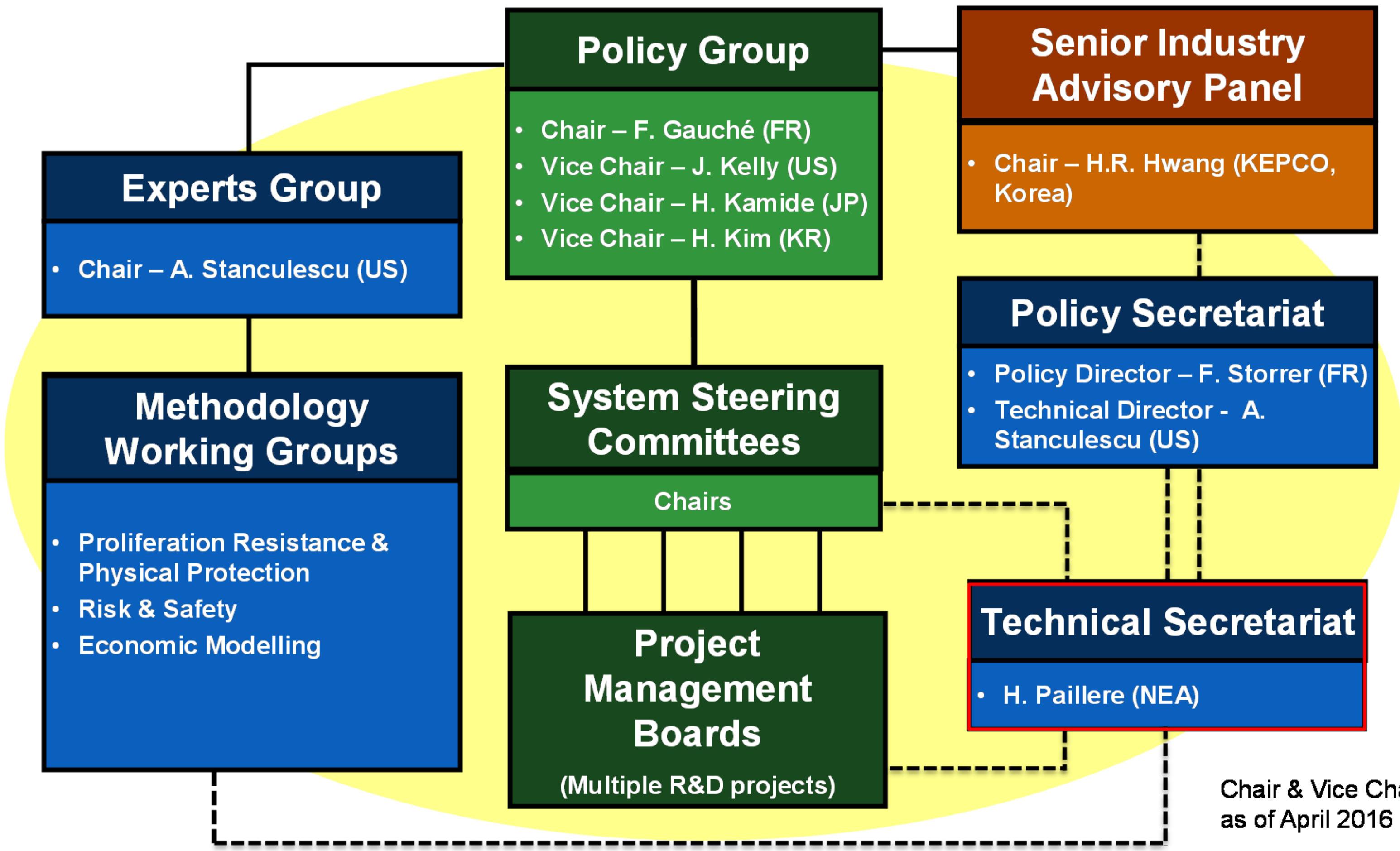
MSR provisional System steering Committee

