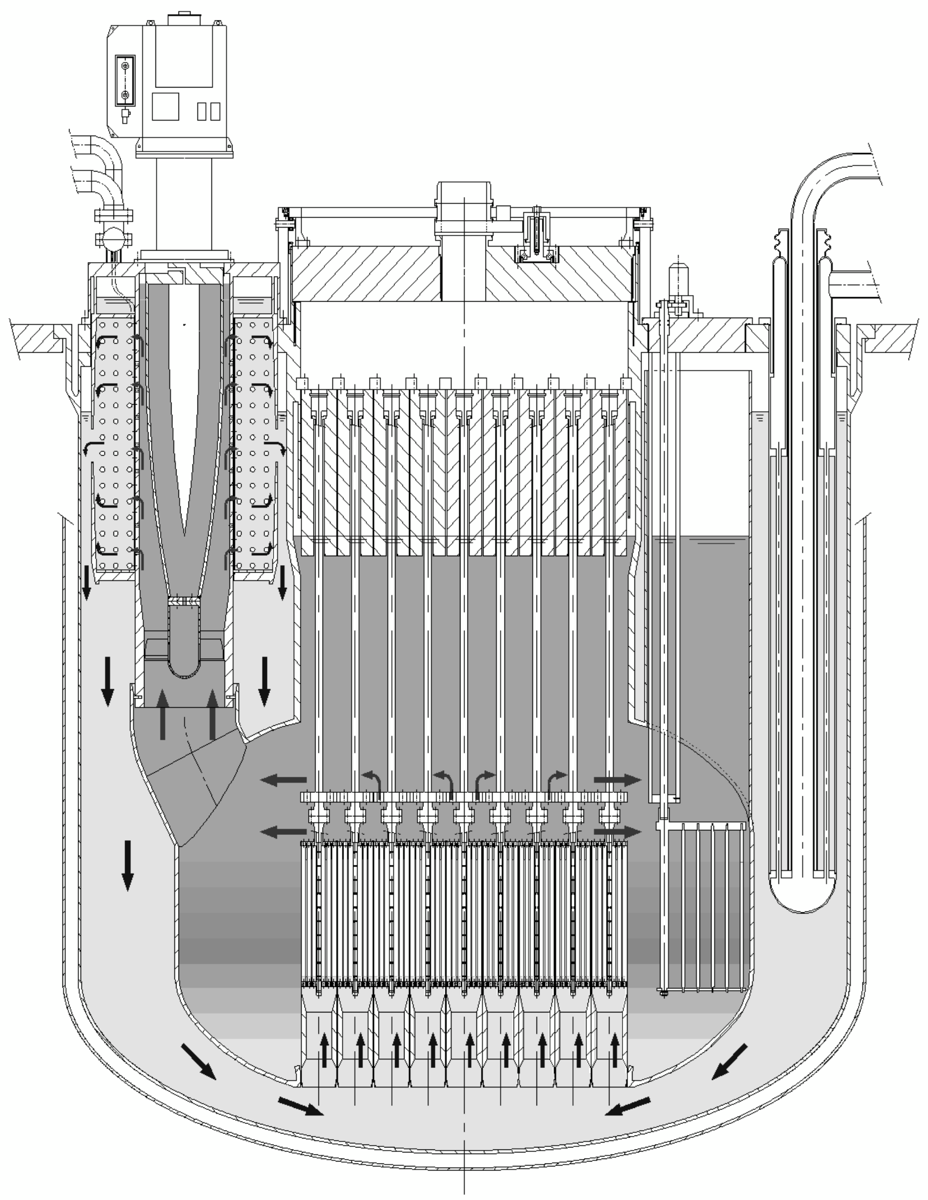


- *new*cleo's irradiation machine used for materials R&D and other uses, offering unique irradiation services based on a hard and intense neutron spectrum
- The plant will have a single AS-30 unit and include hot cells and laboratories
- The reactor is designed to be representative of the LFR-AS-200, and will also be used to validate new components and solutions for our commercial reactors, to increase their operating temperatures and to expand production efficiency and performances
- Reactor conceptual design completed in March 2023, basic design in progress
- **First phase of technical meeting with ASN and IRSN completed in June 2024**

	1st phase Low temp. and power	2nd phase High temp. and full power
Power	**60MWth**	**90MWth**
Core coolant temperature	**inlet 370°C, outlet 440°C**	**inlet 420°C, outlet 530°C**
Steam at turbine inlet	**400°C, 150 bar**	**500°C, 150 bar**
Core coolant	**Pure lead**	
Layout	**Pool-type**	
Circulation	**Forced: 3 pumps**	
Spectrum	**Fast**	
Fuel form	**Extended-stem fuel assembly**	
Fuel	**MOX**	
Secondary side fluid	**Water**	
Steam generators	**3 spiral-tube SG**	
Design life	**60 years**	

LFR-AS-200: Amphora Shaped, 200MWe

R&D and PRECURSOR	MOX PRODUCTION	LFR-AS-30	**LFR-AS-200**



- *new*cleo's commercial nuclear reactor to be deployed in multi-unit mode, with the intention to deploy a fleet
- The First-Of-A-Kind (FOAK) unit is expected at the end of 2033
- Basic Design in progress

MAIRE — **Jan 2024**

Conceptual study for the chemical sector on the production of electrolytic hydrogen, carbon-neutral ammonia, methanol, e-fuels and derivative

SAIPEM — **Sep 2024**

Oil and gas offshore installations and floating nuclear units, connected to the electricity grid on land

DANIELI — **Jan 2025**

Decarbonise steel production by integrating *new*cleo's lead-cooled fast reactors (LFR) with their steelmaking technology

Power	**480 MWth**
Core coolant	**Pure lead**
Core coolant temperature	**inlet 420°C, outlet 530°C**
Layout	**Pool-type**
Circulation	**Forced: 6 pumps**
Spectrum	**Fast**
Fuel form	**Extended-stem fuel assembly**
Fuel	**MOX**
Secondary side fluid	**Water**
Steam generators	**6 spiral-tube SG**
Design life	**60 years**
Lifetime capacity factor	**93%**

LFR technology

Lead has unique properties for developing a fast reactor

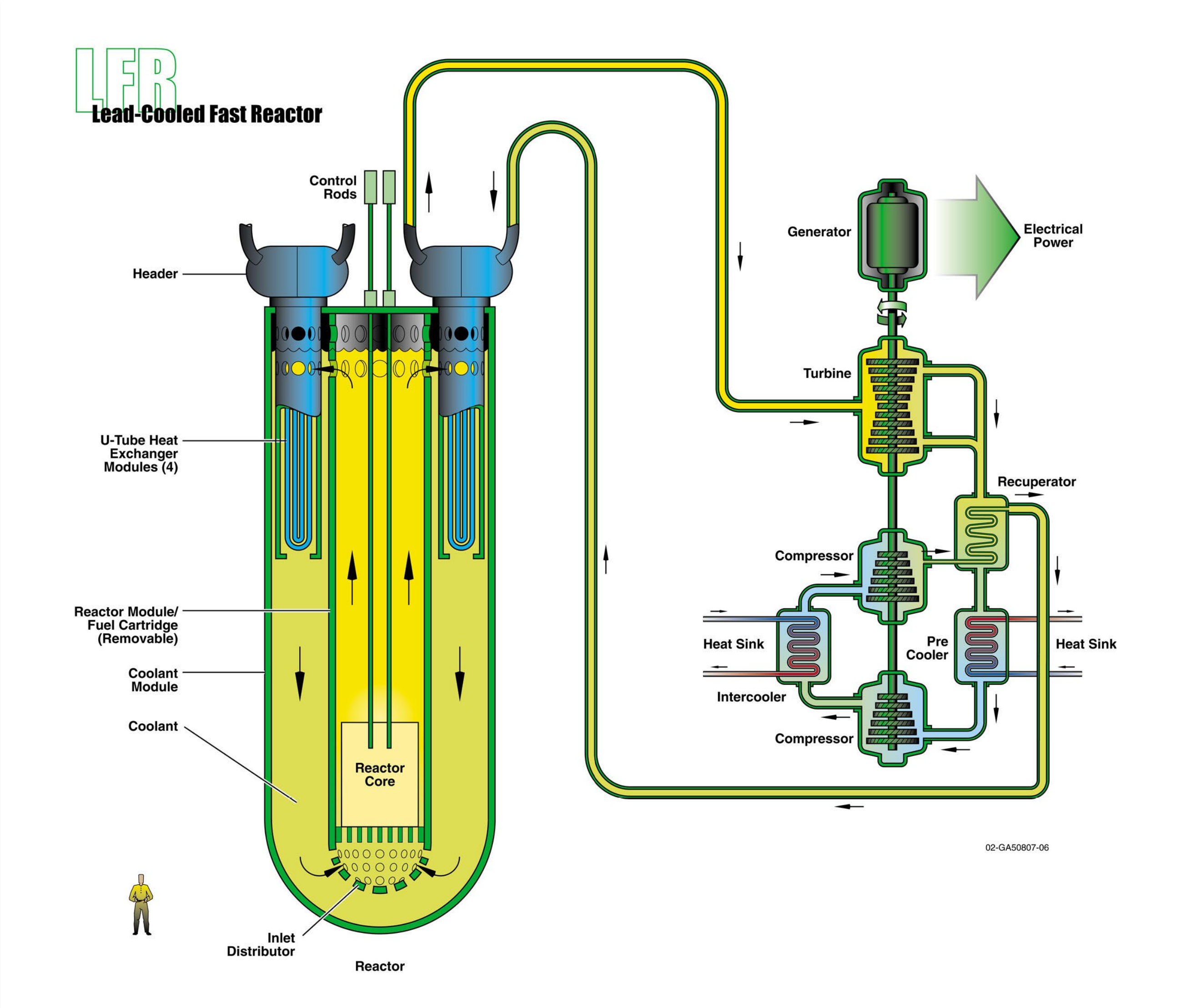
Atomic mass (a.m.u.)	Absorption cross-section	Boiling Point (°C)	Chemical Reactivity (w/ air and water)	Risk of Hydrogen formation	Heat transfer properties	Retention of fission products	Density (kg/m^3) @400°C
207	Low	1737	Inert	No	Good	High	10580
Fast neutron spectrum	Large fuel pin lattice Low core pressure loss	Primary system at atmospheric pressure	No intermediate loop Possible use of low-cost water or air loops for DHR	Reduced risk of plant damage	Reduced risk of fuel cladding overheating	Reduced source term during postulated accidents	No risk of core compaction Core supported by lead

Density (kg/m^3) @400°C	Melting Point (°C)	Opacity	Compatibility with structural materials
10580	327	Yes	Corrosive

