Novelty of the LFR-AS-200 project

Genève

February 9, 2017

CERN

PREPARED FOR PRESENTATION TO

Distinguished invited audience

The CYCLAD project

CYCLAD is novelty-ADS because it couples:

- ✓ a Single-Stage High Power Cyclotron

with

- ✓ a lead-cooled, sub-critical LFR-AS-200.

Pro and contra of lead for use in a ADS

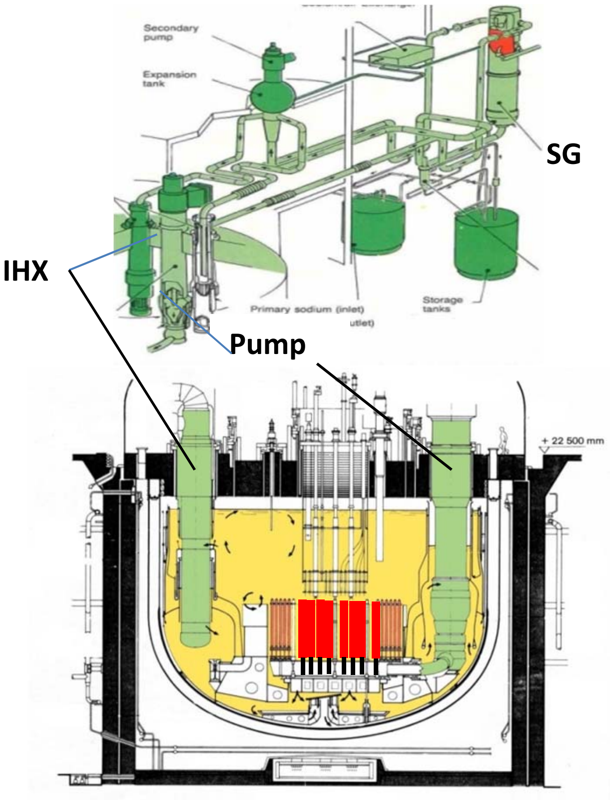
- ✓ Lead can be used as spallation target and reactor coolant
- ✓ Lead has peculiar, safety-relevant properties:
  - chemically inert with air;
  - chemically inert with water;
  - high boiling point and high thermal capacity;
  - low moderating efficiency;
  - good retention of fission products.
- ✓ But presents also technological (mainly corrosion) and system design issues.

Note: this presentation intends to describe the contribution of the LFR-AS-200 project to the resolution/mitigation of the system issues.

Typical LFR project configurations and issues

Most LFR projects are based on pool configuration characterized by a large mass of lead in a high vessel, similar to sodium-cooled reactors, besides the replacement of the Intermediate Heat Exchanger (IHX) with the Steam Generator (SG).

One out of four intermediate loops of SPX1.

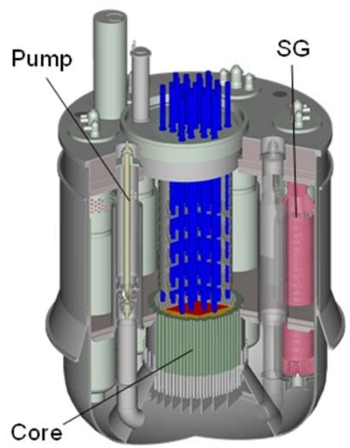


SPX1 Sodium-cooled 1200MWe
Vessel: ϕ=21m, h=19m

Conclusion of the JAEA's FR 750MWe design.

"The specific gravity of LBE is twelve times that of sodium. This property affects structural integrity, a particular concern for earthquake conditions"

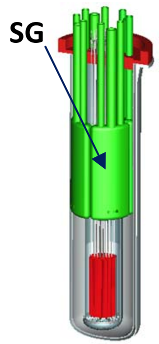
(Appendix A of the Research and Development (R&D) Plan for LFR, May 2006).



JAEA's LBE-cooled 750 MWe
Vessel: ϕ=14,5m, h=18,5m

Serious issues are:

- ✓ Seismic design.
- ✓ Steam generator tube rupture deep in the melt.
- ✓ Refueling



SSTAR
20MWe

Small power projects are proposed to solve the seismic issue.

The Hydromine LFR-AS-200

LFR stands for Lead-cooled Fast Reactor,

AS stands for Amphora-Shaped, referring to the shape of the Inner Vessel

200 is the rated electrical power of the reactor in MW.

The LFR-AS-200 is based on innovative solutions conceived by the Hydromine team in the last ten years and presented for the first time on July 2016 in London at the Imperial College.

