This project has received funding from the
Euratom research and training programme 2014-2018
under grant agreement No 661891

SAMOFAR Final Meeting

Propositions and conclusions concerning the safety evaluation and demonstration of the MSFR

July 4th, 2019

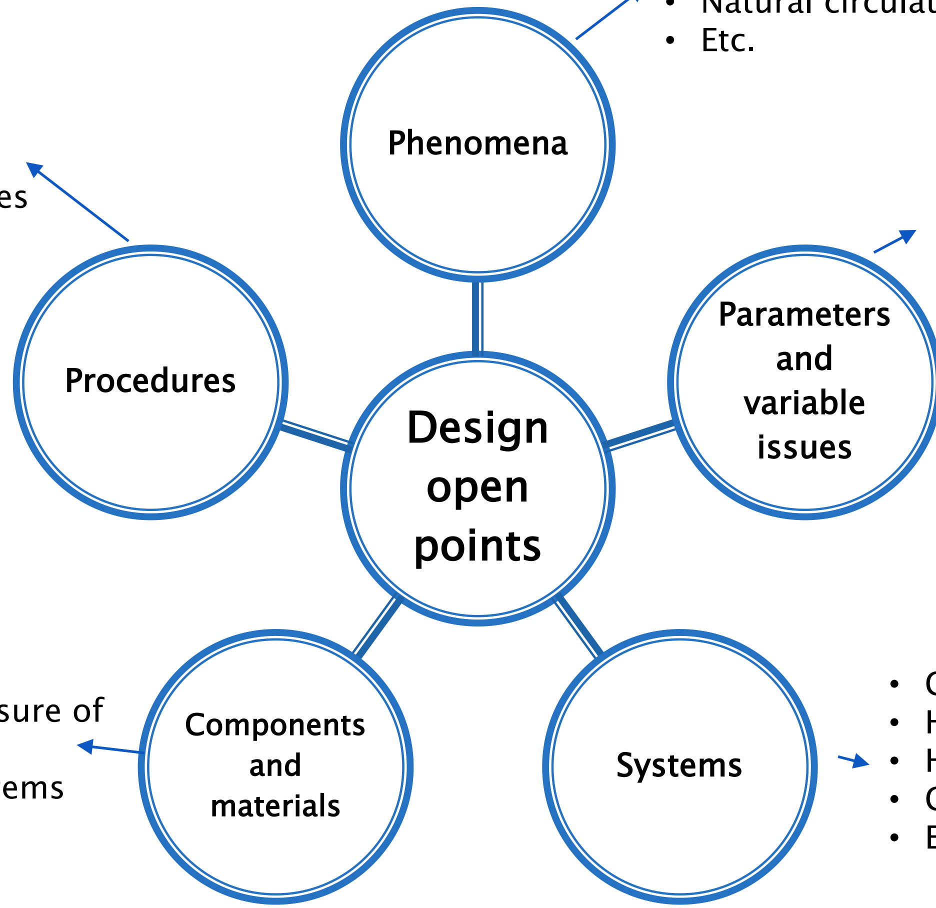
Elsa MERLE for the WP1 partners

Design open points

- Chemical reactions of the salt
- Corrosion
- Natural circulation
- Etc.

- Draining procedures
- Salt sampling procedure
- Reactivity control procedures
- Control strategies
- Etc.

- Level of fuel in the expension vessel
- Etc.



- Circulation pumps
- Component of the upper closure of core cavity
- Fission product removal systems
- Etc.

- Chemical processing units
- Heating system for IHS
- Heat exchangers
- Cooling system for structures
- Etc.

Safety function 1: reactivity control

Related systems: fuel circuit, Emergency Draining System, Core Catcher, processing units

