SNETP FORUM - TS7 ADVANCED REACTOR SYSTEMS

# ACTINIDES CONVERSION IN MOLTEN SALT REACTOR

Paul Gauthé – CEA

Bertrand Morel - ORANO

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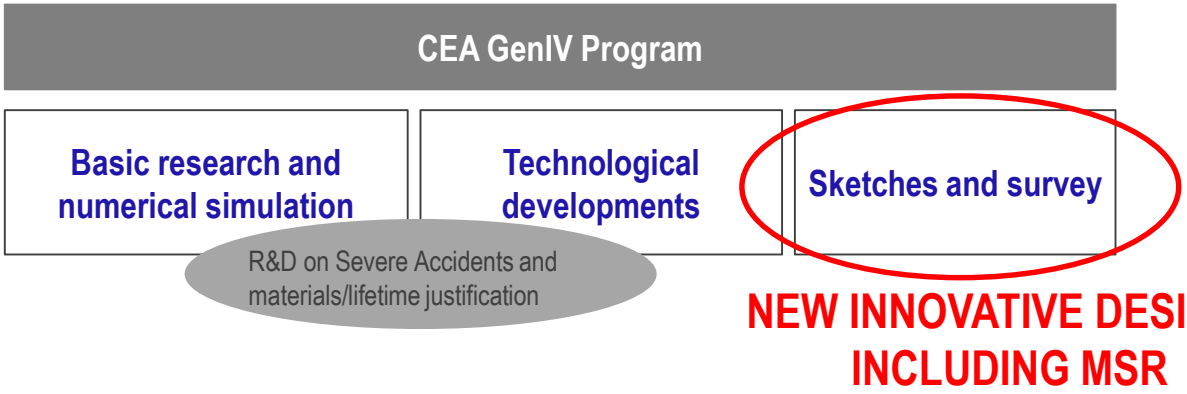
**Closed fuel cycle is the reference strategy**

- U&Pu recycling in existing PWR, already deployed
- Multiple recycling in PWR is considered, R&D program
- R&D on Fast Reactors is still ongoing at CEA
  - → Significant results and knowledge acquired from ASTRID SFR program
  - → Increase the maturity and performances of SFR : safety, economy, fuel cycle
  - → Opportunity to re-open R&D paths : SMR SFR and alternative technologies like MSR
  - → Feasibility of actinides conversion in MSR

**⇒ New R&D program on FR and related closed fuel cycle**



# WHY IS FRANCE INTERESTED IN FAST MSR ?

## Potential assets

### Nuclear fuel cycle

- Multirecycling of Pu
- Minor actinides transmutation

### Intrinsic safety

- Potentially no severe accident
- Strong negative neutronic feedback
- No pressure
- Salt solidification in case of leakage

### Flexibility

- Load following capability

## Feasibility issues

### Salt chemistry

- Mastering solubility and precipitation issues
- Lack of data
- Uncertainties for operating the system

### Materials

- Corrosion
- High temperature
- Structure irradiation (no clad as 1st barrier of containment)

### Safety in operation

- Operation and maintenance processes
- Fission products management, radioprotection

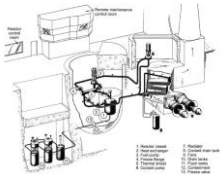
**R&D program started in 2020 aims at assessing the feasibility of fast MSRs and confirm their potential assets**

***Complementary with main R&D ongoing on Gen4 SFR***

## USA experience

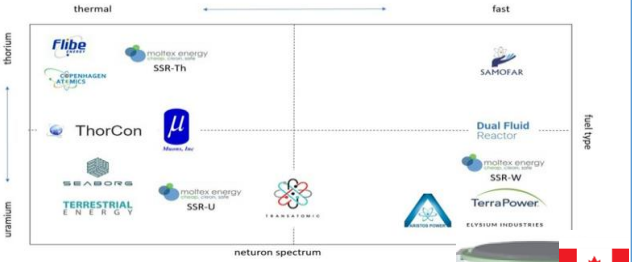
ARE (1954) and MSRE (1965-1970)
Thermal spectrum, Flibe, uranium, 7MWth

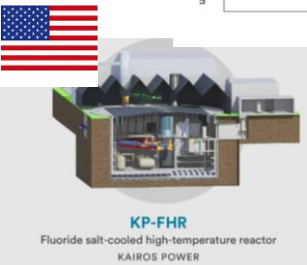




**Renewed interest in MSR since 10 years** : assets for resolving safety & waste issues, innovation attractive for investors, dozens of new concepts

## Startups,
mainly north-american

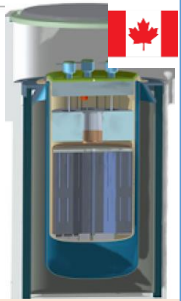


KP-FHR
Fluoride salt-cooled high-temperature reactor
KAIROS POWER

300M$ / 7y from DOE for a test reactor (Hermes-ORNL- 50MWth)

