MSR
Introduction

October 5th 2022

Stephane Bourg
On behalf of the pSSC MSR

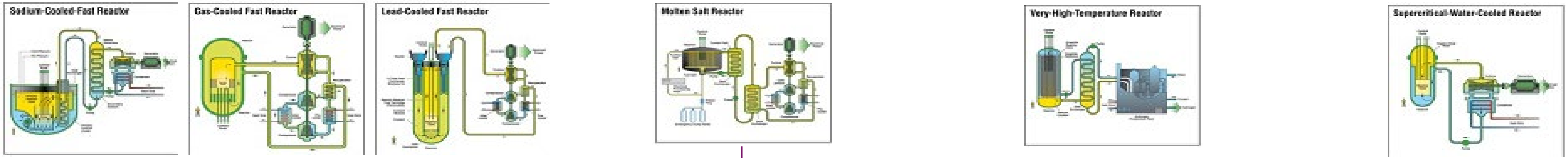
MSR key features

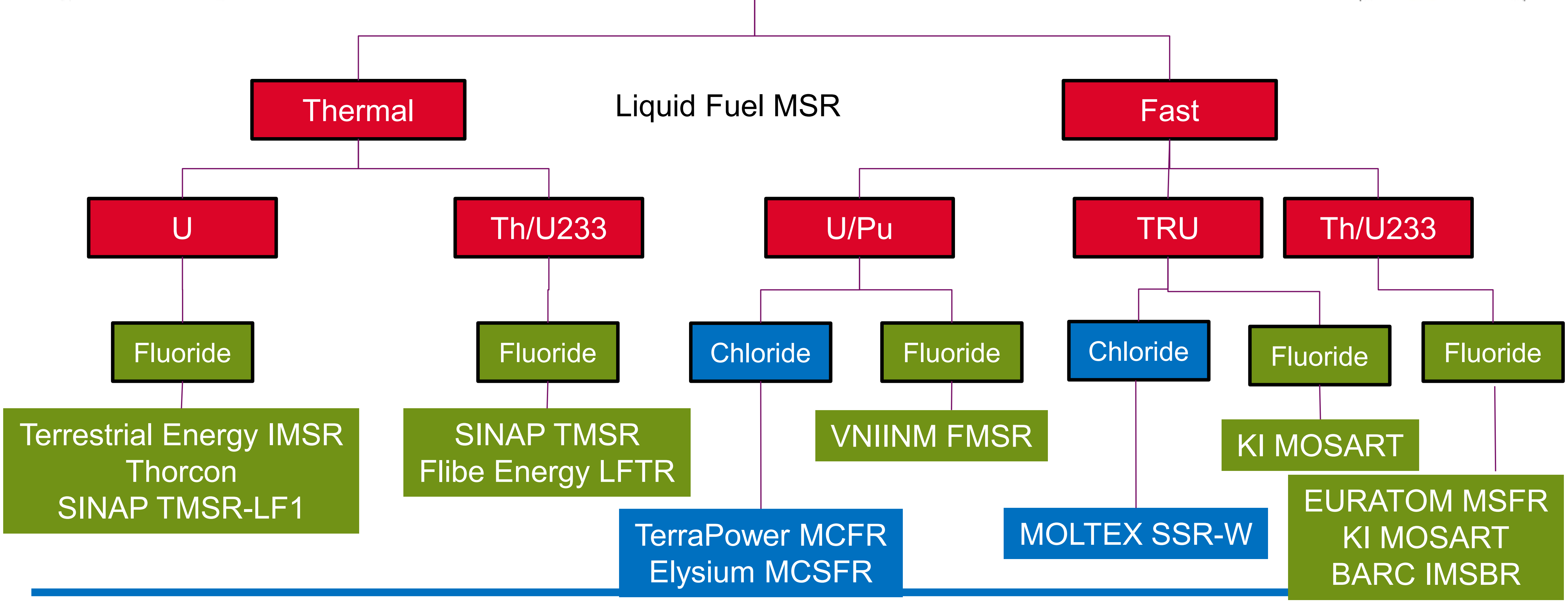
- Uses molten salt as fuel and coolant
- Can reuse fuel from LWR, or burn HEU and Pu
- Has increased power conversion efficiency,
- Is operated at low pressure
- Is ackowledged for its passive safety features
- Can be deployed at large scale or as SMR
- Can be operated as a flexible system

