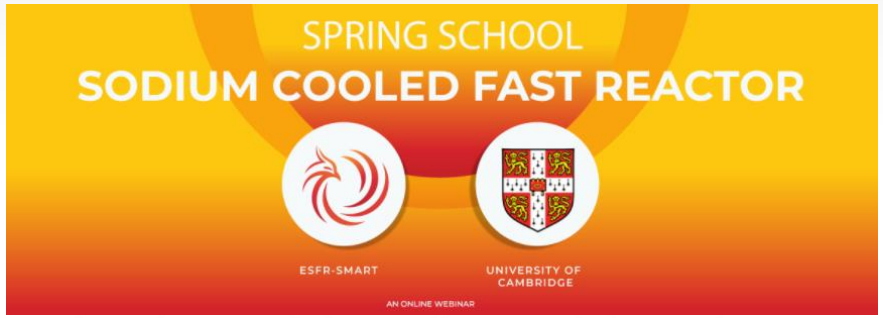
ALFRED

ALFRED and LFR projects

FALCON



ESFR-SMART Spring School

March 29-31, 2021, online Webinar session 5: OTHER COOLANTS

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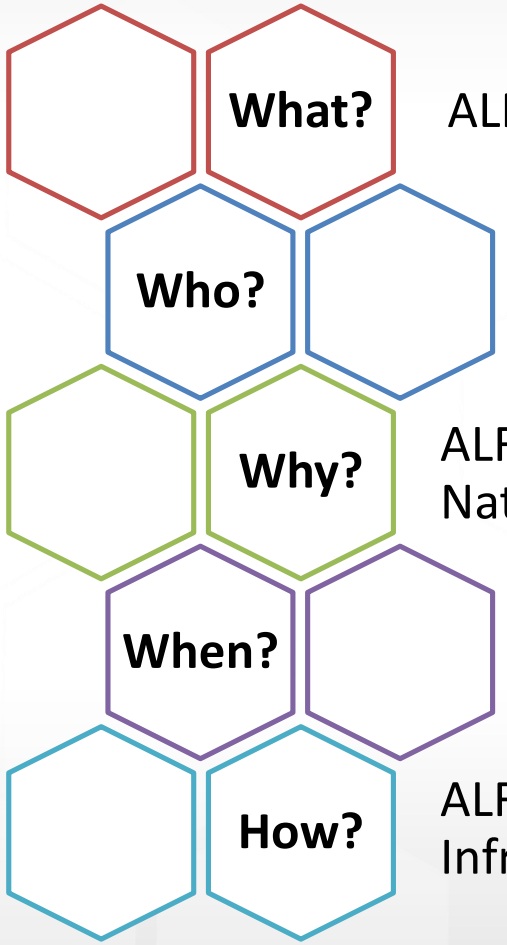
The ALFRED Project in a nutshell



ALFRED is the ETDR for the LFR technology

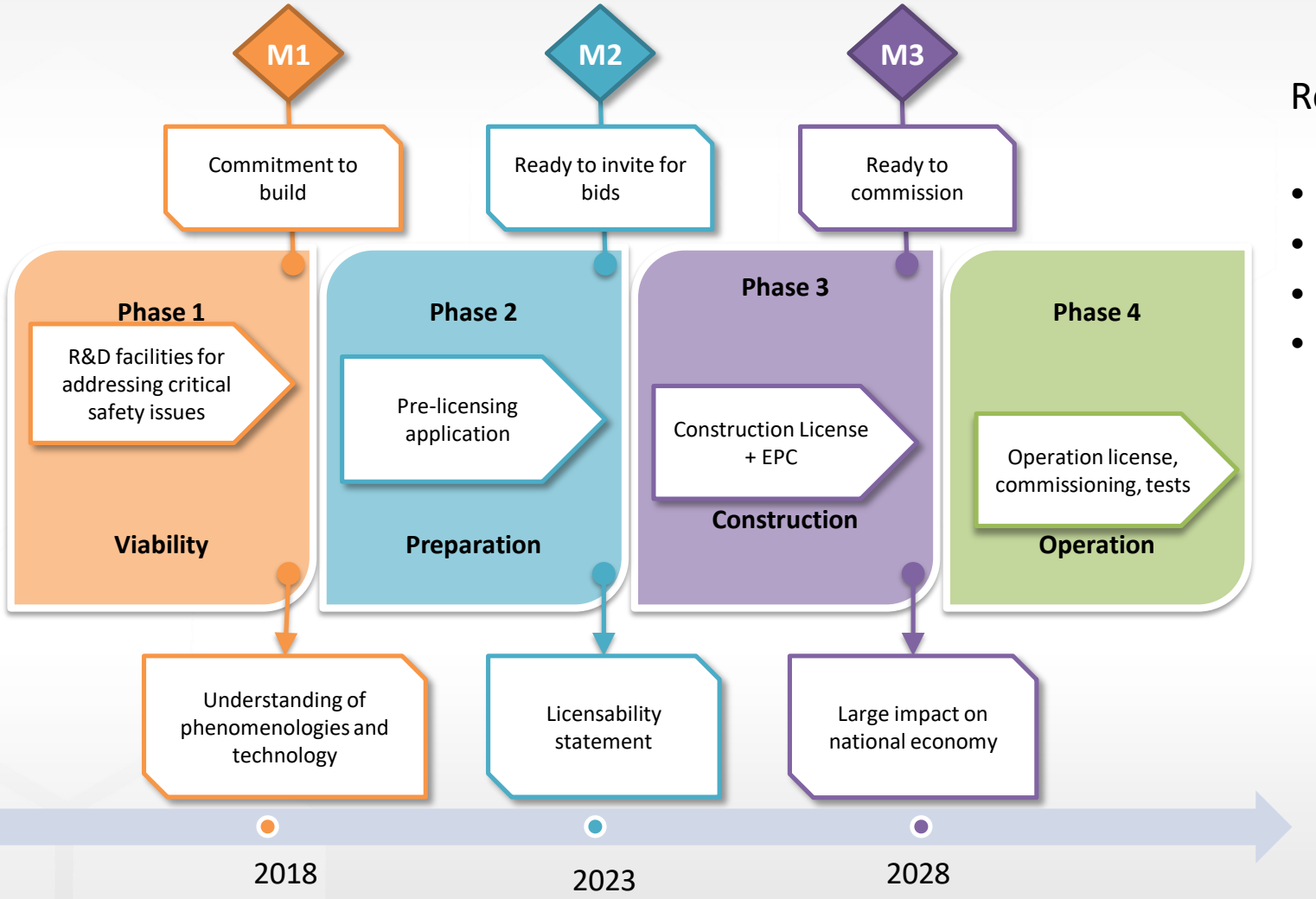
ALFRED Construction is fostered by the FALCON Consortium