Table1: Main design parameters of LFR-AS-200

Core power (MWth)	480
Electrical power (MWe)	200
Core inlet/outlet T (°C)	420/530
Primary loop pressure loss (bar)	1,3
Secondary cycle	Superheated steam
Turbine inlet pressure (bar)	180
Feed water /steam temperature (°C)	340/500

LFR-AS-200, 10 years work for achieving a simple, consistent design

LFR-AS-200 is predictably economic

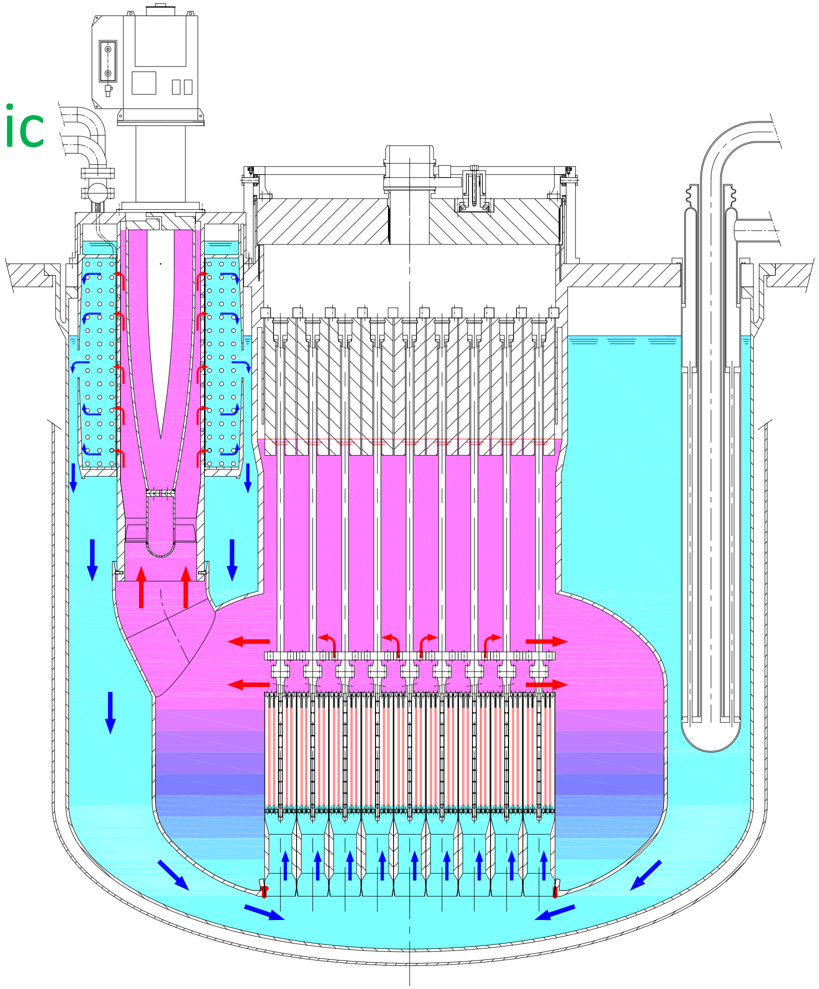
Volume of the primary system

< $1m^3$/MWe !!

~ 4 times less than SPX1

~ 2-3 times less than the best SFR projects

~ 3-5 time less than previous LFR projects



LFR-AS-200 is feasible

Height of the reactor vessel

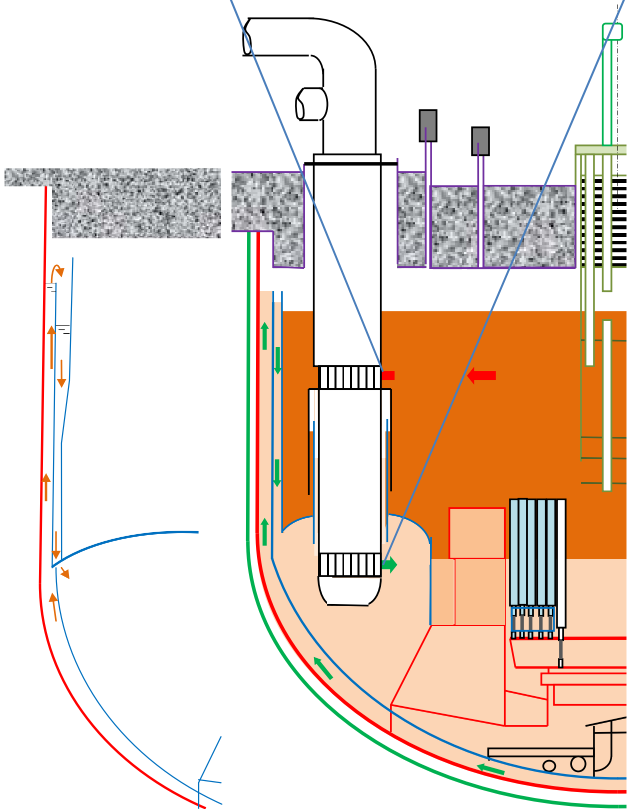
6,2m!!

Note: The Hydromine innovations are certified by 12 patent applications (including six in May 2016); other applications are in preparation.

