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SAMOFAR Final Meeting

Overview of SAMOFAR project: WP1

"Integral safety approach and system integration"

July 4th, 2019

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Elsa MERLE

LPSC Grenoble

CNRS IN2P3 Les deux infinis

Grenoble INP

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SAMOFAR WP1: which topics?

Del. n°	Deliverable title	Lead beneficiary	Delivery date
D1.1	**Description of initial reference design and identification of safety aspects (CNRS, Framatome, PoliMi, EDF, IRSN)**	CNRS	Month 6
D1.2	**Identifying safety related physico-chemical and material data (TU Delft, CNRS, PoliMi)**	JRC	Month 6
D1.3	**Development of a power plant simulator (CNRS, PoliMi, EDF)**	CNRS	Month 24
D1.4	**Safety issues of normal operation conditions, including start, shut-down and load-following (PoliMi, CNRS, EDF, PSI, Framatome)**	PoliMi	Month 30
D1.5	**Development on an integral safety assessment methodology for MSR (IRSN, Framatome, CNRS, POLITO, EDF)**	IRSN	Month 36
D1.6	**Identification of risks and phenomena involved, identification of accident initiators and accident scenarios (POLITO, CNRS, Framatome, IRSN, EDF)**	POLITO	Month 36
D1.7	**Improved Integral power plant design (reactor core and chemical plant) to maximize safety and proposal for safety demonstrator (CNRS, Framatome, FIGES, JRC, PoliMi, POLITO)**	CNRS	Month 48

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SAMOFAR WP1: initial state of the system

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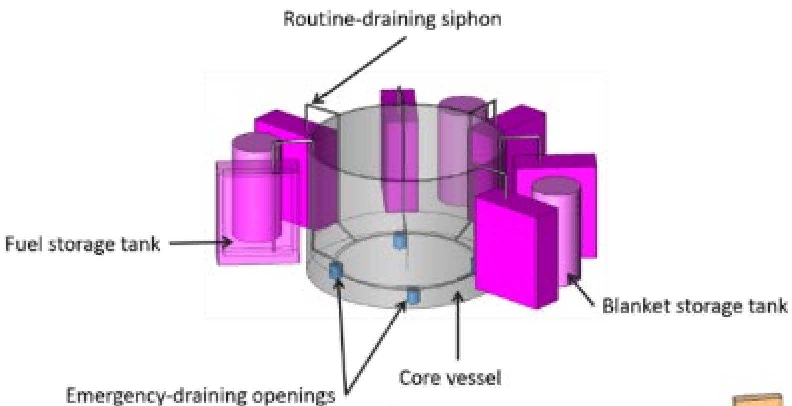
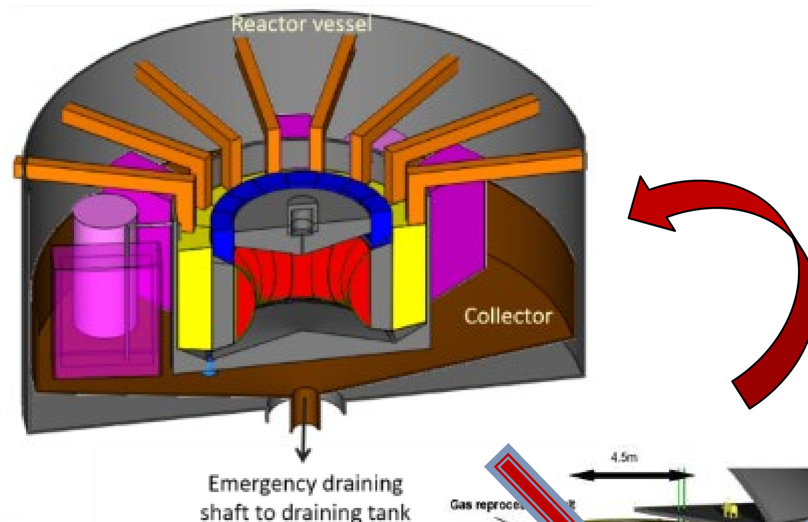
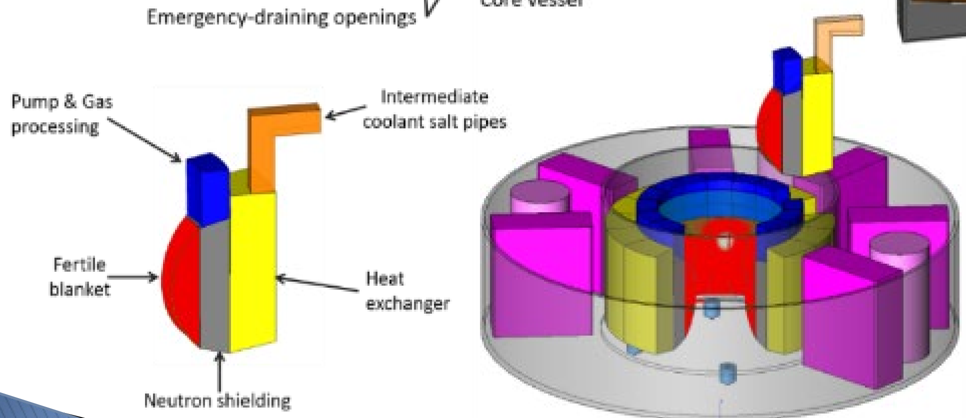
SAMOFAR WP1: innovative integrated design