ALFRED has strategic and socio-economic relevance at EU, National and local level

ALFRED construction is foreseen to be completed by 2030

ALFRED will be supported through a Distributed Research Infrastructure

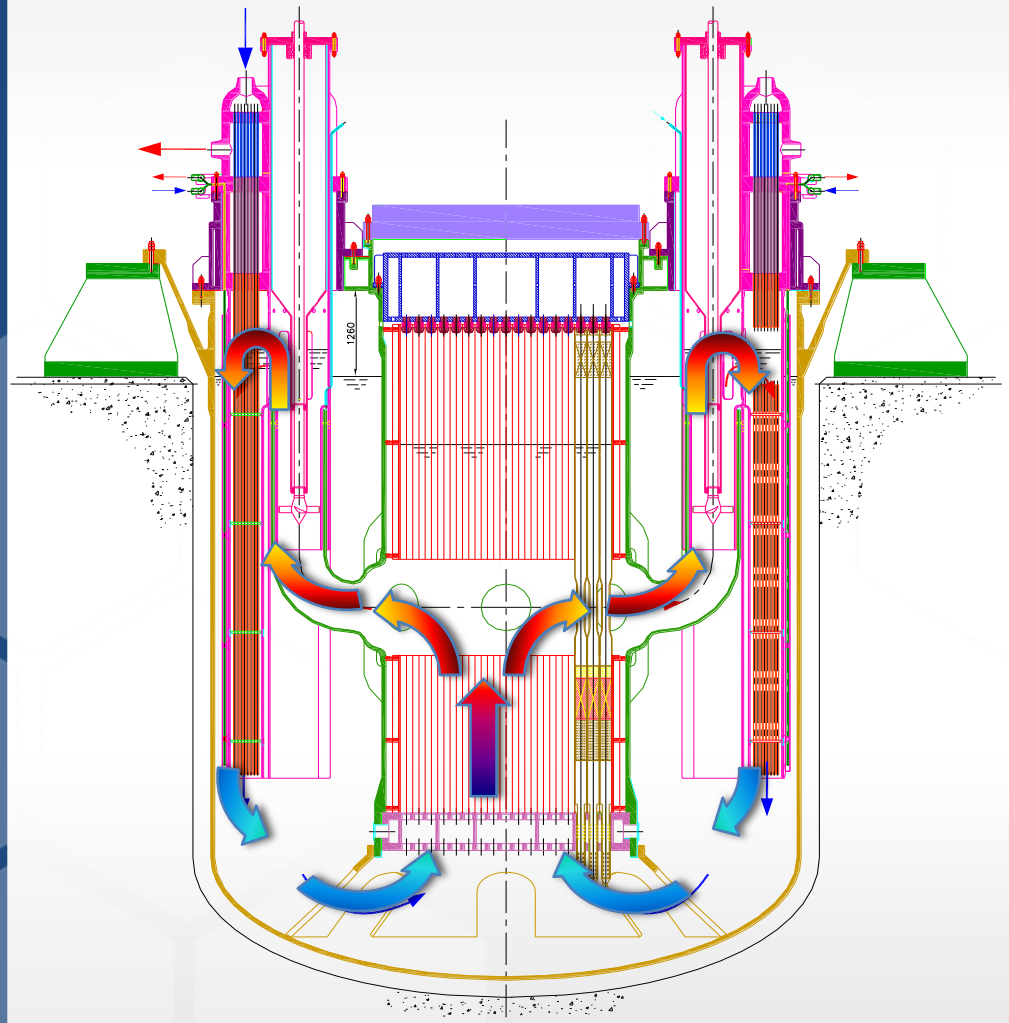
Project Timeline to Commissioning



Recent advancements:

- Pro-ALFRED contract executed
- Research infrastructure identified
- First minor project accepted (20 M€)
- Adoption of **staged approach**

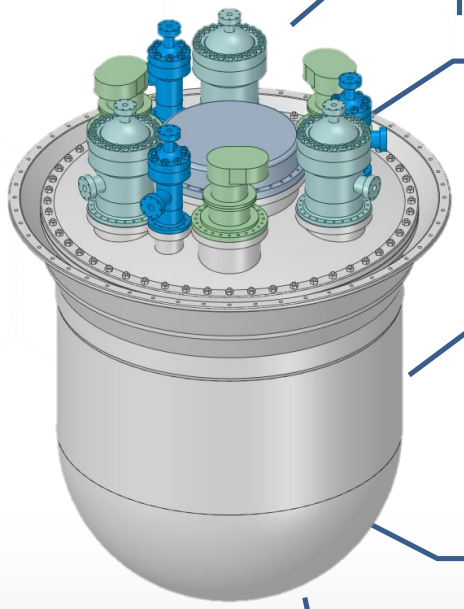
ALFRED – LEADER CONCEPT



- **Reactor cover**: Hot, standard flanged connections
- **Fuel assemblies**: MOX fuel, grid-spaced, hexagonal, wrapped, extended stem
- **Reactivity control**: Two diverse and redundant systems, control and shut-down rods
- **Primary system configuration**: Pool-type, enhanced natural circulation in accident conditions
- **Primary Pumps**: Mechanical, pull-type, in hot leg
- **Steam Generators**: Once-through, bayonet tubes
- **DHR**: Isolation condenser connected to dip-coolers with straight, double-walled tubes
- **Reactor and Safety Vessels**: Hanged, toro-spherical bottom head

Strategy to address the challenges

- ALFRED revised design oriented to **shortening** the time-to-market and leveraging on **SMR features**.
- Main issues:
  - Lead is a corrosive and erosive environment
  - Corrosion is enhanced by temperature
  - Protective oxide layer becomes unstable at high temperature
  - Neutron irradiation is relevant
- But we want the technology to become **competitive** for a future commercial application, which means operating at high temperature.