The SG of LFR-AS-200 differs from current technology

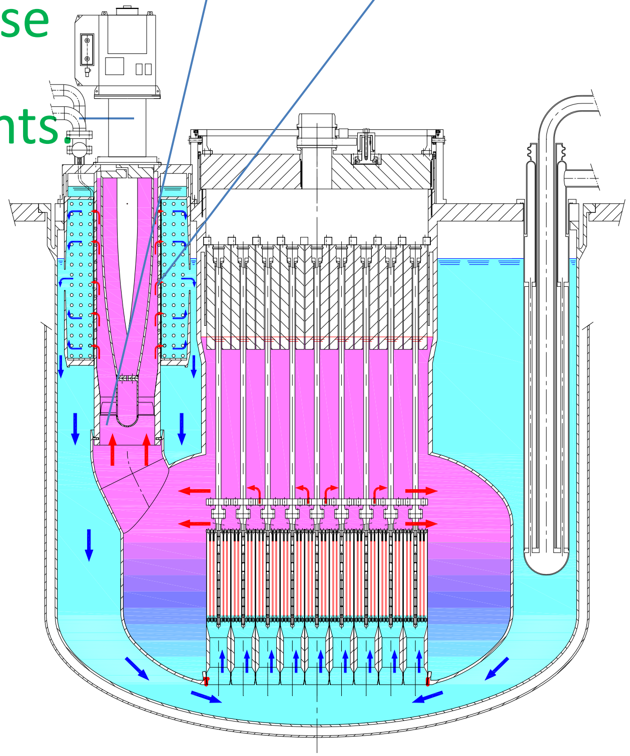
From:
long SG deeply immersed in the melt with top inlet window and bottom outlet window.

To:
short Spiral-tube SG partially raised with respect to the cold collector free level with bottom inlet and top outlet.



Advantages:

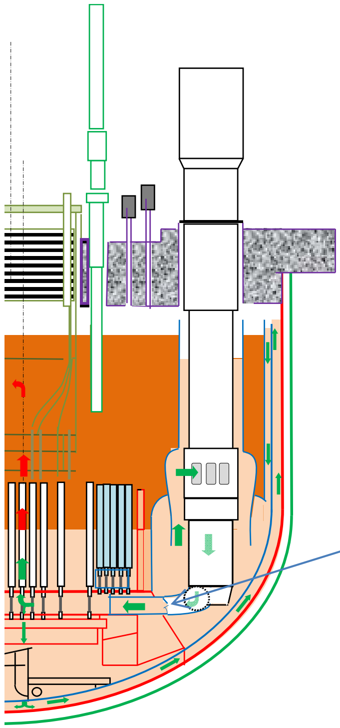
- No risk of steam release deep in the melt and large lead displacements.
- No risk of cover gas entrance into the core.
- Short, compact SG, → reduced RV height.
- No "Deversoir", → reduced RV diameter.



The Pump assembly differs from current technology

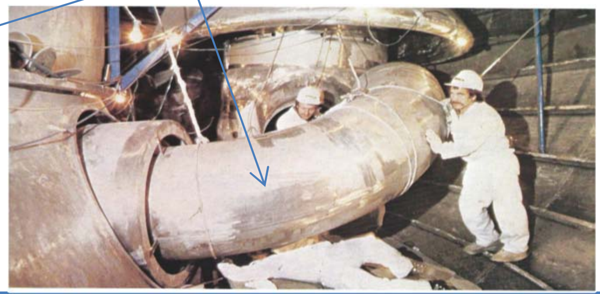
From:
Pumps in the cold collector, in-between the SGs, with long shafts and in-melt bearings.

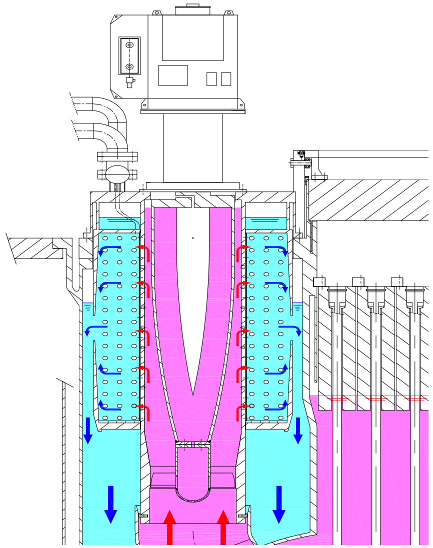
To:
Pump in the hot collector, integrated in each SG to feed the SG, with large hollow shaft filled with lead, and no in-melt bearings.



Advantages:

- Use of available space inside the SG,
  → reduced RV diameter.
- No bearings in lead.
- High mechanical inertia for mild transients from forced to natural circulation.
- Core fed by the hydrostatic head Δh between cold and hot collector,
  → no “LIPOSO”