J. Serp, France

Molten Salt Reactor Workshop at PSI
24. January 2017

Generation IV Organization



Chair & Vice Chair as of April 2016

Molten Salts Enable a Broad Spectrum of Reactors

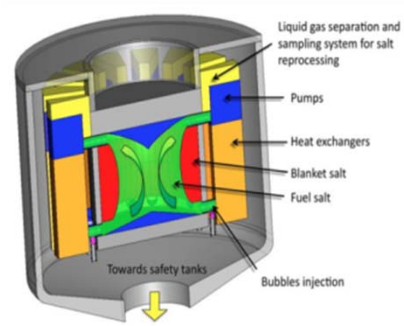
- *MSRs have two primary subclasses – salt-fueled and salt-cooled*
  - *Both subclasses have fast and thermal spectrum variants (epithermal and flux trap systems also possible)*
  - *Salt-fueled systems (e.g. molten salt in fuel rods) can be cooled by non-fuel salt*
  - *Salt-fueled systems can employ non-salt coolants*
- *Fuel cycle of salt-fueled reactors is intimately connected with the reactor*
  - *U/Pu, Th/U, and TRU based fuel systems can be used*
  - *Breeding, burning, converter fuel cycles are all possible*
  - *Open and closed fuel cycles with full or limited fuel salt processing depend mainly on neutron spectrum choice*
  - *Single and two fluid systems are possible*
- *Fuel cycle of salt-cooled reactors resembles that of other solid-fuel reactors*

Studied Concepts

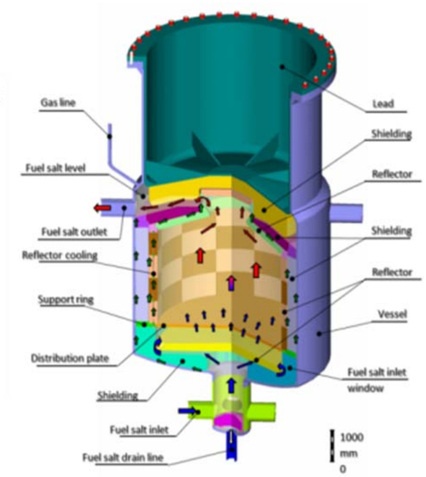
Different reactor concepts using molten salt are discussed an GIF MSR meetings

- ***Molten Salt Fuelled Reactors (the circulating salt is the fuel + coolant)***
  - » *MSR MOU Signatories France and EU work on Th-U MSFR (Molten Salt Fast Reactor)*
  - » *Russian Federation works on MOSART (Molten Salt Actinide Recycler & Transmuter) with and without Th-U support. RF joined the MOU in 2013*
  - » *Switzerland joined the MOU in 2015*
  - » *China, Japan and South Korea (Observers) work on Th-U TMSR with graphite moderator*
- ***Molten Salt Cooled Reactors (solid fuelled)***
  - » *USA and China work on FHR (fluoride-salt-cooled high-temperature reactor) concepts.* ***US joined the MOU (1/2017)***
  - » *Australia works with China on materials development for MSR and FHR*

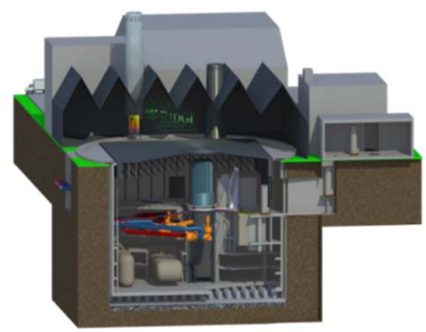
MSFR



MOSART

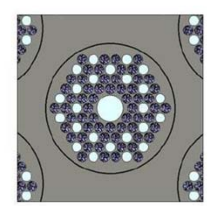


FHR



Pebble Bed

Flat Fuel Plates in Hex Configuration



Fuel Inside Radial Moderator (FIRM)

