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SAMOFAR Final Meeting
Identification of the PIEs with the Functional Failure Mode and Effect Analysis (FFMEA) and the Master Logic Diagram (MLD) approaches

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Main contributors

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Work performed

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

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Objective

Identification of hazards and compilation of a list of initiating events as exhaustive as possible

Selection of relevant items to be considered as Postulated Initiating Events

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Preliminary assumptions

- The design of the system is at a preliminary stage and still in evolution, therefore the **outcomes of the study are not final**, but could/will evolve with the design details;
- Only **the core circuit and the immediately adjacent systems, interacting with it, are analysed**, e.g. the fertile blanket, the intermediate circuit, the wall cooling system, the gas bubbling system and the sampling system;
- The analysed operational mode is the **normal operation** of the reactor during **power production** (P= 3000 MW_{th});
- Since the preliminary design phase, security issues are not taken into account during the study.

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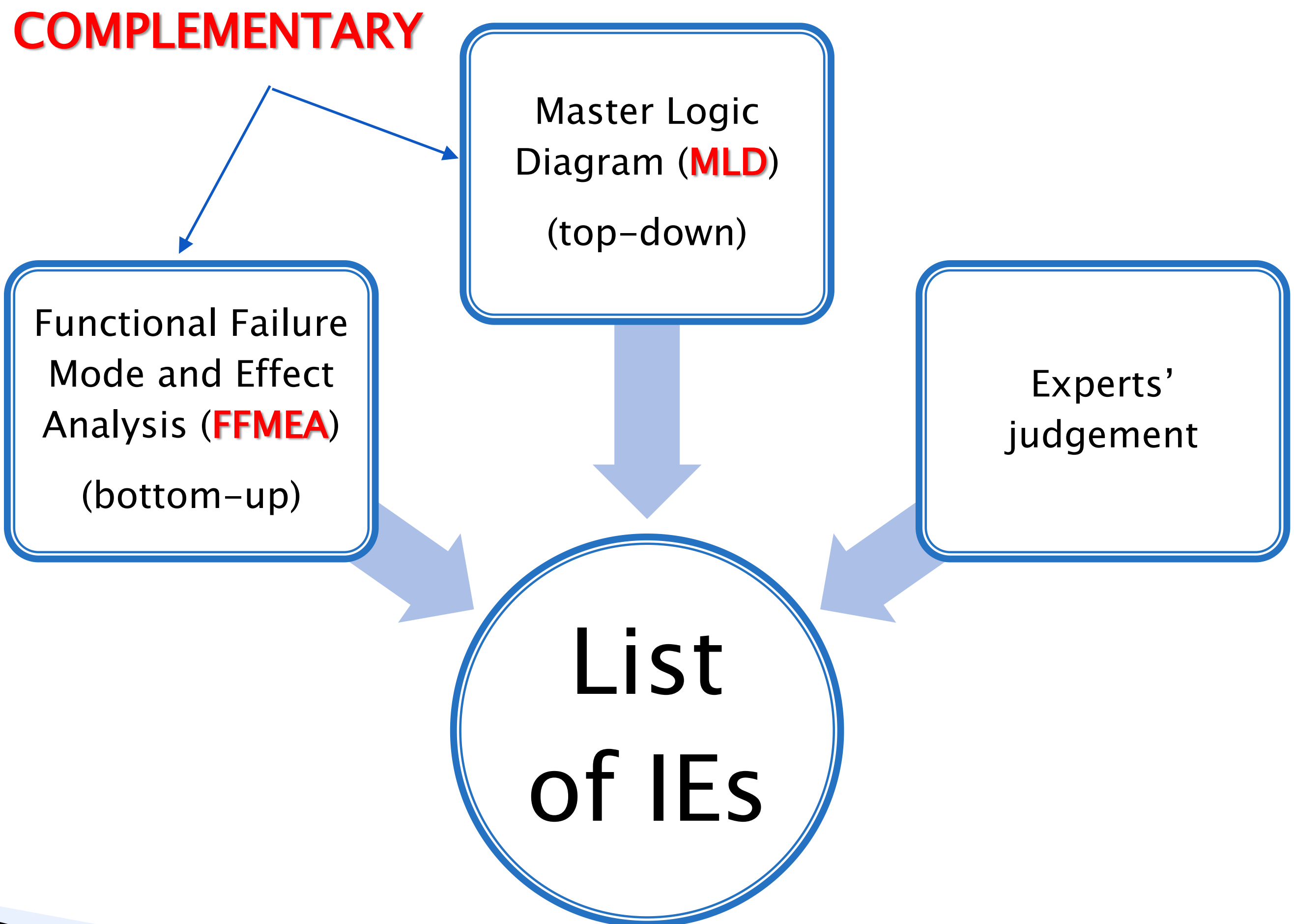
Methodology for the identification of initiators



Why FFMEA and MLD?

