Molten Salt Reactor system
2009-2012 Status

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Chair of the Molten Salt Reactor System Steering Committee
** Former Chairman*

Slides prepared in collaboration with CNRS (France) and JRC (Euratom)

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Organizational status

Members of the MSR System Steering Committee

- *France and Joint Research Center (European Commission), on behalf of Euratom, signed the Memorandum of Understanding in 2010*

- *The Russian Federation and the United States are permanent observers*

- *China (CENTER of TMSR, SINAP/Chinese Academy of Science - CAS) joined the pSSC as observer in 2012*

- *Japan observers participate regularly*

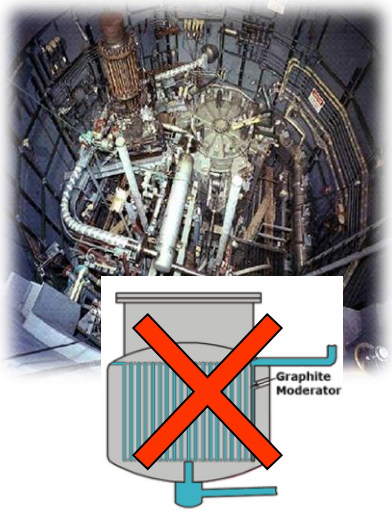
Reference concept : MSFR

From thermal to fast neutron spectrum

The first Molten Salt Reactors (MSR) developed in the USA (1960s and 1970s) were thermal-neutron-spectrum graphite-moderated concepts

Since 2005, European R&D interest has focused on fast neutron MSR (MSFR) as a long term alternative to solid-fueled fast neutrons reactors

MSRE



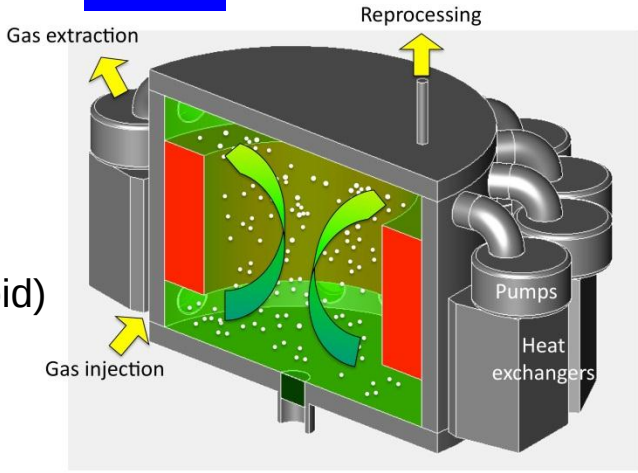
General characteristics of MSR

- Molten fluorides as fuel fluid (no loading pattern)
- Low-pressure and high boiling-point coolant
- Possibility to drain fuel passively towards non-critical volumes
- On-site fuel reprocessing unit

Specific *features* of MSFR

- Strongly negative reactivity feedback coefficients (thermal and void)
- Simplified fuel cycle
- No graphite elements in the core (maintenance)

MSFR



Concepts studied

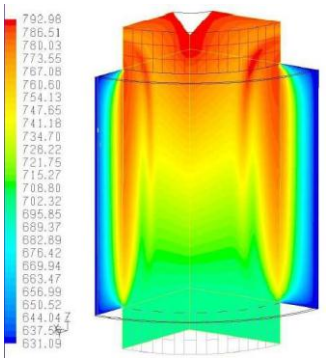
- ***Two reactors concepts using molten salt are studied in the GIF MSR***

  - Molten salt reactors, in which the salt is at the same time the fuel and the cooling liquid
    - » *France and Euratom work on MSFR (Molten Salt Fast Reactor).*
    - » *Russia works on MOSART (Molten Salt Actinide Recycler & Transmuter)*

  - Reactors with solid fuel cooled by a molten salt
    - » *USA and China work on FHR (fluoride-salt-cooled high-temperature reactor) concepts*