Potential interest in terms of heat rejection, reduced waste production…

But technological challenges: temperature, materials, corrosion…

The challenge faced by the GEN IV MSR systemS





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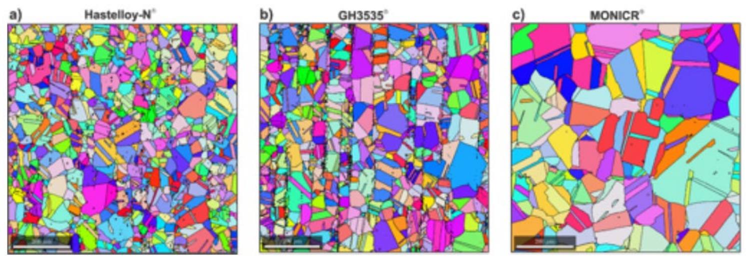
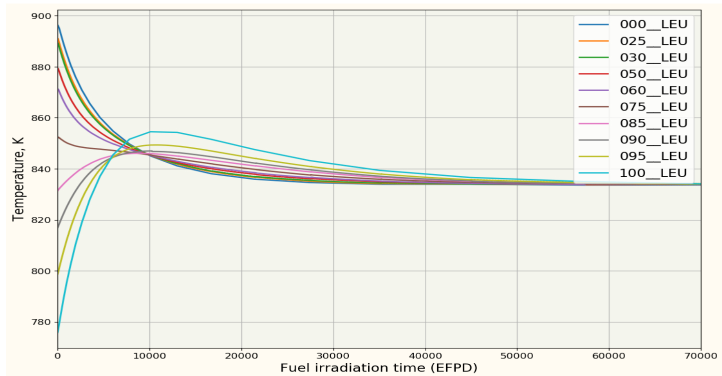
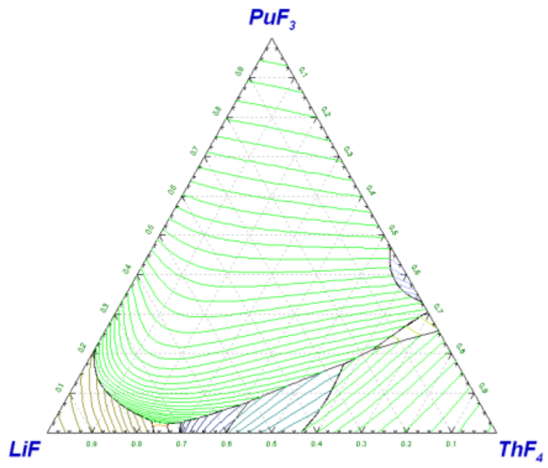
Mainly basic and concept studies

- **Mapping of the different concepts**
  - Fast/thermal, chloride/fluoride
- **Materials**
  - New alloys, graphite
  - Corrosion studies
- **Salts**
  - Physico chemical data acquisition
- **Computational**
  - Neutronics
  - Temperature gradients
- **Safety**
  - White paper on the MSFR concept
  - Heat removal
  - Salt stability

❖ Design definition (core and draining system at least)
❖ Development of simulation tools dedicated (more generic)
❖ Definition of the normal operation procedures
❖ Safety evaluation: accident initiators? Accident scenarios?
❖ Safety approach: severe accident? Barriers? Reactivity control?







Baseline design of molten salt reactor (liquid fuel)

- Salt and material combinations
- Integrated (physics and fuel chemistry) reactor performance modelling and safety assessment capabilities
- Demonstration of the MSR safety characteristics at laboratory level and beyond
- Establishment of a salt reactor infrastructure and economy that includes affordable and practical systems for the production, processing, transportation, and storage of radioactive salt constituents
- MSR safety approach, licensing and safeguard framework
- Explore commonalities with other systems using molten salts or HTR fuels (data on graphite?)

Everything is linked : Safety, Salt And Materials!

Brainstorming workshops on the choice a salt combining reactor, processing and safety requirements

- Melting temperature, volatility, density…
- Corrosion
- Stability domain
- Neutronics
- Actinides and FP solubility
- Behaviour under irradiation
- Interaction with air/water
- Toxicity
- Processibility/polishing
- Availability/cost

Safety issues!!!