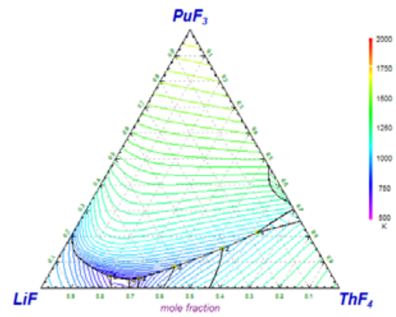
GIF MSR Project

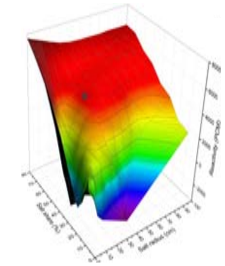
- ***A Provisional Project Management Board has been set up***
  - ***Two meetings per year where members and observers report on their activities and recent progresses***

- ***The project is devoted to Molten Salt Reactors***
  - ***Information is also exchanged on solid fuelled reactors cooled by molten salt***

- ***The various molten salt reactor projects like FHR, MOSART, MSFR, and TMSR have common themes in basic R&D areas, of which the most prominent are:***
  - ***liquid salt technology,***
  - ***materials behavior,***
  - ***the fuel and fuel cycle chemistry and modeling,***
  - ***the numerical simulation and safety design aspects of the reactor***

Liquid fuelled-reactors



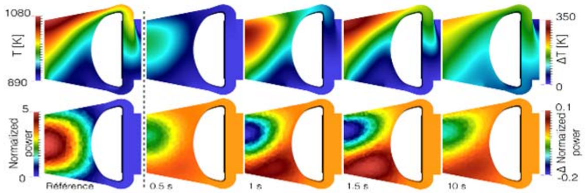


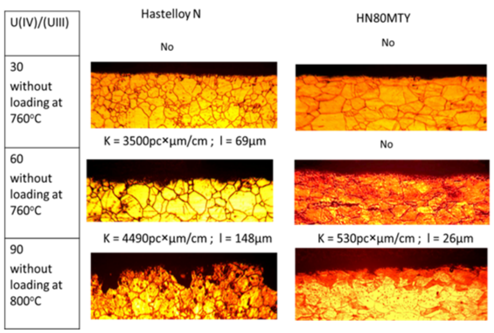
Which constraints for a liquid fuel

- Melting temperature not too high
- High boiling temperature
- Low vapor pressure
- Good thermal and hydraulic properties
- Stability under irradiation

There are some challenges for MSR that must be factored into design

- Must keep system at high temperature to avoid salt freezing
- Life time of components (graphite)
- Chemical interactions with structural materials
- Li or Cl enrichment
- Complexity of a combined reactor and fuel processing system
- Safety of liquid fuels (vs actual LWR) needs to be implemented





Collaboration: Europe

• ***EURATOM/ROSATOM collaboration through parallel funded projects (EVOL-MARS) on liquid fueled reactors:***

EVOL – Evaluation and Viability of Liquid Fuel Fast Reactor System

A European project to develop MSRs

3 years (2010-2013) - 2 M€ (1M€ EC funding)

Coordination agreement with ROSATOM MARS (Minor Actinides Recycling in molten Salt) project

Common objectives of EVOL and MARS

EVOL project has been completed at the end of 2013

Collaboration: Europe

SAMOFAR Project (Started 08/2015: 4 years)

"A paradigm Shift in Nuclear Reactor Safety with Molten Salt Reactor"

EU Partners: TU-Delft, CNRS, JRC, CIRTEN, IRSN, AREVA, CEA, EDF, KIT, PSI, CINVESTAV

Non EU partners: SINAP (China), Univ. of New Mexico (USA) and KI (Russia)

The grand objective of SAMOFAR is:

– prove the innovative safety concepts of MSFR,
– deliver breakthrough in nuclear safety and waste management
– create a consortium of stakeholders to demonstrate MSFR beyond SAMOFAR

Main results will be:

- *experimental proof of concept*
- *safety assessment of the MSFR*
- *update of the conceptual MSFR*
- *design roadmap and momentum among stakeholders*

Technical work-packages:

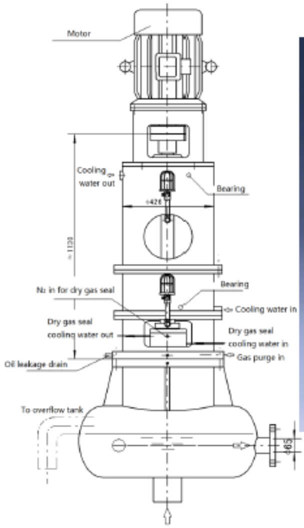
- *Integral safety assessment*
- *Safety related data*
- *Experimental validation*
- *Numerical assessment*
- *Materials compatibility*
- *Salt chemistry control*
- *Fuel salt processing*