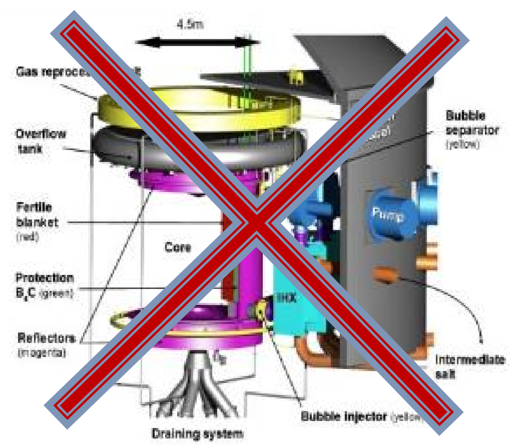
LOLF accident (Loss of Liquid Fuel) → no tools available for quantitative analysis but qualitatively: **Fuel circuit: complex structure, multiple connections → potential leakage**

→ Proposition of the ‘Integrated MSFR design’ to suppress pipes/leaks









SAMOFAR WP1: how to operate the MSFR?

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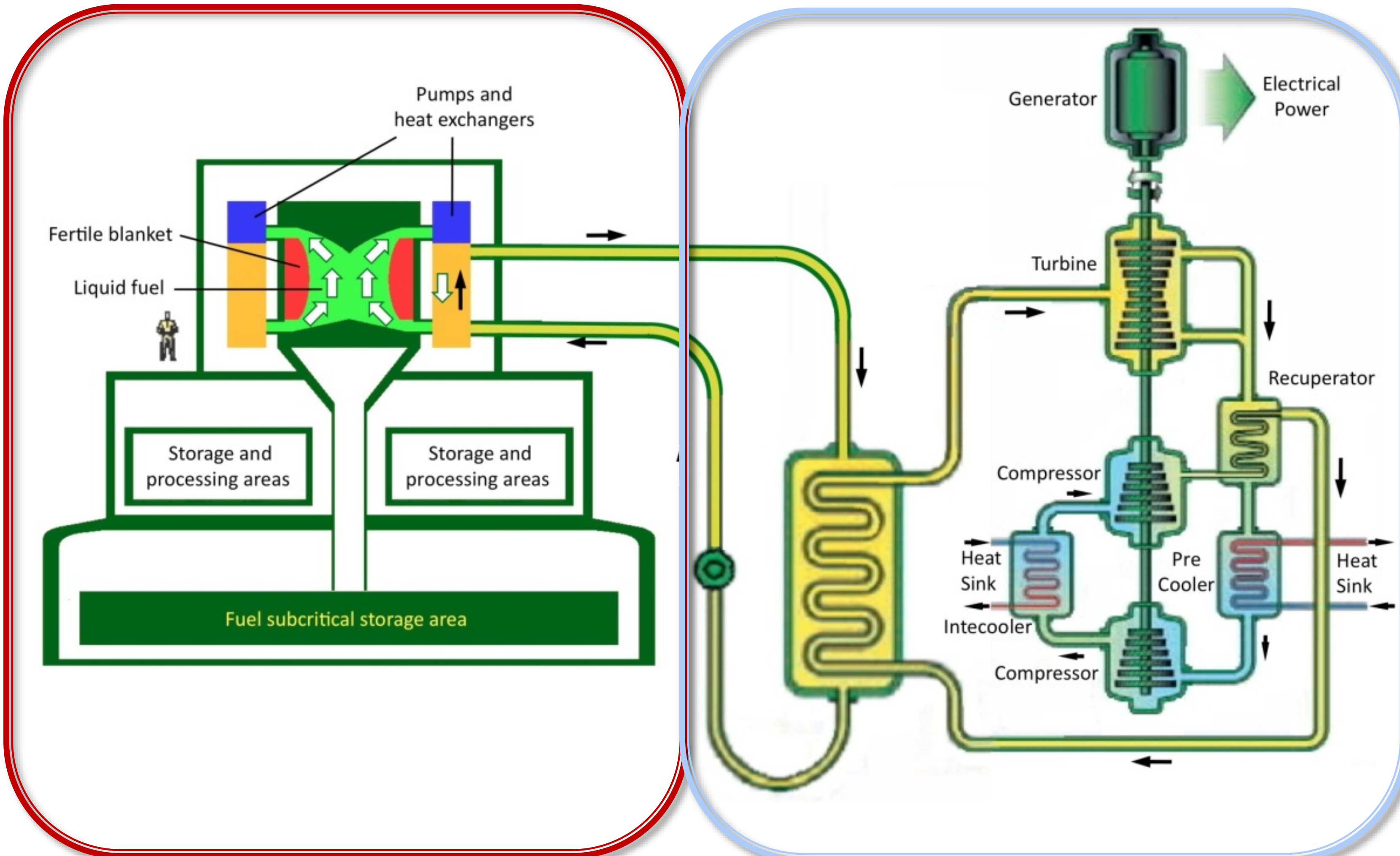
SAMOFAR WP1: how to operate the MSFR?



