IAEA SMR Conference

NAAREA’s XAMR® safety approach

Safety Track

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NAAREA's project

- NAAREA is a French company working on the design of a small molten salt chloride reactor using reprocessed plutonium as the fuel.
- NAAREA's philosophy is to provide energy as a service in a decentralized fashion to industrial sites or remote communities.
- The reactor is meant to be modular to allow for quick installation on site and to be implanted next to the site with the ability to provide :
  - > 30 MWe
  - And/or > 30 MWth either as high-temperature or low-temperature heat.

NAAREA – High Level Presentation

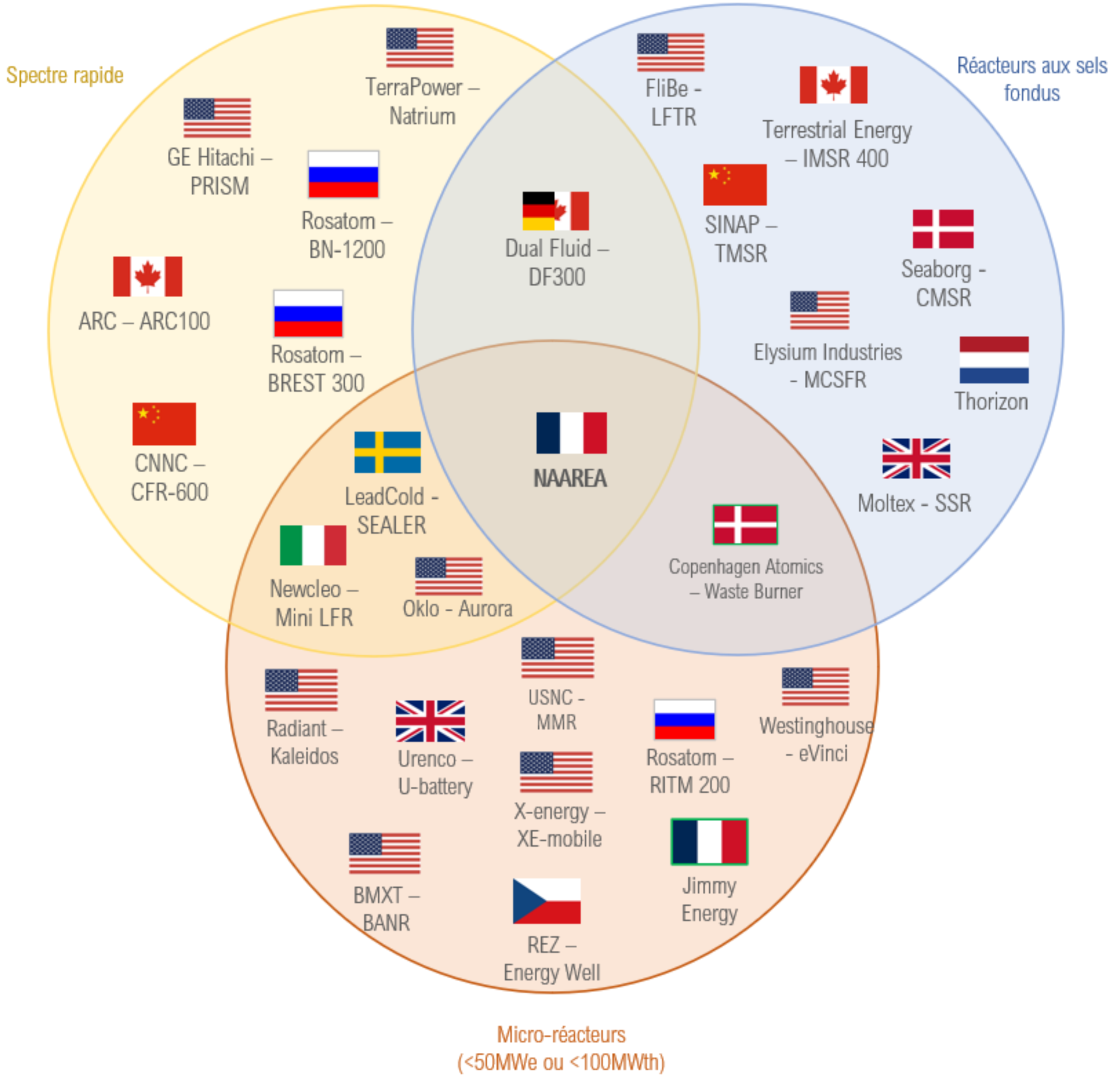
- **What** - French deeptech developing nuclear micro-generators of energy – XAMR or eXtrasmall Advanced Modular Reactor (~40MWe, 15m3, 50 tons)
  - Micro-generator to fit inside ISO 40 HC container (for the nuclear island only, without shielding)
  - Applications : industrial sites, isolated regions, mobility (supertankers,…)