FFMEA

- Identifies **functional deviations** able to compromise system safety
- Does not specify the failure of the specific component
- Therefore, it particularly suits to innovative systems

MLD

- It focuses on **physical phenomena** and **general considerations**
- Does not analyze the specific component
- It suits early design phases

+ PARTNERS HAVE EXPERTISE ON THE USE OF THESE TOOLS

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Methodology for the selection of PIEs

SELECTION ACCORDING TO THE CONSEQUENCES OF THE IE

Group IEs in families

- The grouping of IEs in a family is done according to criteria of **similarity of the consequences** associated to the single IE and of **plant response** in terms of preventive and mitigating actions

Select the PIEs

- The **most severe event** of a family in terms of consequences is selected as a PIE
- It is not always obvious to identify the most severe events: so, it has been chosen to maintained a significant number of IEs as PIEs

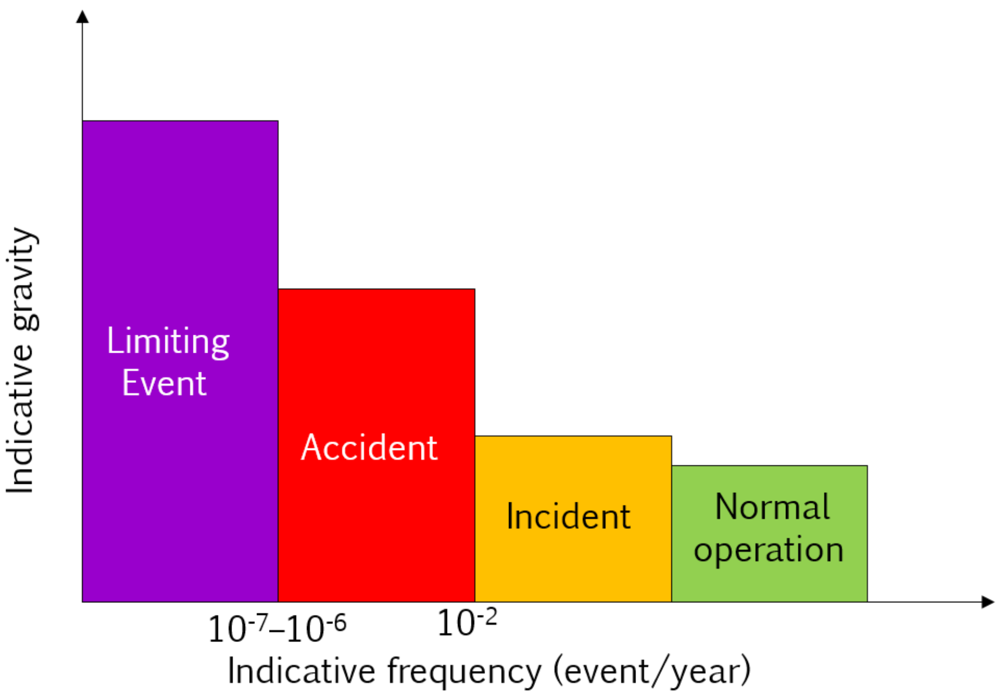
Feedback to the design

- Some questions raised from the application of the methodology as well as suggestions to enhance the safety of the concept
- As the design will evolve, also the safety assessment will be updated

Methodology for the selection of PIEs

SELECTION ACCORDING TO FREQUENCY AND CONSEQUENCES OF THE IE

1. Classification of the events by families
2. Classification of the events of each family in categories
3. Selection of the most representative events in each family and category as PIEs