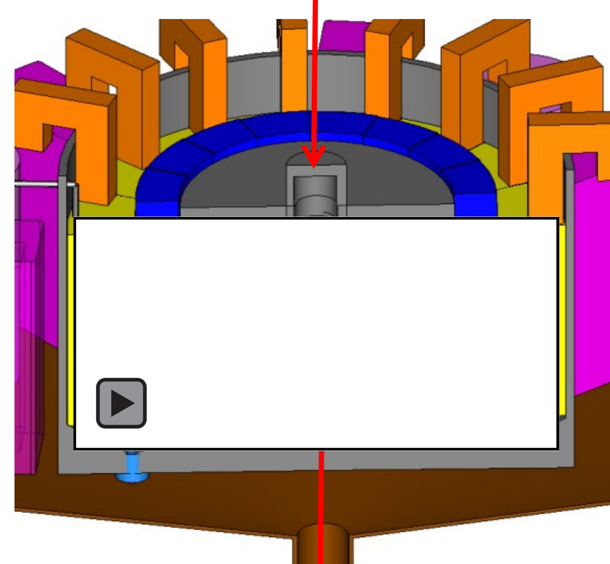
Part developed by CNRS – Java language
⇨ LiCore model

Part developed by PoliMi – Modelica language
⇨ Thermopower library

SAMOFAR WP1: how to operate the MSFR?

(*) CORYS: World Leader of the dynamic simulation for nuclear, transport and hydrocarbides industries / Simulators for the training of operators and for operation studies and definition of new plants during the design phase

SAMOFAR WP1: how to operate the MSFR?



Preliminary definition of the control strategy:

- The **MSFR can be controlled without insertion of external reactivity** in the full power mode (i.e., from 110% to 50% of power) even **with a small number of control variables** i.e. the mass flow rate in the three loops (fuel, intermediate and energy conversion system)
- The **controlled dynamics** for the power is **quite fast → very positive for the load-following capability** of the reactor and for the European requirements
- During the demand increase/decrease**, controlled variables always kept in a safe bandwidth + no problematic behavior of the non-controlled ones**
- **The nuclear part of the reactor is well controlled** with 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**

Startup procedure: approach to criticality

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SAMOFAR WP1: how safe is the MSFR?

