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SAMOFAR Final Meeting
Overview of the safety analysis of the MSFR

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Starting point (1/2)

- Will to identify the risks and safety opportunities of the MSFR

- Consensus that there is a need for a safety methodology suited to the MSFR with due account for:
  - The very early stage of the design
  - A very limited experience feedback
  - Strong specificities of the concept (while keeping the applicable basics of nuclear reactors’s safety)

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Starting point (2/2)

- On solid fuel reactors such as LWR of SFR, a severe accident is usually defined as a whole core melt situation
  - Involve phenomena with regard to which the confinement must be designed
  - Strongly orientate the safety approach both in terms of prevention and mitigation

- For the MSFR, the situations that may lead to large radiologicial releases must be identified and assessed

- The key principle should remain the defence in depth. Thus, the situations likely to lead to large radiological releases must be prevented, and, should their occurrence be postulated, their consequences must be limited

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Work performed

- Definition of the safety methodology
- Risk identification and definition of postulated initiating events
- Confinement barriers definition
- Preliminary use of the Line of Defence method

Definition of the safety methodology (1/2)

- Review of the Integrated Safety Assessment Methodology (ISAM) reckoned by the Generation IV International Forum (GIF)

- Additional consideration of other risks analysis methods

- Then proposal to engage the use and adaptation of the methodology in the SAMOFAR context

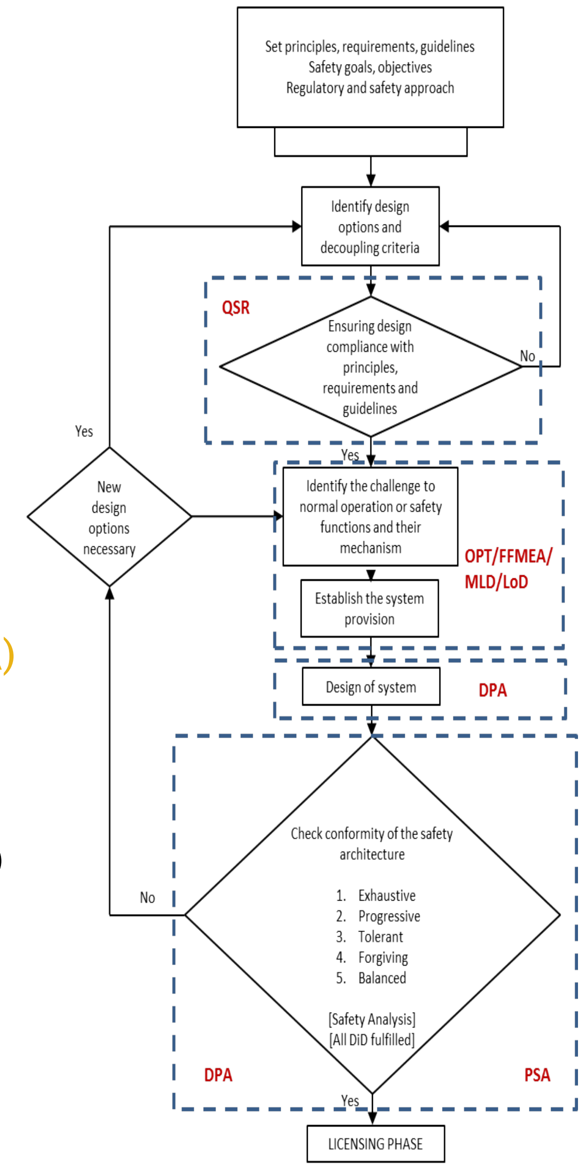
Definition of the safety methodology (2/2)

Main steps:

- Check design compliance with principles and requirements
- Identification of risks and elaboration of a list of Postulated Initiating Events
- Definition of safety architecture
- Check conformity of the safety architecture

Tools:

- Qualitative Safety Review (QSR)
- Functional Failure Mode and Effect Analysis (FFMEA)
- Master Logic Diagram (MLD)
- OPT (Objective Provision Tree)
- LoD (Lines of Defence)
- DPA (Deterministic and Phenomenological analysis)
- PSA (Probabilistic safety assessment)



Risk identification and definition of postulated initiating events (1/2)

- Risk identification performed at the reactor level, during power operation

- Initiating events identified with regard to the risk of fuel circuit failure (i.e., events that should solicitate the fuel circuit and may lead to its failure)

- Exhaustiveness researched:
  - Combined use of bottom-up & top-down approaches
  - Experts panel
  - Review of previous analyses (e.g., ORNL)

