

Molten Salt Reactor-Related Research at the EC-Joint Research Centre and activities supported by EC/EURATOM

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European Commission, Joint Research Centre (JRC), Karlsruhe, Germany

**Joint IAEA-NEA-EC/JRC Workshop on the Taxonomy and Related
Terminology of Fuel Cycles for Molten Salt Reactors**

IAEA Headquarters, Vienna, Austria

3 - 7 November 2025

SCOPE

1. Introduction of Joint Research Centre
2. JRC role in MSR research
3. JRC MS Reference Data Centre
4. EURATOM MSR research programs



JRC – Joint Research Centre

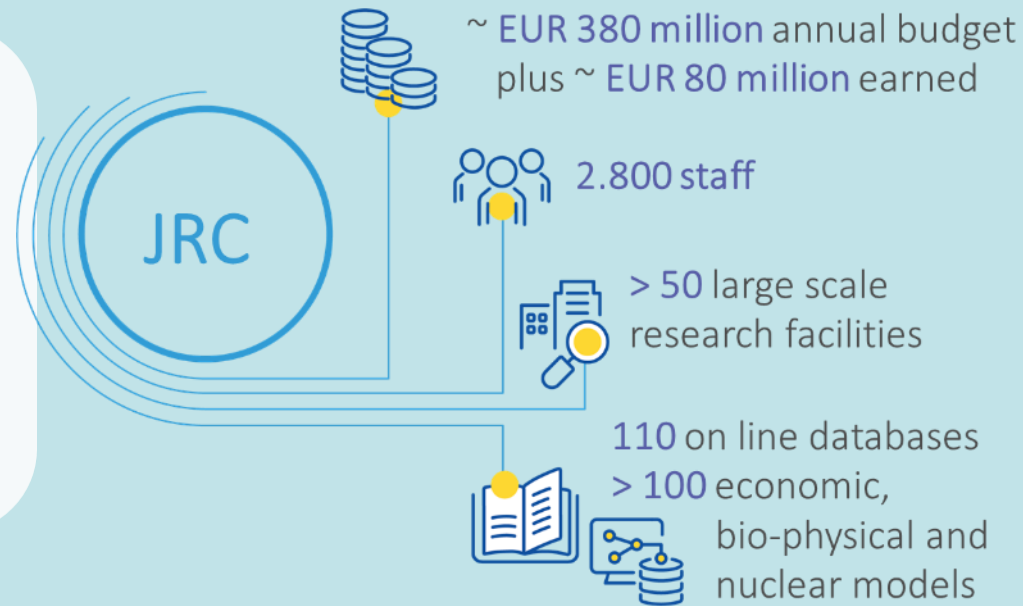
Directorate General of the European Commission

Science for policy

Purpose of JRC

The Joint Research Centre provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society.

Independent of private, commercial or national interests



Headquarters in Brussels

Research facilities in 5 EU countries:

- Belgium (Geel)
- Germany (Karlsruhe)
- Italy (Ispra)
- The Netherlands (Petten)
- Spain (Seville)

Directorate G - Nuclear Safety and Security

Mission

- European Commission's primary **hub for nuclear safety and security research**
- Implementing the EURATOM Research and Training Programme

Infrastructure and Facilities at JRC Karlsruhe

- **Hot Cells:** 24 shielded hot cells for handling and examining highly radioactive materials including irradiated nuclear fuel.
- Remotely operated **shielded glove box laboratories: Minor Actinides Laboratory**
- **Glove box laboratories:** ~200 glove boxes for handling non-irradiated but radioactive materials

Key research areas

- **Nuclear Materials and Fuel Cycle:** Studying the behavior of commercial and advanced nuclear fuels and materials under irradiation to enhance reactor safety and efficiency
- **Nuclear Safeguards and Forensics:** Conducting research to prevent the proliferation of nuclear weapons and to ensure the peaceful use of nuclear materials
- **Nuclear Safety and Security:** Developing measures to protect against nuclear accidents and to secure nuclear materials from illicit trafficking
- **Targeted alpha therapy:** alpha-emitting isotopes for cancer treatment