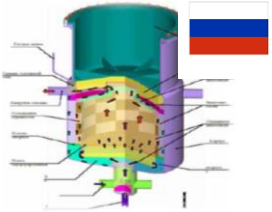

90M$ / 7y form DOE for an integral experiment (MCRE - INL)



IMSR – Terrestrial Energy

## National programs

TMSR 2MWth – Flurorure – thermique – thorium
**Divergence 2021**

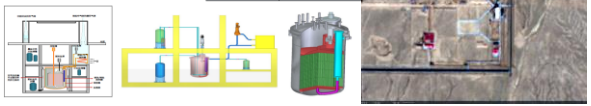


MOSART – ROSATOM/Kurchatov

**2MW TMSR-LF1**

- Demonstrate concept of MSR with liquid fuel and pyroprocessing
- Demonstrate Th-U cycle and its features
- Platform for future reactors and Th-U cycle R&D

| | |
|---|---|
| Power | 2MW |
| Temperature | 630 °C / 650 °C |
| Type | Integrated design |
| Fuels | LiF-$BeF_2$-$UF_4$-$ThF_4$ |
| Residual heat removal | Passive air natural circlation system |



- **Salt selection depends on the reactor objectives : U/Pu cycle vs U/Th cycle, fast vs thermal, large reactor vs SMR…**

- **Fluorides salts often used for thermal spectrum and/or thorium**

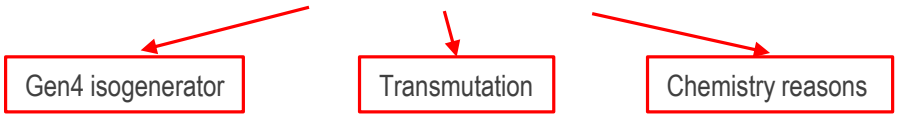
→ Valuable feedback from the ORNL's MSRE

- **Chlorides salts as an interesting alternative for fast spectrum**

- Hardening neutronic spectrum >> **better conversion of actinides**
- More suited for multirecycling of Pu (lower solubility of Pu in fluoride salts)
- 37Cl enrichment necessary but feasible

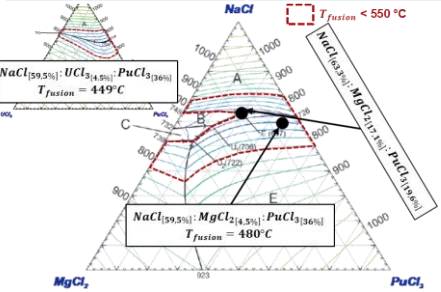
**French context (closed fuel cycle, Pu multirecycling, transmutation) leads to focus on chlorides fast MSR with a focus on actinides conversion (reducing ultimate wastes)**

**Investigation of NaCl-$PuCl_3$ type of salts (+ $UCl_3$, $AmCl_3$, $MgCl_2$, $CaCl_2$…)**



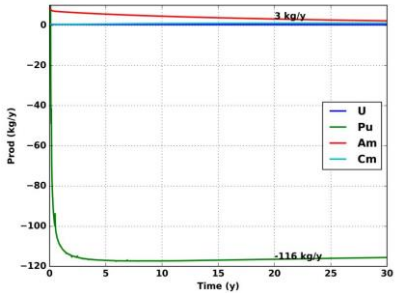
## NEUTRONICS

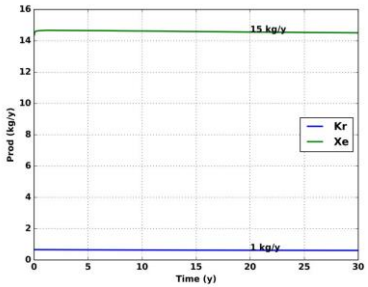
| Salt | $T_{fusion}$, $C_{PuCl_3}$ | $C_{PuCl_3}$ [mol %] for $T_{fusion} < 550°C$ |
|---|---|---|
| NaCl:$PuCl_3$ | (453°C, 38 mol%) | [28, 50] |
| **NaCl:$MgCl_2$:$PuCl_3$** | (424°C, 19.6 mol%) | [0, 50] |




For a 300MWth reactor, conversion of ~100kg Pu /y

***MOSARELA : MOlten SAlt REactor Life-cycle Assessment***
***Fuel salt composition evolution and fission products assessement***



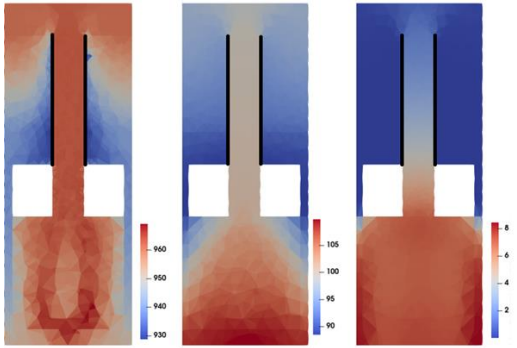




## CHEMISTRY

- Material screening
- Role of MgCl2
- New corrosion facility (MESCAL)