Main results obtained since 2009

1 - Physical studies



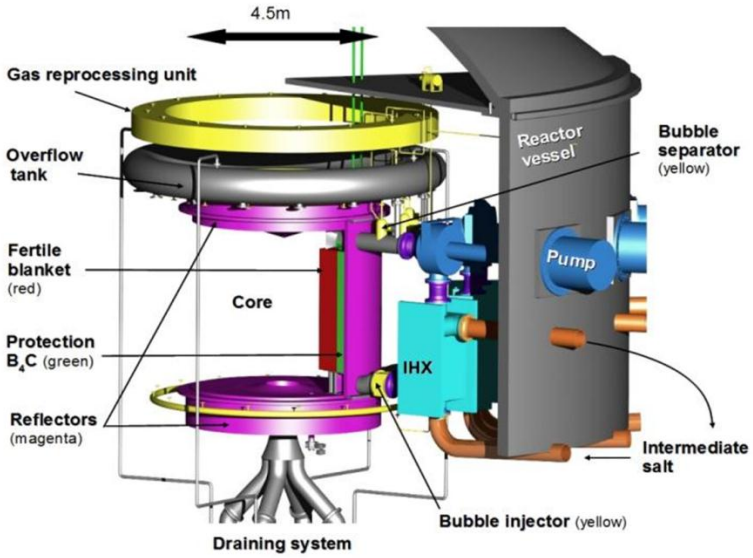
- ***Feedback coefficients evaluation***
- ***First core (^{233} or ^{235}U, transuranic elements) and deployment capacities have been studied in terms of safety and proliferation risk***
- ***Coupling of neutronic and reprocessing simulation codes was studied to assess reprocessing requirements and capacity needs***
- ***Neutronic and thermal-hydraulic coupling models have been initiated***

Main results obtained since 2009

2 – Safety

- **Classical safety analysis is not well adapted to the MSFR**

  ⇨***Safety approach dedicated to MSFR has been initiated***
- **Identification of typical accident initiators for liquid fuel reactor**
- ***Safety-by-design approach : conceptual drawings showing the main MSFR components and their arrangement in the vessel***
- ***Development and validation of a decay heat calculation tool***



Main results obtained since 2009

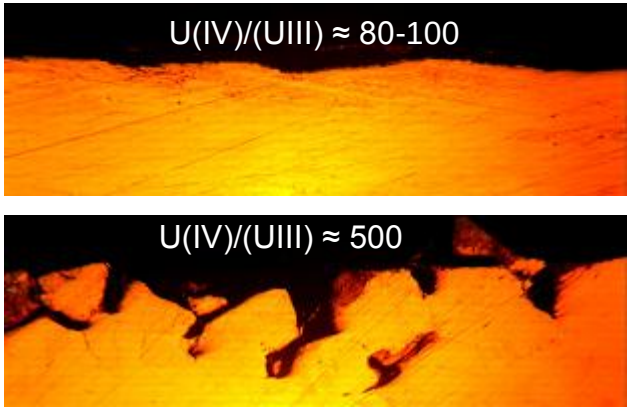
3 – Materials studies

Early ORNL studies led to develop a Ni-base alloy for fluoride salts and have shown that control of the [U(IV)]/[U(III)] ratio in the salt is a key parameter to limit corrosion (Mo, Ni and Cr dissolution)

- *Limited corrosion rate is obtained at 750°C for* [U(IV)]/[U(III)] < 100

- Hastelloy EM 721 or equivalent should be sufficient for an experimental reactor with an efficient salt redox potential control

EM 721 (NiWCr)