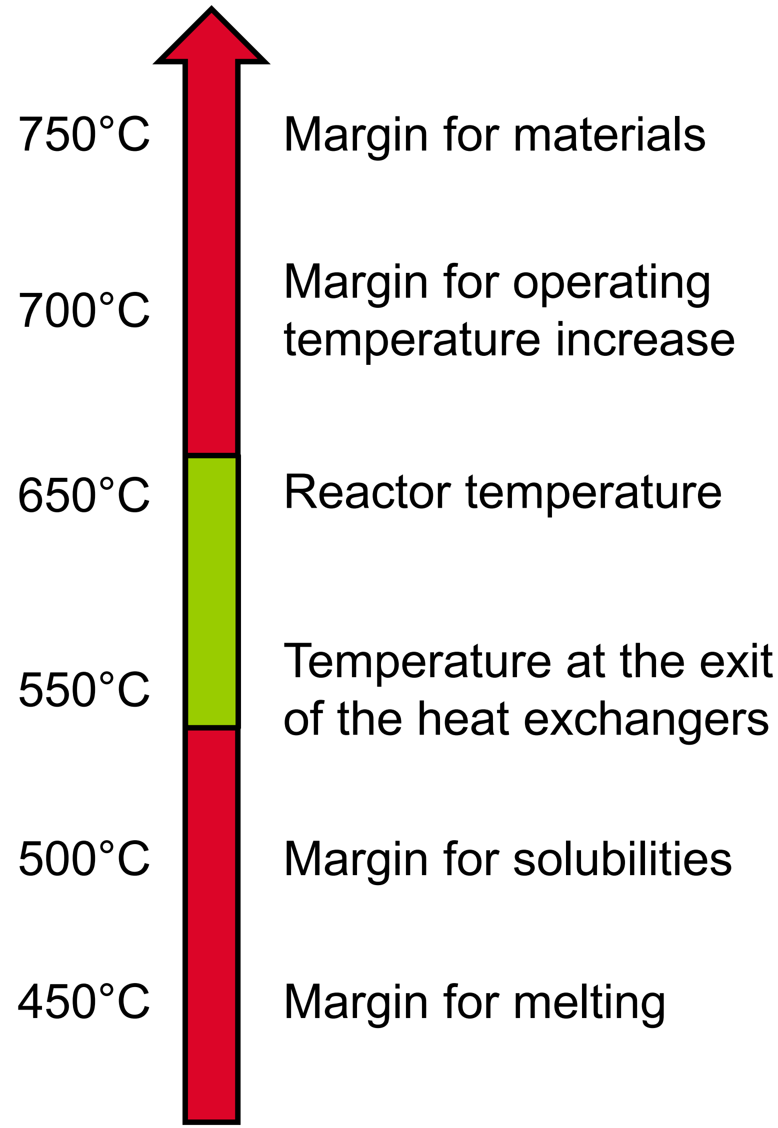


Table 2. Solubilities of PuF_3 and UF_4 in the FLiNaK salt system

Melting 454°C, (727K)

Temperature, K	Individual solubility [4, 5], mol %		Joint solubility, mol %	
	PuF_3	UF_4	PuF_3	UF_4
550°C 823	6.1 ± 0.6	15.3 ± 0.8	1.16 ± 0.14	1.75 ± 0.26
600°C 873	11.1 ± 1.1	24.6 ± 1.2	2.9 ± 0.3	3.5 ± 0.5
650°C 923	21.3 ± 2.1	34.8 ± 1.7	13.2 ± 1.6	11.0 ± 1.6
700°C 973	32.8 ± 3.3	44.7 ± 2.2	19.1 ± 2.3	17.3 ± 2.6
750°C 1023	No data	No data	21.0 ± 2.5	19.0 ± 2.8
800°C 1073	No data	No data	22.5 ± 2.7	20.0 ± 3.0

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Cooperation Areas Have Been Selected as a Means to Increase Efficiency

Task	System Integration & Cross-cutting issues
1.1	Phenomena Identification and Ranking Table (PIRT)
1.2	Multiphysics simulation
1.3	Reactor core physics and fuel cycle
1.4	Plant dynamics

Task	Fuel and Coolant Salt Properties
2.1.	Properties of Fuel and Coolant salts
2.2.	Retention capacity of Fuel salt
2.3.	Fuel Salt Clean-Up
3.4.	Redox control of the Fuel salt

Task	Materials and Components
3.1	Assessment and evaluation of selected materials and manufacturing methods for the reactor plant and fuel salt processing unit:
3.2	Codification of very-high-temperature mechanical design rules for potential application materials and manufacturing methods. Modeling and description of materials behavior and damage development will provide the basis for codification improvements.

