MSR R&D program in EU:

O. Beneš, J.-L. Kloosterman

European Commission, Joint Research Centre
Karlsruhe, Germany

MSR in EU

EU – 28 member states

Nuclear activities in EU: EURATOM (27 MS) + FRANCE (CEA, CNRS, Uni.)

FZD

ÚJV Řež

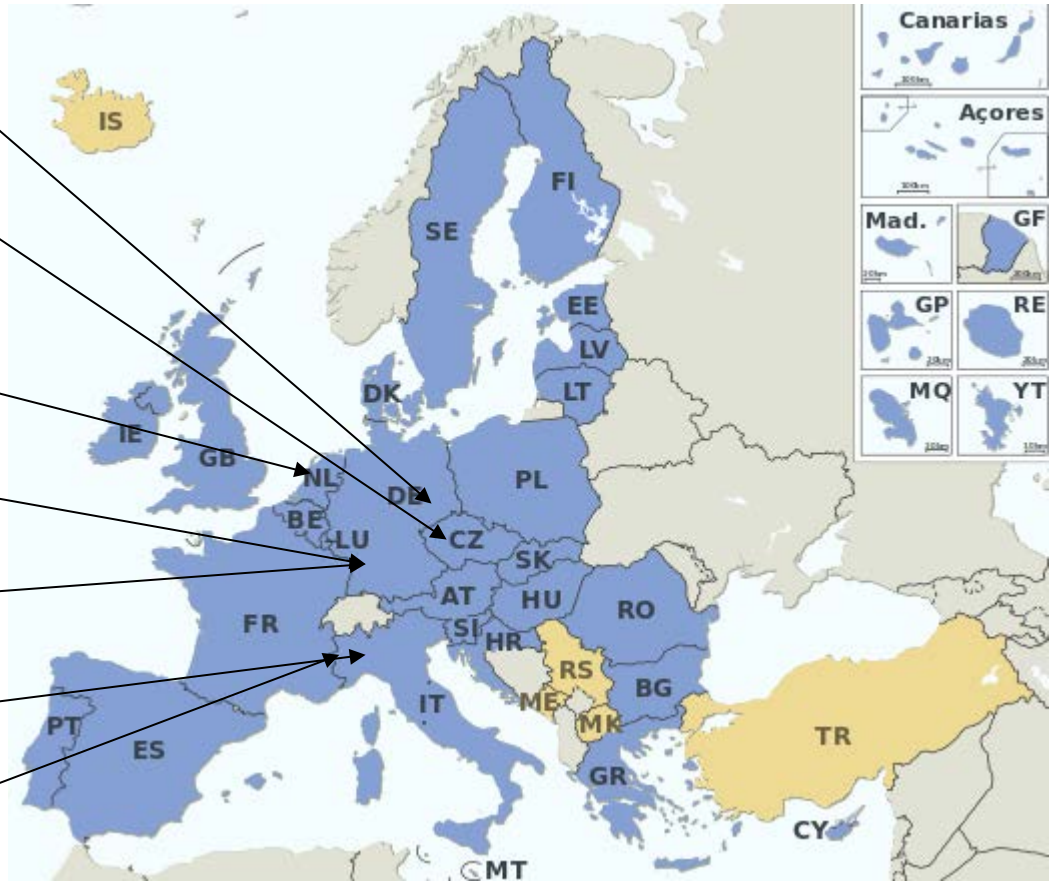
TU Delft

JRC Karlsruhe
(European Commission)

KIT

POLIMI

POLITO



MSR activities at JRC

- MSR activities at JRC since 2002

- permanent member of GIF MSR PSSC (EURATOM representative)
(MoU signature in 2010)

JRC role is to: support member states (NL, FR, CZ, IT)
safety assessment of MSR
no reactor development

- Strongly supported by framework programmes of European Union

Successful MSR EU projects of the past:

MOST (3 years - 2002-2005)

ALISIA (1 year – 2007)

EVOL (3 years – 2010-2013)

SAMOFAR (4 years – Aug. 2015 – Aug. 2019)

SAMOFAR project

Ultimate aim: Develop nuclear energy which is truly inherently safe and produces no nuclear waste other than fission products

4 years (2015-2019) - 5 M€ (3.5M€ EC funding)

Parallel project submitted in Russia

Cooperation with China, Russia, USA, Mexico

- Deliver the experimental proof of the unique safety features of the MSFR
- Provide a safety assessment of the MSFR (nuclear reactor and chemical plant)
- Update the conceptual design of the MSFR
- Deliver a roadmap plus actions towards validation of the technology and demonstration of the reactor