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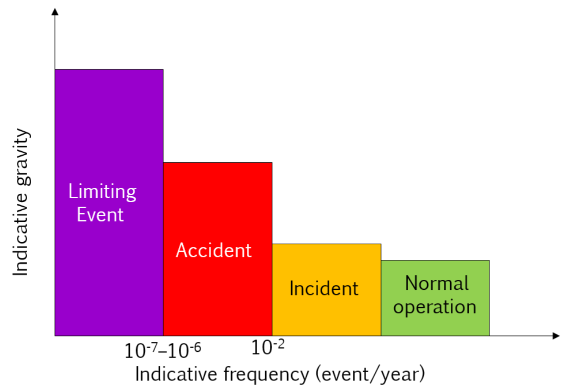
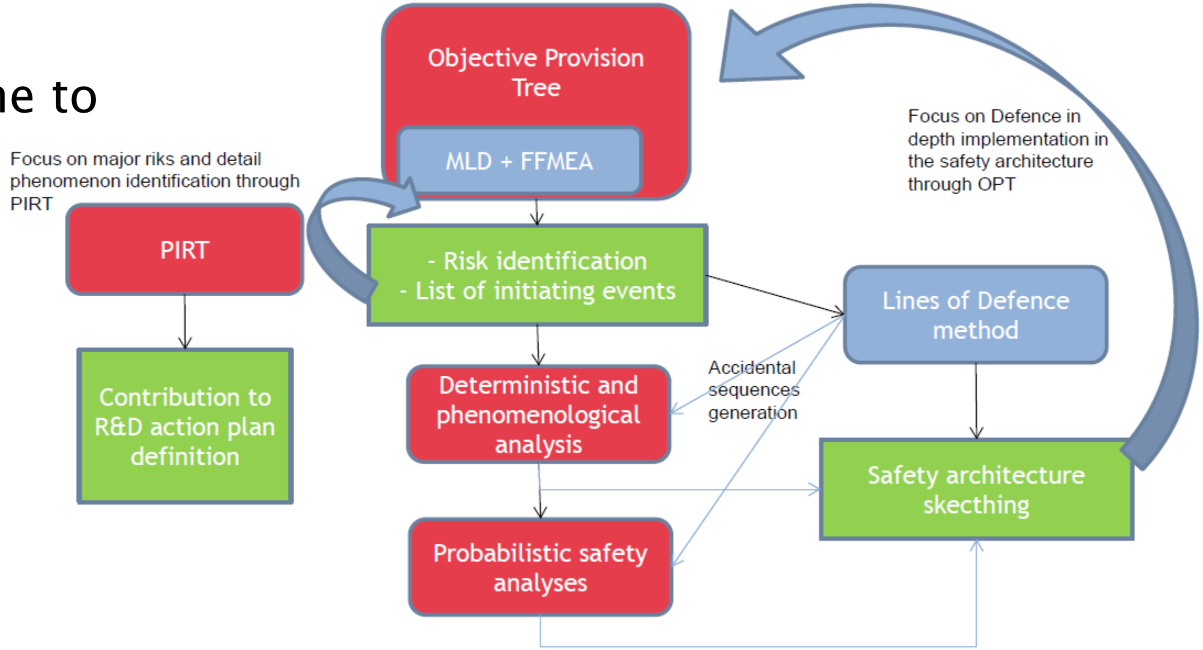
SAMOFAR WP1: how safe is the MSFR?

- Definition of the safety methodology + guideline to apply it on the MSFR:





- Application of the safety methodology on the MSFR for power production:
  - Risk identification and definition of postulated initiating events (initiators of accident/incident)
  - Confinement barriers definition, list of the open design points
  - Preliminary use of the Line of Defence method

See presentations by Stéphane BEILS (Framatome) and Anna-Chiara UGGENTI (POLITO)

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SAMOFAR WP1: how safe is the MSFR?

Safety advantages identified for the MSFR concept

- Liquid fuel and fast neutron spectrum → negative temperature feedback coefficient: **ensures an intrinsic safety with respect to reactivity accidents**
- The 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**
- **Fuel circuit not pressurized + fluoride salt not likely to cause violent exothermic chemical reactions** when it is in contact with the materials of the plant + no violent chemical reaction with air or water
- Fission gases (and possibly some non-volatile and non-soluble fission products) released from the fuel during operation **→ reduces the radiological salt inventory**
- Absence of fuel structures in the core such as cladding and subassemblies **→ removes any risk of fuel compaction**
- Intrinsic temperature feedback effect → may eliminate the need of a control rod system for adjusting the operating conditions + amount of fissile matters dissolved in the critical zone of the fuel circuit just necessary to maintain a critical state **→ intrinsically reduce the risk of accidental reactivity insertion**

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SAMOFAR WP1: how can the MSFR be safer?