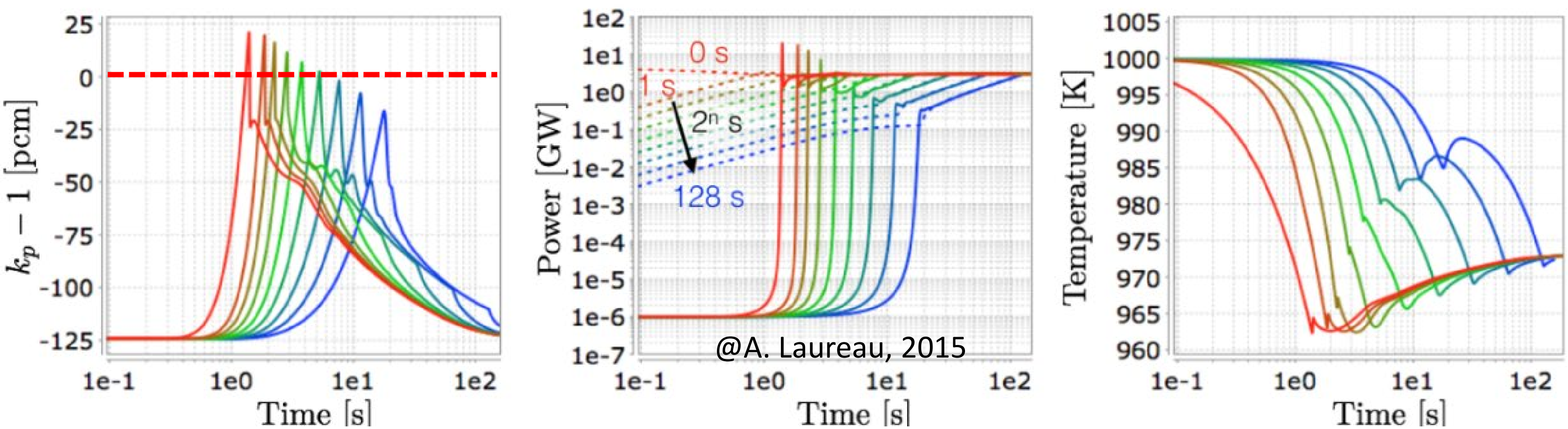
Related procedures: reactivity control, draining procedures, control strategies

SAMOFAR results:

- ***WP5:*** In the chemical processing unit, criticality risk only for the **Actinides inventory**
- ***Safety analysis:*** **confirmation of the safety opportunities of the MSFR**
  - ✓ Liquid fuel and fast neutron spectrum → negative temperature feedback coefficient: **ensures an intrinsic safety with respect to reactivity accidents**
  - ✓ fuel unloading from the core zone is easier and faster compared to the unloading of a solid fuel → **allows to maintain sub-critical the salt and to cool the fuel in a dedicated fuel tank**
  - ✓ Absence of fuel structures in the core such as cladding and subassemblies **→ removes any risk of fuel compaction**
- ***Regarding the control strategies***:
  - ✓ MSFR can be **controlled without insertion of external reactivity** in the full power mode **with a small number of control variables** (mass flow rate in the three circuits)
  - ✓ During the demand increase/decrease, **controlled variables always kept in a safe bandwidth + no problematic behavior of the non-controlled ones**
  - ✓ **Nuclear part of the reactor well controlled** just acting on the mass flow rate of the fuel and intermediate circuits, **moving the control issue to the conventional part of the power plant**

Safety function 1: reactivity control

Most studied safety function before the SAMOFAR project (in the fuel circuit and in the EDS): see *overcooling at low power (1kW to 3 GW)* → ***no cliff edge effects***



<u>Recommendation 1 of the safety analysis</u> = the **reactor behavior in case of prompt critical jump** should be studied in more details including **mechanical effects**…

<u>Recommendation 2 of the safety analysis</u> ***(rapid overcooling event as an example of reactivity insertion events) =*** **Availability of the fuel salt expansion effect appears as absolutely necessary**: a detailed analysis of all scenarios that might lead to fuel circuits' free levels unavailability would be worthwhile, in order to ensure that appropriate design measures ensure a very high reliability of this safety feature

SAMOFAR

Safety function 3: confinement

Safety recommendations: design measures proposed to prevent the risks of loss of the two first barriers such as:

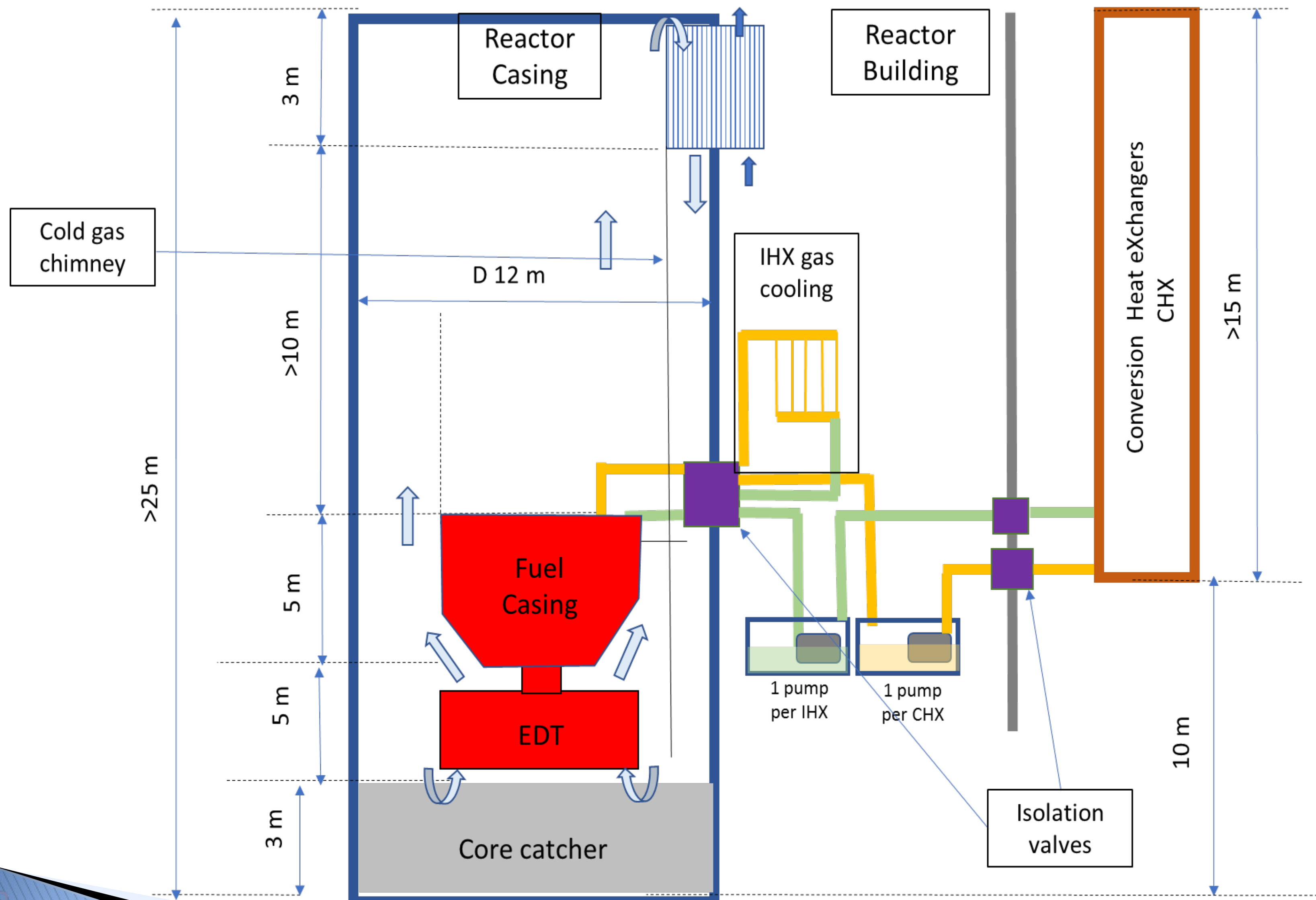
- **Integration of the core catcher within the second barrier**
- All piping passing through a barrier should have an isolation valve → **Consideration of isolation valves on the intermediate salt loops**

⇒ ***Present confinement barrier definition (SAMOFAR result):***

1. **Fuel Casing (FC):** contains the fuel under normal operation conditions - divided into three elements: **a casing around the core vessel**, **a casing for the liquid fuel transfer** (inlet and outlet) through a gastight chamber, **a casing around the emergency draining tank** when the EDS option is chosen
2. **Reactor Casing (RC):** contains the Fuel Casing, the off-gas processing and storage + the Core Catcher - should be **passively cooled** and should **resist a high temperature spilling of liquid fuel** in case of EDT failure
3. **Reactor Building (RB):** prevents gas and aerosols leaks from the Reactor Casing to the atmosphere - Should act as a **heat exchanger between its internal atmosphere and the environment** -> walls thin and metallic, protected by a concrete shield from external missiles, shield forms an **air chimney where air can circulate** (natural or forced convection)