Relatively low power

Compact design
Removable components
Proven technologies

Simple flow path
Efficient natural circulation

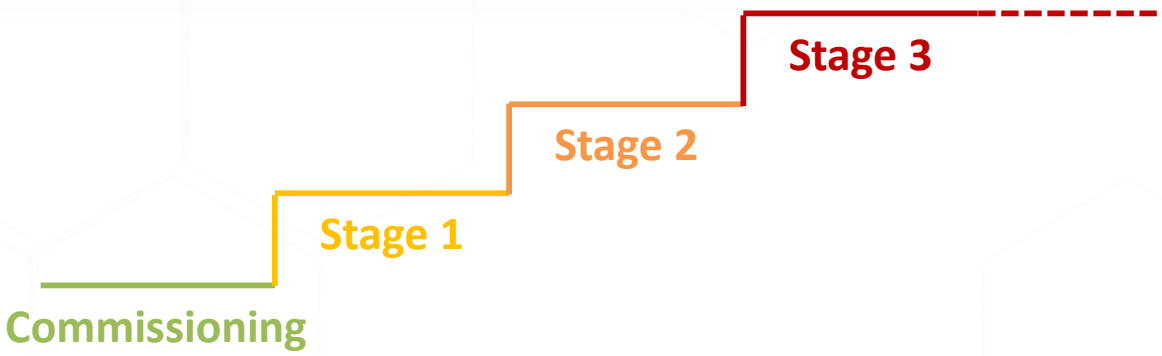
Molten lead as coolant
Excellent intrinsic prop.
Manageable neg. prop.

Pool type Primary System

Staged approach in a nutshell

The operation of ALFRED will be based on a stepwise approach:

- 1st stage: operation at low power in low-temperature range
  - Existing proven materials working in O2 controlled lead environment
- …
- nth stage: operation at full power in high-temperature range
  - Advanced materials or protective measures fully qualified during earlier stages



	1st stage	Final stage
Power	100 MWth	300 MWth
Thermal cycle	390-430°C	400-520°C
Coolant chemistry control	10-6 ÷ 10-8 O2 wt.%	Same, but not effective
Materials	316L, 15-15Ti	Relying on coating or innovative materials

From LEADER to FALCON

2010 End of **ELSY Project**: EU needs a Demonstrator…

2 months later **LEADER** KOM: **ALFRED idea** is born

2011 **Romania** will host ALFRED. MoU among Ansaldo Nucleare, ENEA, RATEN/ICN.

2013 End of LEADER Project: reference **ALFRED concept** is frozen

2 months later **FALCON Consortium** is signed: the ALFRED **Technical Review** starts

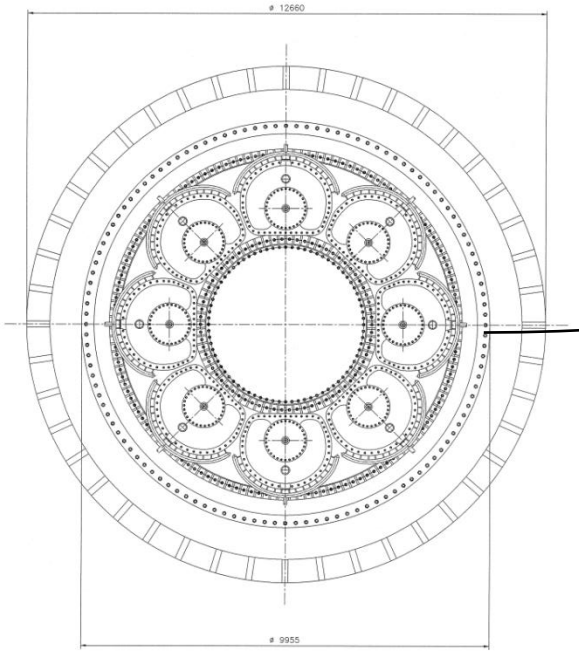
2017 FALCON new vision on ALFRED as **SMFR prototype**

2018 **Revised** concept of **ALFRED**: new reference

2019 **Preliminary** analyses on **FALCON revised** concept of **ALFRED**

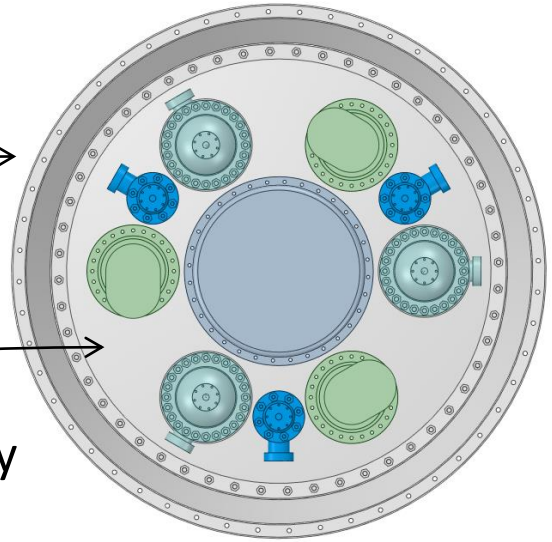
From LEADER to FALCON

- 8 Steam Generators
- 8 Primary Pumps



Simple shapes to avoid fabrication/mechanical qualification issues

- 3 Steam Generators
- 3 Primary Pumps
- 3 Dip Coolers



Space to include connections for auxiliary systems (e.g. Cover Gas Conditioning system under development by ENEA)