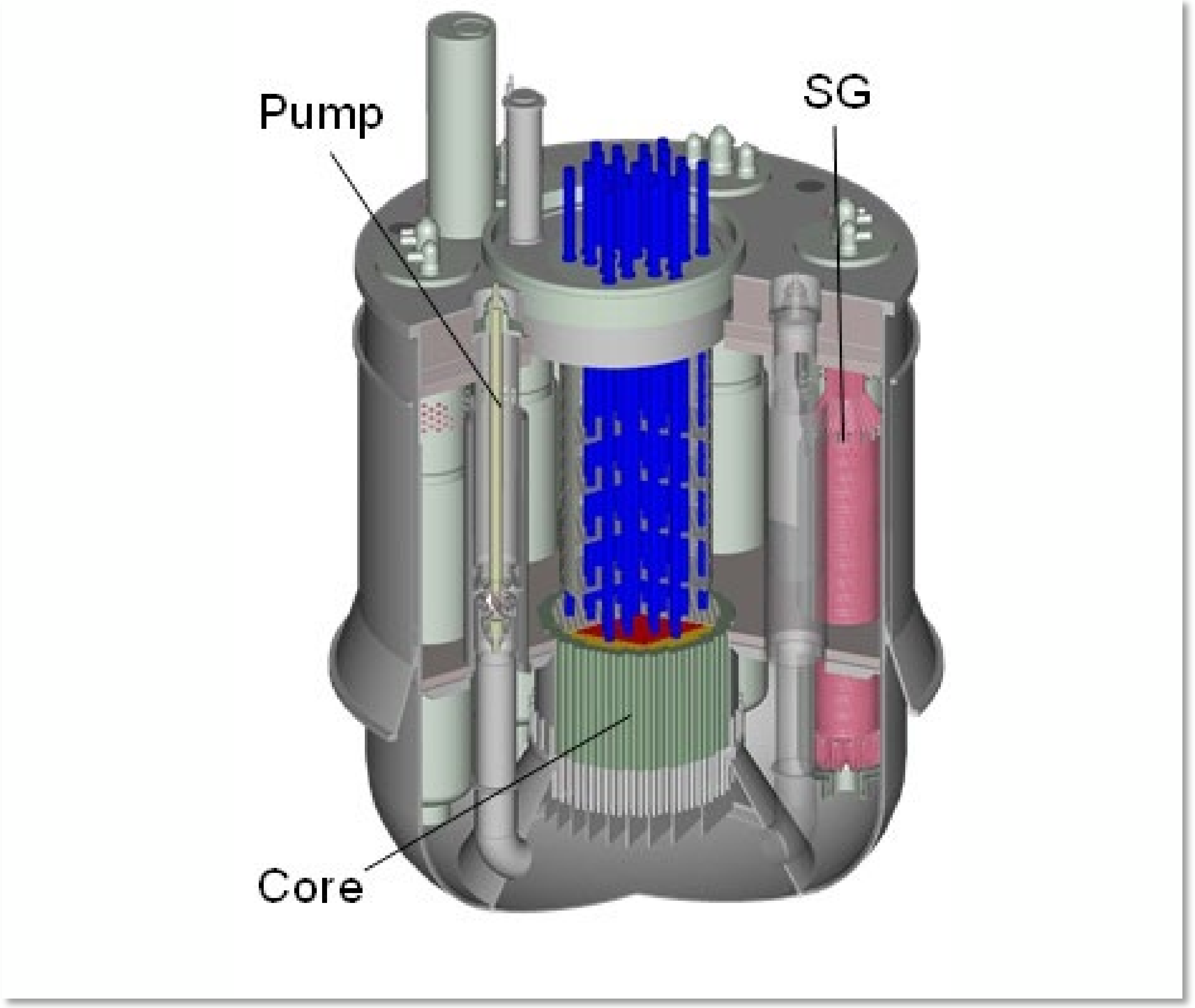
But it also has properties that have discouraged some designers

*new*cleo has identified technical solutions to minimise the impact of the unfavourable characteristics of lead and in some cases has also drawn design advantages.

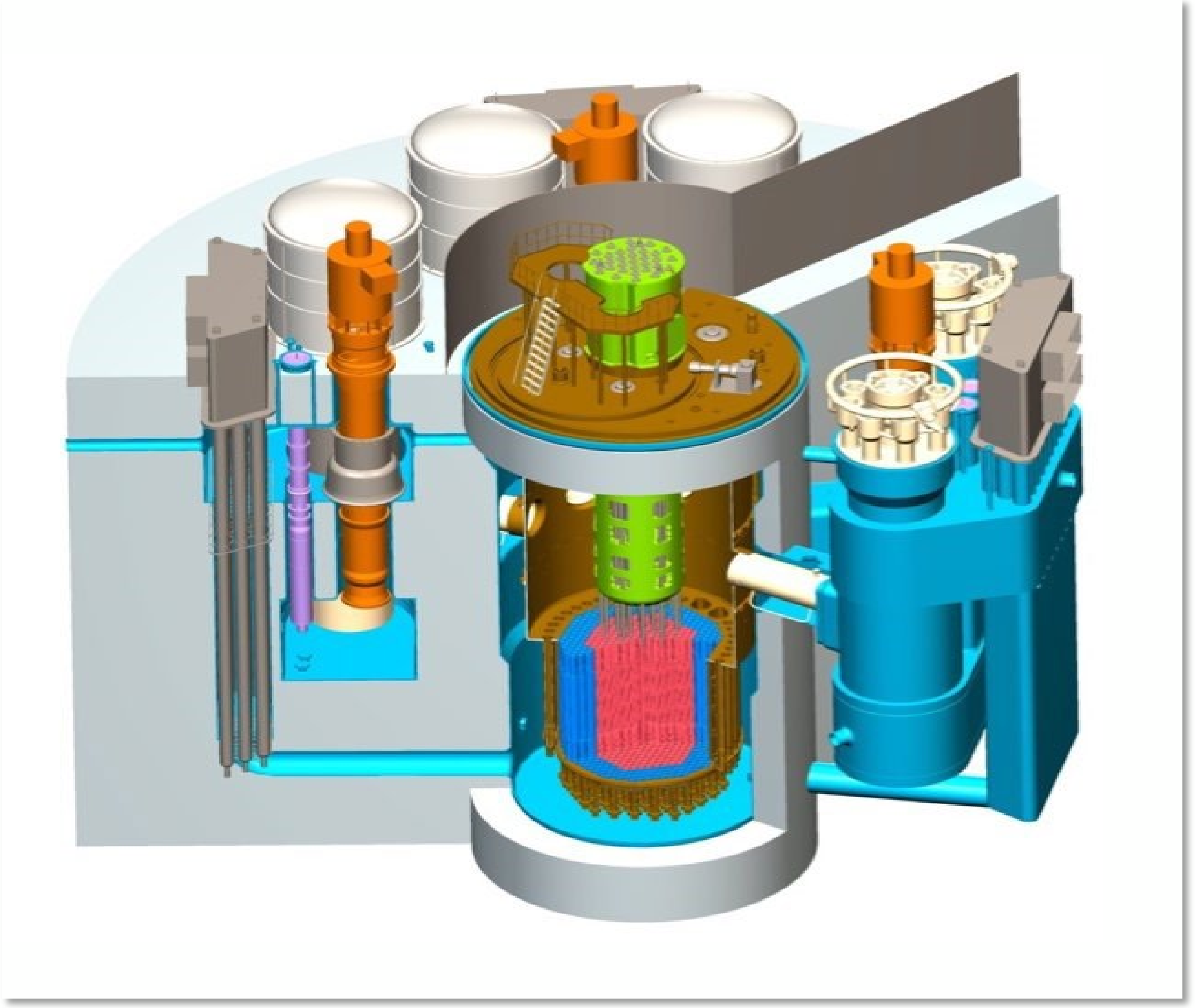
International background



LFR scheme from the Technology Roadmap for Generation IV Nuclear Energy Systems



JAEA’s LBE-cooled



BREST

Concrete structures and semi-integrated configuration

The development of the HLMC technology for nuclear application started in the Soviet Union

Heavy Liquid Metal Coolant (HLMC) technology for nuclear application started in the **Soviet Union for submarine propulsion**:

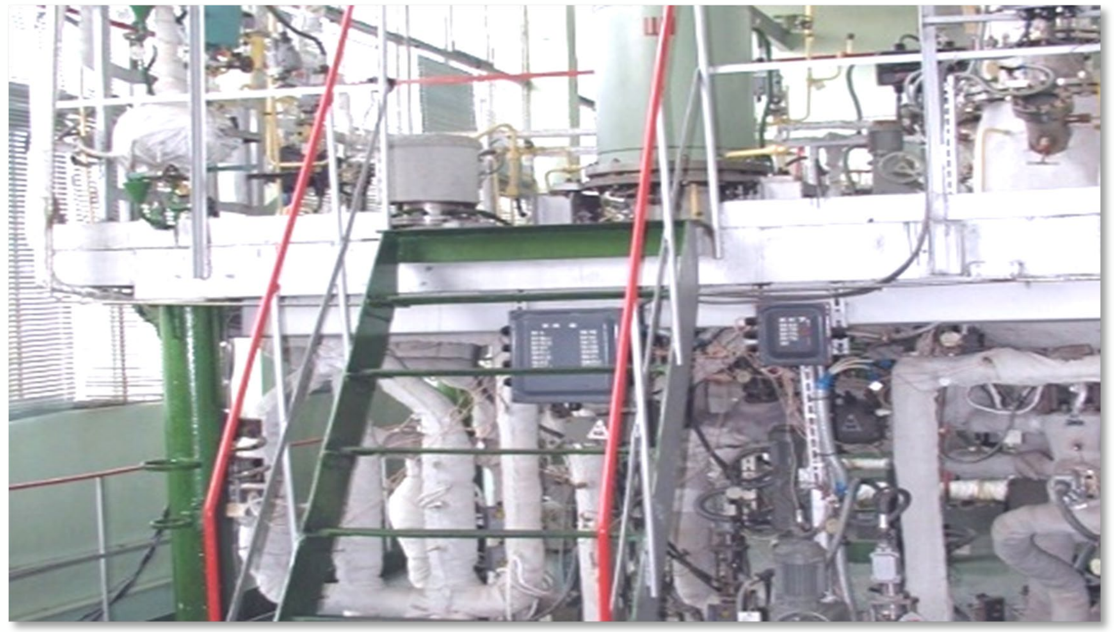
2 submarine prototypes with 2 reactors each,

7 “Alpha Class” Submarines (155 MWt).