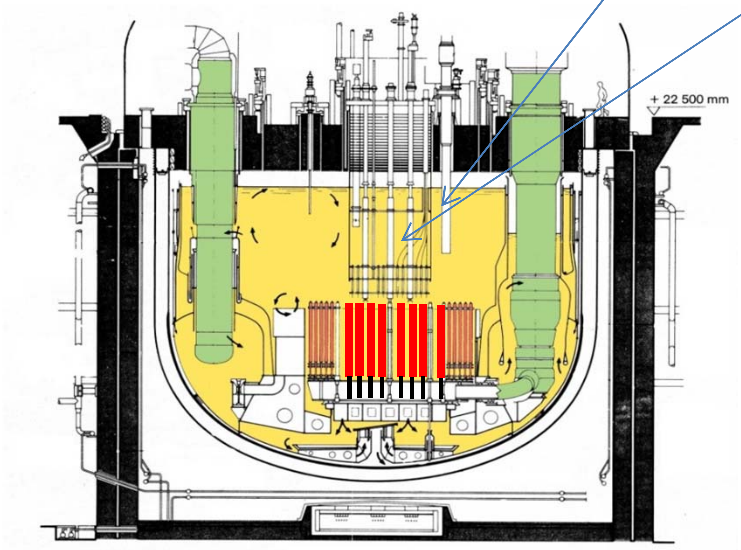


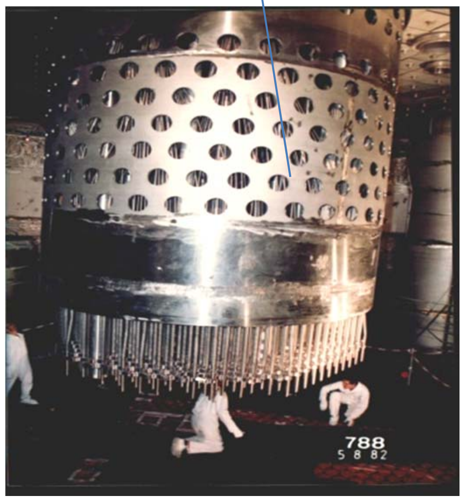
The issue of refueling the LFR.

Refueling is difficult in sodium:
- Both Jōyō and Monju in Japan are at shutdown because of handling accidents.
- Need of a complicate in-vessel refueling machine.
- Need of complicate preparatory interventions.

In-lead refueling is even more difficult:
- Higher refueling temperature.
- Large buoyance effect.

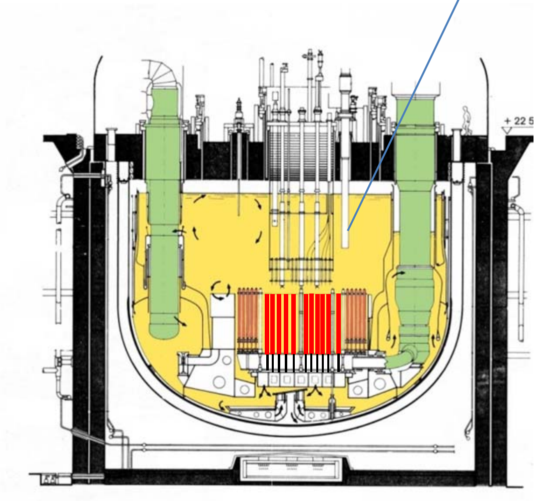
Above Core Structure to be moved for refueling





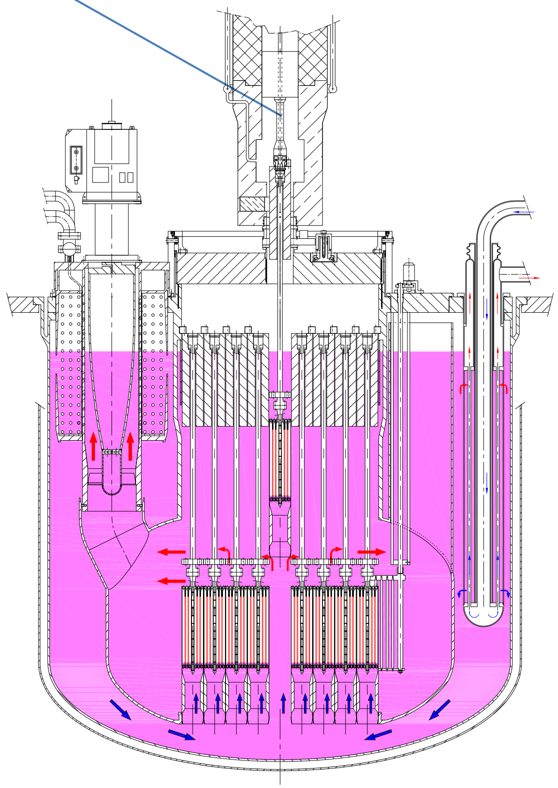
The Fuel Assembly of LFR-AS-200 differs from current technology

From:
Fuel Assemblies immersed in the melt handled by an in-vessel + ex-vessel Refueling Machine.



A cold handle allows easy handling in hot oil.

To:
Fuel Assemblies with stem extended above the lead free level handled by an ex-vessel Refueling Machine.



Advantages:

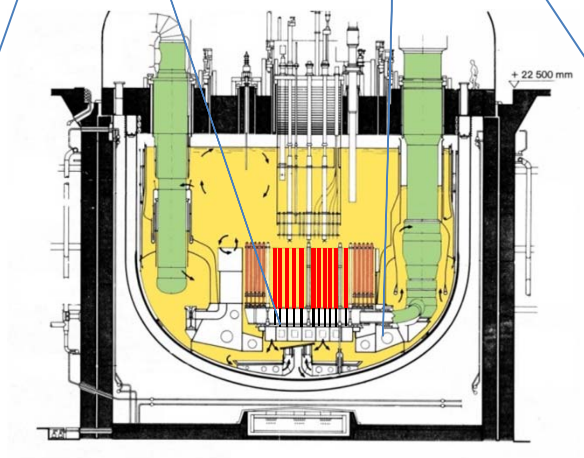
- No in-vessel Refueling Machine,
  ⟶reduced RV diameter.
- No Above Core Structure,
  ⟶reduced RV diameter.
- Buoyance compensated by the emerged portion of the stem.
- Increased reliability.