SAMOFAR project

WP1 – Integral safety assessment

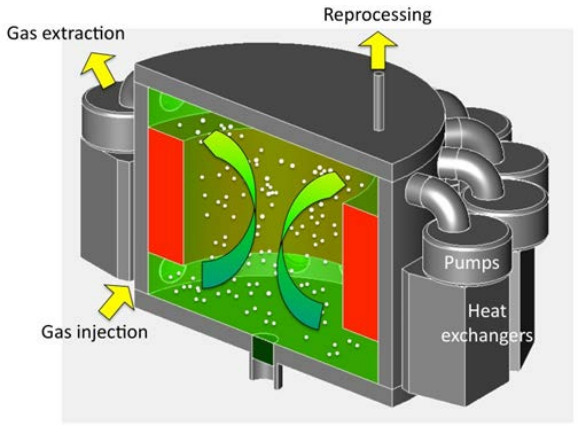
WP2 – Safety related data

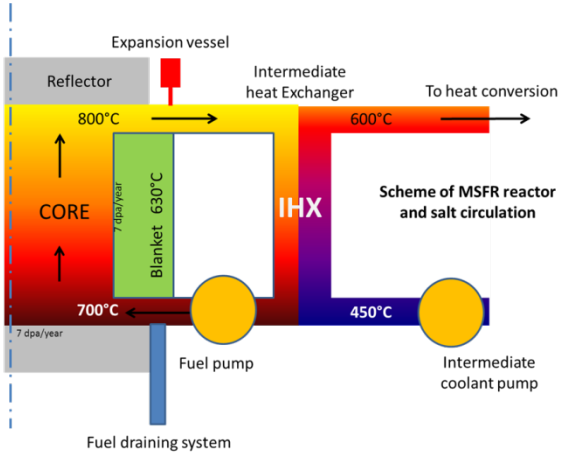
WP3 – Experimental validation

WP4 – Accident analysis

WP5 – Safety evaluation of chemical plant

WP6 – Dissemination and Exploitation





SAMOFAR project

Number	Organisation name	Country
1	Technische Universiteit Delft (TU Delft)	The Netherlands
2	Centre National de la Recherche Scientifique (CNRS)	France
3	JRC - Joint Research Centre- European Commission (JRC)	Germany
4	Consorzio Interuniversitario Nazionale per la Ricerca Tecnologica Nucleare (CIRTEN)	Italy
5	Institut de Radioprotection et de Sûreté Nucléaire (IRSN)	France
6	Centro de Investigaciony de Estudios Avanzados del Instituto Politecnico Nacional (CINVESTAV)	Mexico
7	AREVA NP SAS (AREVA)	France
8	Commissariat a l'Energie Atomique et aux Energies Alternatives (CEA)	France
9	Electricité de France S.A. (EDF)	France
10	Paul Scherrer Institute (PSI)	Switzerland
11	Karlsruher Institut für Technologie (KIT)	Germany

Uniqueness:

JRC Karlsruhe is one of the very few facilities being able to measure high temperature properties of actinide containing fluoride salts.

This provides a significant support to other EU partners dealing with the design and safety assessments of MSR concepts.

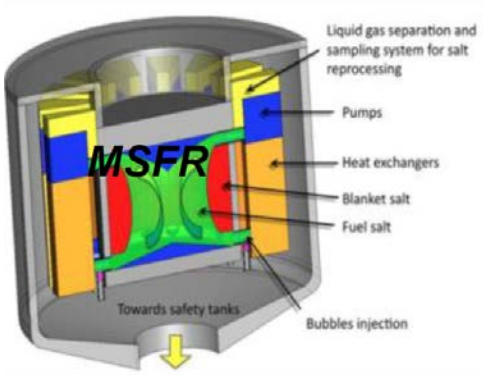
- WP leader of SAMOFAR (experimental data)

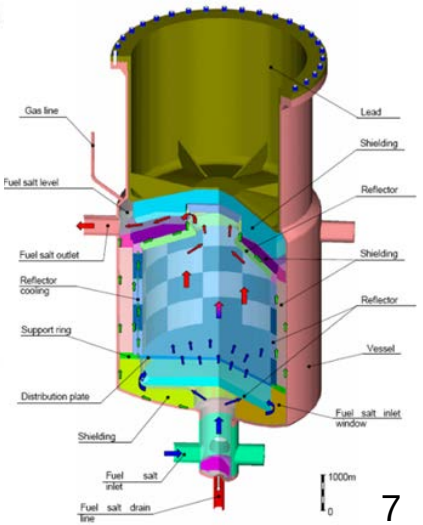
Main concepts studied:

MSFR (EU reference concept)

MOSART (Russian concept)

MSBR (TMSR) (traditional ORNL and Chinese concept)





overview of MSR activities ITU

Basic electrochemical studies of actinides and Ln in molten **fluoride and chloride** media

Synthesis and purification of **An and Ln halides**

Demonstration of **pyrochemical separation** methods for **irradiated materials**

MSR research at JRC

High temperature properties of **An halides** and mixtures
- phase diagrams
- melting points
- vapour pressure
- heat capacity

RAMAN spectroscopy of molten salts

Combined **electrochemistry – spectrometry** (uv-vis, RAMAN, TRLF) of **An chlorides** (and fluorides)

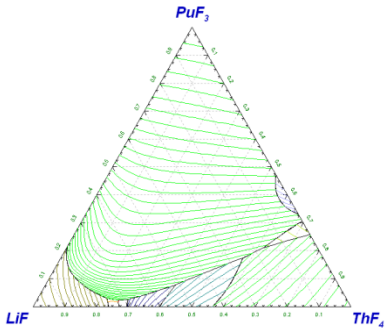
NMR high temperature probe for **molten salts**

3 domains of MSR research at JRC-ITU

Fuel synthesis / purification + Electrochemistry

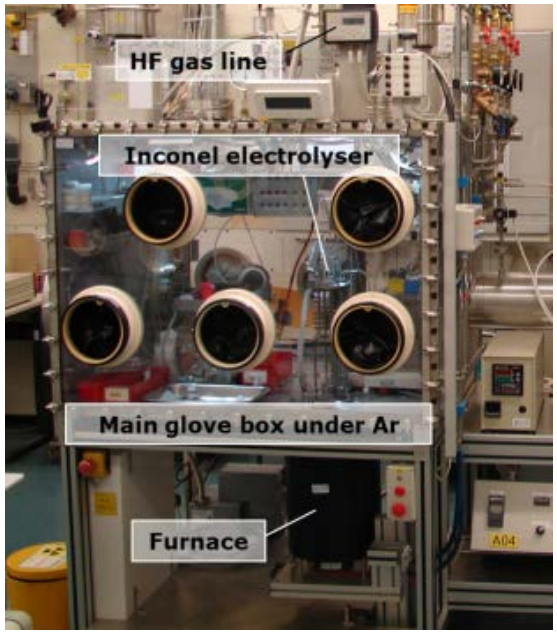
High T properties

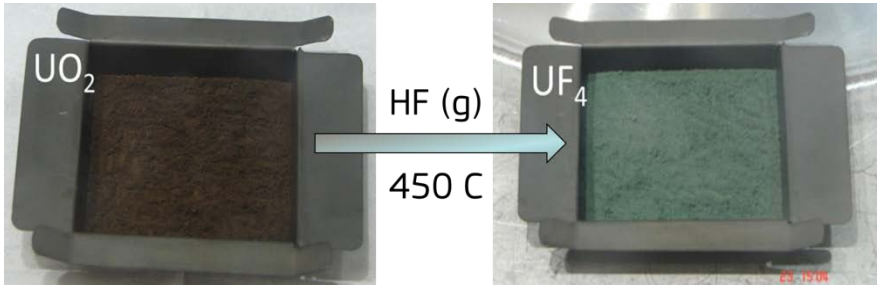
Thermodynamic (CALPHAD) modelling

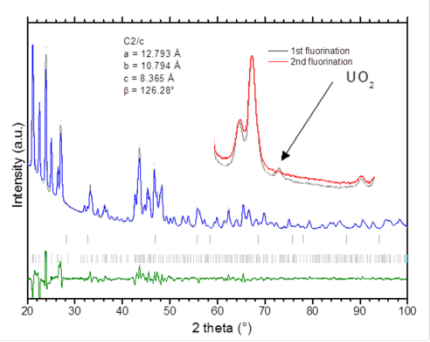


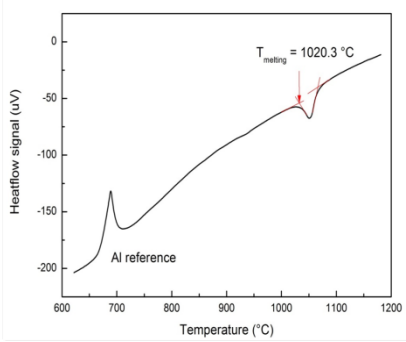
Synthesis & Purification

- Argon GB dedicated to fluoride chemistry
- HF gas line + Inconel fluorination reactor (up to 1200°C)
- ThF_4 and UF_4 synthesised from ThO_2 and UO_2 with very high purity
- UO_2 + HF(g) → UF_4 + H_2O
- XRD pure and m.p. pure (DSC)