JRC role in MSR research

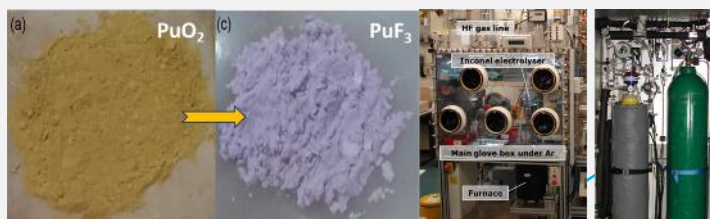
Joint Research Centre is:

- reference center for Thermo-physical and chemical data of MSR fuels
- developer of Thermodynamic Molten Salt Database (JRCMSD)
- carrying out electrochemical studies (reprocessing, redox control)
- providing fuel mixtures for irradiation experiments
- performing Post Irradiation Examinations
- investigating fuel behavior under accidental conditions (high T, FP behavior etc.)



JRC MS Reference Data Centre

Synthesis and purification of An and Ln fluorides and chlorides



Basic electrochemical studies of An in molten chloride and fluoride media and Pyrochemical reprocessing



High temperature properties of An-containing chloride and fluoride salts

- phase diagrams
- melting points
- heat capacity
- thermal conductivity
- density

(Drop and DSC calorimeters)



Corrosion studies of MSR construction material candidates in molten fluoride and chloride media

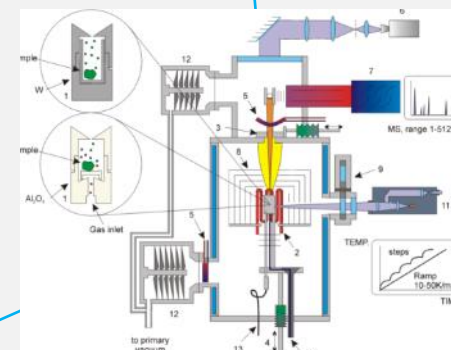
irradiation experiments SALIENT-01 and -03



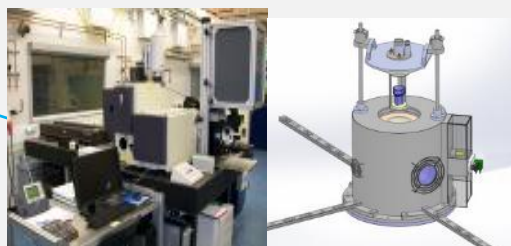
JRC MS Reference Data Centre

Vapor pressure of An-containing chloride and fluoride salts

(Knudsen cell up to 2800 K)



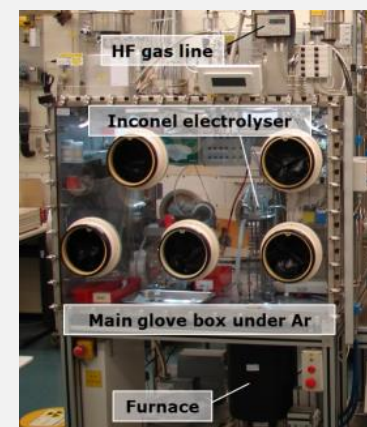
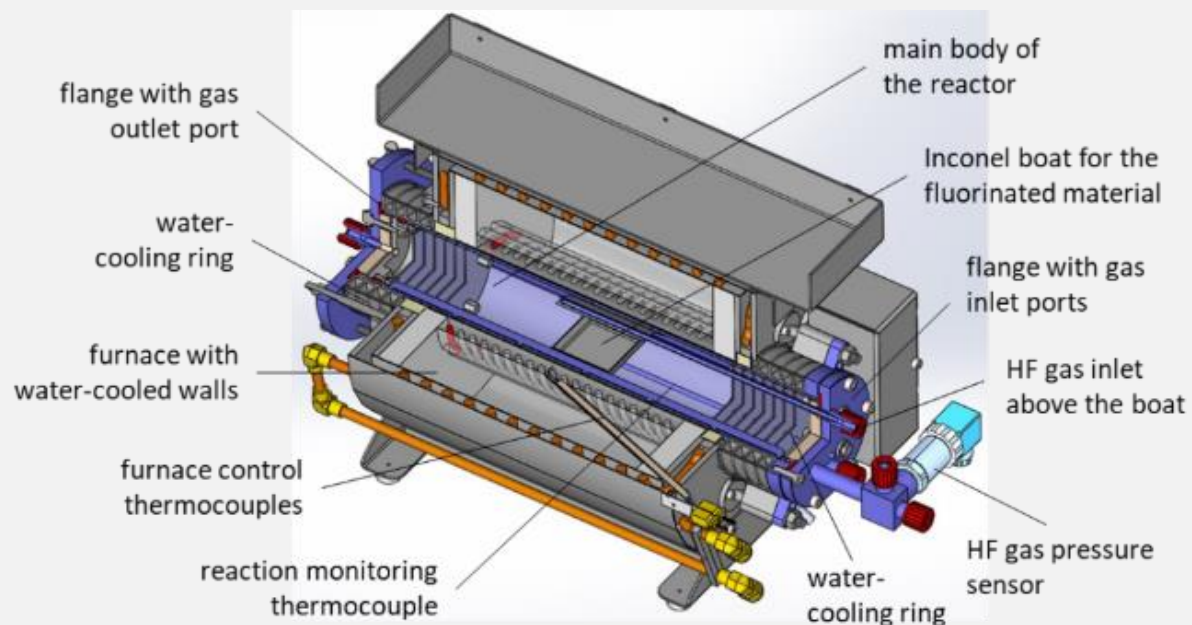
RAMAN spectroscopy of An-containing chloride and fluoride salts and combined electrochemistry-spectrometry of An-containing chloride salts