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Results – I

SELECTION ACCORDING TO THE CONSEQUENCES OF THE IE

PIE-F-1	Loss of liquid fuel in the upper part of the core cavity: Breach the upper reflector with rupture of the structure cooling system (without damages to the expansion vessel system)
PIE-F-2	Loss of liquid fuel in the upper part of the core cavity: Breach in the upper reflector with rupture of a radial fuel outlet pipe (without damages to the structure cooling system)
PIE-F-3	Loss of liquid fuel in the bottom part of the core cavity: Rupture of a pipe of the reactivity control system
PIE-F-4	Loss of liquid fuel in the bottom part of the core cavity: Breach in the lower reflector (with rupture of the structure cooling system)
PIE-F-5	Loss of integrity of the core cavity: Complete (internal + external) rupture of the pressurized sampling device
PIE-F-6	Loss of integrity of the core cavity: Breach of a heat exchanger plate/channel
PIE-F-7	Loss of integrity of the core cavity: Rupture of blanket tank wall between fuel and fertile salt with rupture of the cooling circuit for internal structures
PIE-F-8	Loss of pressure/volume control in the core cavity: Obstruction of the vertical inlet pipe for the fuel from the core to the expansion vessel
PIE-F-9	Loss of pressure/volume control in the core cavity: Rupture of the connection between the free surface of the fuel storage tank and the free surface of the core for the gas in the part between the core cavity and the valve
PIE-FM-10	Loss of liquid fuel flow: Complete rupture of the pump
PIE-FM-11	Loss of criticality control: Reactivity insertion accident: Accidental insertion of fuel

Results – II

SELECTION ACCORDING TO THE CONSEQUENCES OF THE IE

PIE-FM-12	Loss of criticality control: The welded joints taking the recirculation sectors in the correct position collapse
PIE-F-13	Loss of chemistry control: Rupture/obstruction of reactivity bubble injector
PIE-FM-14	Loss of chemistry control: Rupture of horizontal bubble injector for salt cleaning
PIE-F-15	Loss of chemistry control: External rupture of the gas separation chamber from the liquid part
PIE-F-16	Loss of chemistry control: External rupture of the gas separation chamber from the gases part
PIE-FM-17	Overcooling: overworking of one of the fuel salt pump
PIE-M-18	Overcooling of the intermediate circuit: conversion circuit pump overworking
PIE-FM-19	Overcooling: Over-working of the pump of the intermediate circuit
PIE-M-20	Loss of heat sink: Leakage of intermediate salt
PIE-M-21	Loss of heat sink: complete rupture of one or more than one intermediate pump
PIE-M-22	Total loss of electric power

Results – III

SELECTION ACCORDING TO THE CONSEQUENCES OF THE IE

PIE-M-23	Mechanical degradation: external aggression (e.g. earthquake)
PIE-M-24	Mechanical degradation: Ejection of a conversion system component in direction of the fuel circuit
PIE-M-25	Chemical degradation: Chemical reaction between different fluids (e.g. hot part of intermediate circuit and water)

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Results – IV

SELECTION ACCORDING TO FREQUENCY AND CONSEQUENCES OF THE IE

- F1: Reactivity insertion
- F2: Loss of fuel flow
- F3: Increase of heat extraction/over-cooling
- F4: Decrease of heat extraction
- F5: Loss of fuel circuit tightness
- F6: Loss of fuel composition/chemistry control
- F7: Fuel circuit structures over-heating
- F8: Loss of cooling of other systems containing radioactive materials
- F9: Loss of containment of radioactive materials in other systems
- F10: Mechanical degradation of the fuel circuit
- F11: Loss of pressure control in fuel circuit
- F12: Conversion circuit leak
- F13: Loss of electric power supply

Results – V

SELECTION ACCORDING TO FREQUENCY AND CONSEQUENCES OF THE IE

- F1: Reactivity insertion

Category	PIE
Incident	• Limited precipitation of fissile matter on cold parts and release in core • Involuntary/excessive addition of the fuel salt • Addition of fuel salt with a too high concentration of fissile matter • Addition of too cold fuel salt • Failure/spurious shut down of the bubbling system • Fuel circuit structures over-cooling • Fertile salt over-cooling • Insufficient addition/ involuntary removal of fuel salt - negative reactivity insertion • Addition of fuel salt with a too low concentration of fissile matter - negative reactivity insertion • Addition of too hot fuel salt - negative reactivity insertion • Too high bubbles injection - negative reactivity insertion
Accident	• Detachment of the thermal protection • Incorrect fuel salt composition (too high amount of fissile mater) and/or too fast loading • Addition of fuel salt in the fertile blanket
Limiting event	• Important deformation of the fuel circuit leading to an increased core volume (e.g. fall of a sector, deformation of fertile blanket wall, etc...) (PIE-FM-12) • Fertile blanket loading with fuel salt • Fuel salt freezing scenario • Bulk precipitation of fissile matter (e.g. inlet of water)

Comparison FFMEA and MLD

SIMILARITIES

- Both methods suit **early phase design**;
- They do **not depend on component definition**, while the link with the component will appear in a second time;
- They are **qualitative**;
- The results are in good agreement.