The Shanghai Institute of Applied Physics (SINAP/CAS) and the TMSR program

The near-term Goal of TMSRs project :

- 2MW Pebble-bed FHR (TMSR-SF1)
- 2MW Molten Salt Reactor with liquid fuel
- Build up R&D abilities (include research conditions, key technology and research team, Molten-Salt Test Loops, radiochemistry research platform etc.) for future TMSR development, including

Long-term Goal of TMSRs: ~100MW



3D-design

NG-CT-10: nuclear graphite

SiC heat exchanger

GH3535 domestic alloy

Collaborations: USA - China

Recent U.S. MSR Relevant Developments

- University lead integrated research projects ($5 M each) focused on addressing technical issues for FHRs initiated from 2015 till to 2018
  - MIT, UC-Berkeley, U-Wisconsin, and U-New Mexico form one team
  - Georgia Tech, Texas A&M, and Ohio State form other team
- US-Czech collaboration on F^7LiBe reactivity worth measurement is under development

U.S. and China Have Begun Cooperating R&D on FHR (CRADA)

- Purpose for CRADA is to Accelerate Development of FHRs
- CRADA supports and is funded by SINAP's thorium MSR program
- CRADA is limited to solid fueled MSRs
  - Nearly all technology developed will be applicable to MSRs
  - CAS is providing the entirety of CRADA funding, with an estimated $5 million a year.
  - The collaborations under the new agreement are authorized for 10 yrs.

Collaborations: SINAP -ANSTO

ANSTO-SINAP Joint Research Centre

Project is supported by the Commonwealth of Australia under the Australian-China Science and Research Fund

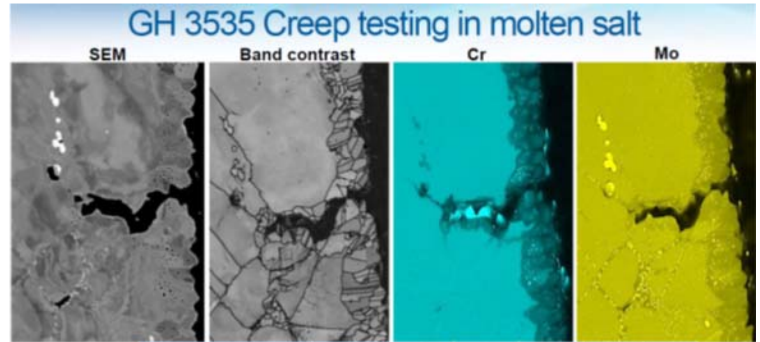
- *Molten Salt Corrosion*
- *Radiation Damage Effects*
- *High Temperature Materials*
- *Weld Modelling*

Candidate Ni based alloy properties and assessment (principally GH3535)

- Neutron irradiation followed by corrosion in FLiNaK
- Creep and corrosion kinetics in FLiNaK
- Creep in FLiNaK – longer term lower stress tests
- Investigation of dopants such as Te to simulate fission products
- Effect of Ni plating for corrosion protection
- Post-test molten salt analysis, effect of impurities

Graphite

- Develop molten salt infiltration assessment by neutron tomography
- Investigate different grades (density/grain size)
- Compare effects of irradiation (ion beam and neutron)
- Surface properties and surface chemistry of graphite after irradiation and/ or molten salt corrosion
- Investigate surface treatment of graphite to reduce oxidation and/or molten salt effects



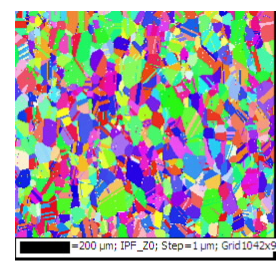
EDS chemical composition (Average wt%)

Region	Ni	Mo	Cr	Fe	Mn	Si
Bulk sample	71.1	16.3	7.3	4.1	0.7	0.5
Salt affected regions (st dev)	82.8 (0.5)	12.1 (0.4)	1.5 (0.2)	3.2 (0.2)	0.2 (0)	0.1 (0)

20 µm

Materials Studied:

1. GH3535, a Chinese variant of Alloy N with the nominal composition of Ni–16Mo–7Cr–4Fe and Si used as an O getter.
2. Various Grades of Nuclear Graphite.