Synthesis of 2 salts for SALIENT

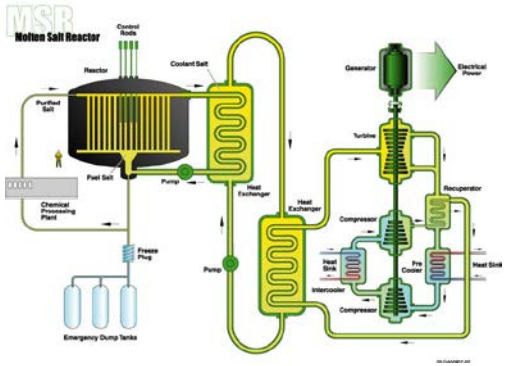
MSR properties

For the MSR design:

- Neutronic properties
- Melting temperature
- Heat capacity
- Vapour pressure
- Actinide solubility
- Chemical stability to high T
- Density and Viscosity
- Thermal conductivity
- Stability to radiation

Thermochemistry

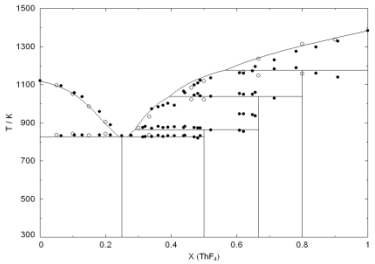
SAMOFAR



MSR properties

In the last decade ITU has developed an expertise in determination of High temperature properties of An fluorides and mixtures