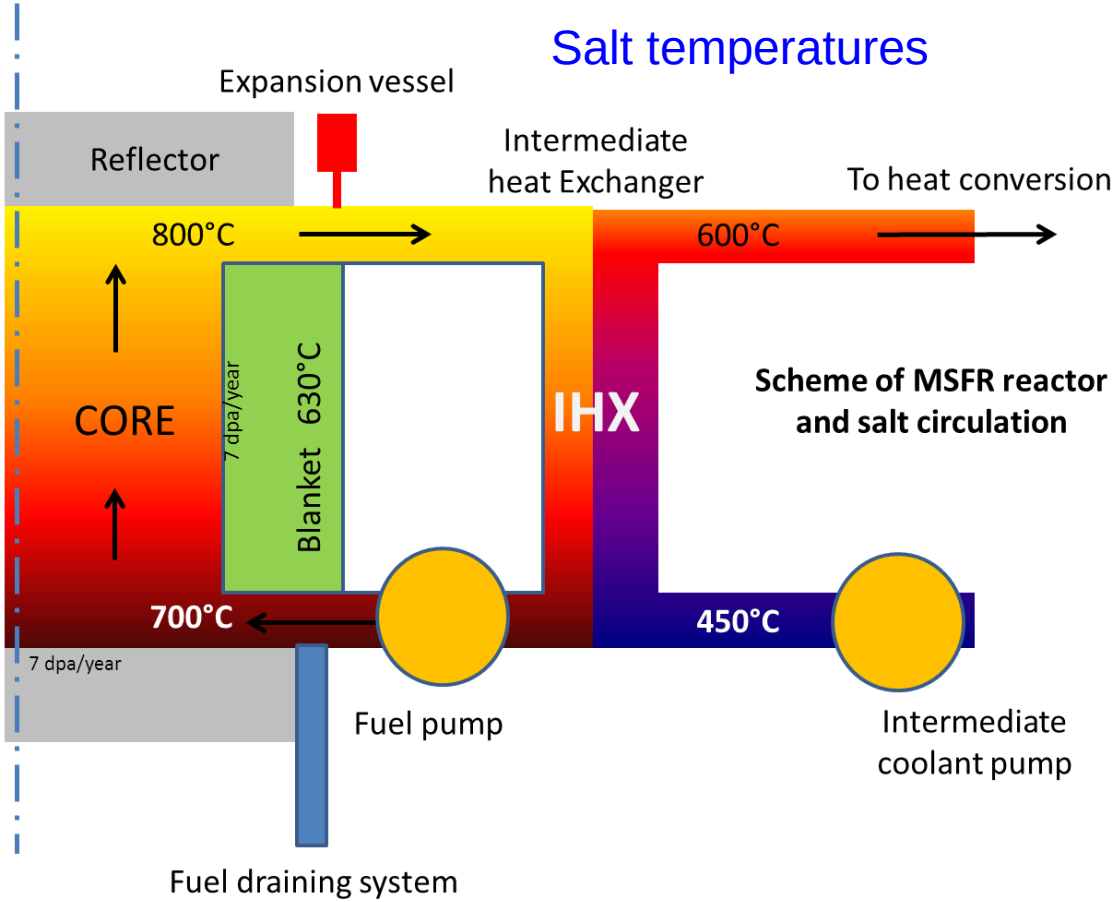
Main results obtained since 2009

3 – Materials studies

- Effort is made on the reactor vessel design to decrease the operating temperature in order to limit the corrosion rate, mechanical constraints, creep…

→ Metallic materials will not be at the salt temperature in the hot spots (reflectors and blanket wall) thanks to thermal screens and cooling systems

→ Dose rate calculations



Main results obtained since 2009

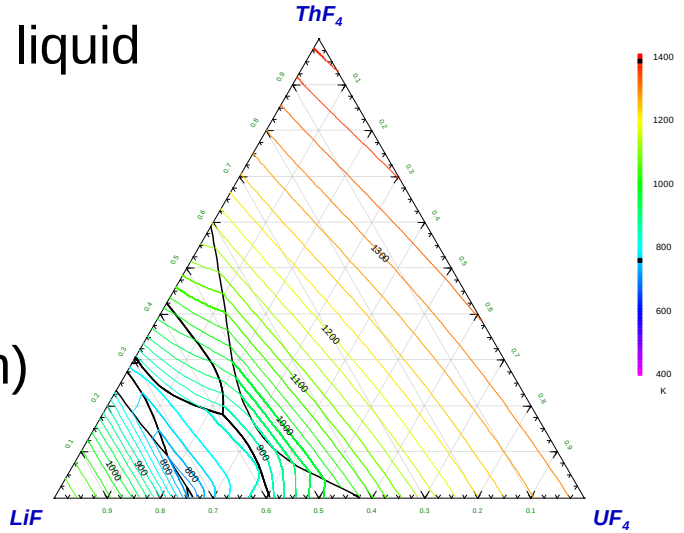
4 – Salt properties

- **Experimental investigations**

Physico-chemical properties of fluoride salts
Synthesis and purification of actinide fluorides

Heat capacity determination of pure solids and liquid solutions
Heat of transition and fusion determination
Enthalpies of mixing of liquid solutions

Equilibrium data determination (phase diagram)
Melting temperature, solidus and liquidus points, solubility