DOE-NE Has Decided to Invest in the Molten Chloride Fast Reactor Through a Public-Private Partnership

- ***First U.S. Government liquid fueled MSR funding in 40 years!***
- ***Award made following a competitive process***
- ***$40M of government funding over 5 years with a substantial private match (>20%)***
- ***Southern Company Services is the lead for the program***
  - ***TerraPower, ORNL, EPRI, and Vanderbilt University are the supporting institutions***
  - ***TerraPower is the reactor design lead***
  - ***Effort will be housed at ORNL***
  - ***http://www.southerncompany.com/news/2016-01-15-so-nuclear-technology.cshtml***

In order to ensure that nuclear energy remains a key source for US electricity generation well into the future, it is critically important that we invest in these technologies today — DOE Secretary Ernest Moniz

MCFR Commercial Development Roadmap Has Three Phases

Early validation

- Completed by 2019
  - Supported jointly by U.S. Government and Southern Nuclear Services led consortium

Critical test reactor

- Mid 2020s

Commercial prototype

- By 2035

Contract is still under negotiation.

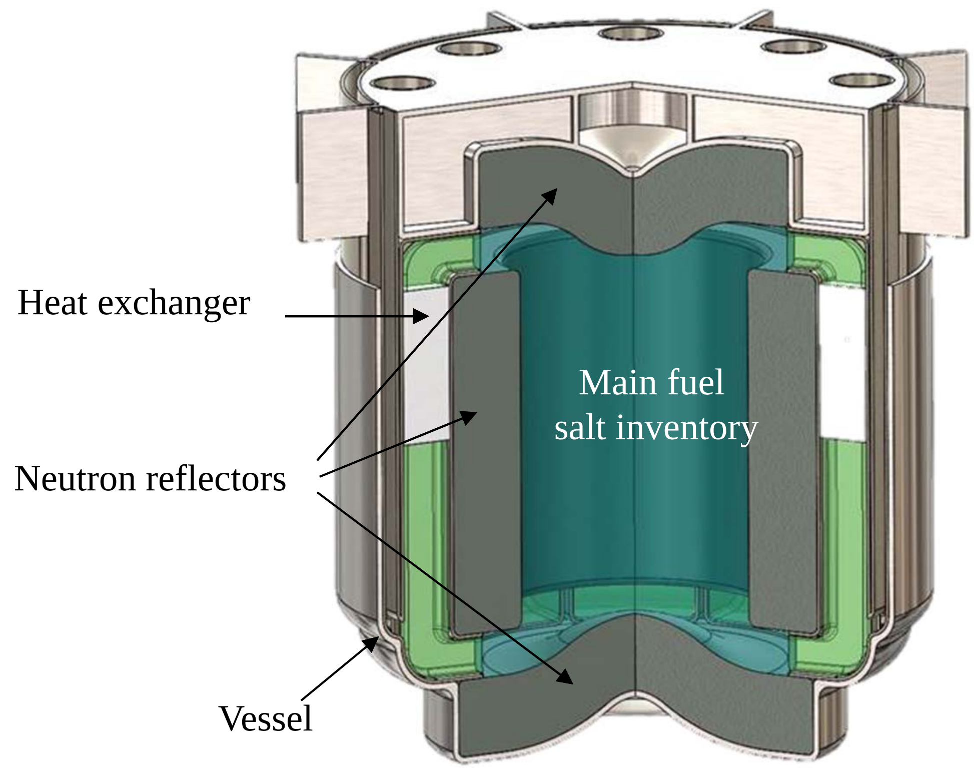


Image courtesy of TerraPower

The MCFR core is composed of the reactor vessel, fuel salt, neutron reflectors, and primary heat exchangers.

Thank you for your attention