- Preliminary classification of the events by families and by categories depending on their expected or targeted likelihood

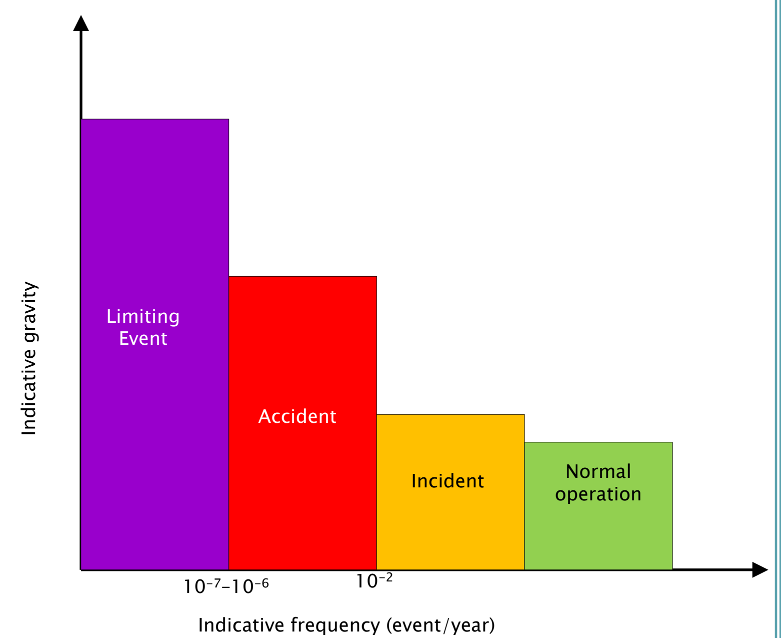
Developed in next talk

Risk identification and definition of postulated initiating events (2/2)

Families identified for the MSFR:

- Positive Reactivity Insertion
- Negative Reactivity Insertion
- Loss Of Fuel Flow
- Increase of heat extraction/Over-cooling (OVC)
- Decrease of heat extraction/LOHS
- Loss Of Fuel Circuit Tightness (LOFCT)
- Loss of fuel composition/chemistry control
- Fuel circuit structures over-heating
- (Loss of cooling of other systems containing radioactive materials)
- (Loss of containment of radioactive materials in other systems)
- Mechanical degradation of the fuel circuit
- Loss of pressure control in fuel circuit
- Conversion circuit leak
- Loss of support function

Risk categories



Developed in next talk

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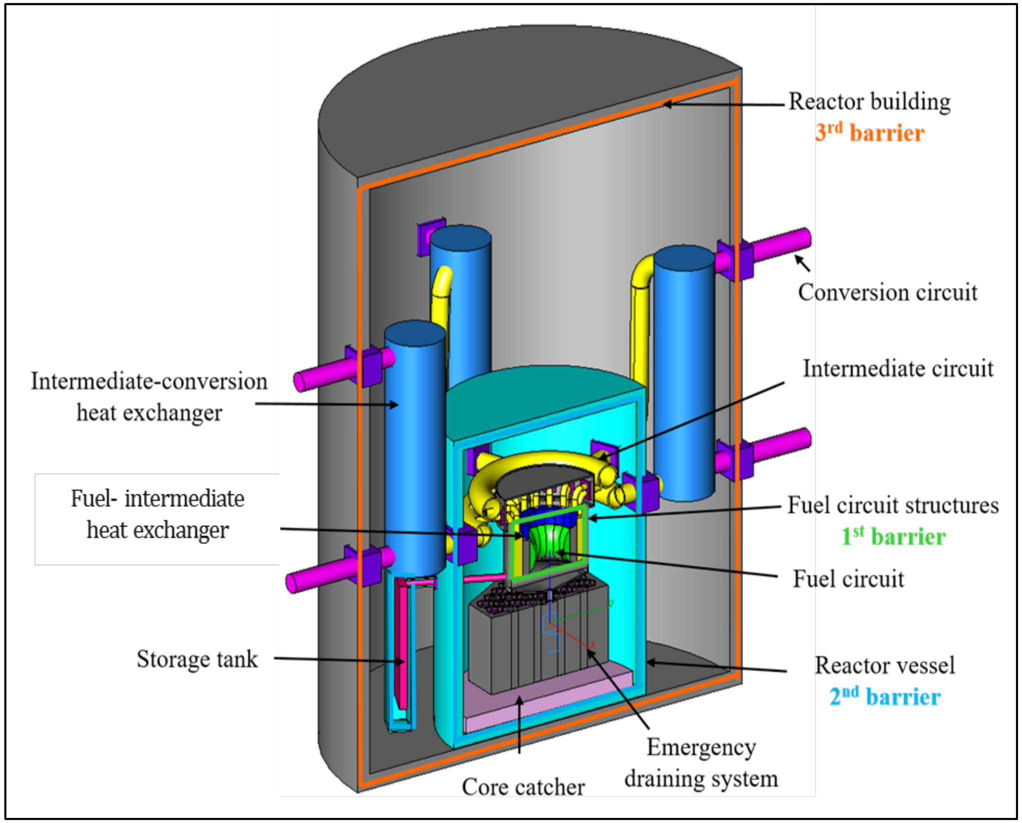
Confinement barriers definition