Synthesis of Actinides: Experimental set-up

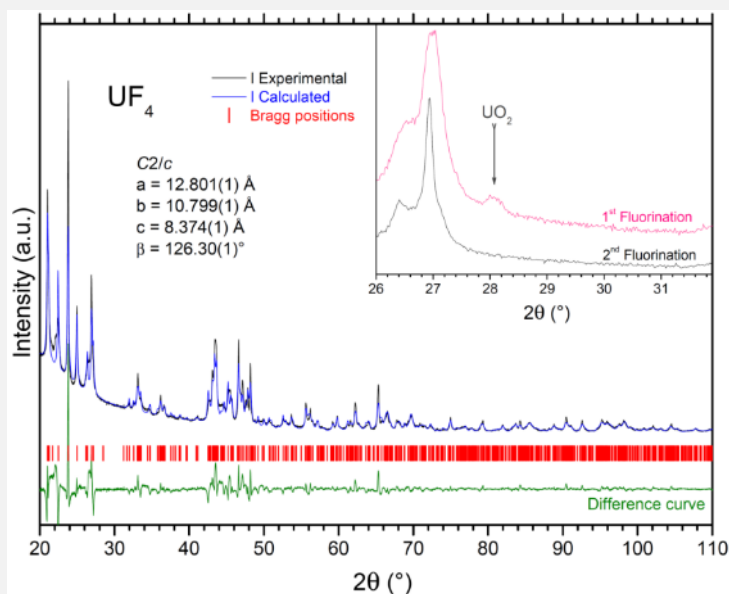
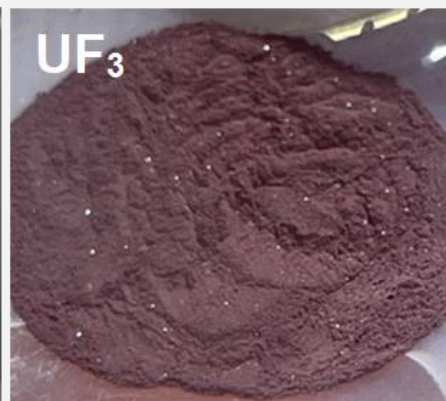
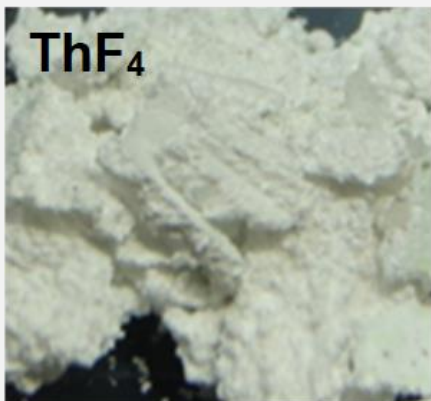
Ar glove box (O_2 , $H_2O < 5\text{ppm}$) connected with a pure HF gas line

Inconel fluorination reactor (up to 1200°C , up to 15 g batch, flow-through)



Europe-unique installation possibility to handle gram scale of higher actinides + pure HF gas