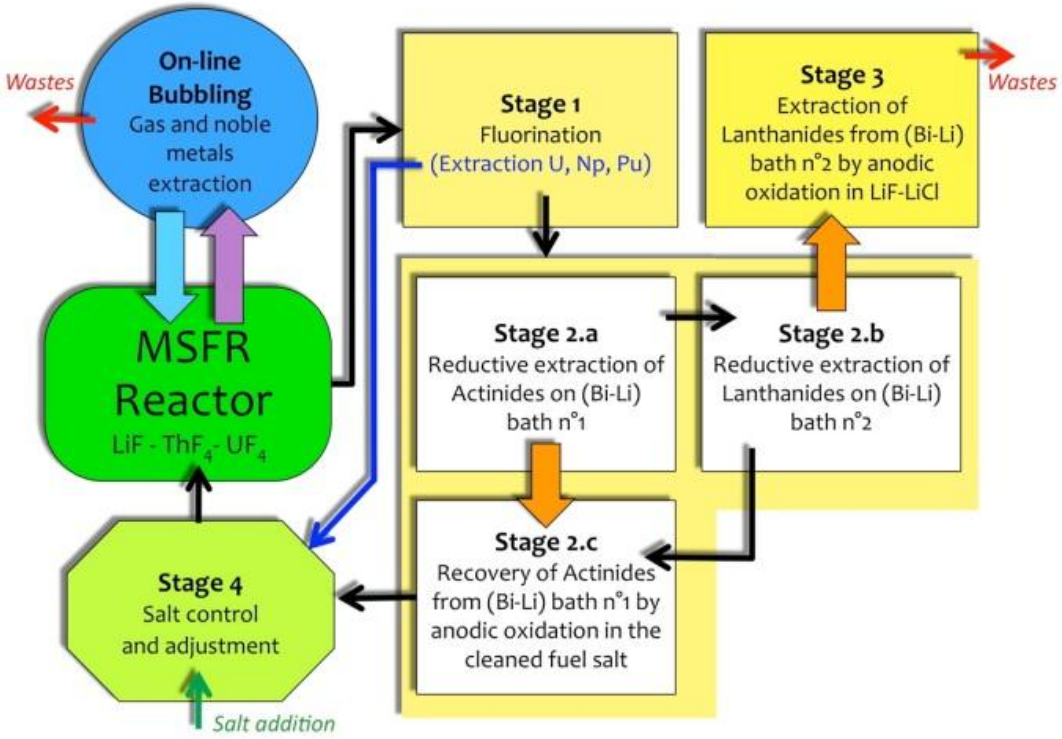
- **Thermodynamic modeling**

Database has been developed at ITU since 2002

Main results obtained since 2009

5 – Salt reprocessing

- *Assessment on a reprocessing scheme adapted to MSFR (extrapolated from MSBR, US)*
- *Core process is reductive extraction : thermodynamic feasibility has been demonstrated*
- *Innovative process for the recovery of the salt and metallic phases*
- *Performance assessment*



Main results obtained since 2009

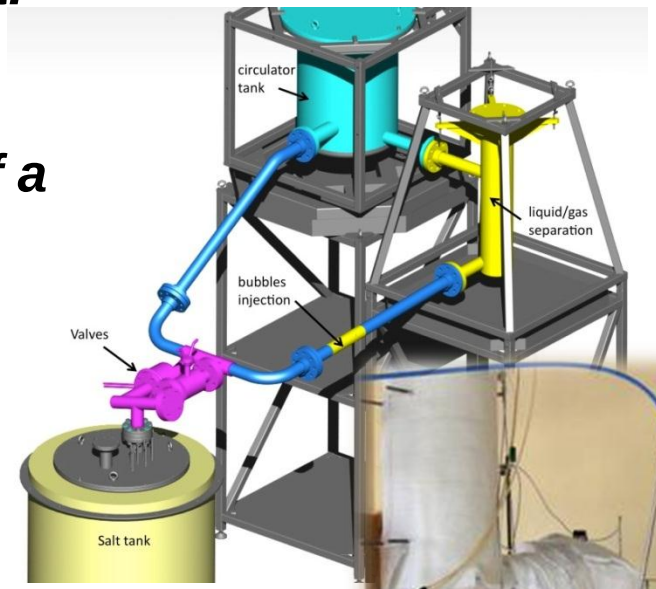
6 – Forced Fluoride For Experimental Research molten salt loop