- Reference case (for fuel salt in the fuel circuit, during power production) among several proposals studied:
  - **1st barrier** for fuel containment during normal operation;

    → fuel circuit structures
  - **2nd barrier**: fuel containment in case of failure of the first barrier (e.g;, first barrier leakage or fuel salt draining in the EDS)

    → reactor vessel
  - **3rd barrier** for protection of the two first barriers with regard to external hazards. May have a dynamic confinement function (and static confinement function in case of postulated failures of the two first barriers)

    → reactor building



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Preliminary use of the Lines of Defence (LoD) method (1/3)

- Objectives:
  - Guarantee that every accidental evolution of the reactor state is always prevented by a minimum set of homogeneous safety provisions (called lines of defence)
  - Determine whether sufficient safety provisions are put in place between initiating events and a given accidental situation

- Lines of defense:

TYPES	QUALITY

• **Prevention** measures / low occurrence frequency of the initiating event
• Measures aimed at **limiting** the consequences of the initiating event by means of specific equipment or human actions
• **Intrinsic behaviour** and natural resistance to the progression of the initiating event
	• **Strong LoD**, type "a" (10^{-3} – 10^{-4}/year or /solicitation):
	  • active system with redundancies
	  • passive systems
	  • intrinsic behaviour of the plant with large grace periods
	• **Medium LoD**, type "b" (10^{-1} – 10^{-2}/year or /solicitation):
	  • active systems without internal redundancy
	  • intervention of the operator

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Preliminary use of the Lines of Defence (LoD) method (2/3)

- The definition of the severe accident is key in the usual application of the LoD method. For example, on the ASTRID sodium fast reactor project, at least two strong lines and one medium lines “2·a + b” is researched for prevention of a severe accident situation

- Cliff edge effects studies allowing to precisely define severe accident for the MSFR must be continued

- Considering the barriers envisaged, a situation with potential for large and early radiological releases in the environment would require at least failure of the two first barriers (the fuel circuit and the reactor vessel)

→ The general objective retained is to prevent the situation of failure of the two first barriers, with a potential for large radiological releases in the environment, by two strong and one medium lines of defence (2a+b)

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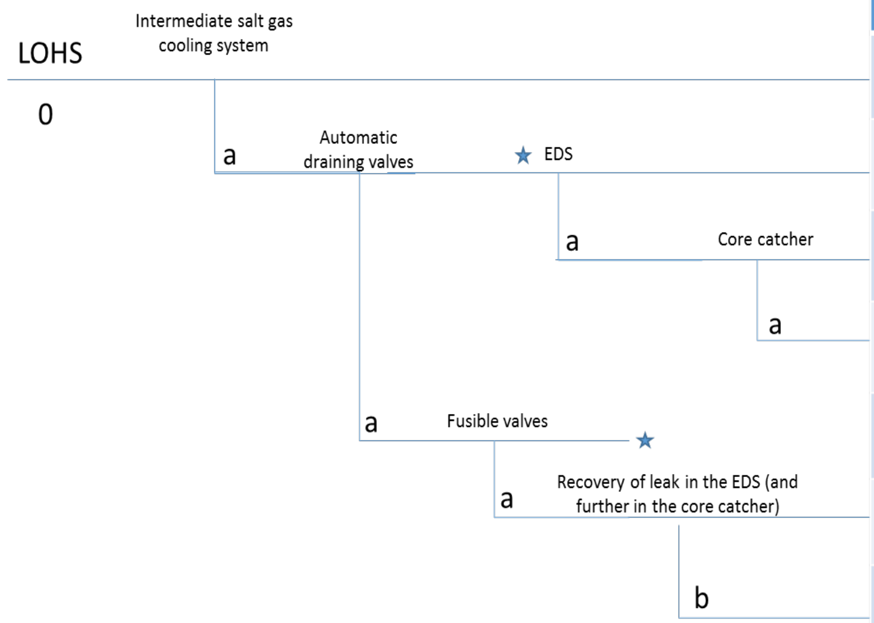
Preliminary use of the Lines of Defence (LoD) method (3/3)