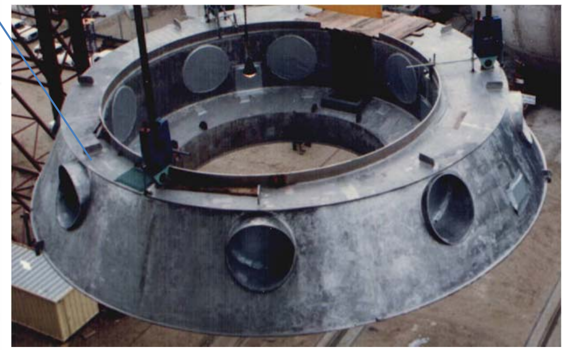
The issue of ISI of the core support system

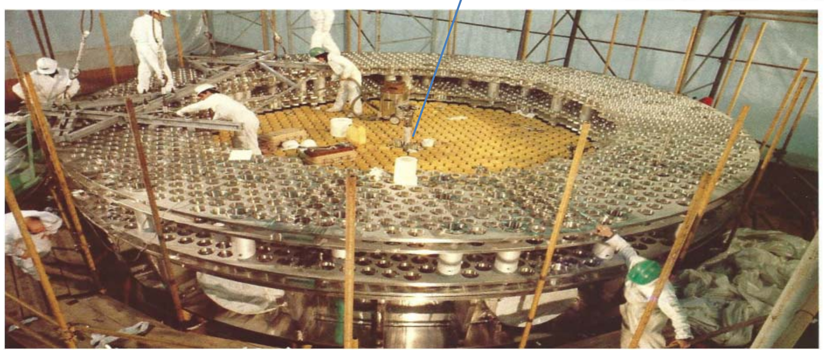
The classical core support structures, Diagrid and Strongback, are critical components subjected to thermal transients and neutron damage. Their collapse could bring about effects of control rod extraction.

Their ISI is difficult in sodium because of deep location and complexity.

Their ISI in lead would be even more difficult.



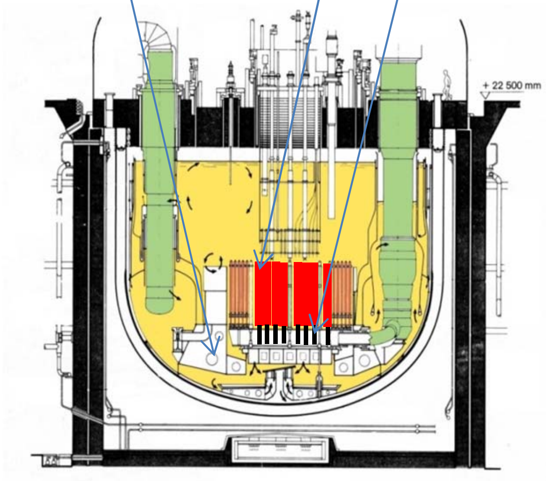




The Core of the FR-AS-200 is self-sustaining

From:
Fuel Assemblies (FA) supported in lead at the bottom by Diagrid and Strongback.

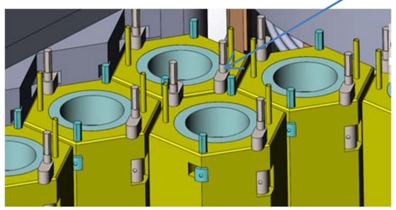
To:
Core anchored at the top to a barrel in gas space.

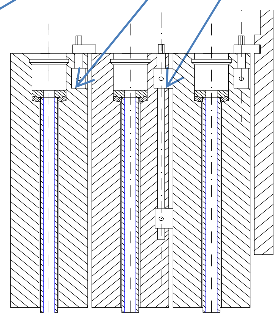


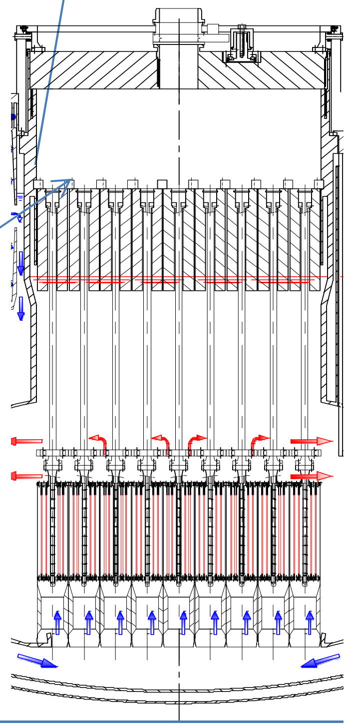
Advantages:
- No Diagrid.
- No Strongback.

No support system subject to thermal transients and neutron damage (only disc cams integral part of the FAs).
No need of disconnecting all FAs instrumentation at refueling.
Increased availability.