## SIMULATION

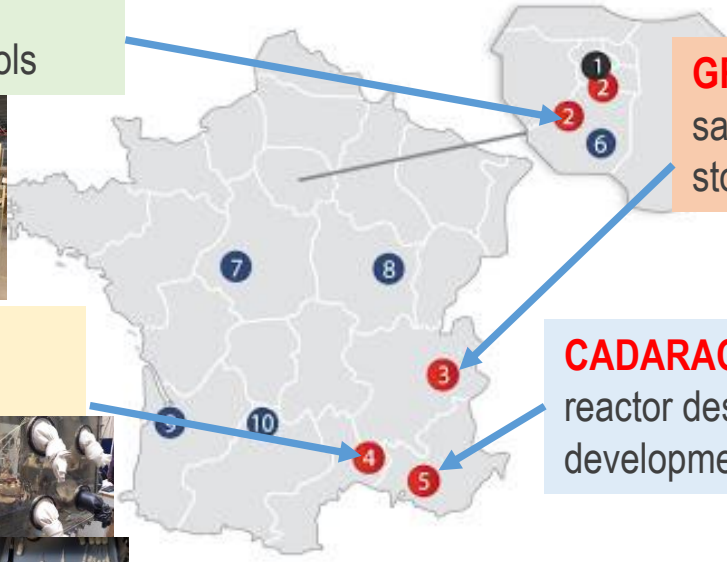
- First coupled calculations on simplified cases
- Neutronics (APOLLO) and CFD (TRIO)



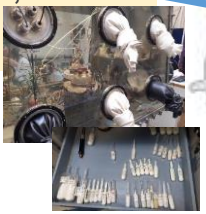
**SACLAY** : corrosion, materials, simulation tools

MESCAL facility

**GRENOBLE** : solar salts, thermal storage salts




**MARCOULE** : actinides chemistry, fuel cycle, ATALANTE hot lab



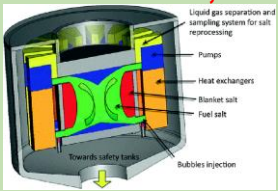
**CADARACHE** : neutronics, reactor design, technological developments

**2021-2024 PERSPECTIVES**

- ~ 8 TO 10 FULL TIME RESEARCHERS
- 5 TO 7 PHD
- 2 TO 3 POST-DOC
- TO BE CONFIRMED !

+

**CNRS expertise : MSFR design, simulation tools, thermochemistry**



## 1- Converting all Pu isotopes and minor actinides will enlarge Orano's portfolio of used fuel recycling options and reduce volume and long-term radiotoxicity of the ultimate nuclear waste

➔ *Coupling MSR to the La Hague fuel reprocessing plant, where the molten salt can be produced and recycled in synergy with the plant*

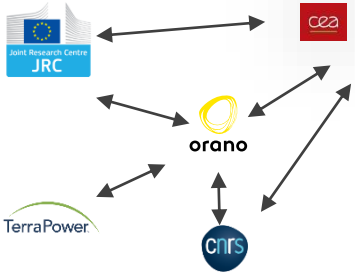
## 2- Orano can leverage its expertise in design, operation & maintenance of high activity facilities

➔ *MSR have similar characteristics on which Orano's design approach can bring a differentiated value*

**La Hague is a unique nuclear mechanical and chemical plant with complex processes to operate**

- High activity process dealing with U, Pu, chloride…
- Treatment and conditioning of HA gaseous and liquid effluents
- Harsh environment ➔ operation and maintenance by remote
- Fault tolerant design

## Orano has started R&D on Chloride Molten Salt and joined a team with TerraPower and Southern Company to build a critical mock-up within 5 years

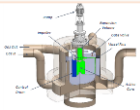



## In addition, CEA, Orano, CNRS, EDF and Framatome are preparing an "Actinide convertor" collaborative development program in the frame of the French post-Covid recovery plan

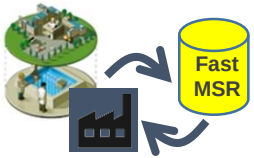

TerraPower has a strong expertise in chloride molten salts and has developed several test facilities (U salt synthesis, thermo-hydraulic loops, corrosion test bench,…)

R&D on technological issues and key topics

TerraPower
Southern Company



Critical mock-up




First experimental small fast MSR + salt pilot in La Hague

Commercial product

today → ~2025 → 2030-2040

Actinide convertor development roadmap

There is a long-standing and renewed interest in MSRs in the world

A French R&D program has been launched on fast MSRs using chloride salts, a promising concept for multirecycling of Pu and MA transmutation

The R&D program requires highly technical nuclear competences and financial investment : International cooperation is vital to succeed in the R&D program leading to a commercial MSR

**Willingness to increase engagement with key international partnerships and seek to leverage synergies with bilateral and multilateral programs :**

- SAMOSAFER and future European projects
- JRC on fuel salt data acquisition
- Gen4 International Forum
- SNETP partners ?
- …

# THANK YOU FOR YOUR ATTENTION



Contact persons :

- Paul Gauthé, CEA Innovative reactor R&D projet manager
paul.gauthe@cea.fr
- Bertrand Morel, ORANO, R&D director
Bertrand.morel@orano.group