Total of 15 reactors including 3 land system reactors; plus one replacement reactor for submarines

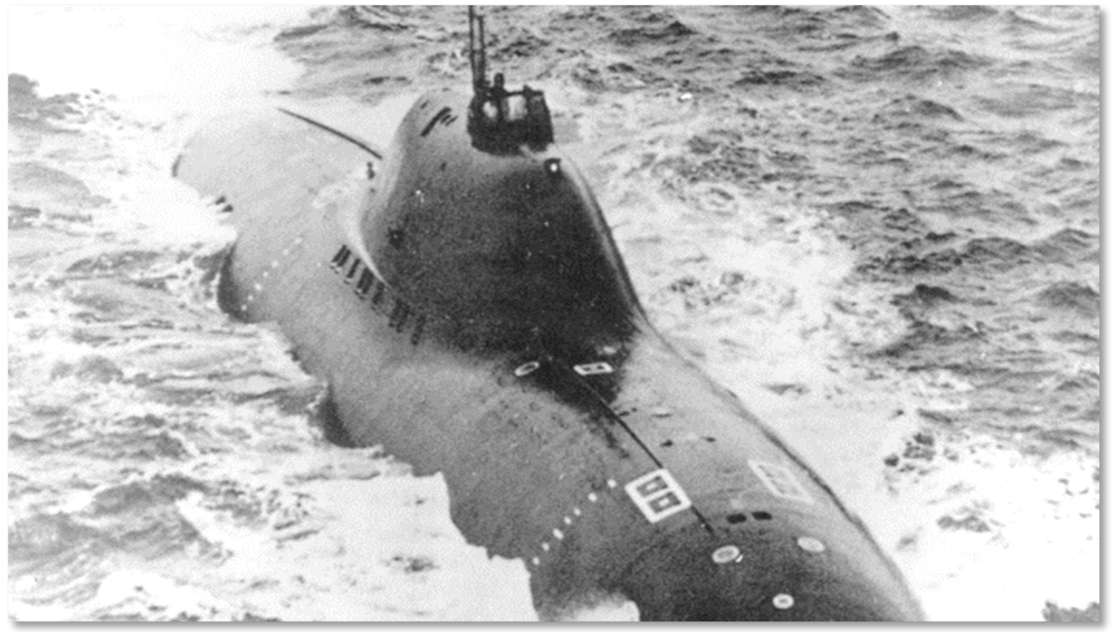
The acquired experience base for HLMCs in the Soviet Union amounts to 80 reactor years

A LFR has never been built (only Russia has started the construction of BREST-300 on 8 June 2021)



1951 **Pb-Bi setup**

1963 **Prototype nuclear submarine Project 645**



1971 **Nuclear submarine-705 demo**

1976 1996 **Nuclear submarine-705 serial**

Construction of BREST-300 is part of the “Proryv project”

Proryv project: practical demonstration of all elements of the closed nuclear fuel cycle

built on 80 reactor years experience with LBE-cooled submarines

Pilot Demonstrational Energy Complex (PDEC), in construction © SCC

2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030

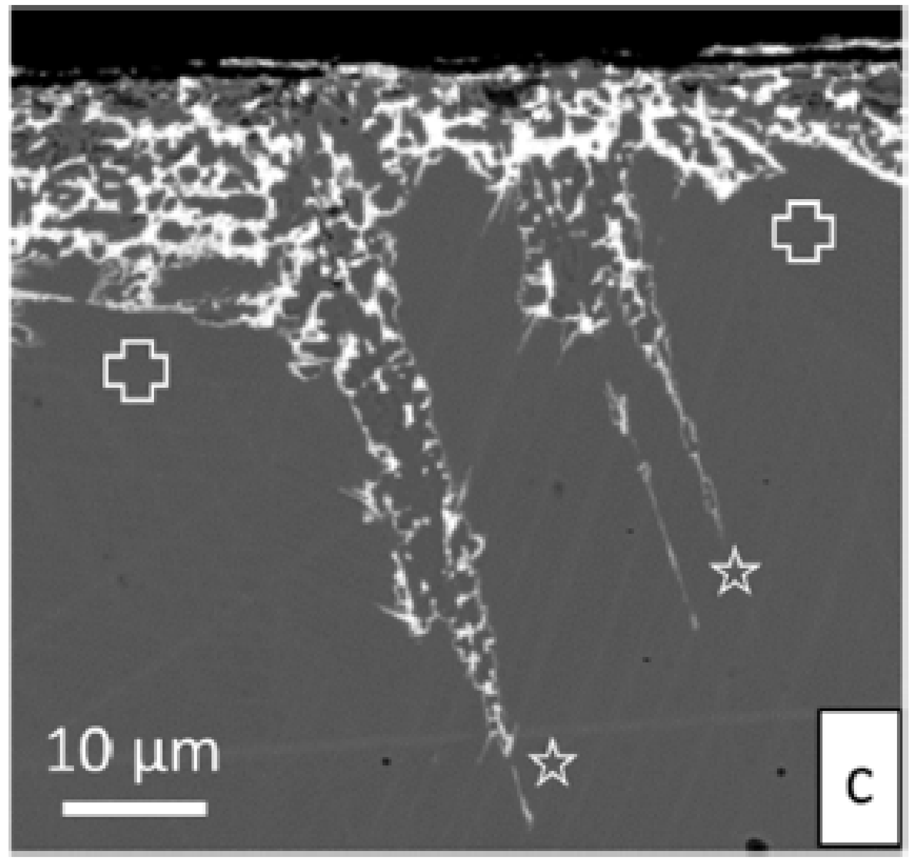
2020–2023: Construction and commissioning of the **Fuel (re-) fabrication module**

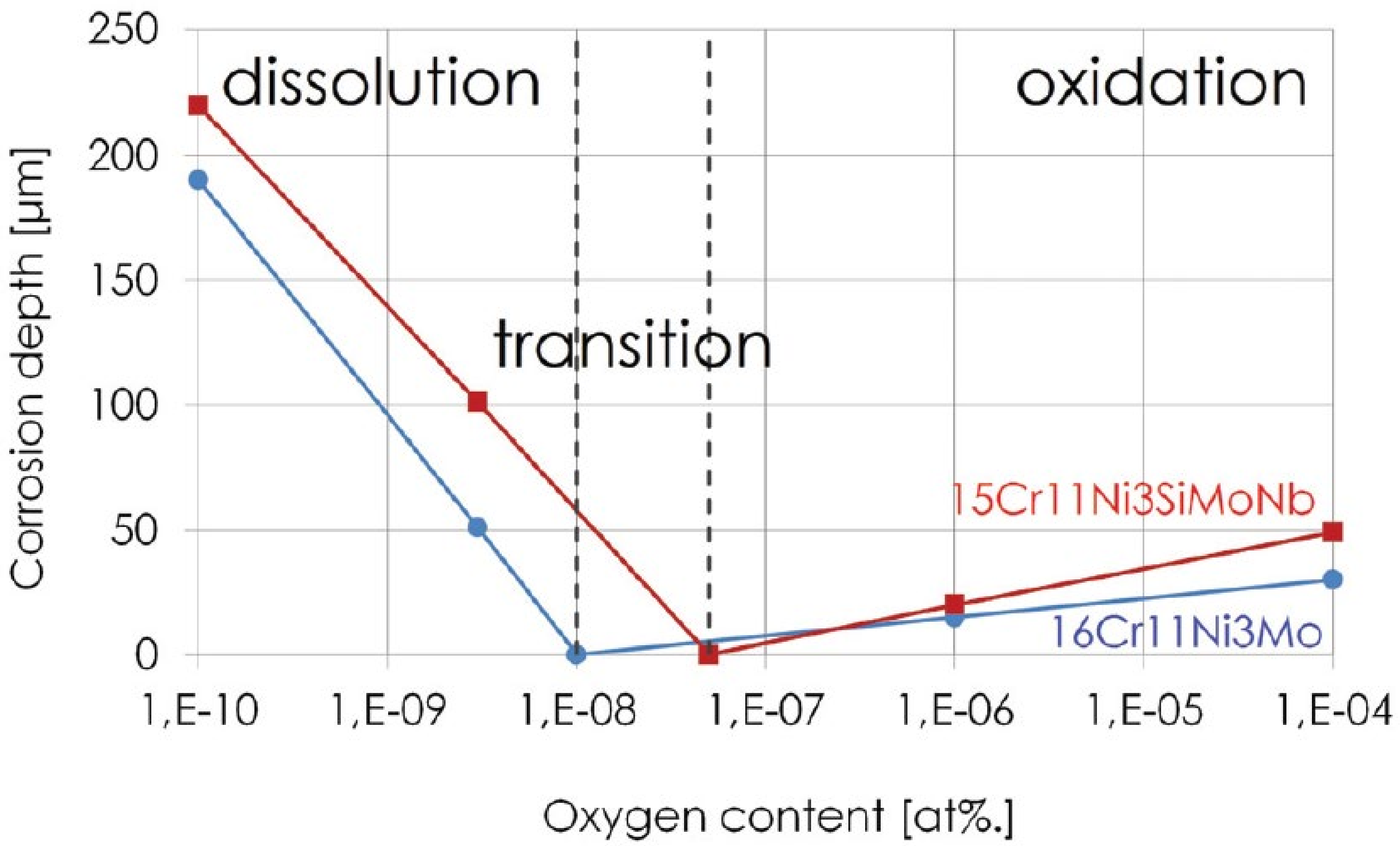
2020–2026: Equipment manufacturing, construction of the nuclear power plant with the **BREST-OD-300 lead-cooled fast reactor**

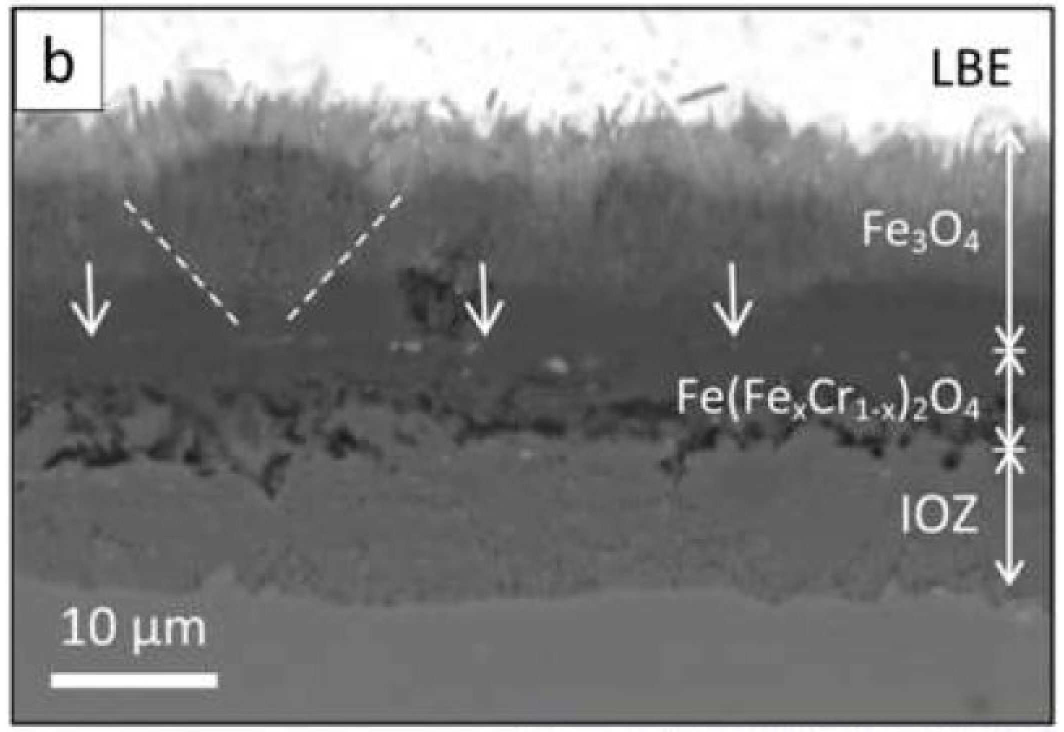
2025–2029: Construction and commissioning of the **Reprocessing module**