LEADER CONFIGURATION

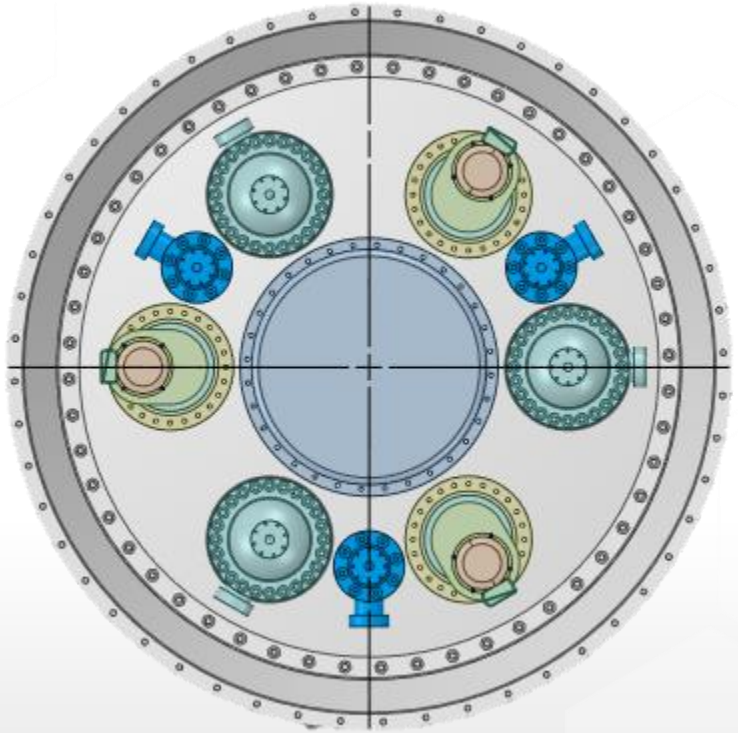
REVISED CONFIGURATION

Design Description

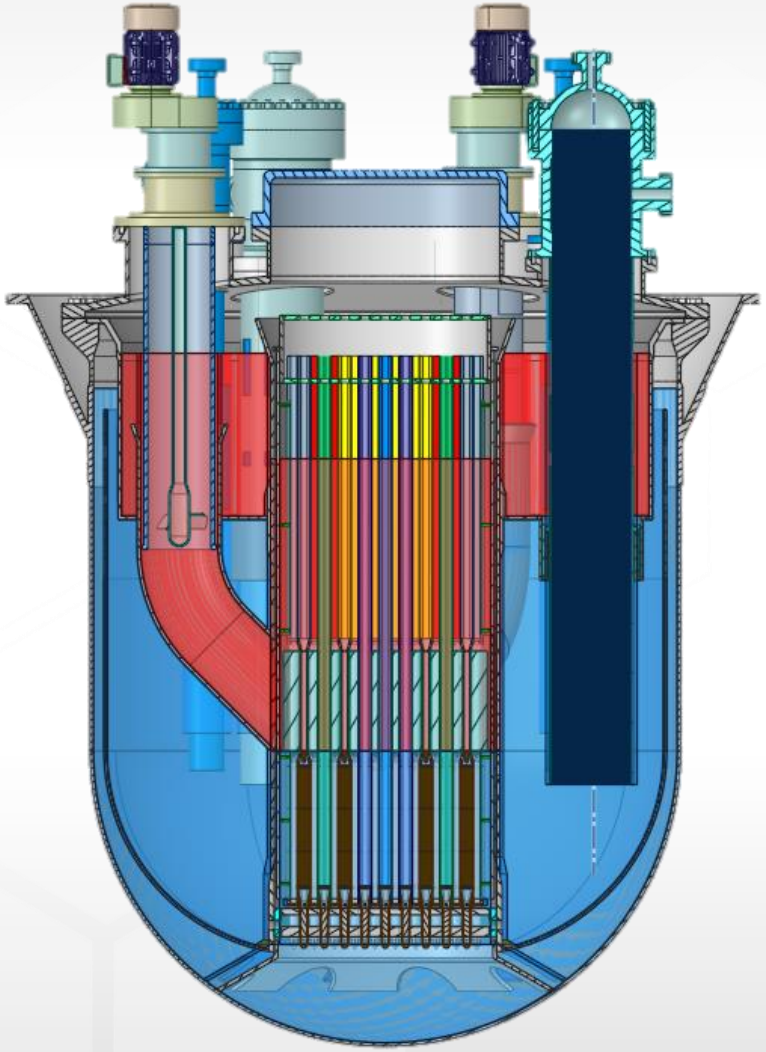
The Reactor Coolant System is liquid lead loop completely enclosed within the Reactor Vessel and Reactor Cover, composed by the following major components:

- 1 Inner Vessel
- 1 Internal Structure
- 3 Steam Generators
- 3 Primary Pumps
- 3 Dip Coolers (DHR-2)

These components hung inside the lead from the top, where are connected to the nozzles of the Reactor Cover.



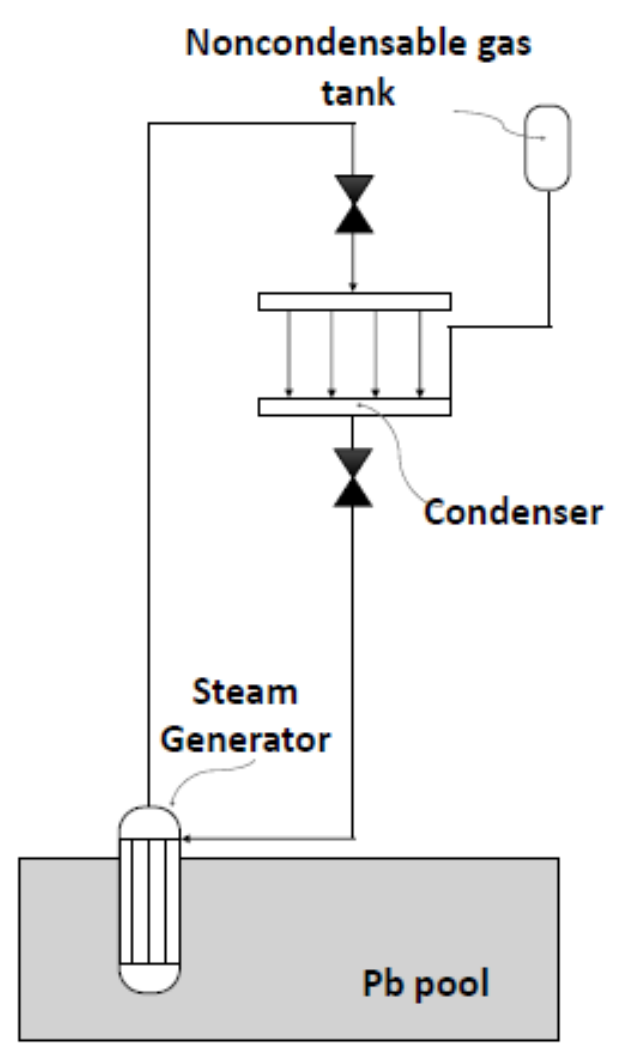
Design Description



ALFRED Enhancements:

- Introduced diverse DHR-2 system
- Increased grace time to freezing when DHR system are in operation
- Eliminated Pool Thermal Stratification
- Eliminated direct connection SGs – core
- Introduced Hot Safety Vessel (No Liner)
- Elimination of double wall SGs
- Ensured Refueling operations with FA under lead
- Staged approach to by-pass technological limits

ALFRED DHR

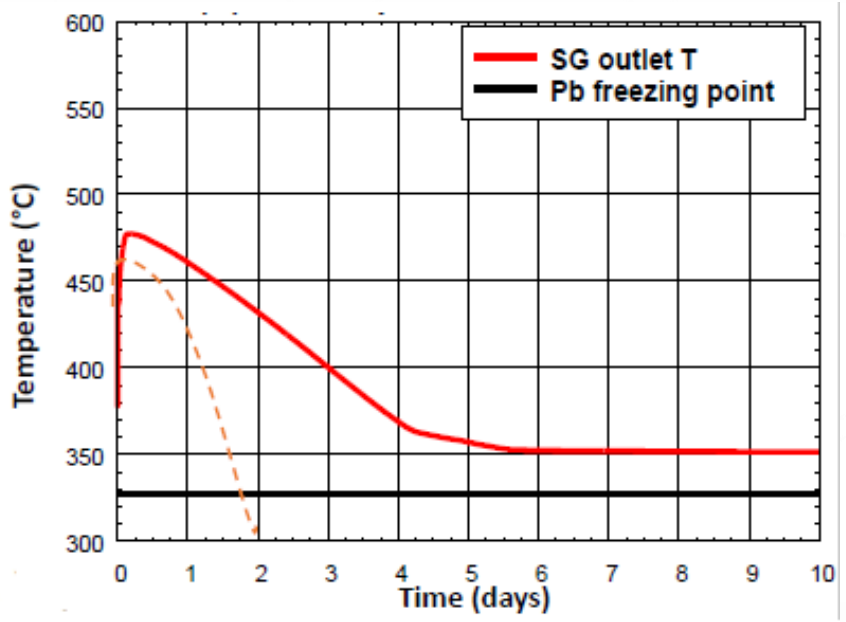


ALFRED has an innovative Decay Heat Removal system
Patented by Ansaldo Nucleare, passively controls heat removal
It is based on non-condensable gases

In LFRs coolant freezes at 327°C
Decay heat is:

- 10% of nominal power in few sec.
- 1% of nominal power after 1 hour.
- 0.1% after few days.

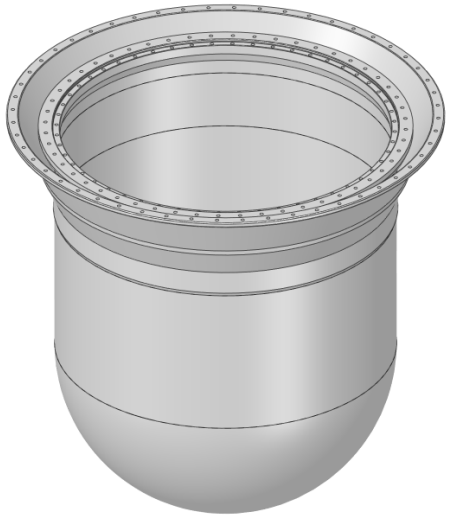
A 10% non cond. gas mass fraction reduces by 25% the HTC



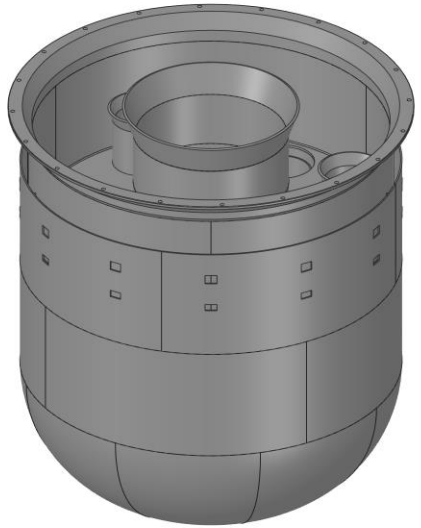
Several numerical simulations have been performed → **proof of principle**
SIRIO facility first tests will provide experimental basis
PIACE Project to extend the campaign → **proof in relevant environment**

Reactor Coolant System – Main equipment

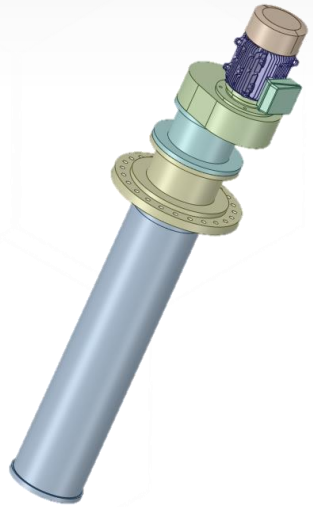
Reactor Vessel



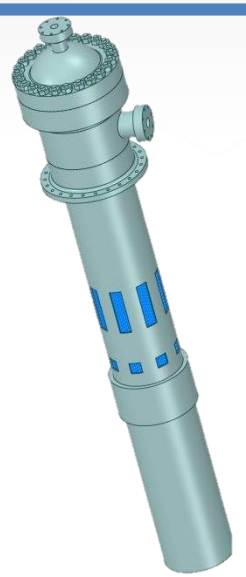
Internal structure



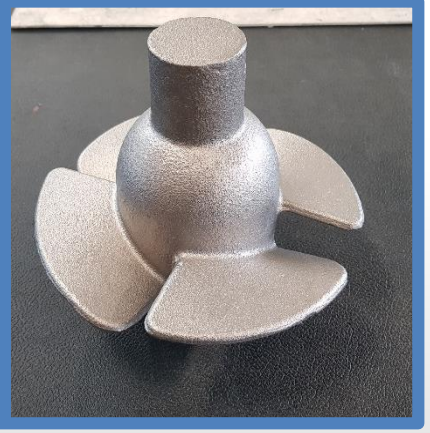
Pump



Steam gen.

