MOLTEN SALT REACTOR

Quelle motivation à examiner les MSR ?

Bernard CARLUEC Fellow Expert (Framatome)

Elsa MERLE Docteur ès sciences, Enseignante-chercheuse (Phelma-I.N.P.G.-L.P.S.C.-IN2P3, C.N.R.S.)

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Context

- **AREVA NP and then Framatome is involved in the development of Gen IV reactors and follows the international R&D on this subject**
- **In Western Europe, MSR R&D is mainly performed by the French CNRS (and in the frame of the European Project SAMOFAR related to the safety of MSR)**
- **This presentation is the result of an intensive discussion between CNRS and AREVA NP experts during summer 2016 to:**
  - Assess the different concepts labelled as MSR
  - List the main motivations which could motivate the development of MSR

The types of MSR concepts (1/3)

- **Two kinds of reactors may use molten salts:**
  - Reactors with solid fuel where molten salts are the coolant: this allows to operate at high temperature without pressurization and with high power density
  - Reactors in which the fissile (and possibly fertile) materials are dissolved in molten salts:
    - The molten salts are both the fuel material and the coolant
    - The molten salts are in a closed circuit. The fuel is critical in a dedicated zone and other parts are designed for avoiding criticality
    - Another concept is envisaged with a liquid fuel (dissolved in salts) inside pins cooled by other salts, without fuel, outside the pins

The types of MSR concepts (2/3)

- **In thermal neutron spectrum, the concept with solid fuel can be considered as an evolution of the gas-cooled modular HTR.**
  But because of the higher power density, the inherent core coolability of HTR cannot be achieved and the concept requires safety systems
- **In fast neutron spectrum, the sodium-cooled reactors with solid fuel are more relevant (i.e., better thermal and neutron characteristics)**

The concept with liquid fuel is considered further because of its higher attractiveness

The types of MSR concepts (3/3)

- **Finally, the types of MSR concepts depend on:**
  - Composition of the selected salts. Previous studies have examined a large range of fluids to contain the dissolved fissile (and fertile) materials. They concluded to focus on salts, i.e., fluoride or chloride
  - Neutron spectrum: moderated or fast
  - Fissile (and fertile) material:
    - $^{233}U/Th$ with or without trans-uranium (Pu) from LWR
    - $Pu/^{238}U$

A rough analysis of these alternatives has been performed to preliminary select the most relevant concept

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History (1/2)

- **MSR concept was studied at the beginning of nuclear energy**
- **In the USA, MSRE (Molten Salt Reactor Experiment) was a 8MWth MSR developed by Oak-Ridge National Laboratory. It operated from 1965 to 1969:**
  - Salts: fluoride (^{7}LiF (65%) – BeF_2 (29%) – ZrF_2 (5%))
  - Moderated neutron spectrum: graphite
  - High temperature: up to 650C

History (2/2)

- **The main results from the MSRE experience were:**
  - Development of the Hastelloy N as structure material for the fuel circuit. Hastelloy N is a “superalloy” containing predominantly nickel. It is characterized by its capability to survive under high-temperature, high-stress and severely corrosive environment.
    It is used in chemical industry.
  - Development of the chemical regeneration of salts
  - Demonstration of the neutronic stability
  - Capability to use different fissile material: ^{235}U, ^{233}U, Pu

MSRE has been followed by the MSBR project (Molten Salt Breeder Reactor)

MSBR was a commercial reactor (1 GWe)