- **When** -
  - Full-scale prototype before 2030, series reactor following shortly
  - Smaller scale demonstrators beforehand (natural convection inactive loop, forced convection inactive loop, forced convection active loop)
  - Filing for *Dossier d'Options de Sûreté* (nuclear safety application) end of 2023

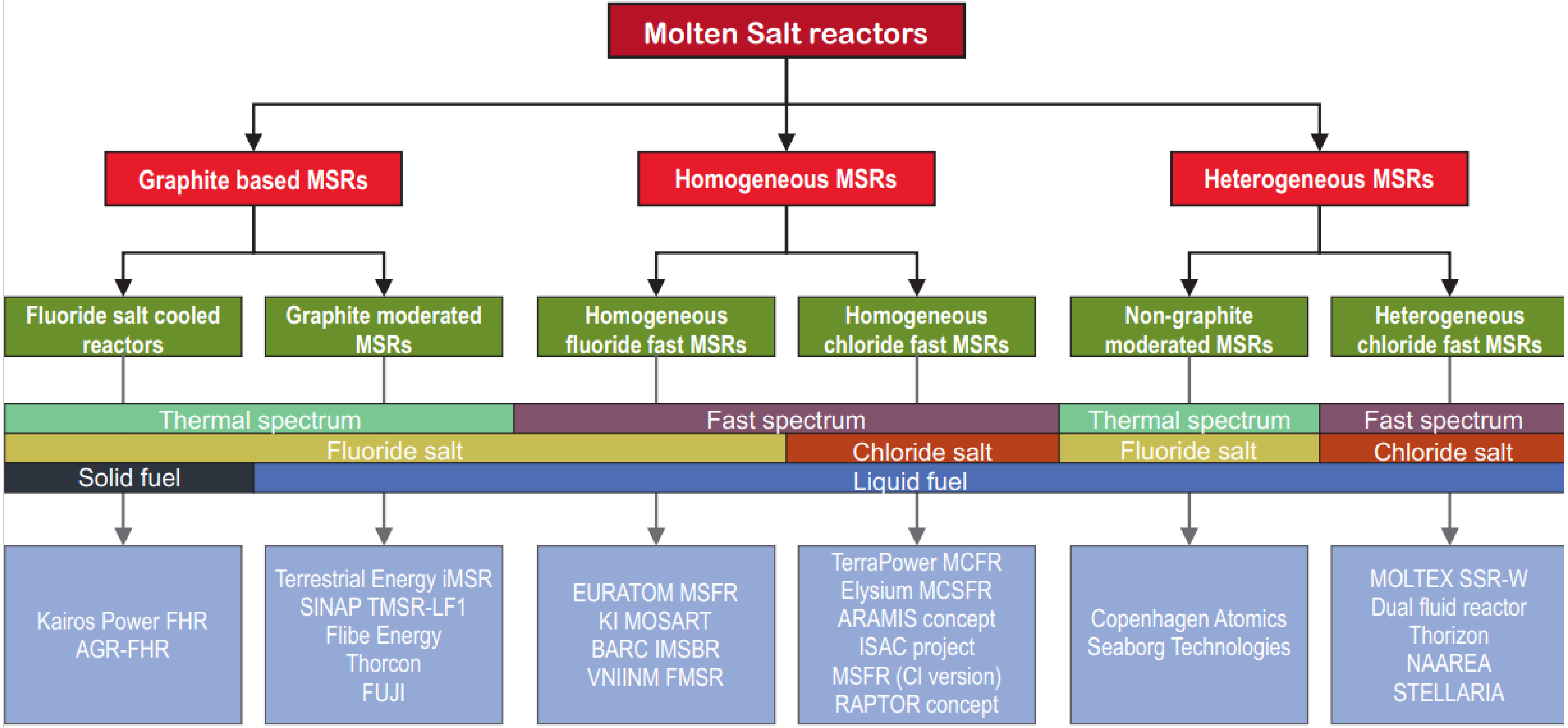
- **Who** - Naarea is composed of some of the best experts in the French nuclear industry (CEA, ASTRID, Phenix, Superphenix) and other leading French industries)
  - Working jointly with Dassault and Assystem for technical support
  - Partnerships with Orano, ASN and CEA
  - ~200 employees (September 2024)