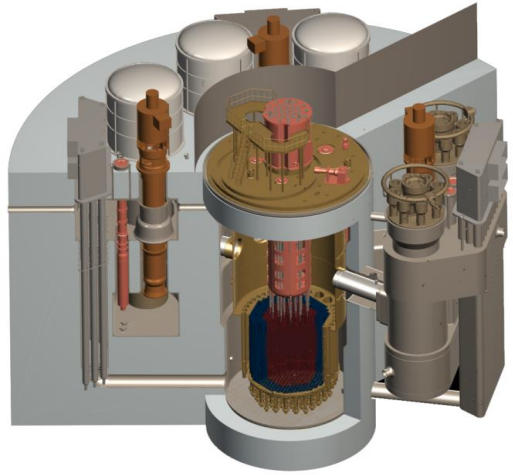


Fuel Assembly



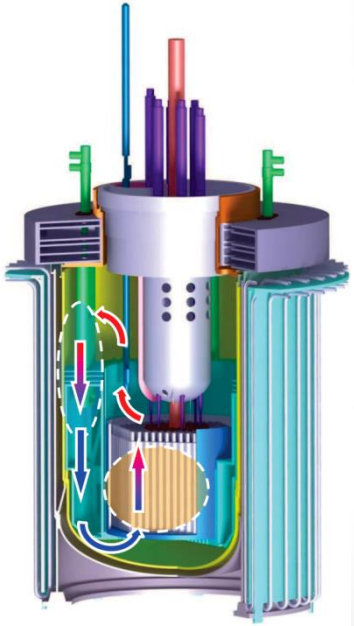
Some examples of Current LFR and LFR/ADS initiatives

FALCON

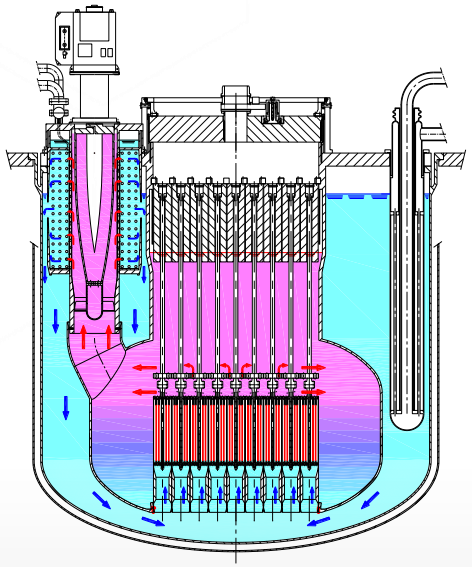


BREST-OD-300
300 MWe Russia

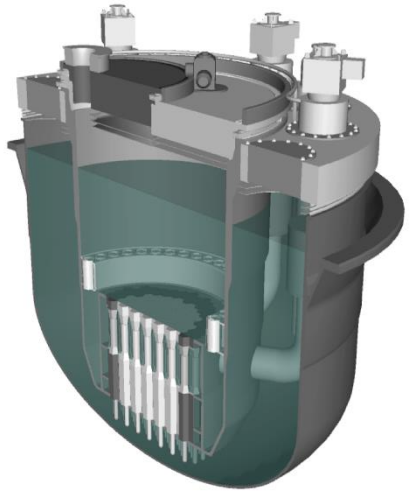
LeadCold SEALER
(1-10 MWe, Sweden)



CLEAR-1
(10 MWth, China)

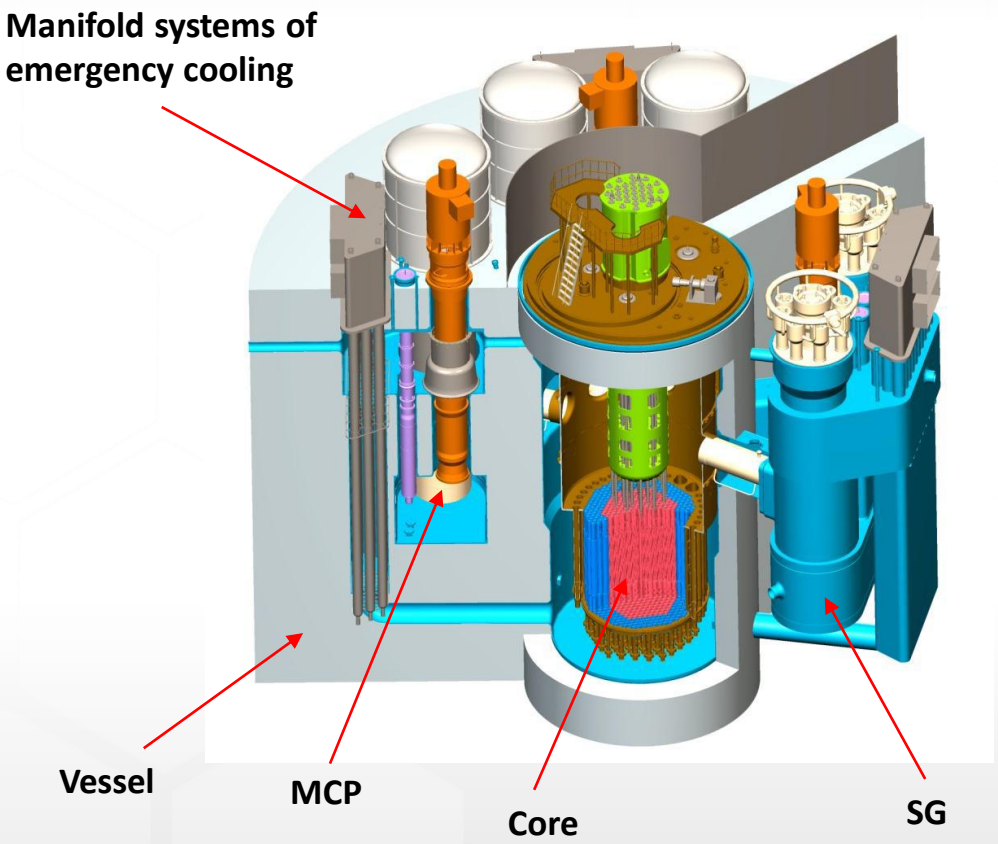


Hydromine AS-200
(200 MWe, USA)



Westinghouse LFR
(power: 450 MWel, USA)