Corrosion of steels by lead is a major technology challenge

Dissolution	Flowing Pb for 3000h at 550°C	Oxidation



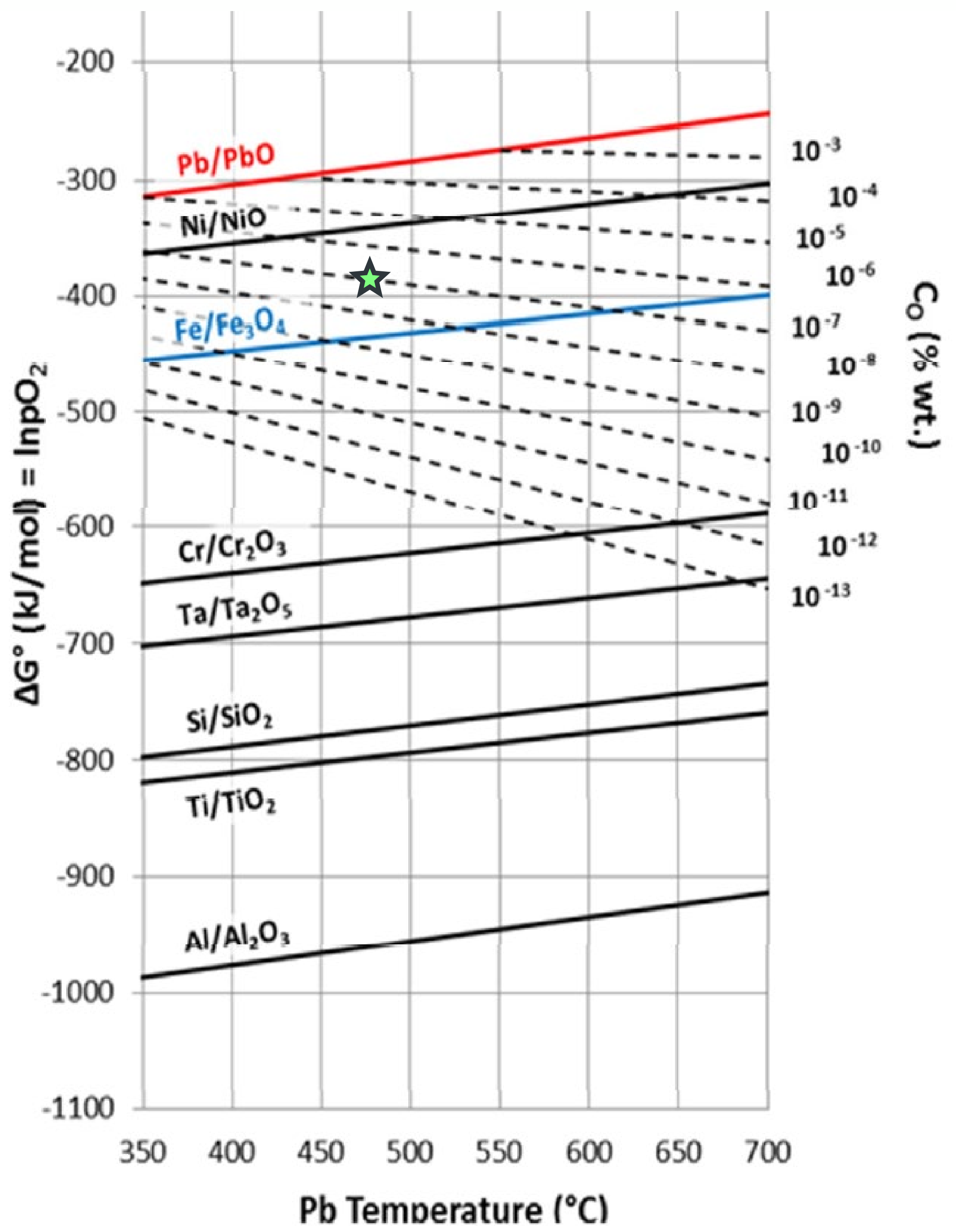


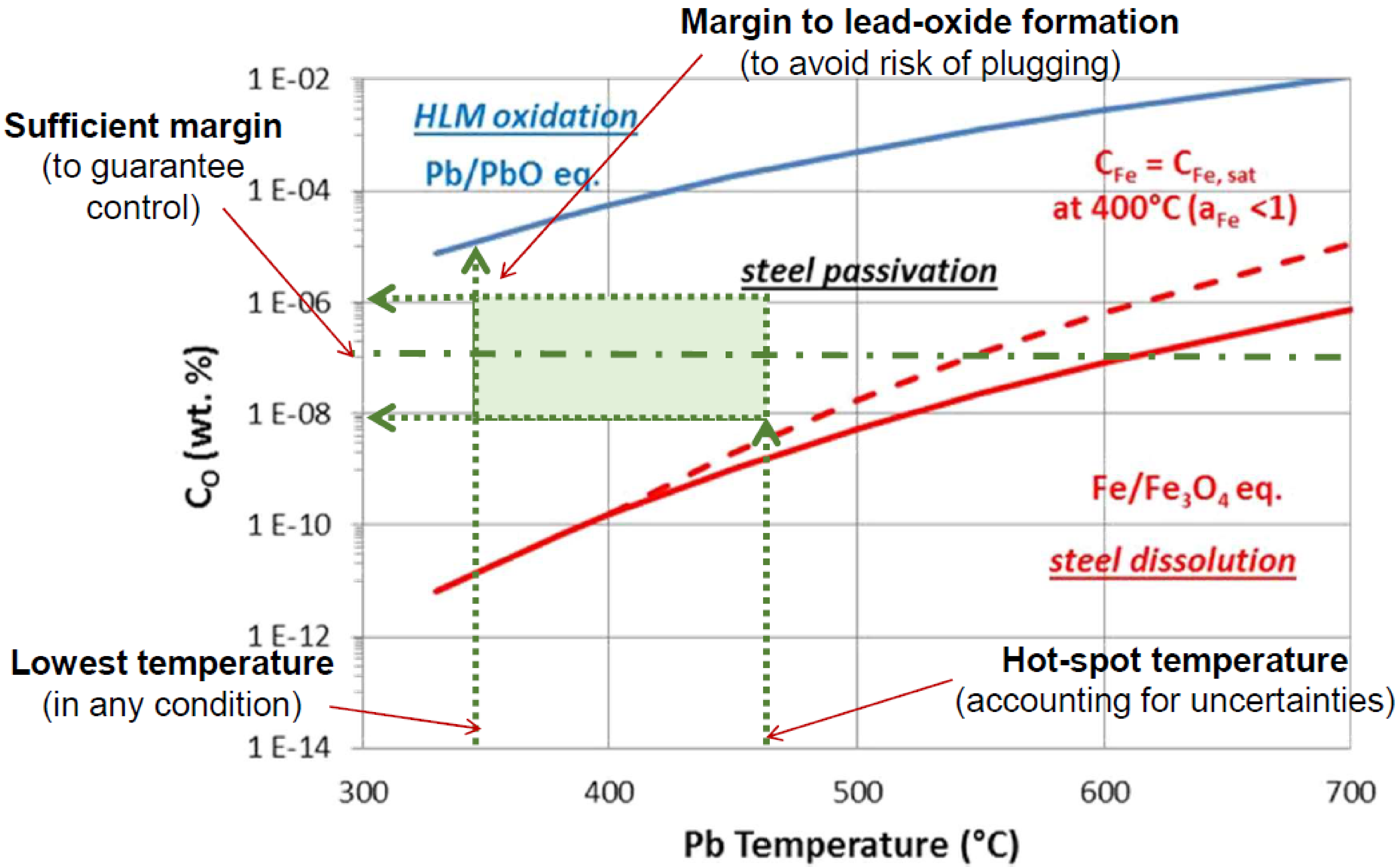


I.V. Gorynin, G.P. Karzov, V.G. Markov, V.S. Lavrukhin, V.A. Yakovlev. Met. Sci. Heat. 41 (1999) 384