Phase diagrams



Melting points

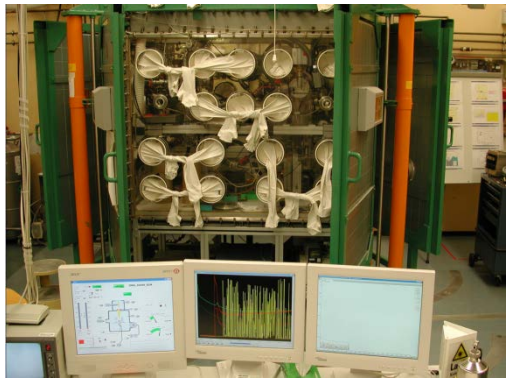
Heat capacity

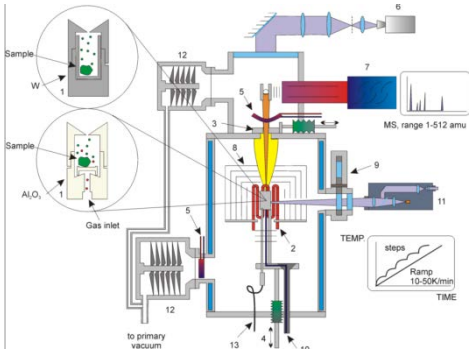
Solubility of An

Drop and DSC calorimeters
up to 1800 K

Vapour pressure

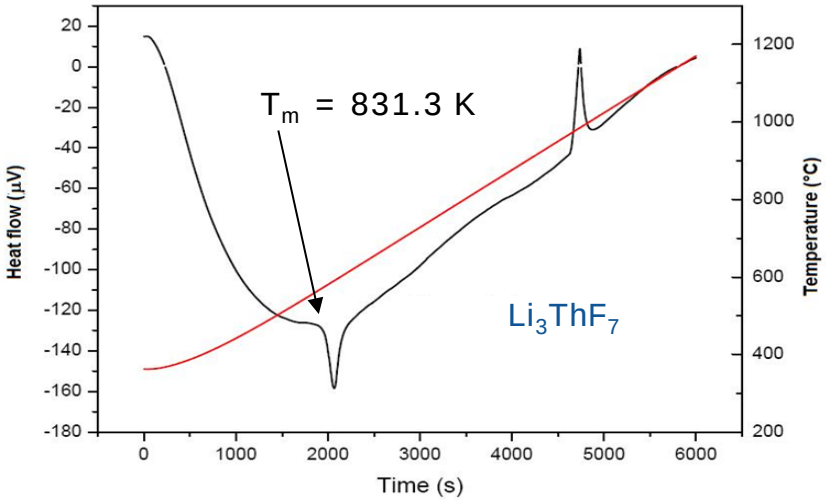
Knudsen cell with MS
up to 2800 K



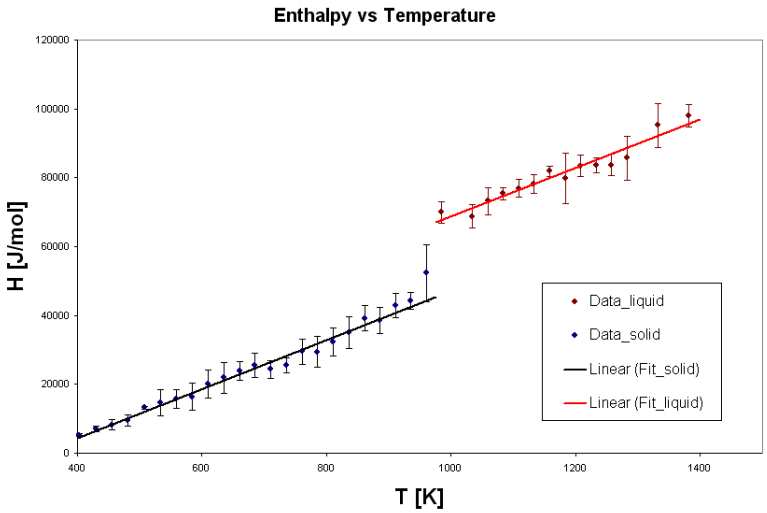


MSR properties

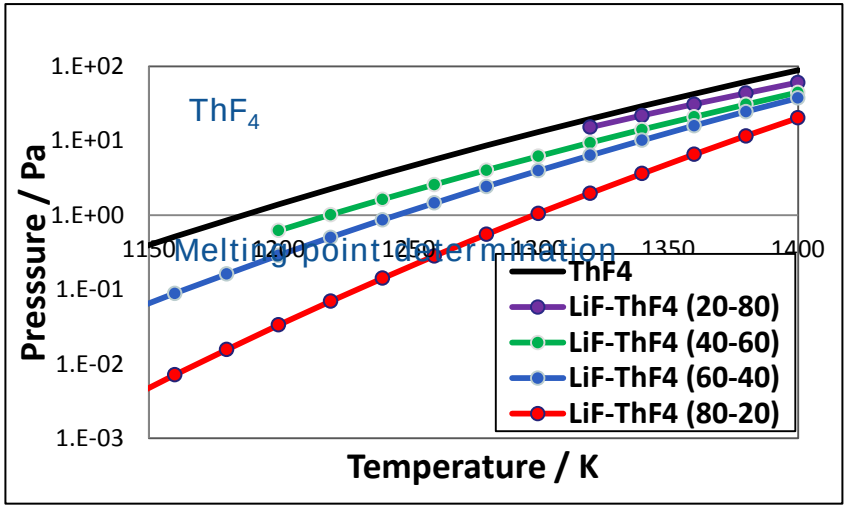
Melting point determination



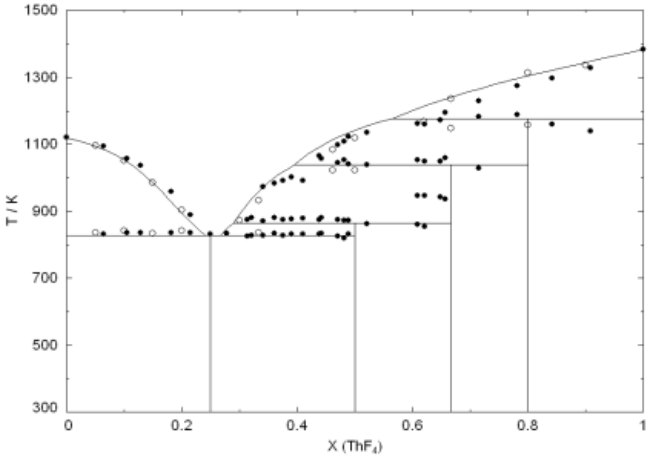
Heat capacity determination



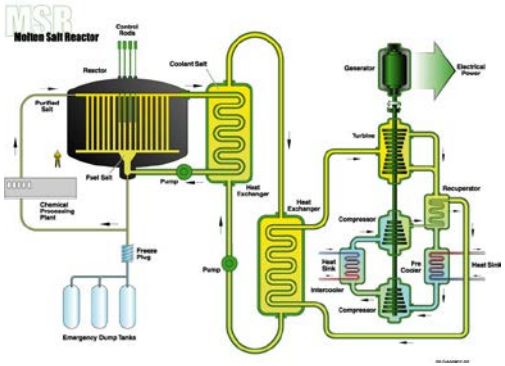
Vapour pressure



Phase equilibrium data



For MSR design:



- Neutronic properties
- Melting temperature
- Heat capacity
- Vapour pressure
- Actinide solubility
- Chemical stability to high T
- Density and Viscosity
- Thermal conductivity
- Stability to radiation

Thermochemistry

Thermodynamic modelling
(all properties linked to Gibbs energy)

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Thermodynamic database

1. Optimization of the MSFR concept

Initially proposed fuel:

LiF-ThF_4 eutectic (78-22 mol%) + PuF_3 (5 mol%)

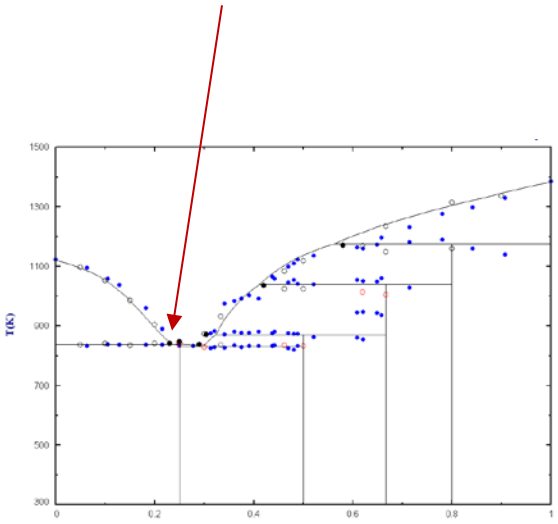
but ....

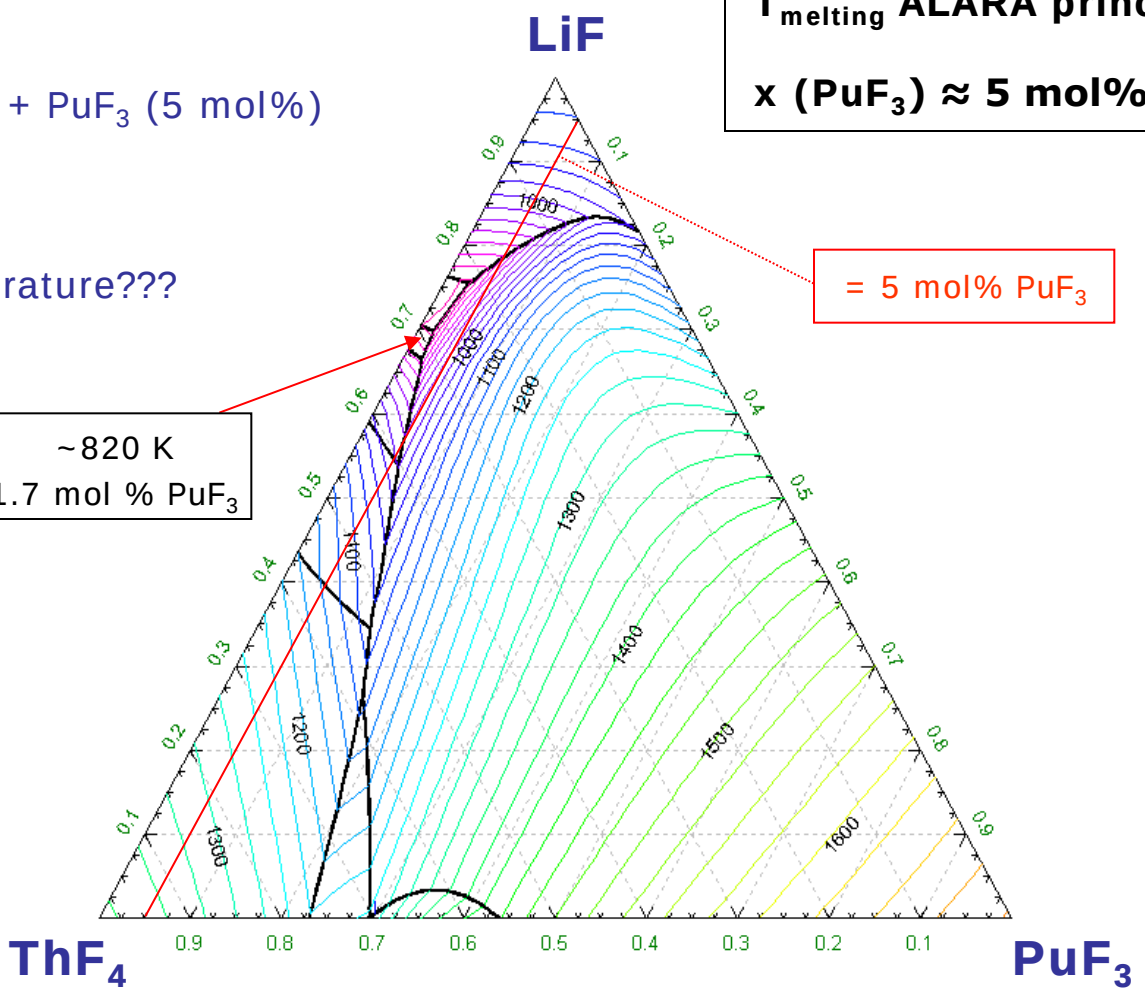
is this the lowest melting temperature???