- **How** - 4th generation fast neutron nuclear reactor :
  - Molten salts : Chloride salts at 700°C
  - Mox fuel and fast reactor : closing the fuel loop and using byproducts of conventional nuclear plants
  - SiC monolithic core
  - SCO2 turbine

Technological assessment of competition



Molten salt taxonomy



- Each of this type of reactor has its specific safety approach.

Molten salt safety

Safety of MSRs

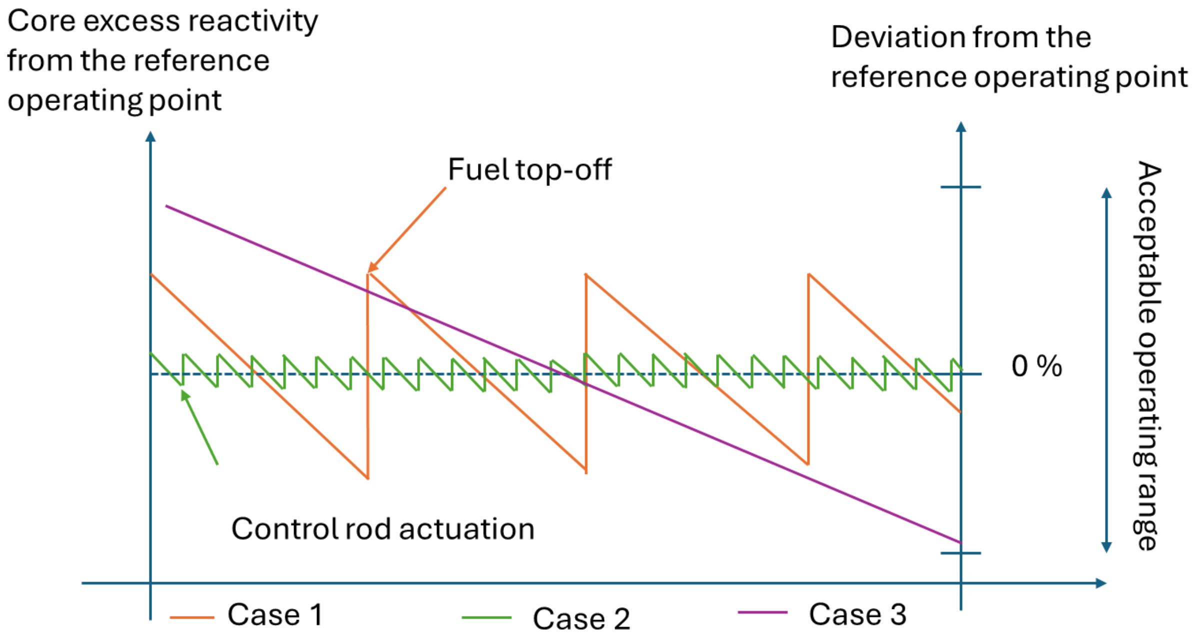
- As every nuclear reactor, a molten salt reactor must ensure the control of the fundamental safety functions, namely :
  - Reactivity management
  - Decay heat removal
  - Containment of radionuclides

- Current guidelines for safety demonstration also requires that a beyond design-basis or extended condition be defined as the most severe accident that can occur inside the plant.

- This presentation will briefly look over these four safety items and how they are implemented inside NAAREA’s reactor.

Reactivity management

- In a MSR, reactivity management can be done in several ways :
  - The use of « traditional » movable absorbers (rods, drums, movable reflector, etc)
  - The on-line or batch processing of the fuel salt to remove FP and add fissile nuclides
  - The design of a core big enough to achieve a breeding ratio > 1 with a low reactivity excess



Reactivity management

- Additionally, molten salt reactor can be flushed to remove the fuel from the active core, which removes the need for reactivity management systems as long as the drain tanks are designed to remain subcritical.