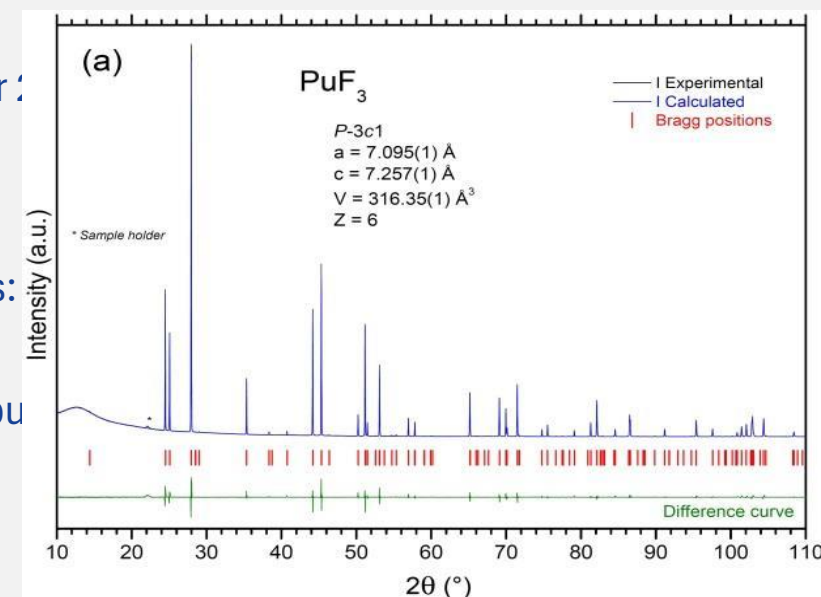
Synthesis of An fluorides: Achieved results



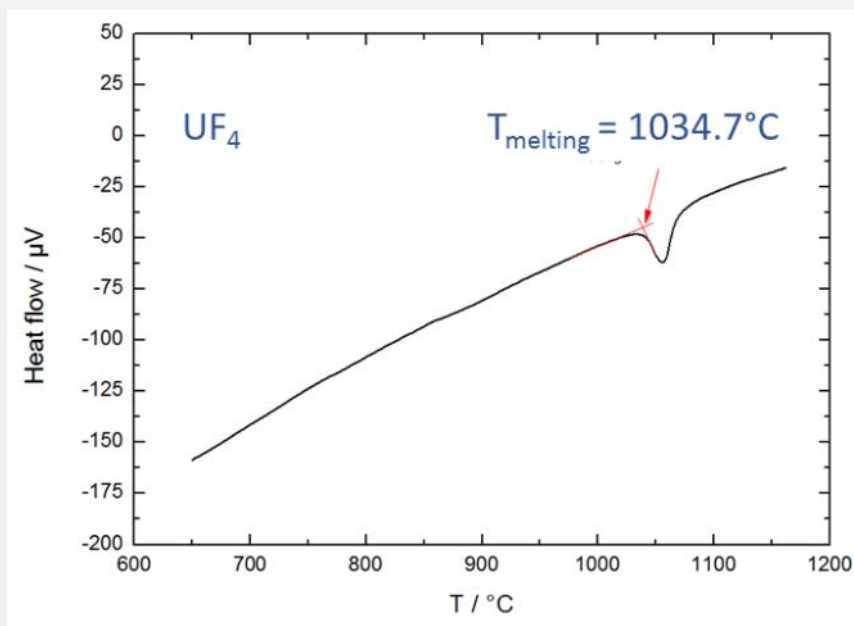
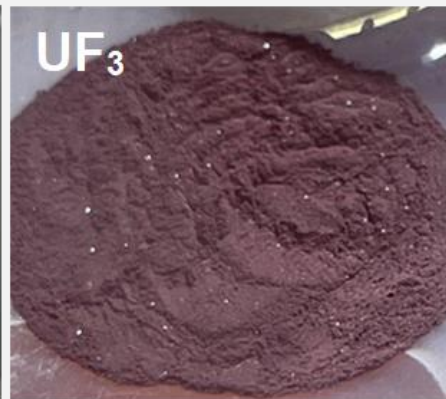
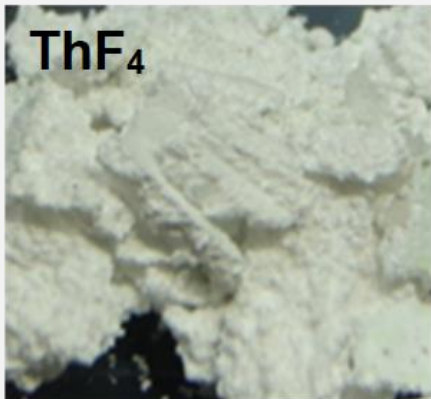
XRD: no evidence of remaining oxide after fluorination steps