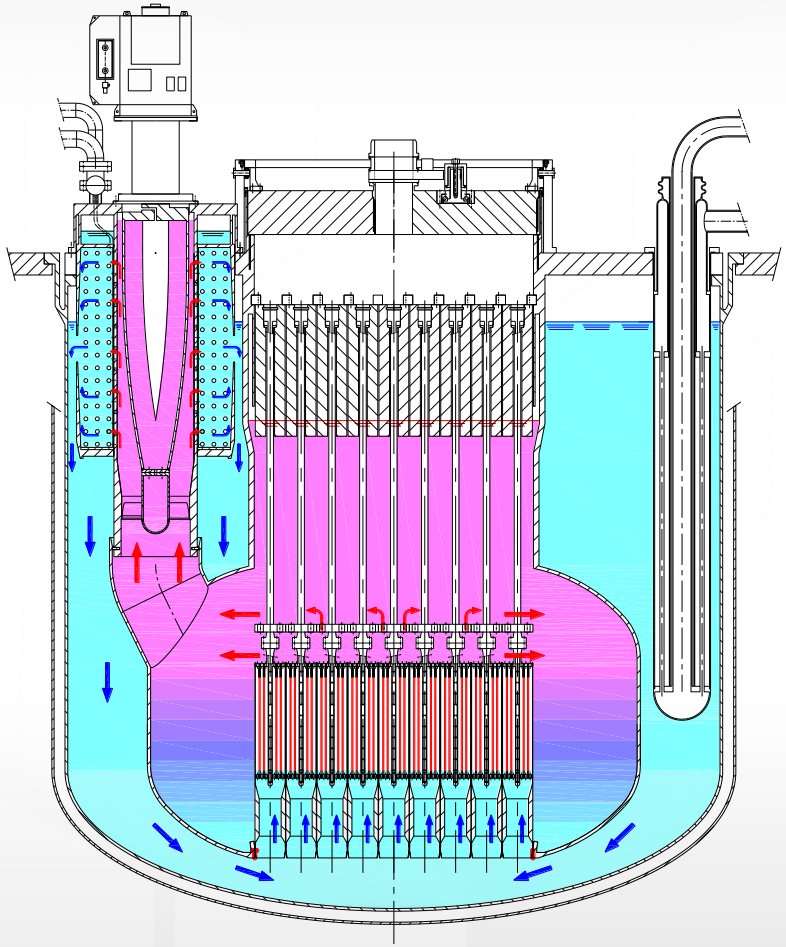
BREST-OD-300 prototype for a commercial Reactor



Thermal power [MWth]	700
Electric power [MWe]	300
Primary coolant	lead
Number of loops	4
Average temperature of lead coolant at the entrance/exit of the core [°C]	420/535
Fuel material	U-Pu Nitride
Number of fuel assemblies	169
Fuel charge [t]	20.6
Power Conversion Efficiency [%]	43.5

Hydromine AS-200

Hydromine



The Hydromine AS-200 concept is a highly compact 200 MWe LFR:

- Achieved by elimination of components
- ~ 4 times more compact than the Superphenix (SPX-1) SFR
- ~ 2-3 times more compact than than the best SFR projects
- ~ 3-5 times more compact than than previous LFR projects

Core power (MWth)	480
Electrical power (MWe)	200
Coolant	Lead
Core inlet/outlet T (°C)	420/530
Primary loop pressure loss (Bar)	1.3
Secondary cycle	Superheated steam
Turbine inlet pressure (Bar)	180

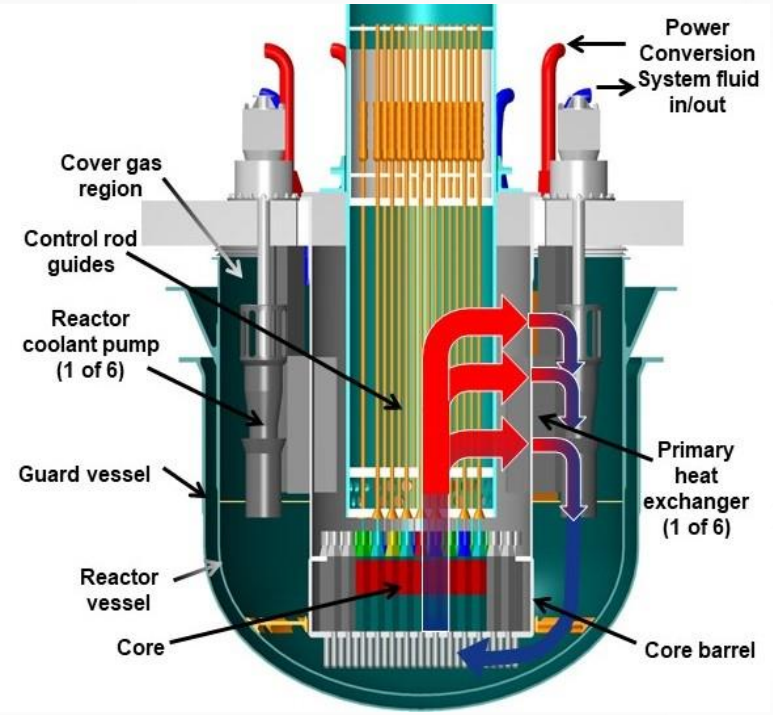
Westinghouse's Lead Fast Reactor

Aim for economic competitiveness,

simple and robust design,

passive safety and lifecycle requirements since early design phase

- 950 MWt (~450 MWe)
- Hybrid, micro-channel type heat exchangers
- Thermal energy storage system to provide load-following



Department for Business, Energy & Industrial Strategy

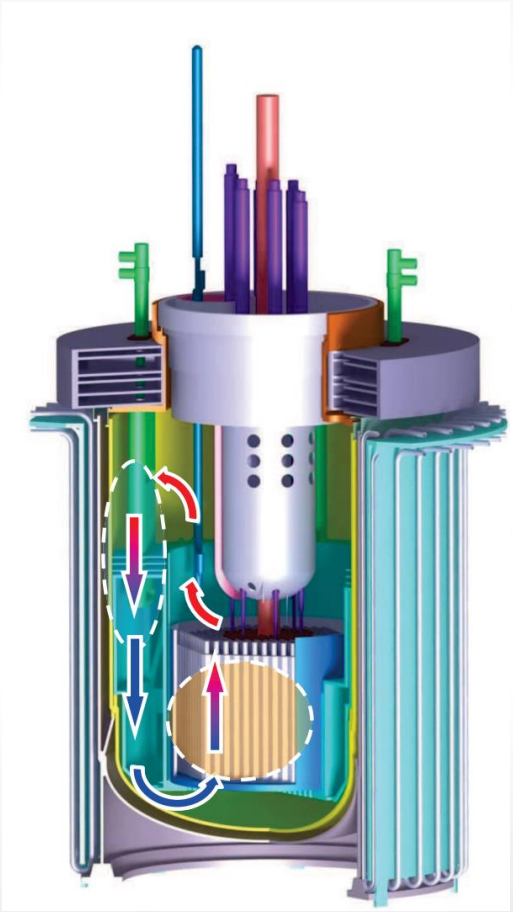
Advanced Modular Reactor (AMR) Feasibility and Development Project

Recently selected as one reactor concept to be developed under Phase 2

Developed with the support of Ansaldo Nucleare, ENEA, and other key UK organizations.