Oxygen injection is an enabler for low T operation

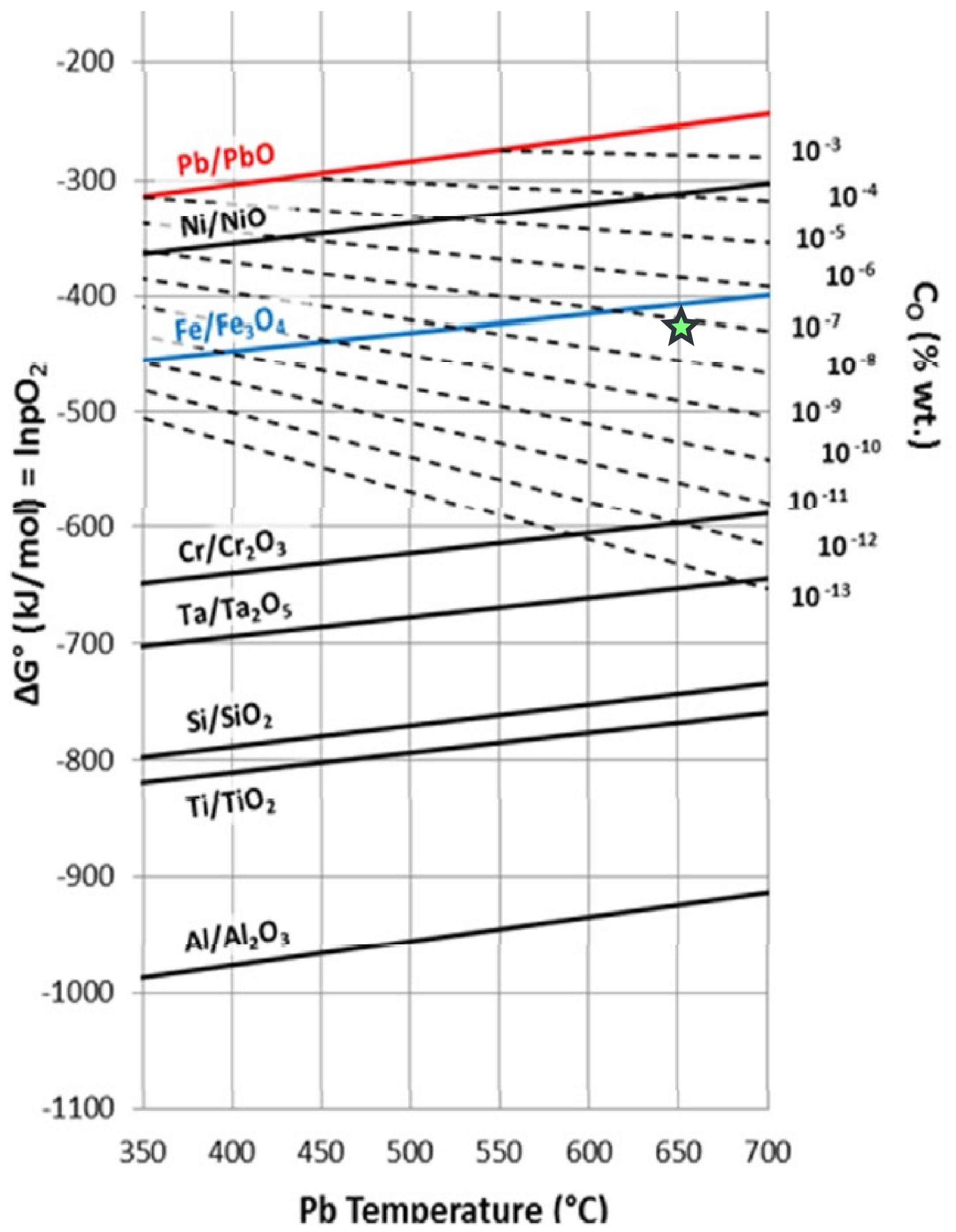
Impact of temperature – low T



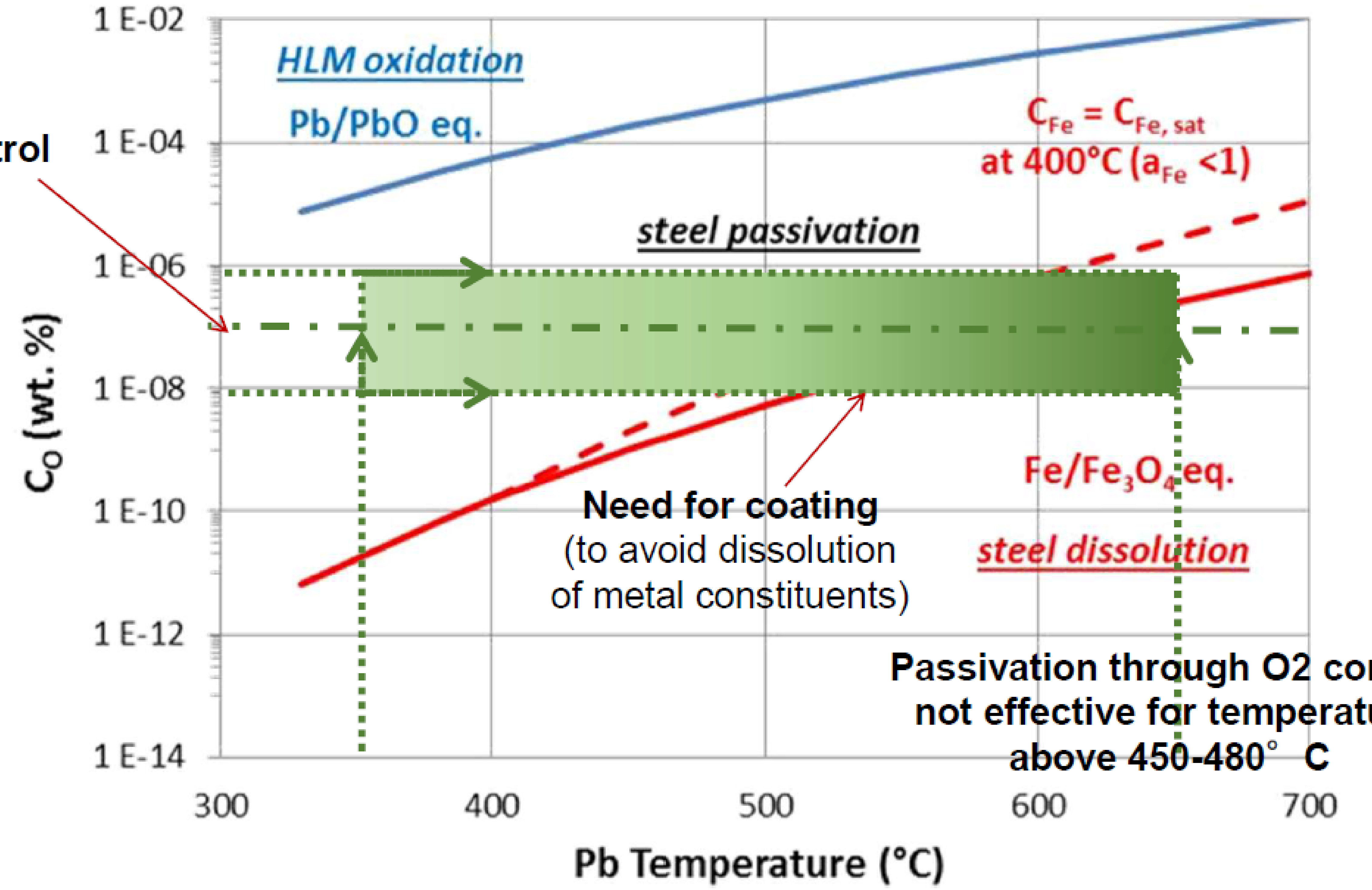


But high temperature remains a big challenge

Impact of temperature – high T



Same O_2 control window

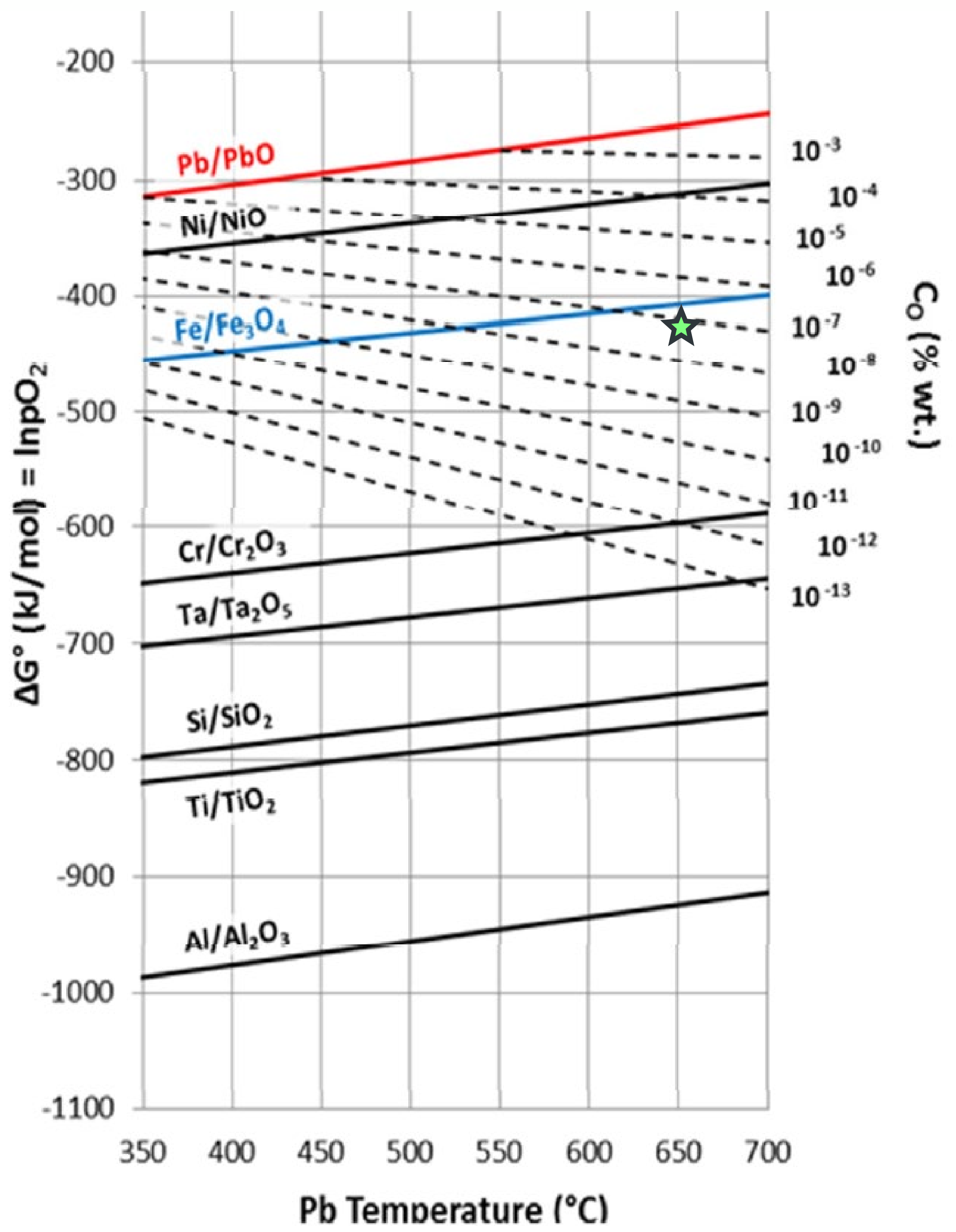


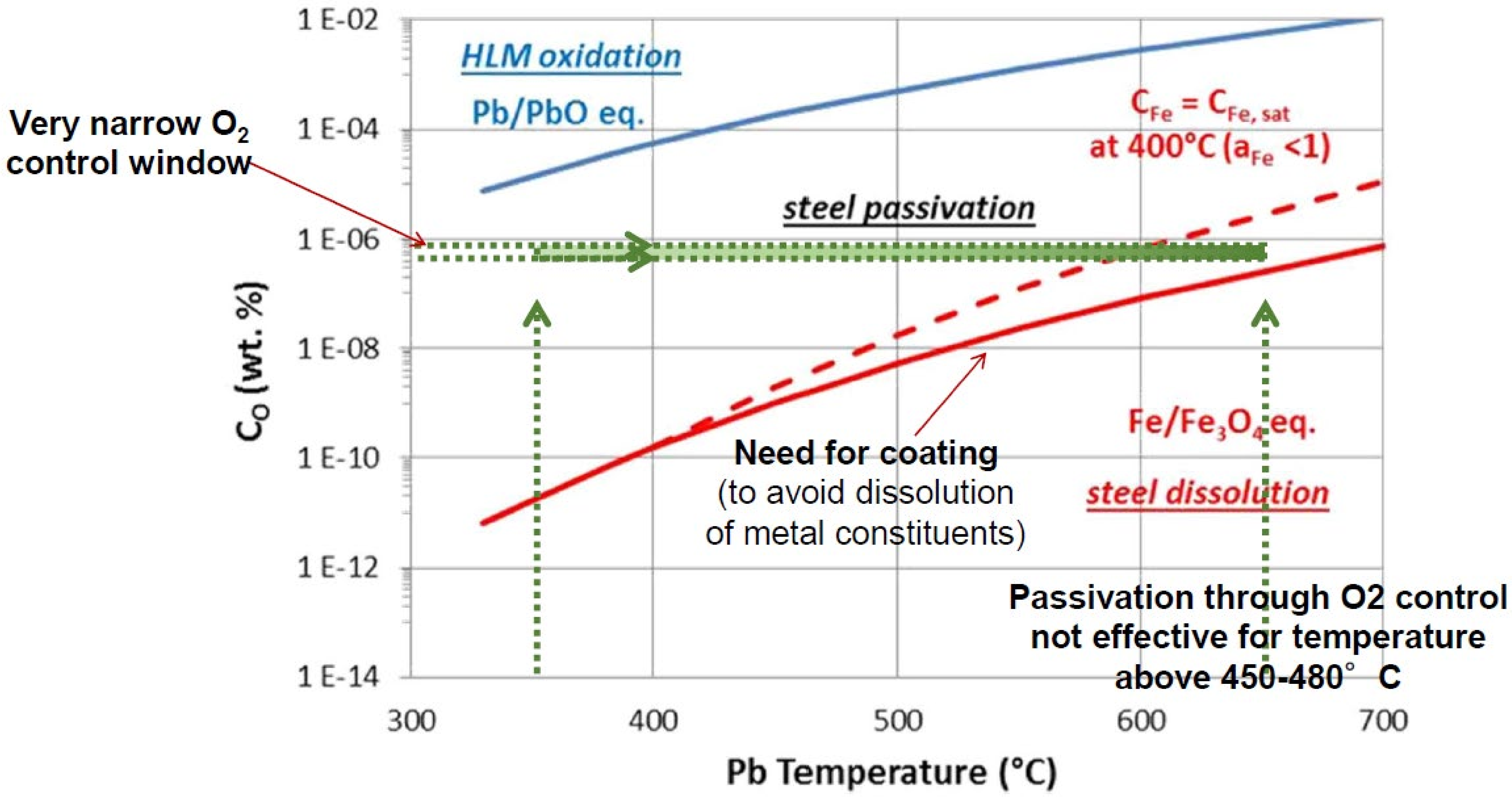
Need for coating
(to avoid dissolution
of metal constituents)