- ***Technological studies : construction of a molten salt loop is under progress (FFFER project)***

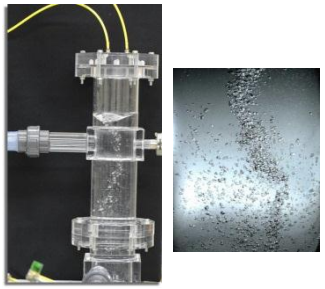
Studies dedicated to on-line bubbling clean-up process and to technical developments of some components :

✓*Cold plug system (a safety system based on a passive concept to drain the salt)*

✓*Gas-salt separation device*



Clod plug test assembly : running test



R&D objectives

- ***Physic***

  Neutronic and thermo hydraulic coupling models

  Hydraulic and thermal design

- ***Safety***

  Conceptual drawings (operational draining system)

  Collaboration with the Risk and Safety Working Group (adapt the Integrated Safety Assessment Methodology to MSFR)

  Accidental scenarios (heat exchanger loss, salt / Air-water interactions …)

- ***Molten salt loop***

  Gas extraction

  Particles extraction

- ***Materials***

  Ni based alloys castings and tests

- ***Salt reprocessing***

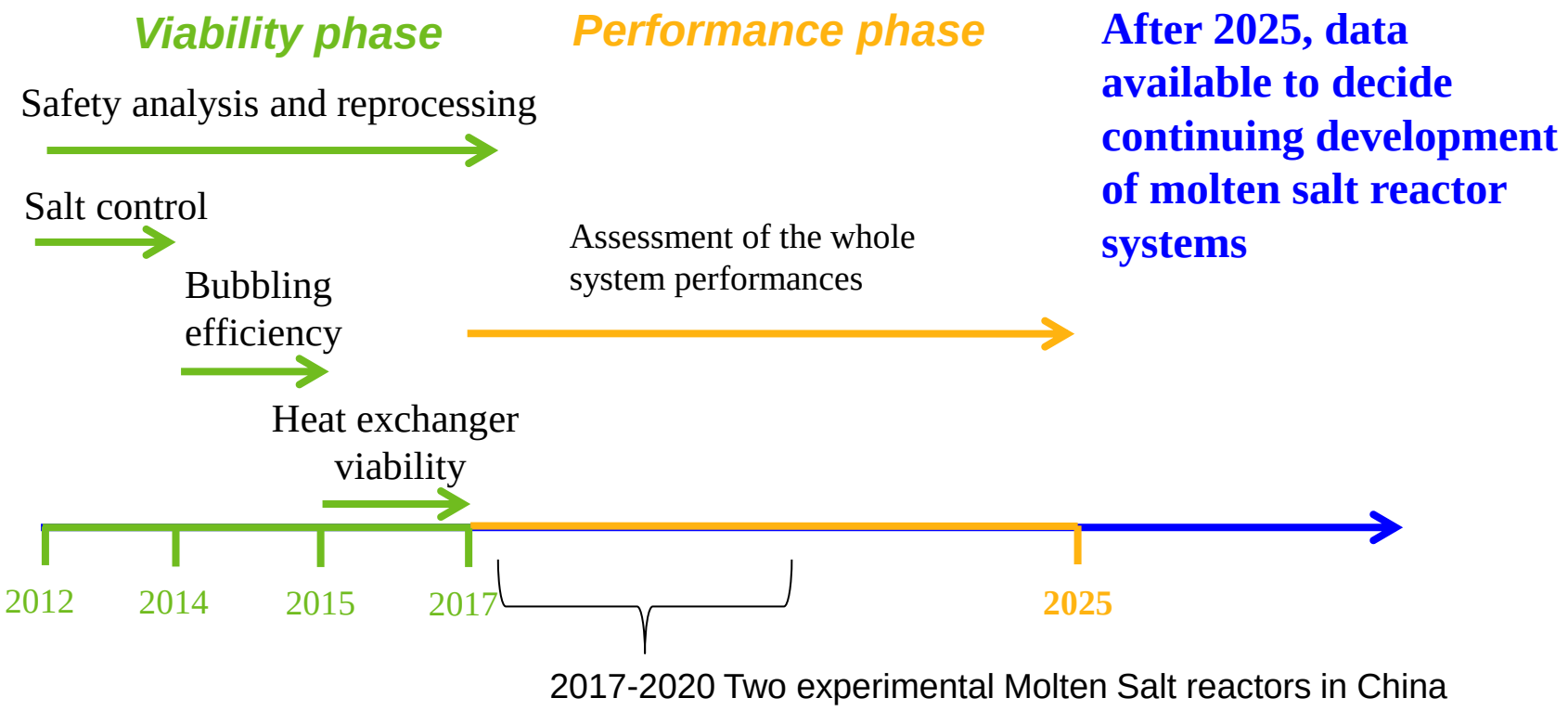
  Lanthanide and actinide reductive extraction tests