China's CLEAR-I Reactor

Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences



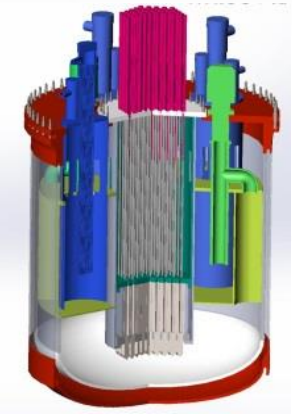
Parameters	Value
Thermal power	10 MW
Primary coolant	LBE
Fission fuel	UO_2(19.75%)
Driven force	Natural circulation
Subcritical mode k_{eff}	0.98
Primary coolant inventory	~700 t
Reactor core inlet/outlet temperature	260℃/390℃
Circulation height	2 m
Secondary coolant	Water
Secondary coolant pressure	4 MPa
Secondary coolant temperature	215℃/230℃
Primary heat exchanger	4 (2 independent loops)
Main vessel height	6300 mm
Main vessel diameter	4650 mm

China General Nuclear Power Group (CGN)

中广核 CGN

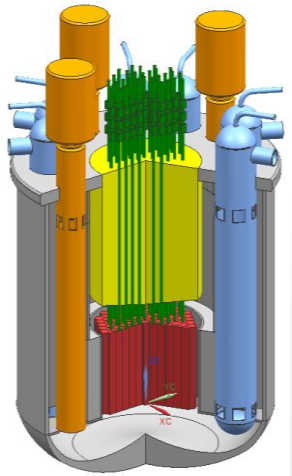
FALCON

CLFR series Lead/LBE cooled fast reactor design



CLFR-10: LBE cooled Multifunction Micro Nuclear Power

- **LBE cooled**, <200t
- **Multi-power-model**, based on user requirements (1~20MWe)
- **Battery-type core,** long-core-life (10~30y), whole core replaced
- **Factory-made**, easy transportation (highway/railway/shipping)

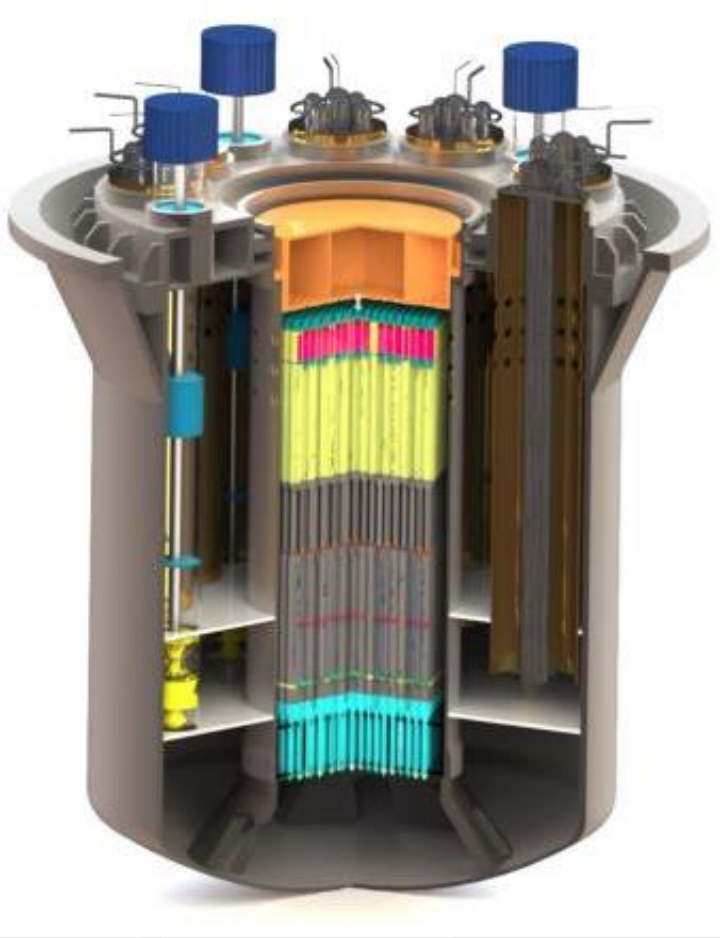


CLFR-300: **Lead Cooled Demonstration Reactor**

- **Lead cooled fast reactor** with 300MWe
- **Extremely safe**: inherent safety, passive cooling system
- **Flexible operation**: high speed starting and stopping, flexible load, complement with renewables energy
- **High modular level**: design, construction, decommissioning

Concept design of 100 MWe LFR BLESS

State Power Investment Corporation (SPIC)



• Thermal Power	300 MWt
• Electric Power	120 MWe
• Fuel	UO_2
• Enrichment	14%/16%/19.75%
• Active zone height	70 cm
• Active zone diameter	242.2 cm
• Core vessel diameter	256 cm
• No. of Fuel assemblies	247
• No. of Fuel rods per FA	127
• Fuel rod diameter	9.29 mm
• Linear power density	116 W/cm
• Coolant	LBE
• Core inlet temp.	340 °C
• Core outlet temp.	490 °C
• Operation pressure	0.1 MPa

LeadCold SEALER

SEALER stands for "Swedish Advanced Lead Reactor". It also means "Person providing a stamp of quality".

- Very small LBE-cooled reactor
- 19.75% enriched UO_2-fuel
- 3-10 MW electric
- Core life: 10-30 years
- Reactor vessel: 2.7 x 6.0 m
- Transportable to/from site
- Fuel cladding remains below 450°C