Passivation through O2 control not effective for temperature above 450-480° C

But high temperature remains a big challenge

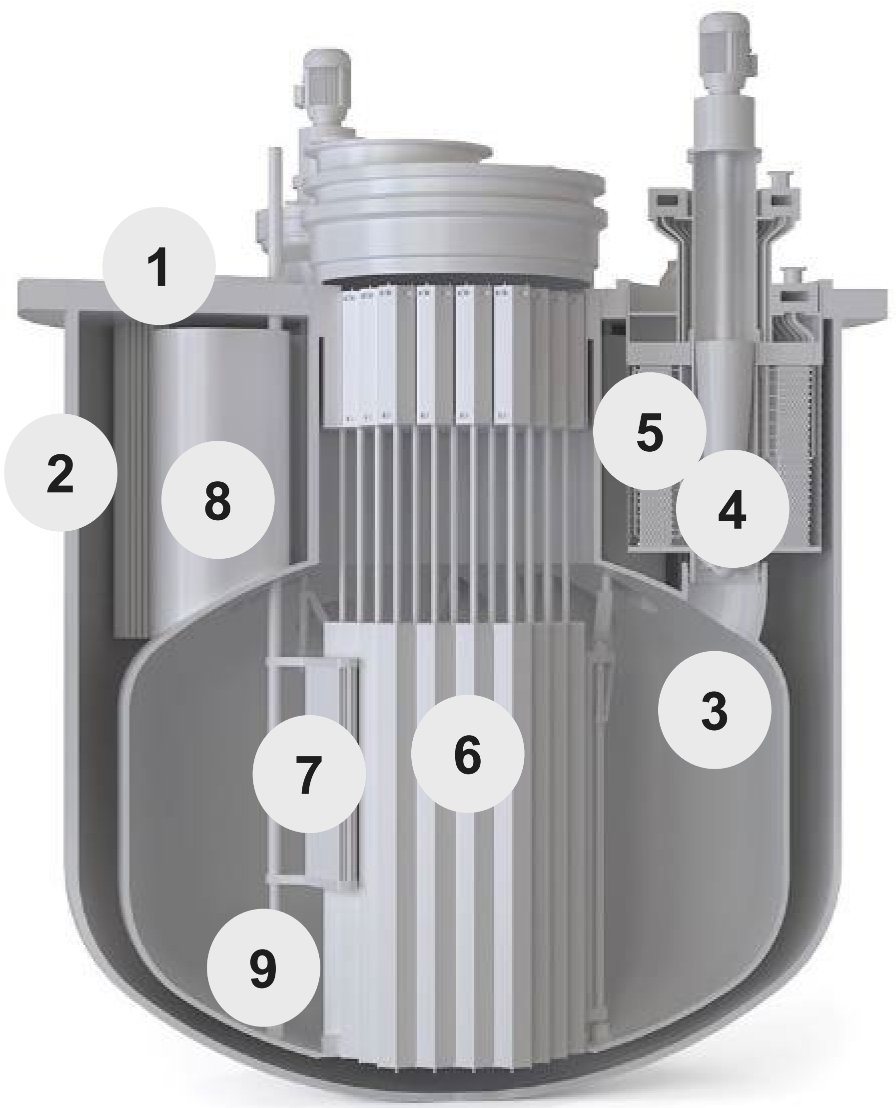
Impact of temperature – high T





Materials strategy

Materials strategy

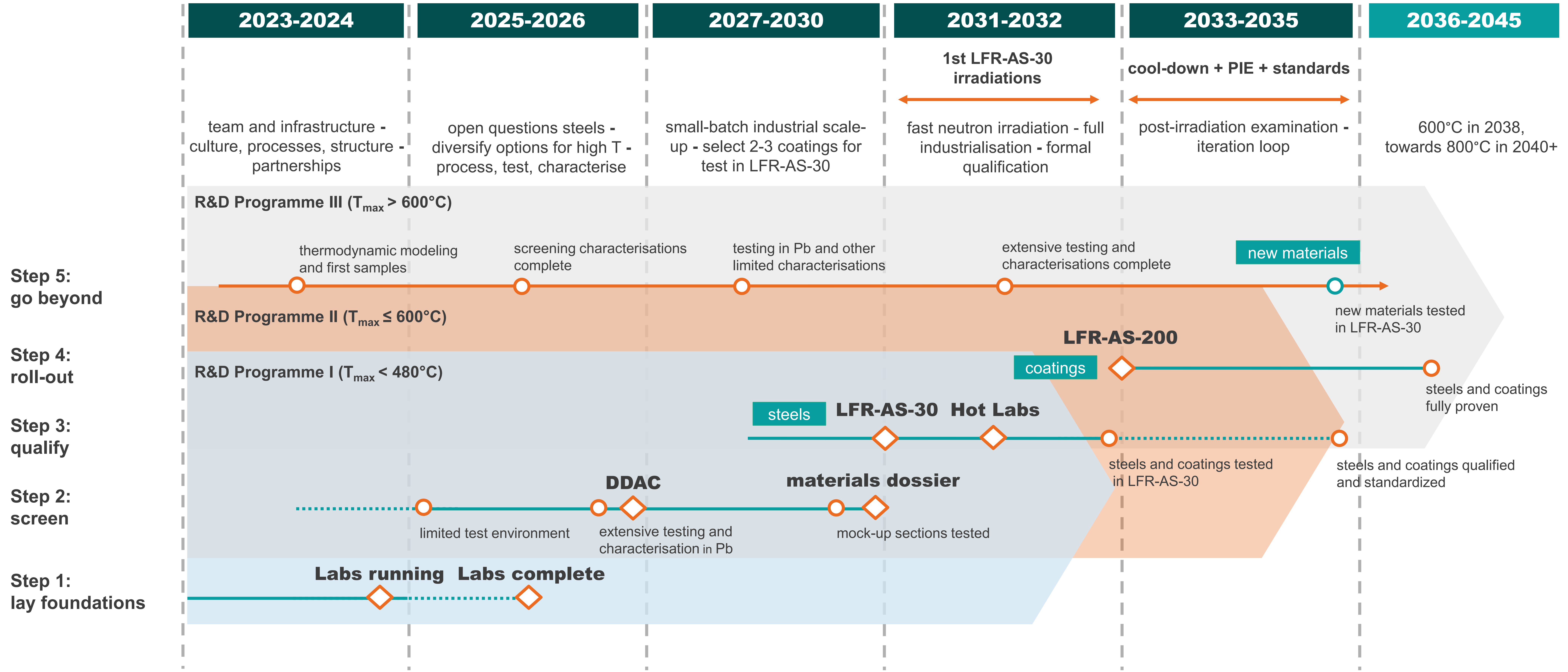


*new*cleo LFR-AS

Component	Phase I ≤ 480°C_{peak}	Phase II ≤ 600°C_{peak}	
NOT REPLACEABLE			
1. Roof structure	standard steels		
2. Reactor vessel	standard steels		
3. Amphora-shaped inner vessel	surface modification or new bulk materials		
REPLACEABLE			
4. Primary pump	standard steels	surface modifications	new bulk materials
5. Steam generator	surface modification		
6. Fuel assemblies	standard steels		
7. Control rods			
8. Decay heat removal system			
9. Other internals			
	chemistry and irradiations		

- Limited R&D needed
- R&D needed: qualification in Pb
- Extensive R&D needed

Strategic ladder



Infrastructure

ENEA | ENVIRONMENT PARK Parco Scientifico Tecnologico per l'Ambiente | iit ISTITUTO ITALIANO DI TECNOLOGIA | Politecnico di Torino

MATERIALS

standard alloys | surface modifications | new materials

INFRASTRUCTURE

chemistry | metallurgy | characterisations

SITES

Brasimone @ENEA

Energy Center @PoliTo

COSYET @EnviPark

Advanced materials characterization tools

ISTITUTO ITALIANO DI TECNOLOGIA

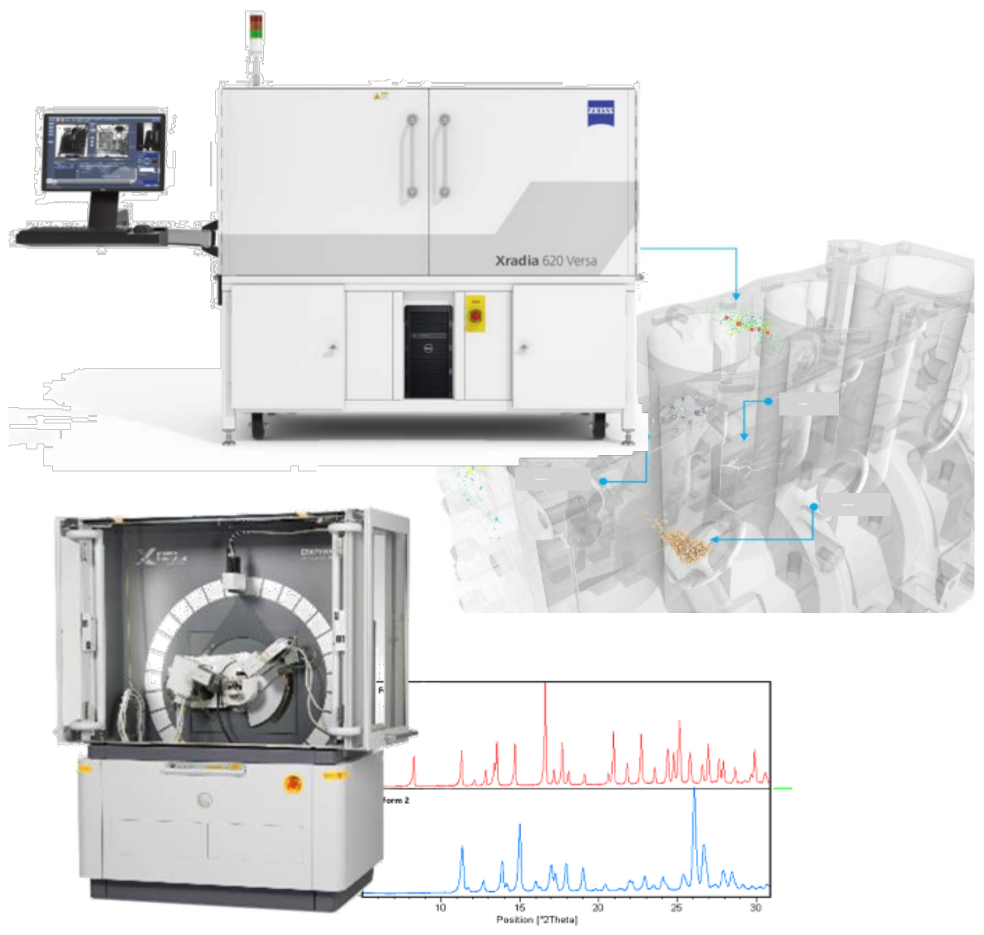
ENVIRONMENT PARK Parco Scientifico Tecnologico per l'Ambiente