Special case for AnO₂/AnF_x

- XRD is very sensitive to oxide impurities: region around 28.5° 2θ
- the most intensive diffraction of oxide but no diffraction of fluorides



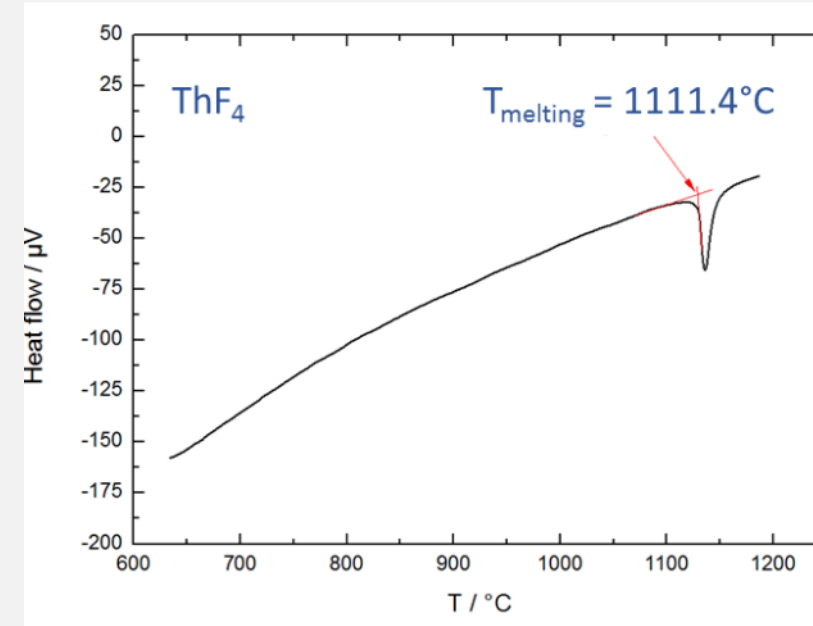
Synthesis of An **fluorides**: Achieved results