Cams



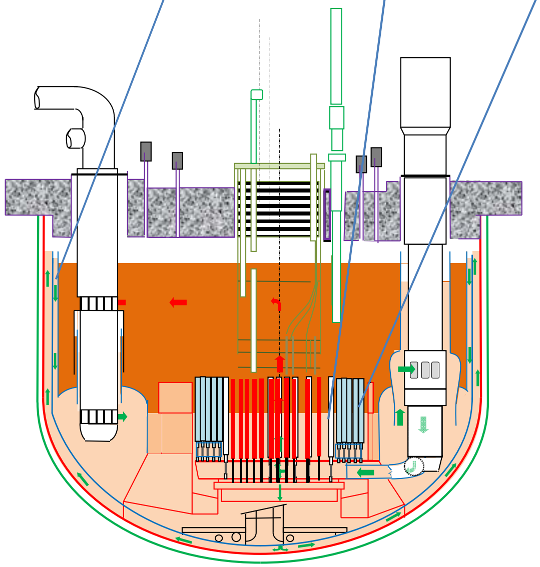




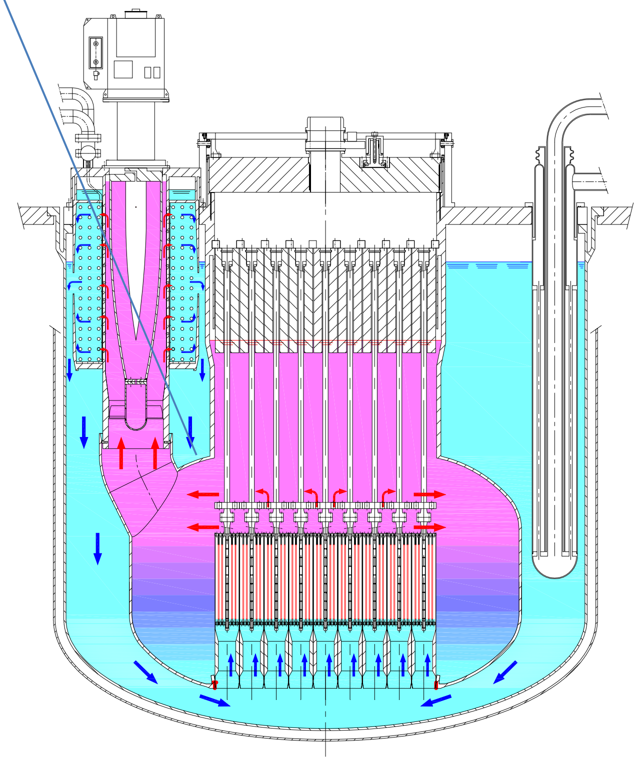
The Amphora-Shaped Inner Vessel

From:
Inner Vessel, large at top and smaller at bottom, containing Shielding Assemblies (and Breeding Assemblies).

To:
Amphora-Shaped Inner Vessel, no Shielding Assemblies (and no Breeding Assemblies).



Advantages:
- No need of Shielding Assemblies,
  → reduced RV diameter,
  → increased availability,
  → reduced waste inventory.

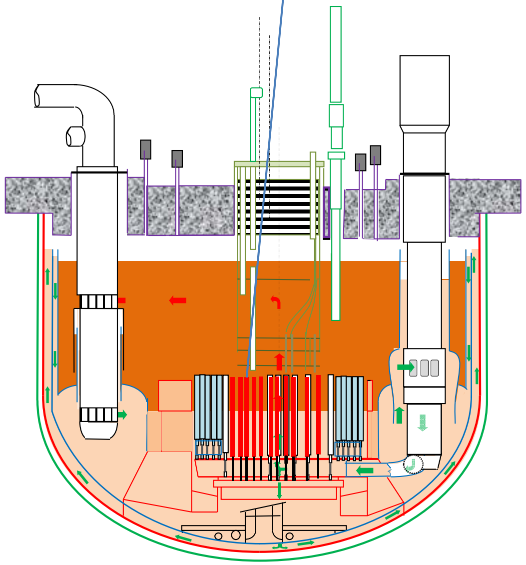


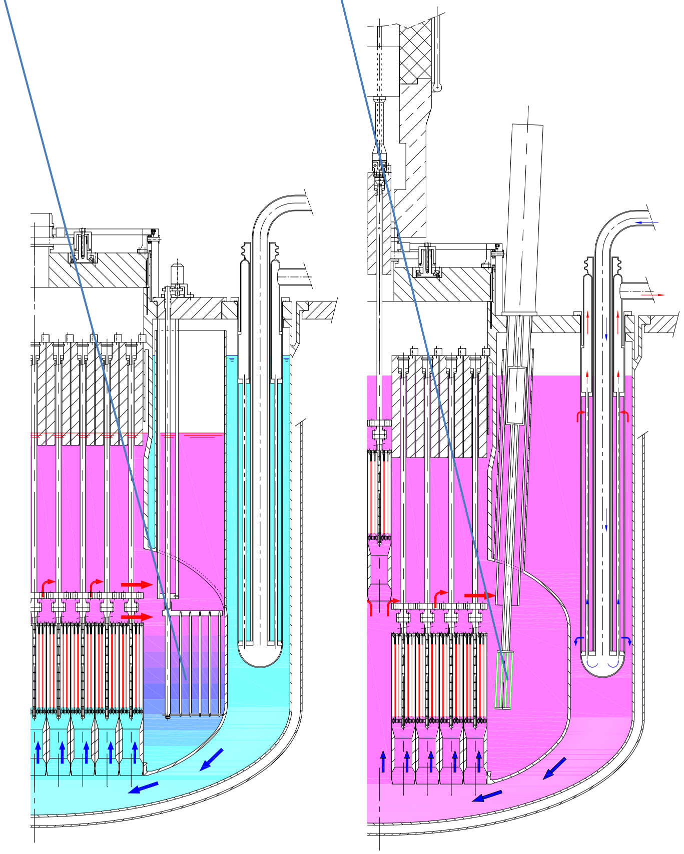
The ex-core control rods

From:
In-core control and shut down rods.