SAMOFAR

Safety function 3: confinement



SAMOFAR

Safety function 2: heat extraction

Related systems: intermediate/energy conversion circuits, cooling systems, processing units

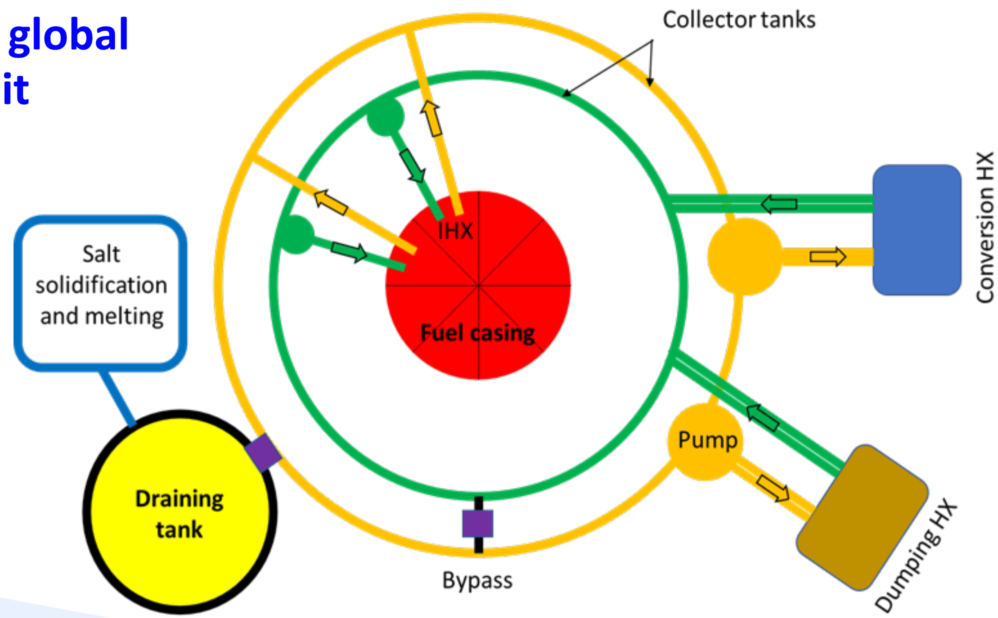
Related components: fuel heat exchangers and pumps, intermediate heat exchangers…

Related phenomena: natural convection, gas cooling

Result 1 of SAMOFAR (WP3): study of the **heat exchanger/cooler configurations to optimize the natural convection** in the fuel circuit including the **evaluation of the risk of instability**

Result 2 of SAMOFAR (WP5): daily batch of processed fuel → decay heat = **180 kW initially**

Result 3 of SAMOFAR: Proposition of a **global arrangement of the intermediate circuit**