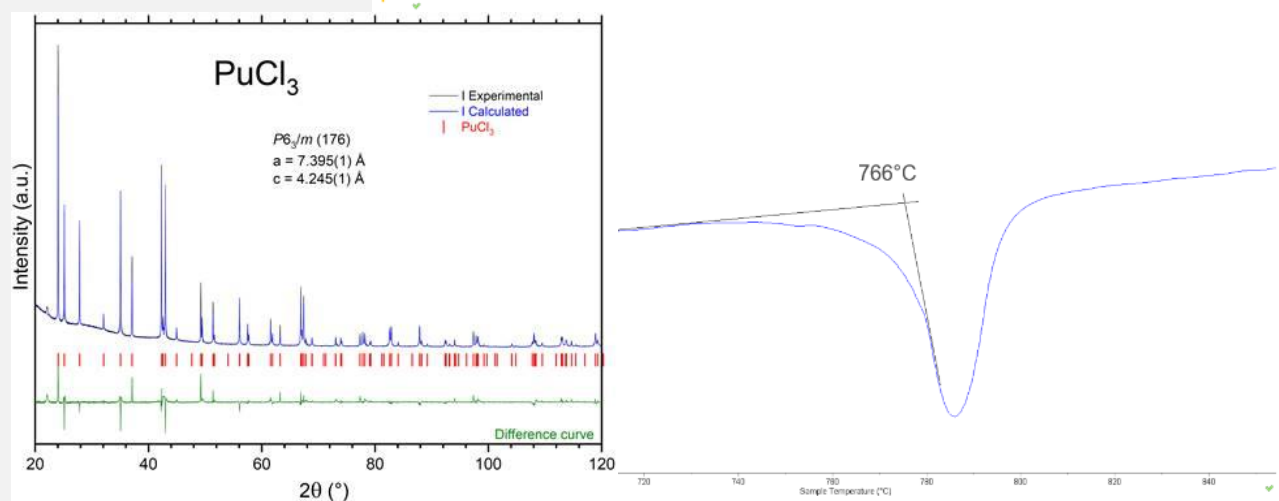
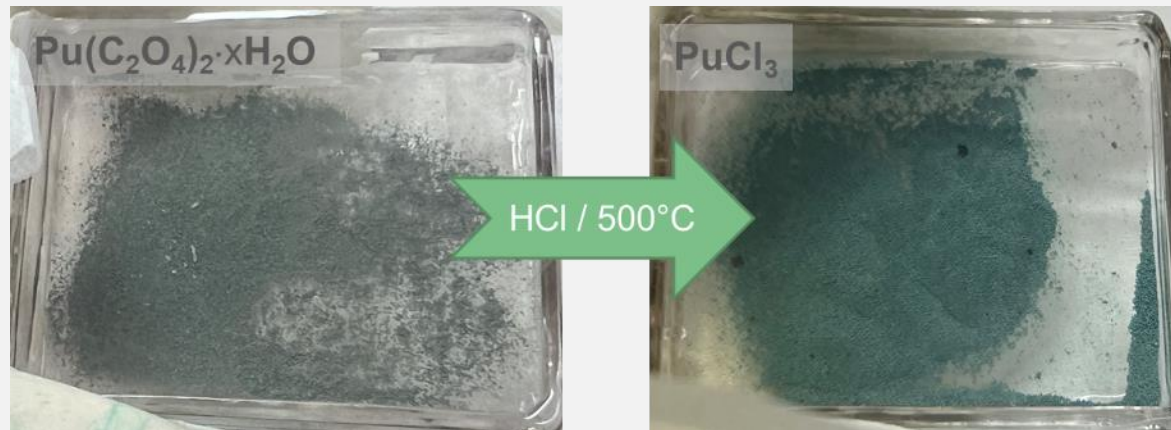
DSC: Melting point – very good indication of the purity

Heating / cooling curves with one single peak and no shoulders indicates purity of the phase

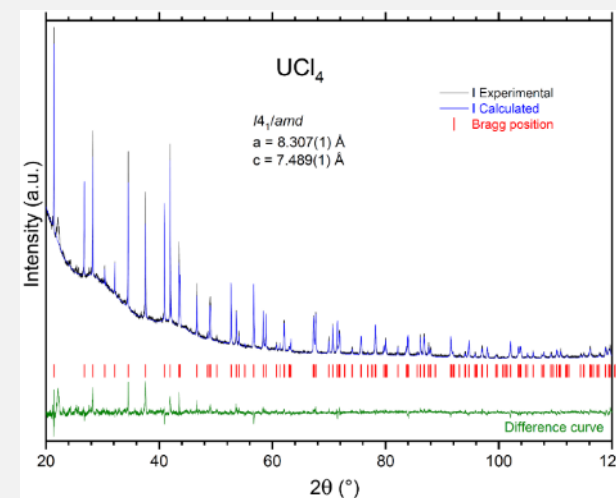
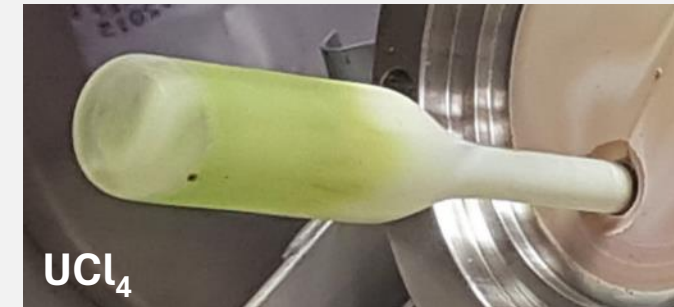
All fluorides achieved with purity >99% (no impurities detected)



Synthesis of An chlorides: Achieved results



PuCl_3 achieved phase pure and thermally stable
as proven by DSC on **pure compound**



UCl_4 synthesis to test the equipment: phase
pure compound achieved, but in mg scale,
purification by sublimation was necessary

High temperature properties of MSR fuels

We master :