To:
Ex-core control and shut down rods.

Advantages:
- Reduced core dimensions.
- No disconnection of rod drives for refueling.

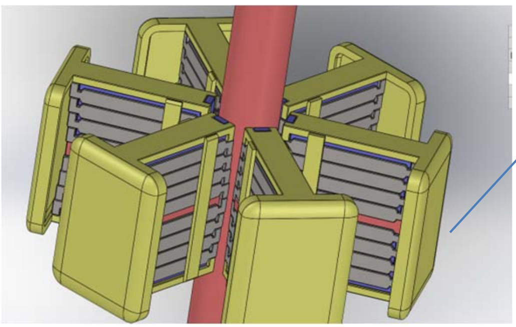




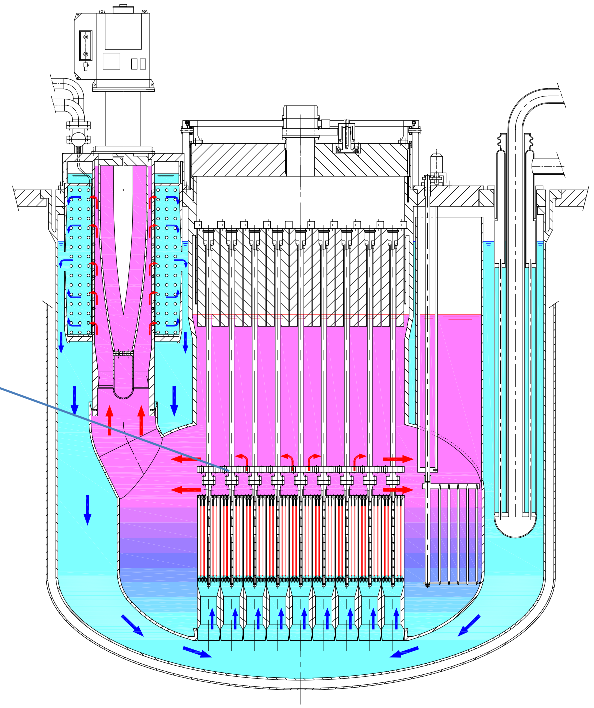
Resistance to cyber attacks

Logics and operators backed up by passively actuated systems to shut down the reactor.

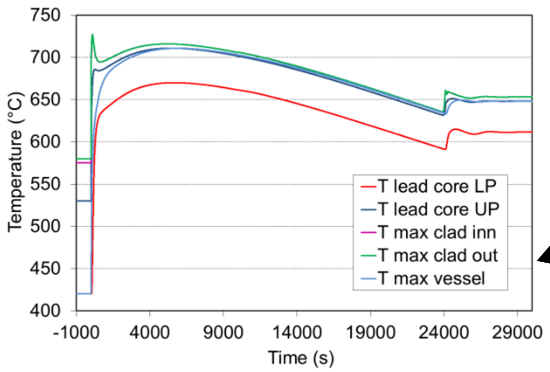
In a LFR there is a margin of hundreds K between the operating temperature and the safety limit, hence, e.g., thermal expansion can be used to open the core and shut down the reactor in case of failure of logics or of operator intervention.



Bi-metallic expansors open and shut down the core when temperature exceeds normal operating limits.

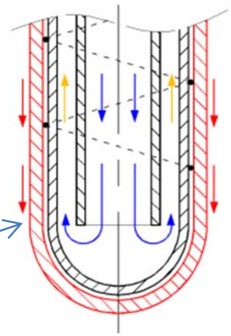


Resistance to cyber attacks 2/2



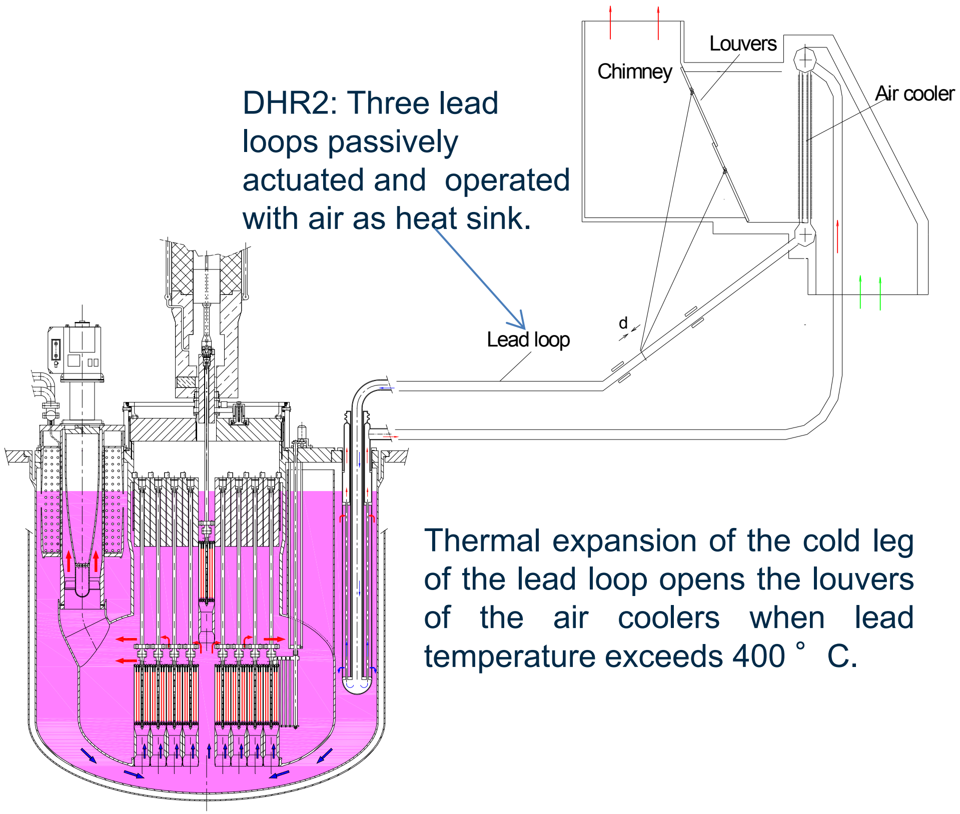
Passive shut down is complemented by two independent, passive, diverse, redundant DHR systems to face the Unprotected Loss Of Offsite Power (ULOOP).