DIFFERENCES

- They are based on **different approaches**:
  - FFMEA: functional approach
  - MLD: phenomenological approach
- Few events appear **only in one** of the two methods (e.g. Chemical reaction between differen fluids in MLD); on the other hand, FFMEA brings more details onto the failure modes;
- Only FFMEA sketch a plausible accident evolution;
- Only MLD graphically highlights logical connections among hazards.

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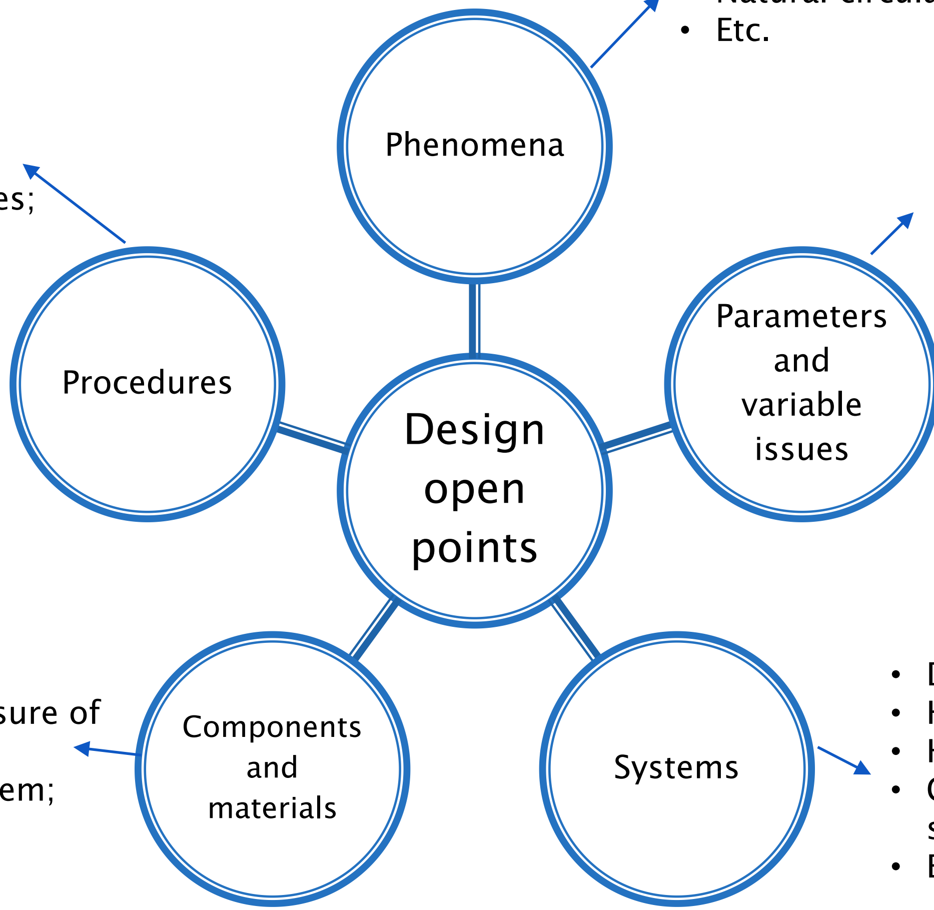
Design open points



- Chemical reactions;
- Natural circulation;
- Etc.

- Draining procedures;
- Salt sampling procedures;
- Reactivity control procedures;
- Etc.

- Fuel circuit pressure;
- Etc.

- Circulation pump;
- Component of the upper closure of core cavity;
- Fission product removal system;
- Etc.

- Depressurisation system;
- Heating system for IHS;
- Heat exchanger;
- Cooling system for structures;
- Etc.

Conclusions

- These **methodologies can be iteratively applied**, following the design development; similarly, the lists of the PIEs evolve with the detail of the design and the investigation of the physical phenomena governing the behavior of the system, through deterministic analyses.
- The **events identified with the FFMEA also appear with the MLD** with few differences. Most of the time, these events are classified in the “limiting event” or “accident” categories.
- The list of PIEs obtained with the second method (based on frequency and consequence) takes also the events with high occurrence frequency and low expected consequences. Therefore, it was used to perform the successive steps of the safety analysis (LoD).

Thank you for the attention

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