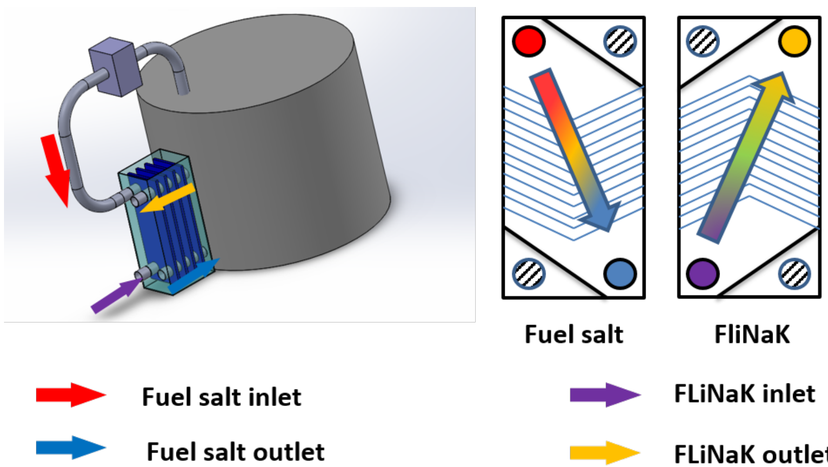


SAMOFAR

Safety function 2: heat extraction

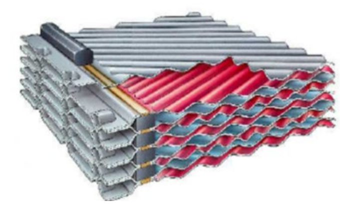
<u>Result 4 of SAMOFAR:</u> study of mechanical pumps for the fuel circuit → **selection of magnetic driven pumps (no openings needed in the sector lids)** instead of mechanically-driven pumps

<u>Result 5 of SAMOFAR:</u> 2 new studies of heat exchangers for the fuel circuit (**2 safety functions → cooling and confinement**)



framatome

PSHE (Plate Stamped Heat Exchange) – acceptable configuration found for the MSFR requirements