Safety Cooperation on MSRs within GIF

October 5th 2022

David Holcomb
On behalf of the pSSC MSR

Safety Cooperation Remains at an Open Scientific Level

- Reactor safety adequacy is determined by the processes and laws of each member state
- Fundamental safety concepts are applicable to any regulatory process
  1. Contain the radioactive material
  2. Provide adequate cooling of both the active and used fuel
  3. Control reactivity
- Fundamental information and methods employed to make safety decisions should be publicly available
- GIF MSR safety cooperation focuses on developing fundamental information and validating methods suitable for use in safety decisions
  - Includes appropriate quality assurance
  - Does not include evaluation of specific design features

Salt Thermochemical and Thermophysical Properties are Being Cooperatively Established

- MSR performance depends on the thermochemical and thermophysical properties of the salts
- Multiple partners are measuring salt properties
- Key issue is adequate quality assurance in the measurements
  - Values can be significantly impacted by contamination and measurement process error
- Database is publicly accessible
- Molten salt database training course scheduled for November 9th 2022 at University of South Carolina
  - https://sc.edu/study/colleges_schools/engineering_and_computing/research/research_centers_and_institutes/general_atomics_center/molten_salt_working_group/index.php

The Molten Salt Thermal Properties Database–Thermochemical (*MSTDB-TC*) and Molten Salt Thermal Properties Database–Thermophysical (*MSTDB-TP*) databases are now available for public use. *MSTDB-TC* contains Gibbs energy models and values for molten salt components and related systems of interest with respect to molten salt reactor technology. *MSTDB-TP* consists of tabulated thermophysical properties and relations for computing properties as a function of temperature or composition.

https://sc.edu/study/colleges_schools/engineering_and_computing/docs/research/mstdb_access.pdf

Members Have Cooperatively Demonstrated Elements of GIF Safety Adequacy Evaluation Process

- Parallel (largely independent) efforts to implement elements of the GIF Integrated Safety Assessment Methodology (ISAM) by groups of member states
  - Collaborative discussions are key element of GIF pSSC semiannual meetings
- Initiating Event Identification
  - *Molten Salt Reactor Initiating Event and Licensing Basis Event Workshop Summary - DOI:* 10.2172/1561637 (US Centered)
  - A methodology for the identification of the postulated initiating events of the Molten Salt Fast Reactor – DOI: 10.1016/j.net.2019.01.009 (EU Centered)
- Phenomenon Identification and Ranking
  - Molten Salt Reactor Fundamental Safety Function PIRT – DOI: 10.2172/1824962 (US Centered)
- Lines of Defense Analysis
  - *Application of the lines of defence method to the molten salt fast reactor in the framework of the SAMOFAR project* – DOI: 10.1051/epjn/2019031 (EU Centered)

MSR Risk and Safety Task Force Remains Under Consideration

- Would be joint activity of the MSR pSSC and the Risk and Safety Working Group
- Modeled on the prior sodium fast reactor safety design criteria task force
  - Safety Design Criteria for Generation IV Sodium-cooled Fast Reactor System
  - Safety Design Guidelines on Safety Approach and Design Conditions for Generation IV Sodium-cooled Fast Reactor Systems
  - Safety Design Guidelines on Structures, Systems and Components for Generation IV Sodium-cooled Fast Reactor Systems
- Substantial activity requiring significant support over multiple years
- Potentially competing IAEA activity on developing and applying design safety standards for MSRs
- Need to reach cooperative agreement about roles for each organization
- Key limitation in the number of staff with sufficient experience in both safety analysis and molten salt reactor design (physics, chemistry, material science)

Conclusion

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- More and more activities around MSR worldwide, more than 40 concepts…
- Within GIF, 3 centers of interest:
  - Fuel and coolant salt properties
  - Materials and components
  - System Integration, Cross-cutting issues
- Safety issues are a key driver for the R&D roadmap, from reactor design to salt chemistry
- Exchange with Risk and Safety Working Group for the creation of a task force on the global MSR safety approach
- More experimental facilities are needed to check/validate salt physico-chemical behaviour, material behaviour under representative conditions (loops, salt polishing, critical mock-ups…)