- MAIN STEPS
  - 1) Description of the initiating event
  - 2) Potential consequences and required number of LoDs
  - 3) Possible lines of defence in the current MSFR architecture & event trees
  - 4) Preliminary outcomes

Example (1/2) : Schematic event tree of the loss of main heat sink event (decay heat removal function)



Potential consequences	Required LoDs (minimum)	Possible LODs identified in the current MSFR architecture
0		0
Availability loss (fuel salt in the EDS)	b	a
Investment loss (fuel salt mixed with the diluant salt of the core catcher)	a	2a
Loss of the second barrier with a large source term in the reactor building	2a+b	3a
Investment loss (damaged core vessel)	a	3a
Loss of the second barrier with a large source term in the reactor building	2a+b	3a+b

LoDs with regard to reactivity control function are:

- negative thermal feedback effects at fuel circuit level
- fuel sub-criticality by the geometry of the EDT
- then, sub-criticality through fuel salt spreading and mixing with a diluant salt at core catcher level

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Example (2/2) : Loss of main heat sink event
Some outcomes

- The interest to study a core catcher in complement to other decay heat removal systems, is confirmed
- The absence of credible common cause failures between the cooling systems of intermediate salt, of the emergency draining tank and of the core catcher should be further ensured
- In the course of the accidental sequences, the risk of an intermediate heat exchanger leak should also influence the scenario and should be further studied
- Other design arrangements may be studied (as long as they cope with the LoD requirements)
- Events likely to challenge the fuel salt cooling when the fuel salt is in the routine draining tanks during reactor shutdown states, should also be considered and analyzed according to the LoD method, in order to define of a comprehensive set of safety provisions as regard fuel salt cooling.

Conclusions

- The SAMOFAR project has allowed to achieve great progresses in the understanding of the MSFR specific safety issues, with several outputs in terms of safety methodology proposal, risk identification and orientation of the design

- It has also allowed to identify further R&D axes as regard safety with:
  - the pursuit of risk identification, encompassing the whole plant, all initial states, and all risks (including also toxicity, radioprotection…)
  - the study of possible cliff edge effects, including the evaluation of the consequences of :
    - a complete loss of decay heat removal systems
    - a postulated fuel salt leak out of the secondary barrier
    - a prompt critical power excursion

- Besides, other safety related topics are to be further studied such as:
  - MSFR operation, regulations and in-service inspection (as a starting point for the safety analyses)
  - fuel salt composition management
  - materials development and qualification
  - corrosion risk management
  - definition of a R&D roadmap addressing the codes and simulation needs, as well as the experimental basis needed in support

- Several of these challenges will be addressed in the SAMOSAFER project.

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Thank you for your kind attention

Questions?