DHR1:Three water-steam loops passively operated with water as heat sink.



Lead-water, double-wall bayonet-tube bundle heat exchanger at Brasimone site.

DHR2: Three lead loops passively actuated and operated with air as heat sink.



Thermal expansion of the cold leg of the lead loop opens the louvers of the air coolers when lead temperature exceeds 400 ° C.

Hydromine Nuclear Energy

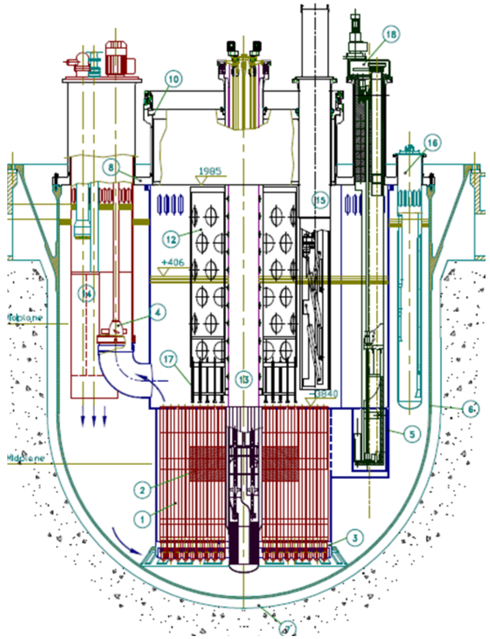
Conclusion 1– LFR-AS-200 enhances safety while dispensing of hitherto classical critical components

Components/systems no more needed	Rationale for elimination	Impact
Intermediate loop	Lead properties.	Compact Reactor Building, easy operation, cost reduction (about 30% of the cost of NSSS in a SFR).
Above core structure	Use of FAs with extended stem.	Reduced diameter of the RV, no need of its displacement for refuelling.
In-vessel refuelling machine	Use of FAs with extended stem.	Elimination of a mechanically critical component to be operated in opaque medium.
"Deversoir " or equivalent component	SG-outlet window at top of the SG.	Reduced diameter of the RV, reduced vibration risk.
Diagrid	Self-sustaining core.	No need of a component difficult to inspect.
Strongback	Core supported by the roof via the barrel.	No need of a component difficult to inspect. No structure fixed to the RV
"LIPOSO" , hydraulic connection pump to diagrid	Pumps in the hot collector.	Elimination of a mechanically critical component.
Pump bearings in lead	Low required NPSH for the pumps.	Elimination of a mechanically critical component.
Flywheel on the pump system	Use of rotating lead inertia.	Smaller footprint on the reactor roof.
Core shielding assemblies	Use of the ASIV.	Reduced diameter of the RV, simplicity.
Blanket assemblies	No net Pu generation.	Reduced diameter of the RV, simplicity, increased proliferation resistance.

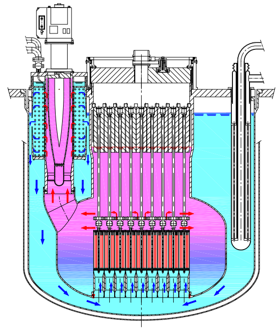
Hydromine
Nuclear Energy

Conclusion 2 - CYCLADS will rely on the simplifications of LFR-AS-200 with respect to the subcritical system of EFIT (IP-EUROTRANS project)

	EFIT	LFR-AS-200
Thermal power	416	480
Primary system volume/unit power	~4,5m³/MWe	≤1 m³/MWe
Vessel height	10,9m	6,2m
Steam Generator	Helical-tube, deeply immersed	Spiral-tube raised above the lead free level of the cold collector, and outlet window at lead free level of the cold collector.
Refueling	✓ In-Vessel Rotor-Lift Machine, ✓ Extendible-arm Fuel Transfer Machine, ✓ Above-Core-Structure ✓ Ex-vessel Fuel Handling System	✓ Ex-vessel Fuel Handling System.
FA support	Diagrid and Reactor Vessel	Self-standing core supported by the Reactor Roof.



EFIT
Vessel: ϕ=9,8m, h=10,9m



LFR-AS-200
Vessel: ϕ=6m, h=6,2m