Safety related Challenges / R&D studies needed for the MSFR concept

- **Prevention of corrosion** of the structures in contact with the salt must be shown to be sufficient + development of **measures of surveillance**
- Confirm experimentally the **absence of risk of severe chemical reactions** of the salt + evaluate the consequences of a contact between salt and water (**risk of steam explosion**)
- Evaluate the **risk of precipitation and concentration of fissile matters** in the salt + **criticality risk** of the salt out of the reactor zone
- Evaluate the **risk of fission products extracted from the fuel circuit during operation stored** out of the reactor (radiological source term, residual power, criticality risk)
- Define the **monitoring of the reactor and the salt treatment units**, features for **in-service inspection and repair or replacement** of equipment in contact with the salt
- **Risk identification exercise** to be further continued **for all initial states / operation modes** (start-up, shutdown phases etc…) **and all the facilities**
- Continue the definition and studies of the **severe accidents** with a focus on the reactor **behavior in case of a postulated prompt-critical jump**

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SAMOFAR WP1: integrated results

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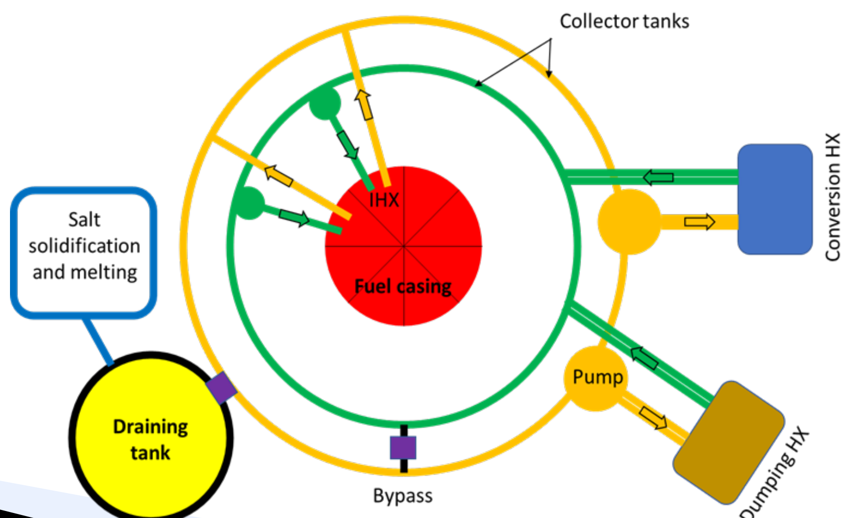
SAMOFAR WP1: design evolutions

- **Safety optimization of the emergency draining system**: initial water cooling system replaced by a gas cooling in natural convection
- Selection of key components of the fuel circuit: **pumps and heat exchangers**
- Proposition of **decay heat extraction devices redundant and independent** for cooling under various circumstances (fuel kept in the core, fuel into the emergency draining tank, fuel in the Core Catcher)
- **First proposal for the intermediate salt circuit configuration** following the conclusions of the safety analysis (structure description and approximate sizing)
- **General structure and sizing of the power plant** derives from the safety analysis conclusions



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SAMOFAR WP1: design recommendations

Intermediate Heat Exchangers: **very sensitive component** - operate under the most effective conditions, with a large area (leak probability) and high temperature gradient (mechanical constraints) + important safety role of radioactive matter confinement → Dedicated recommendations

Barriers: use **3 confinement barriers to limit the nuclear material release in the environment, namely the Fuel Casing** (contains the fuel under normal operation conditions); **the Reactor Casing** (contains the Fuel Casing, the off-gas processing and storage, and the Core Catcher); **the Reactor Building** (prevents gas and aerosols leaks) - Isolation valve on all piping passing through a barrier

Passive Decay Heat Extraction: be able to safely maintain the fuel inside the Fuel Casing or the Reactor Casing in case of power blackout of the site

Core catcher: passive cooling and as independent as possible from the decay heat extraction in the core and the EDT to **avoid a common cause of failure** - Specificities:

- **thermal inertia** (sensible and melting heats), using large amount of high thermal diffusivity and refractory materials (draining of salts up to 1500°C)
- **radial heat conduction** to lead the decay heat to the peripheric walls
- **vertical heat conduction** from the liquid salt to the gas phase or to the walls by radiation
- **natural convection cooling** by the air inside the Reactor Building (fins, chimneys)

Gas and fuel transfers: to **avoid misuse of transfer lines for the material entering and exiting the core**, better to use pipes where only gases and liquid can pass with a pipe size limited to avoid powder or solid phases transfer to the core (no risk of reactivity insertion by transfer of pure fissile material)

See presentation by Elsa MERLE (CNRS)

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Thank you for your attention!