SEM

Crossbeam 350 c/w 3D EDS-EBSD (SEM + FIB)
GeminiSEM 360 VP c/w EDS-EBSD (SEM)
Sigma 360 HV c/w EDS-WDS

3D material structure mapping
high-detail surface images
detailed chemical composition analysis

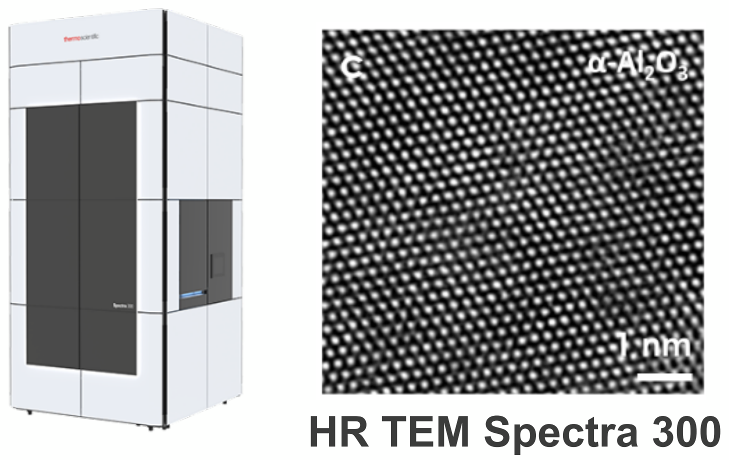
CT, X-ray



XRadia Versa 610 c/w in-situ option
Empyrean III PixCel3D MultiCore

3D internal structure visualisation
crystallographic phase analysis

TEM



HR TEM Spectra 300

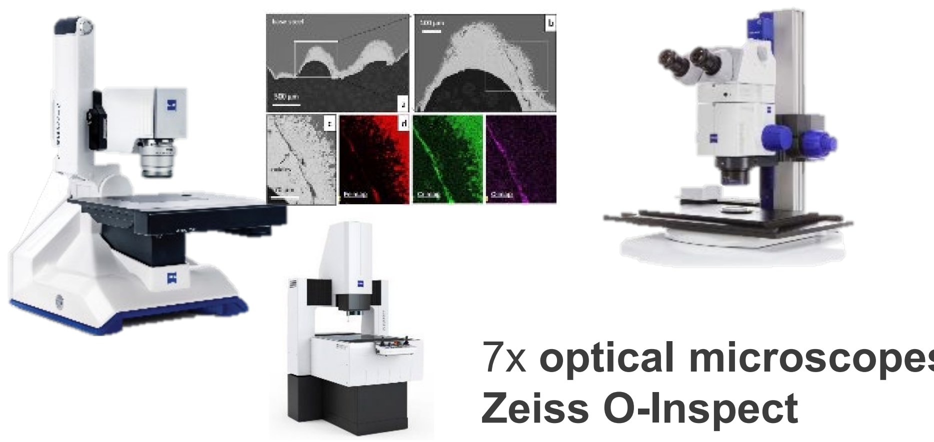
High-resolution atom scale imaging

AFM

TOSCA

Atomic-scale surface analyses

Optical microscopes, metrology



7x **optical microscopes**
Zeiss O-Inspect

Strain analysis, surface inspections, imaging
dimensional measurements w/µm precision

Indentation

STeP SHTV

Micro- and nano-scale indentation and scratch

Equipment for materials testing & metallurgy

Environmental testing in Pb

18 capsules for corrosion tests in **stagnant lead**, with advanced temperature and oxygen control

Two 200kW **lead loops** for corrosion and erosion tests, with advanced temperature and oxygen control

State-of-the-art *new*cleo designed experimental facilities

Mechanical tests in air

12x **Mechanical** test machines

20x **Creep** machines

Charpy

Tensile, **tensile-fatigue**

DIC Aramis

Simulated material deformation
Tensile, compression, and bending tests
Long-term stress testing

Casting, heat treatments

new compositions and microstr.

Transformations

Thermo-mechanical tests

R&D programs on materials

R&D programme I – standard steel products

1

316L

2

316L(N)

3

316Ti

4

AIM1 and 1515Ti

European context

Guideline for Pb corrosion tests

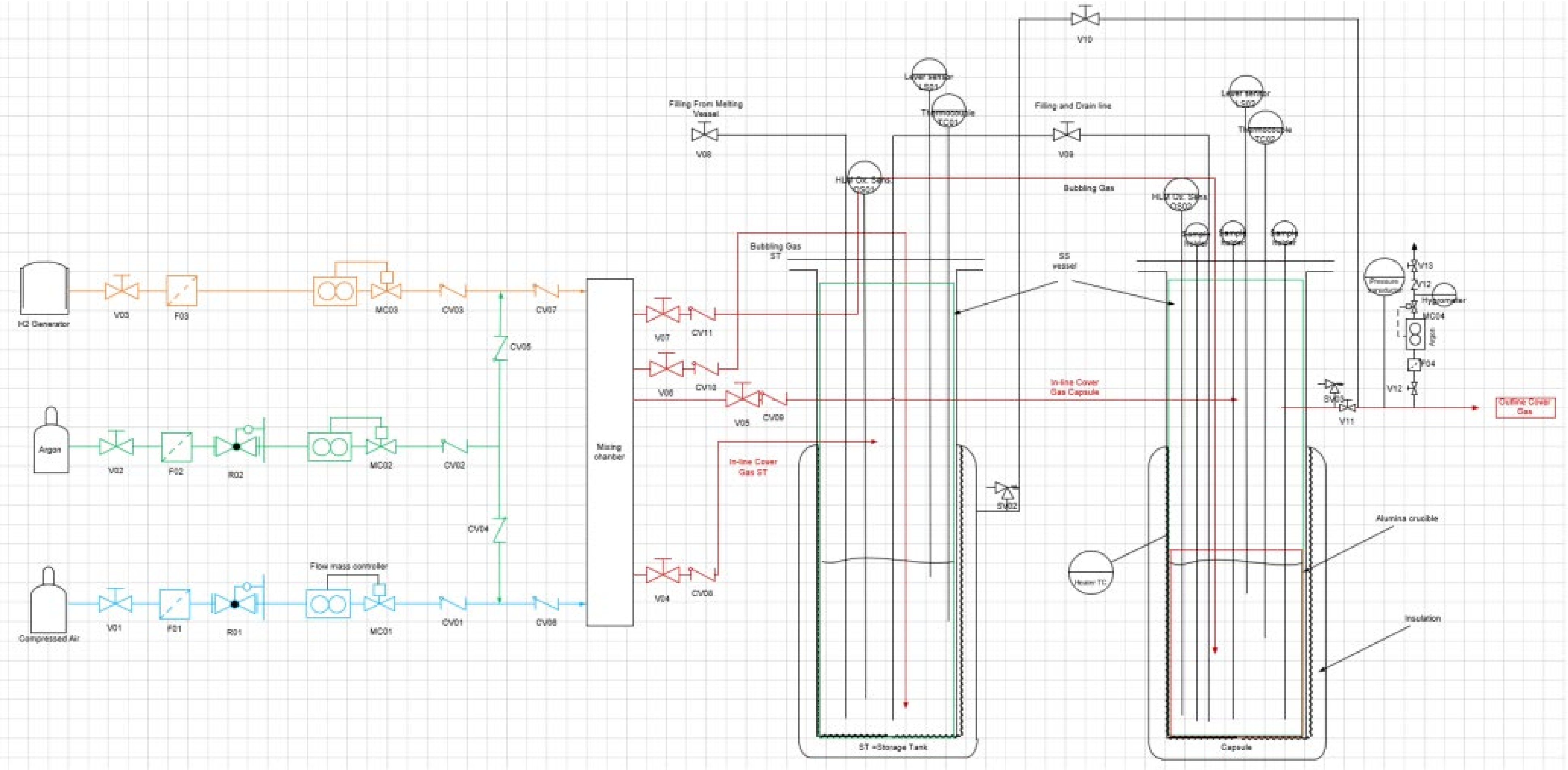
Experimental set-up :

- Minimum volume: 500 ml liquid lead or LBE if possible (if less → justify the risk or impact on the test in progress)
- Chemically inert structural materials *(preferably ceramics or refractory materials)*

During the experiment, monitoring is required:

- Temperature (+/-3°C)
- Oxygen concentration (tolerance depending on test conditions)
- Duration
- Lead flow (for dynamic experiments)

The experiments design : the surface exposed to the volume of Pb to have an **S/V** ratio to be justified and to analyze the impact on test



Example of Capsule design

European context

Guideline for Pb corrosion tests

RCC-MRx Appendix A2

- **Goals :** how to validate qualification results, reduce interpretation doubts, understand the mechanisms → develop a standard that the regulator may accept
- **When applicable** : As soon as included in RCC-MRx (2025), can be updated at each new edition, replaceable by the future standard
- **Philosophy : Recommendations (few obligations) on monitored parameters, adaptability, but all must be justified**
- **Final use : Free to use this guide or not**

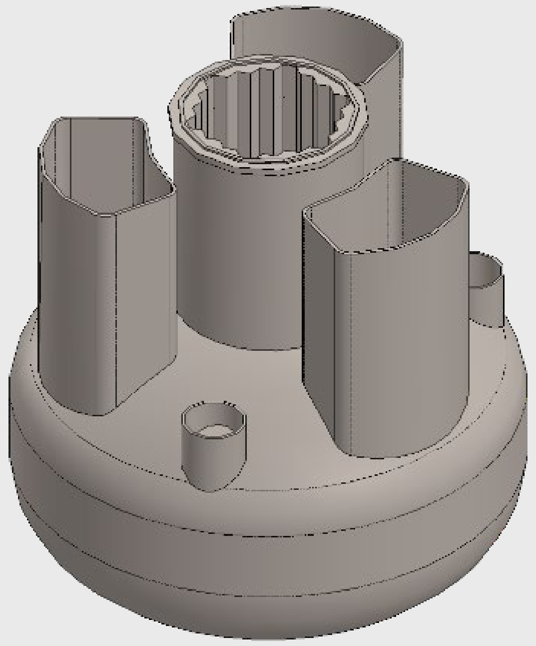
ROBIN HUB, QuaDESim+

- **Goals :** validation and credibility of R&D, industrially-oriented research results, create a robust data base, create a standard based on the results and experience feedback
- **When applicable** : After CONNECT-NM analysis and validation of standard (around 2030) *Industrials can't wait this timing*
- **Philosophy of standards : More obligations, less adaptability, more criteria fixed**
- **Final use : obligation to respect the standard**