Selection criteria:

$T_{melting}$ ALARA principle

x (PuF_3) ≈ 5 mol%





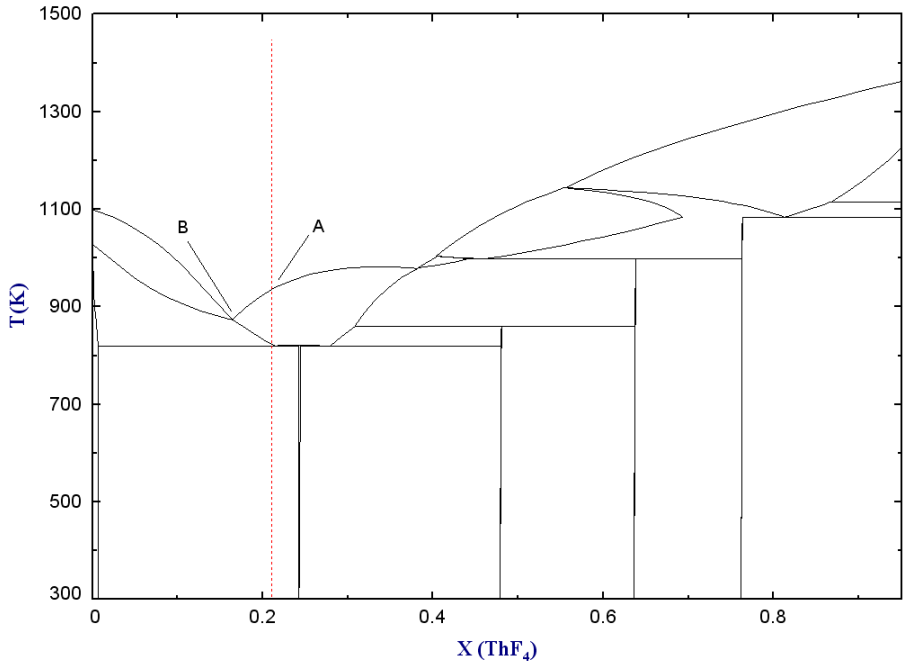
1. Optimization of the MSFR concept

Reference system of the MSFR
$LiF\text{-}ThF_4\text{-}PuF_3$ (74-21-5 mol%) … solvent is $LiF\text{-}ThF_4$ (78-22)
- liquidus point is **935 K** (662 ° C)
- inlet temperature is 980 K (712 ° C) (50K margin)

Point A

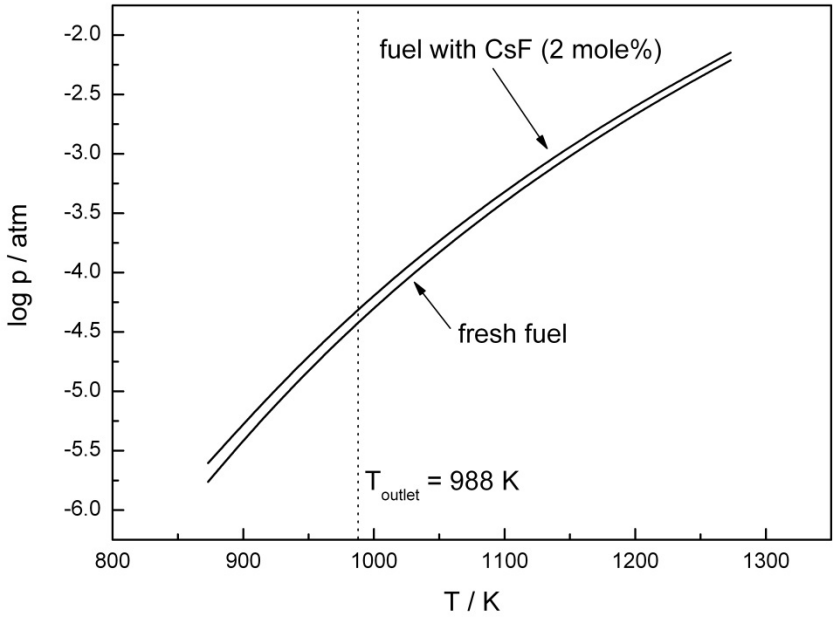
Point B

$LiF\text{-}ThF_4\text{-}PuF_3$ (78.6-16.4-5 mol%)
- liquidus point is **873 K** (600 ° C)
- inlet temperature is 923 K (650 ° C) (50K margin)