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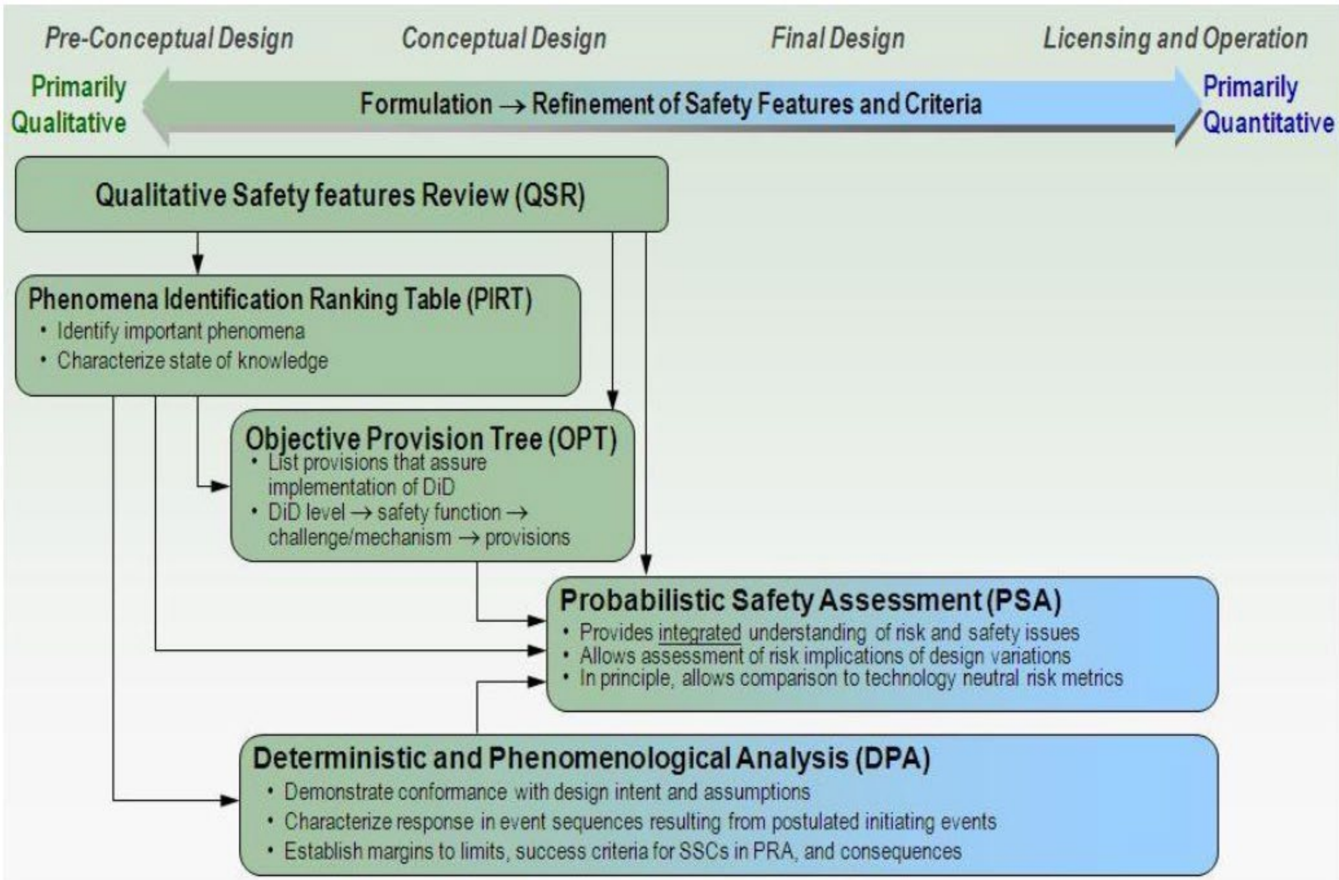
APPENDIX

ISAM Task Flow



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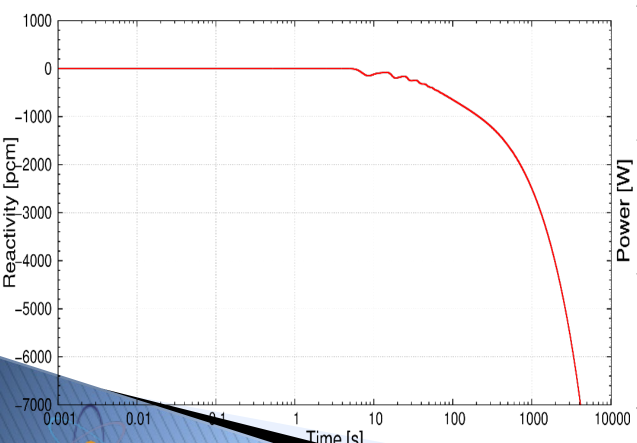
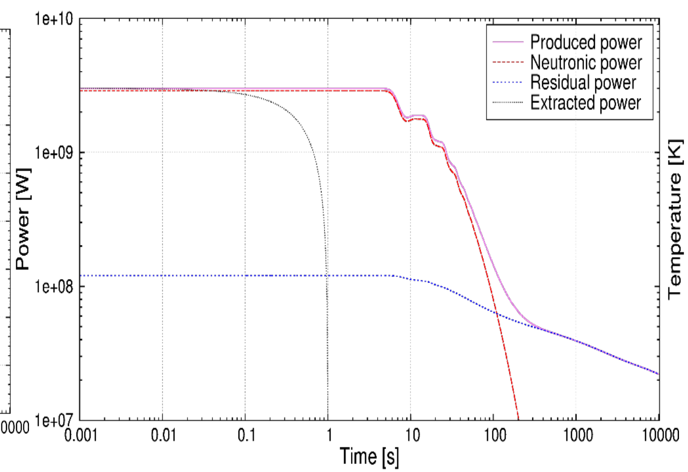
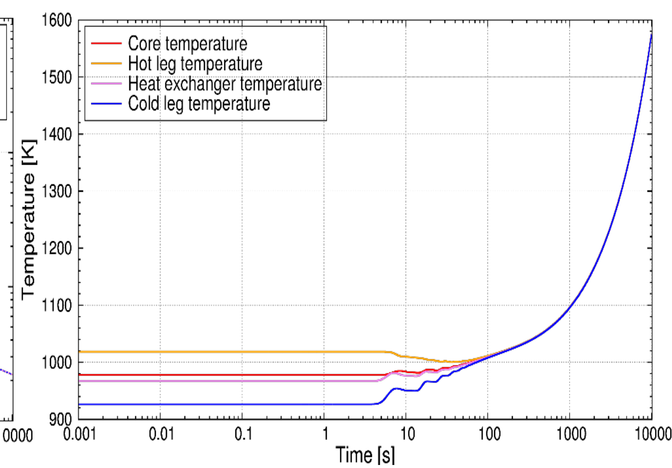
Loss of main heat sink / natural behavior of the plant