R&D programme II – surface modifications

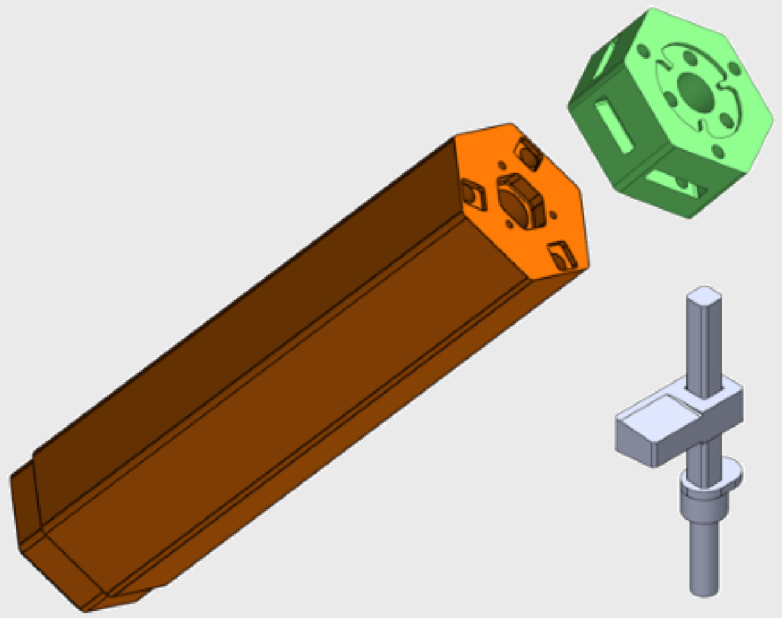
1

Vessels



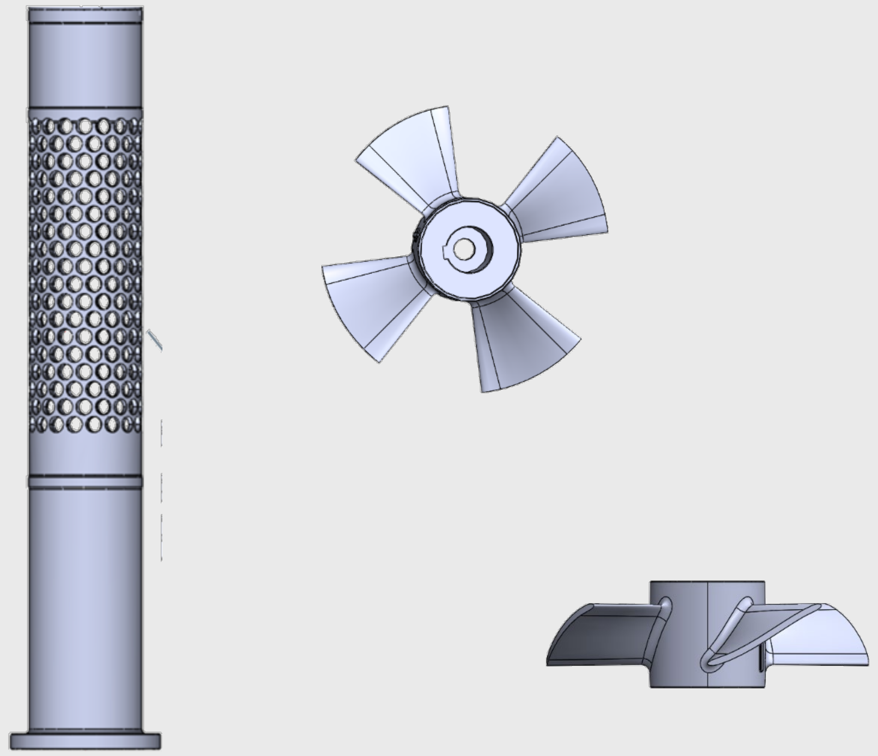
2

Core



3

Out of core



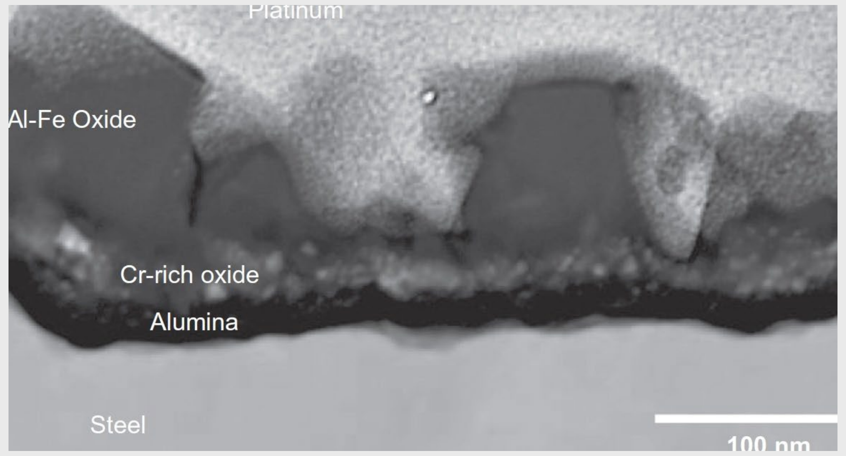
R&D programme III – new bulk materials

1

Corrosion-resistant austenitic steels

2

Embrittlement-resistant ferritic steels

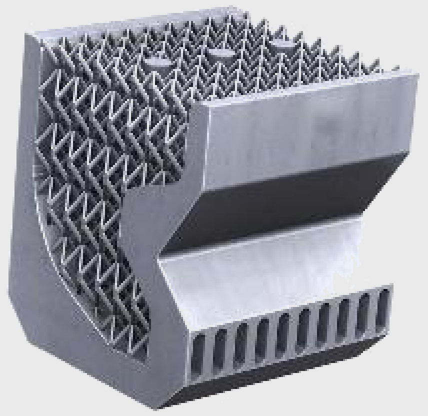


3

Advanced materials

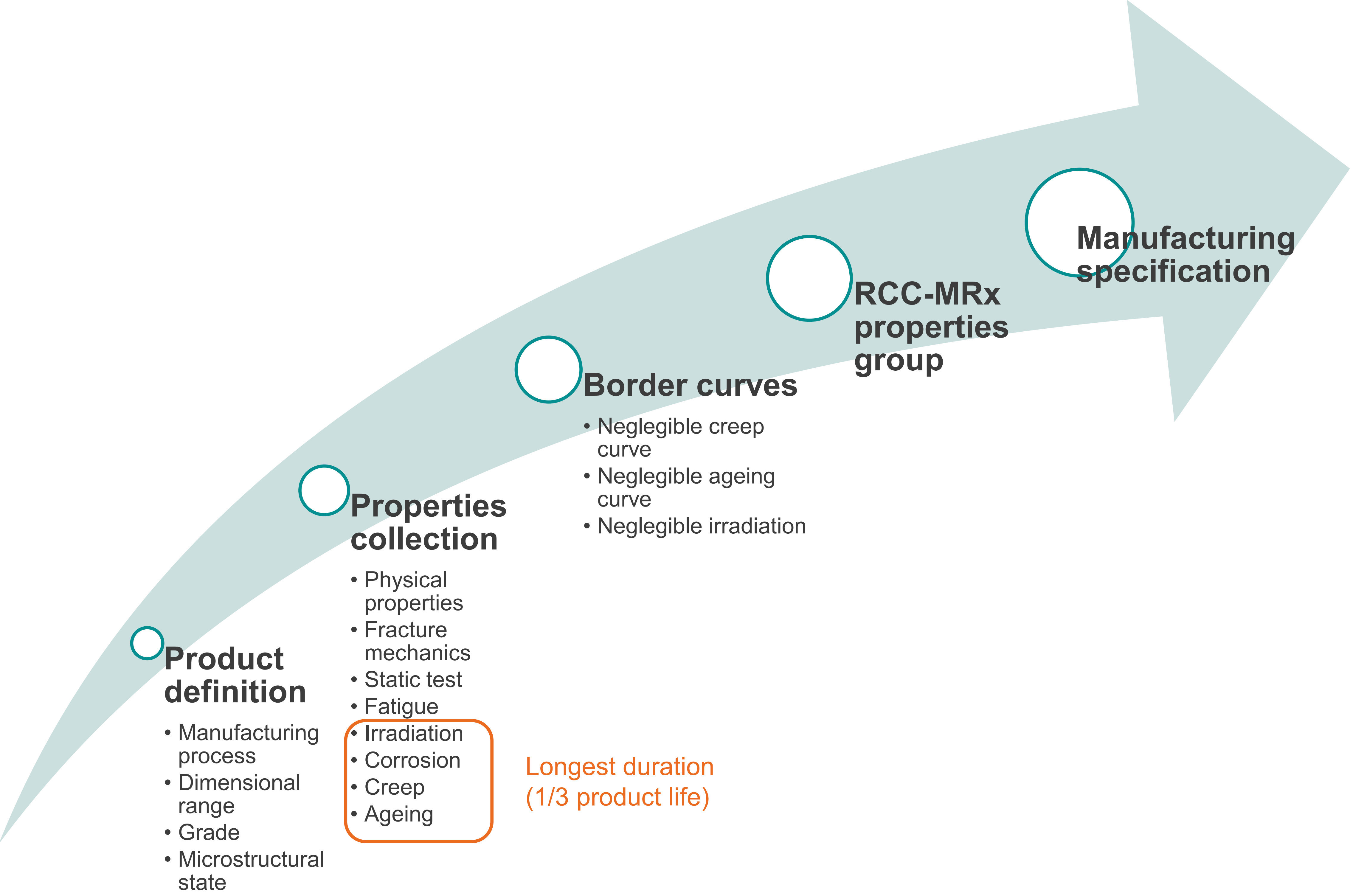
4

Advanced manufacturing



New material qualification

How to include a new material into a code such as RCC-MRx?



1. Collect part of properties during Material development and start long duration test

2. Contact ASNR to start product qualification and open material file

3. Prove material properties on additional industrial heats

4. Collect material performances up to 10 years life (creep, ageing)

5. In service monitoring program to extend product life

Conclusion

& challenges

Summary & key challenges

1 — ***new*cleo's project**
- MOX manufacturing
- LFR technology

2 — **LFR technology**
- Corrosion as a key challenge
- Oxygen injection to control it

3 — **materials strategy**
- Diversification to pursue high T
- Strategic ladder

4 — **R&D programs**
- Qualification of steels in Pb
- Surface modifications
- New bulk materials

1. Technology risk: lack of fast reactors in Europe to develop in-pile experimental programs
2. Standardization & regulatory framework
3. Supply chains, financing schemes

Thank you