MSBR has not been finalized

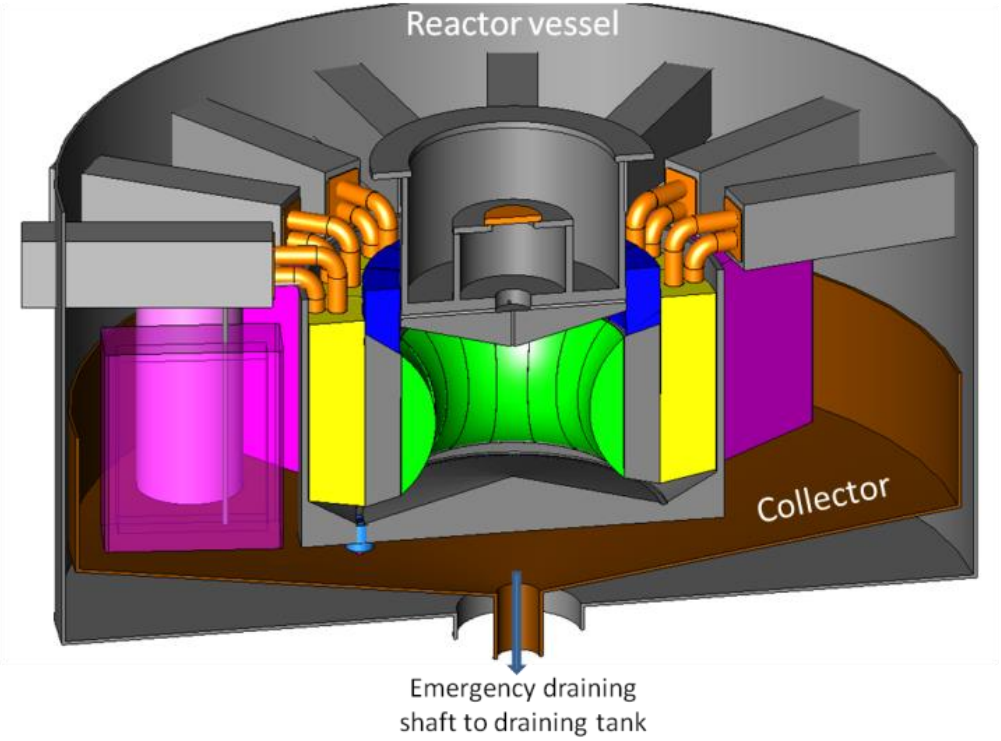
Reference concept

- *Salts: lithium fluoride basically*
- *Neutron spectrum: fast*
- *Power density: to be defined*
- *Fuel cycle: no selection: ^{233}U/Th, Pu/^{238}U*
- *Generation mode: no selection: breeder, iso-generation, Pu burner*
- *Chemical treatment process: to be defined consistently*
- *Reactor power: no selection: no fundamental issues connected to the power (similar design), except the amount of regeneration needs which are power dependent*

This concept is also recognized by GIF, Europe, Russia, China and India

Reference concept

- **MSFR concept by CNRS**
  - Lithium fluoride
  - Fast neutron spectrum
  - $^{233}U/Th$
  - 3GWth
  - Core volume: $18m^3$
  - 1 ton of Th per year (full power)



Preliminary assessment of the reference concept

- **The identification of the potential assets is performed with regards to the GIF criteria for GENIV systems:**
  - **Economy**
  - **Safety**
  - **Environmental impact**
  - **Proliferation resistance and physical protection**
  - **Adaptation to the electrical grid needs (*additional criterion from industry*)**

Preliminary assessment of the reference concept
1 - Economy

- **Economy is the first driver for development of MSR:**
  - **Simplified fuel cycle (no extraction of residual fissile material from spent fuel)**
  - **High burnup ratio: no limitation due to irradiation damage on structure**
  - **Reactor simplicity :**
    - Fuel tank without internal structures except irradiation and thermal protections of the walls
    - No mechanical devices for plant operation, except pumps
  - **No pressure in the circuit in normal operation and no chemical exothermic reactions with molten salts capable to generate pressure in the containment building**

Preliminary assessment of the reference concept
2 – Safety

- **With fast spectrum negative feedback effect immediately occurs when the salt temperature varies: intrinsic safety advantages with regards to reactivity accidents**
- **No chemical reaction with air (no fire) and water (no hydrogen production)**
- **Fission gases are continuously released from the core and stored in tanks not damaged by the core accidents**
- **No risk of fuel compaction and risk limitation for other reactivity insertion (the core contains the exact amount of fissile needed for criticality)**
- **Capability to remove the fuel (i.e., draining) from the critical zone**

Preliminary assessment of the reference concept
3 – Environmental impact

- **Fast neutron spectrum and high burnup ratio drastically reduce the amount of minor actinides in the wastes, in particular with the ^{233}U/Th fuel cycle**
- **Capability to burn trans-uranium elements generated in the LWR**
- **Fast neutron spectrum increases the amount of natural resource: 100% of U and 100% of Th compared to 0.7% of ^{235}U**
- **Fluoride and fast neutron spectrum: no wastes difficult to manage such as ^{36}Cl and graphite**

Preliminary assessment of the reference concept
4 – Proliferation resistance and physical protection

- **Limitation of transportation of fissile materials, except if breeder mode**
- **With ^{233}U/Th fuel cycle misappropriation is difficult (high gamma emission)**

Preliminary assessment of the reference concept
5 – Adaptation to the grid

- **The immediate negative feedback effect due to salt dilatation leads to very limited temperature variation even in case of large power variation need**
- **Control rods for adjusting the generated power could be unnecessary**

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Adapted to electrical grid with significant of intermittent production sources (renewable)

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