- Heat from the intermediate salt circuit is no longer removed as well as from the fuel salt circuit
- Shutdown of chain reaction and neutronics power
- Temperature increase due to the delayed neutron precursors (beginning) and to the residual power
- Thermal inertia thanks to the intermediate circuit: the fuel temperature exceeds 1200°C after more than 2 hours
- Risk of fuel structures (Hastelloy N) degradation and fuel salt leak
- Risk of release and dispersion of the fission products contained in the fuel salt
- At the intermediate circuit level
  - Risk of intermediate structures degradation and intermediate salt leak
  - Risk of intermediate salt decomposition if the fluoroborate is selected







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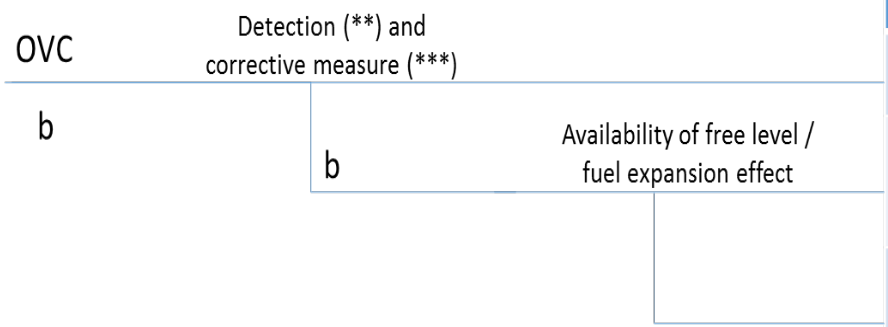
Schematic event tree of the overcooling event (reactivity control function)



Potential consequences	Required LoDs (minimum)	Possible LODs identified in the current MSFR architecture
None significant	-	b
To be further assessed to ensure acceptability of the consequences(*)	-	2b
Prompt-critical jump with a potential threat for confinement barriers (****)	2a +b (****)	2b (+ the fuel expansion effect)

(*) it should be checked that the energy conversion system is designed with sufficient inertia to intrinsically limit the rapidity of the event and avoid prompt criticality, when fuel expansion effect is available. Otherwise, additional LoDs would be needed.
(**) Example of detection measure: detection of temperature decrease in cold leg of fuel or intermediate circuit, power variation
(***) Example of corrective measure: stop of the energy conversion system, valve closure on the intermediate circuit
(****) need to be consolidated through more detailed evaluation of :
- Reactivity insertion transients with less/non effective fuel expansion effect
- The reactor behavior in case of prompt critical jump

Overcooling event
Main outcomes

- Design of the reactor, and of the energy conversion system, and start-up procedure, should be such that the worst overcooling scenario possible remains sufficiently progressive with a time constant for the temperature decrease of the intermediate salt cold leg above 30 seconds (to avoid prompt criticality)
- Detection and corrective measures for rapid overcooling scenarios must be defined
- In complement, the availability of the free levels to allow the fuel salt expansion appears absolutely necessary. Design measures must ensure a very high reliability of fuel thermal expansion through those free levels (at least as a strong LoD or even more)
- The reactor behavior in case of prompt critical jump should be studied in more details

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