FIGES engineering

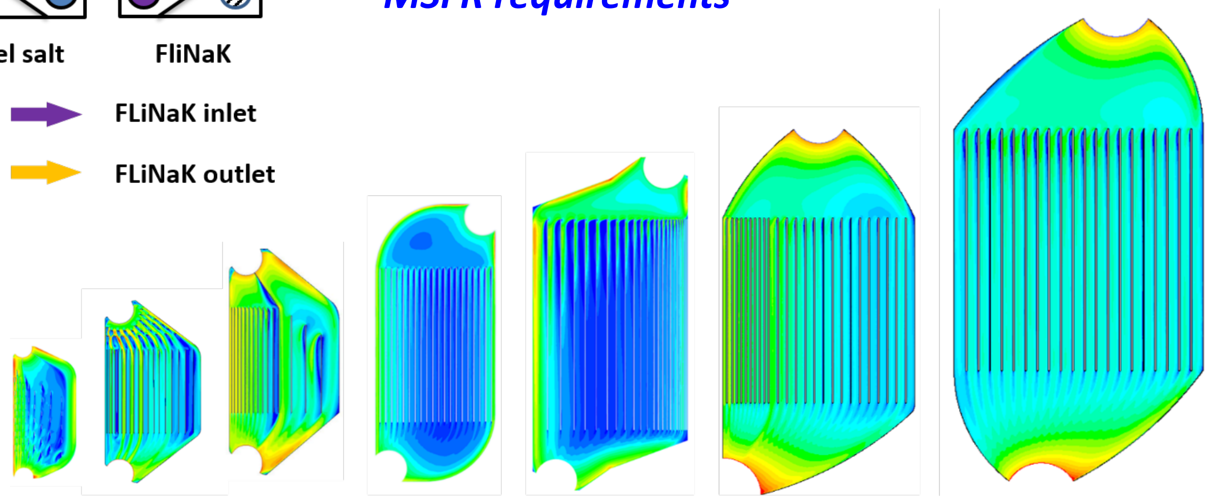


Plate type heat exchangers – study of the flow for different geometric designs

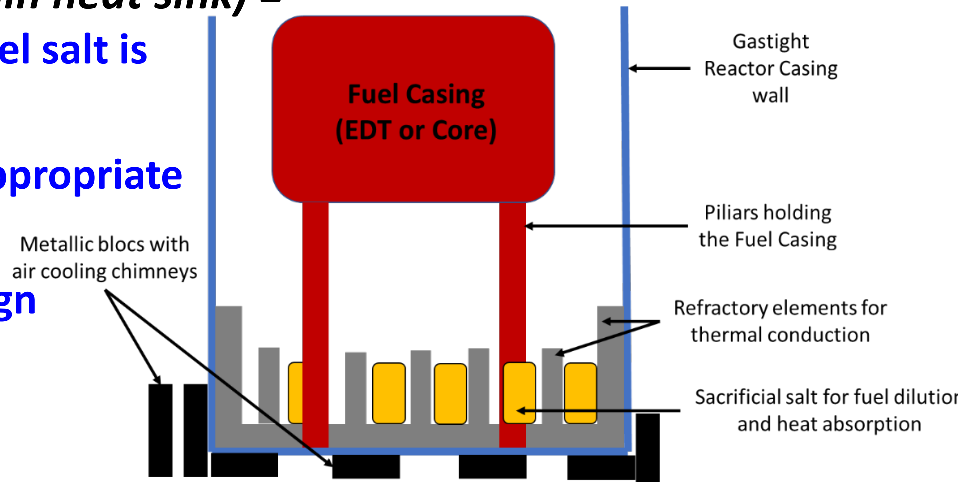
SAMOFAR

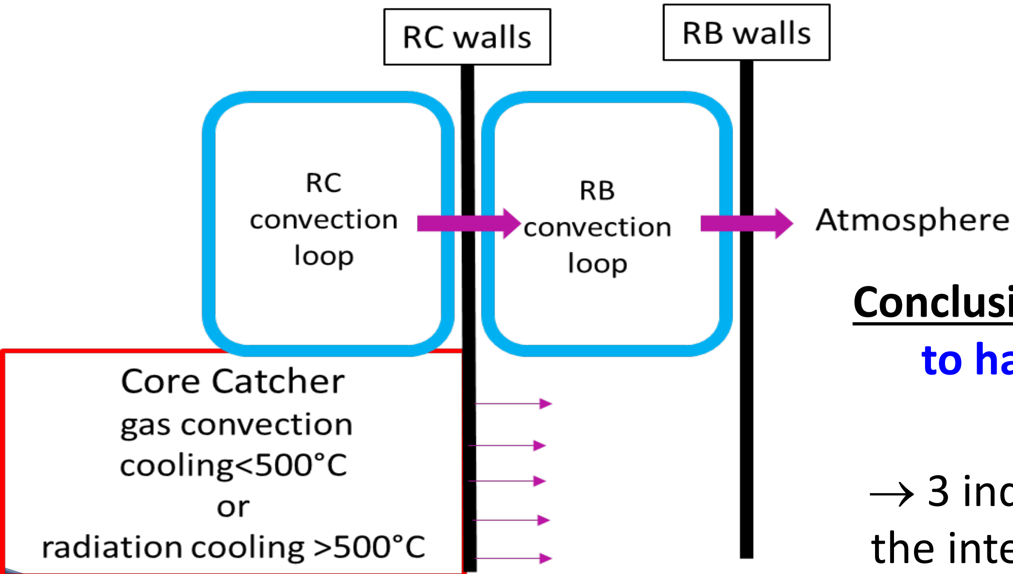
Safety function 2: decay heat extraction

<u>Conclusion 1 of the safety analysis</u> (***loss of main heat sink) =***
need to **further study the situation where the fuel salt is drained in the EDS , with subsequent EDS failure**

→ the fuel salt will go in the **core catcher with appropriate cooling means to be defined**

→ Proposition of a preliminary **core catcher design**





<u>Conclusion 2 of the safety analysis</u> = important to have redundant and independent DH extraction systems

→ 3 independent DHRS systems: 1. Cooling of the intermediate fluid by the air of the RB / 2. Cooling of the fuel in the EDT by the gas of the RC / 3. Preliminary thinking of 2 core-catcher cooling systems

Conclusions and Recommendations

Strong orientation for the MSFR development = **leverage the favorable intrinsic features of the concept** to come up with both a simple and convincing design and safety architecture

R&D axes identified as regard safety studies likely to strongly orientate the design:

- **Pursuit of the risks' identification**, encompassing the whole plant and all initial states (also shutdown states, start-up…) and all risks (including chemical/radioprotection ones)
- **Further study of possible cliff edge effects** for the large size 'reference MSFR'
- **Safety related topics to be further studied and/or experimentally validated for the design definition**:
  - **MSFR operation and regulations** (as a starting point for the safety analyses)
  - **Inspection and control** (including fuel salt composition management, Corrosion risk management, fuel solidification management)
  - **Materials development and qualification** (including at high temperatures under irradiation)
  - Design and experimental validation of the **heat exchangers**
  - **Study of the sensitivity of the safety analysis to the design** (see impact of using chloride salts, of U/Pu fuel cycle, of SMR with the cliff edge effects related to a reduced power…)
  - **Definition of a roadmap of the R&D developments to a demonstrator** (i.e. the calculations and experimental needs to validate the choices with a definition of the associated demonstration steps)

See next projects (SAMOSAFER…)