  Salt properties

  Measure and control of the U(IV)/U(III) ratio

  Thermodynamic database with TRU elements

Perspectives

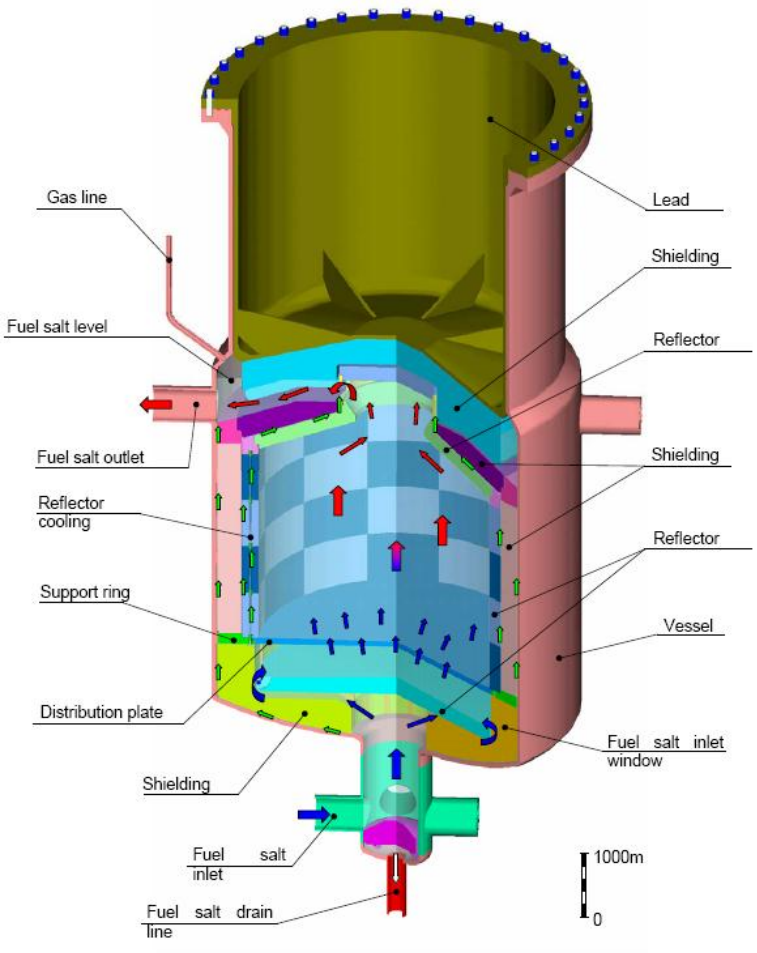


Thank you for your attention

MOSART (Molten Salt Actinide Recycler & Transmuter)

System may operate in the actinide recycler, MA transmuter and Th-U sustainable modes

- **Conceptual feasibility**
- ***Physical and chemical properties of molten salts***
  - Melting temperatures, viscosity, solubility, density, thermal conductivity and heat capacity
  - Experimental data on reprocessing steps
- ***Corrosion experiments, studies on hydrogen isotopes permeation on core materials***



FHR

System with :

Clean molten salt reactor coolant

Coated-particle fuel

- ***Conceptual design for an FHR test reactor***
- ***Fuel qualification***
- **Developing a liquid fluoride salt flow loop to test high temperature components**
- **Thermal Hydraulics, Safety, and Licensing Tests**
- **A cooperative research program between U.S. Department of Energy and the Czech Republic Ministry of Industry and Trade** (reactivity measurements of lithium isotopically selected salts)
- **DOE – CAS cooperation in FHR development**