- In NAAREA's case :
  - The reactor is small so the breeding ratio is < 0,2 and the third solution cannot be used.
  - The reactor is meant to be located onsite with limited operators and thus solution 2 is not practical.
  - Hence, two reactivity controls systems were added to the reactor :
    - Control drums located inside the reflector which are used for long term compensation of the reactivity (180 ° rotation over a 4 years) and for core normal startup and shutdown. These drums are used in DBC2 situations.
    - Control rods also located inside the reflector, which are used for rapid shutdown of the reactor in DBC3 and 4 situations.
  - Salt flushing is also considered a reactivity management system for DEC-A situation.

Decay heat removal

- As in every reactor, decay heat must be removed to prevent a temperature rise inside the reactor which would threaten the integrity of the containment barrier.

- This decay heat removal can be done either inside the fuel circuit region or inside the drain tanks.

- Decay heat removal inside the fuel circuit usually has several drawbacks :
  - It adds moving parts (vanes and/or pumps) and heat exchangers inside the circuit which has a negative effect on total fuel volume.
  - If such a system is made to be passive, it is going to act a constant drain on the core power and will increase the probability of salt solidification inside the circuit.

- Generally speaking, unless the volumes considered are designed for this purpose, salt solidification inside a tank or a pipe should be avoided at all cost.

Decay heat removal

- For decay heat removal, NAAREA’s approach is to :
  - Not consider decay heat removal systems inside the core to limit the total fissile inventory and increase the compacity of the fuel circuit.
  - To use normal heat removal systems in selected DBC2 conditions where these systems are available to maximize reactor uptime.

- Long-term DHR is done inside the flush tanks, of which there are 3.
  - Two redundant tanks are fitted with an active cooling system used in normal operation and a passive system used for DBC2 to DBC4.
  - One overflow tank dedicated to DBC3 and DBC4 conditions is equipped with passive decay heat removal.
  - Salt can be transferred between the first two tanks if one is them is unavailable.

- These tanks are designed to allow salt solidification without adverse effects.

Containment

- As for every nuclear reactor, three barriers must be added between the radionuclides and the environment.

- In the case of a MSR :
  - There is no cladding of solid fuel to contain fission products, either gaseous or volatile.
  - Most of the gaseous and volatile fission products will naturally leave the fuel and be found inside the gas treatment system of the plant.

- Consequently, most of the radionuclides inventory will not be found inside the core but inside the gas treatment system of the plant.

Containment

- In NAAREA’s case, the choice has been made to :
  - Use the fuel circuit along with the drain tanks and the gas treatment plant as the first containment barrier.
  - Enclose these circuits inside a guard vessel, which is not in contact with the salt or corrosive gases during normal operations. This vessel acts as the second barrier and is designed to maintain integrity in case of internal and external aggressions.
  - The whole guard vessel is inserted inside a nuclear building with a nuclear ventilation system which acts as the third barrier.

- For specific conditions, the outer layer of the reactor building can be considered a barrier .

- This approach allows NAAREA to achieve a very limited level of release in all conditions.

Severe accidents

- Severe accident is defined by IRSN as :

"A severe accident in a nuclear reactor is an accident in which the containment safety function coming out of the nuclear is severely degraded, either in the reactor or during fuel handling and storing".

- These accidents are considered highly improbable and the classification of the systems used to handle them is generally lower as the one for more probable transients.
- In the case of a MSR, this definition also includes the loss of containment inside the gas treatment plant of the system.
- It is common to identify potential accidental sequences which can lead to a severe accident.

Severe accidents

- In NAAREA's case, considering :
  - The tight planning to which the company is adhering
  - The lack of data on the behaviour of the salt and/or the equipment in demanding conditions
  - The complexity of identifying situations which can lead to a large and early release in the current state of the design

- NAAREA has chosen to define a severe accident as the complete ruin of the first two barriers of containment in any area of the facility with a significant radionuclide inventory.

- Consequently, a set of adapted requirements has been put on the third barrier to ensure that the radionuclides contributing the most to the external dose are retained inside the building.

- NAAREA's current objective is to achieve no impacts (evacuation, sheltering, iodine prophilaxis) on population outside of the plant.

Thanks

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