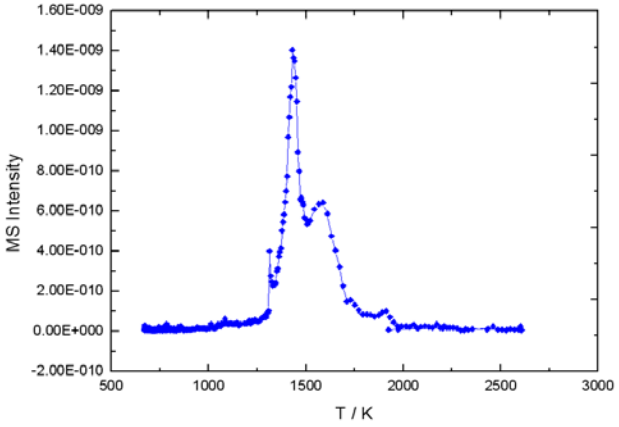


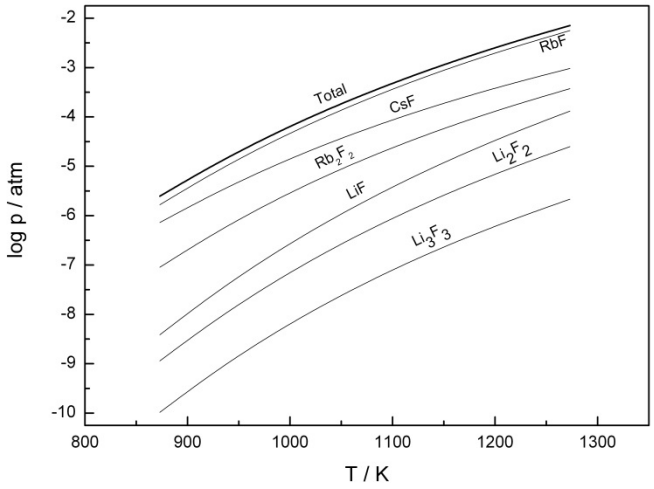
1. Fission product influence on MOSART fuel

Case of LiF-RbF-PuF_3 (43.9-54.8-1.3) fuel
(alternative of MOSART fuel, m.p. 744 K)



Cs realease from MOX





Thermodynamic database

ITU Salt Database: (46 binary systems)

	LiF	NaF	KF	RbF	CsF	BeF_2	CaF_2	LaF_3	CeF_3	ZrF_4	ThF_4	UF_4	PuF_3	UF_3
LiF		X	X	X	X	X	X	X	X	X	X	X	X	X
NaF			X	X	X	X	X	X			X	X	X	X
KF				X	X		X	X					X	
RbF					X			X					X	
CsF								X					X	
BeF_2										X	X	X	X	
CaF_2								X			X			
LaF_3													X	
CeF_3											X	X		
ZrF_4														
ThF_4												X	X	
UF_4													X	X
PuF_3														
UF_3														

Fuel types one can fully describe:

$LiF–BeF_2–NaF–PuF_3$

$LiF\text{-}NaF\text{-}KF\text{-}RbF\text{-}CsF\text{-}LaF_3\text{-}PuF_3$

$LiF\text{-}NaF\text{-}BeF_2\text{-}UF_4\text{-}ThF_4$

$LiF\text{-}NaF\text{-}UF_3\text{-}UF_4$

$LiF\text{-}ThF_4\text{-}UF_4\text{-}PuF_3$

Properties of fuel concepts such as **MSFR**, **MSBR**, **MOSART** can be optimized/predicted

Database most likely provided through bilateral contracts (non-disclosure)

Summary

- Quite significant activities in MSR program in EU (Euratom+France signatories of GIF MoU)
- EU MSR reference concept – MSFR
- MSR research driven by national and EU projects (currently running SAMOFAR)
- Several start-up companies in EU (Moltex, Copenhagen Atomics …)
- International collaborations (out of EU) extremely important to support EU MSR program
- JRC Karlsruhe a world unique place to obtain experimental data on fuel salt systems