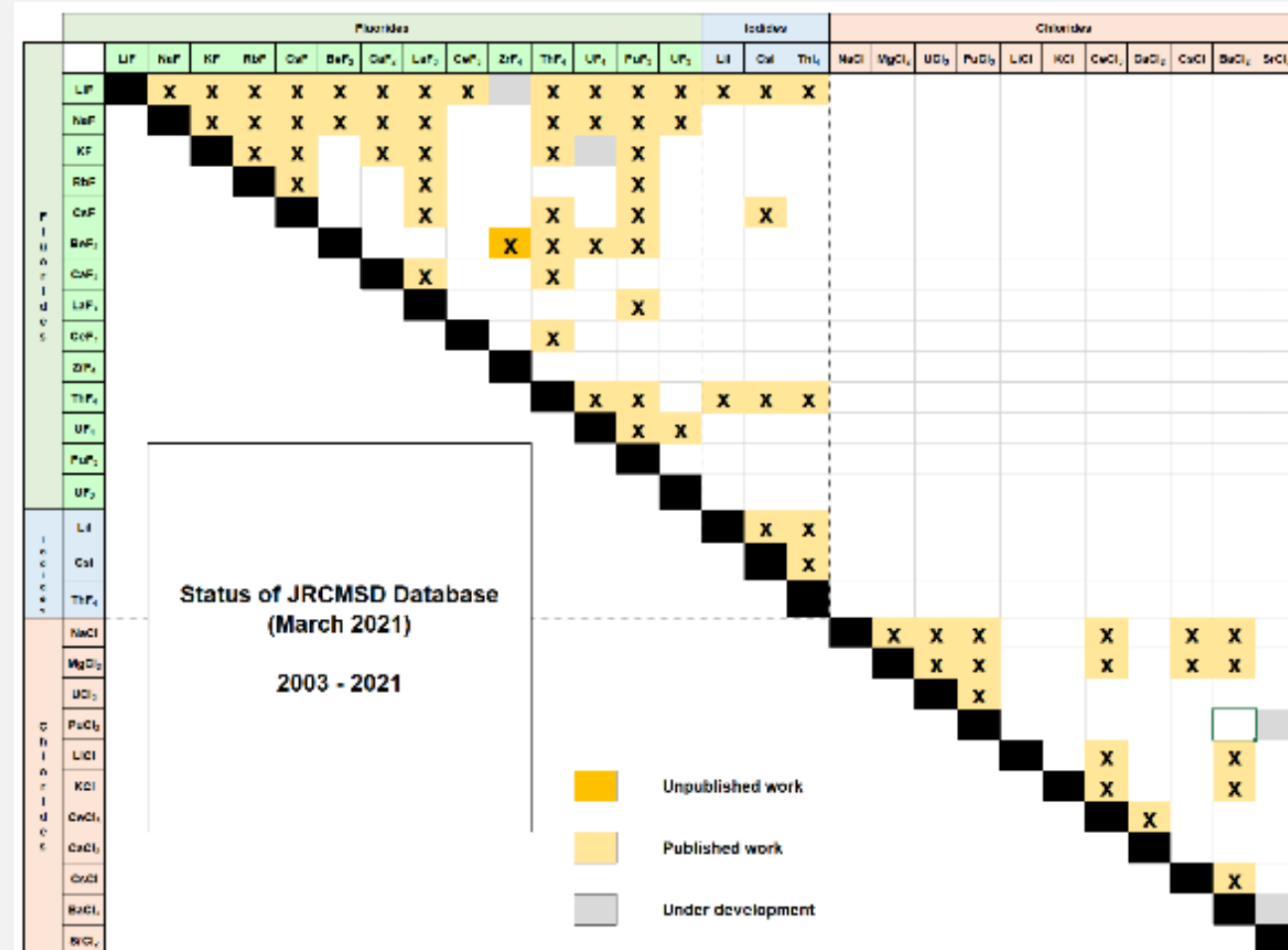
- synthesis of An fluorides and chlorides
- electrochemical studies
- melting points (FP effect)
- phase diagrams (exp. + modelling) (FP effect)
- vapour pressures (FP effect)
- heat capacity (FP effect)
- mixing enthalpy
- density
- FP release from fuel (PIE including)
- Irradiation studies (including safety assessments)

We own :

- JRC Salt Database

Under development :

- Raman studies – structure
- Thermal conductivity
- Viscosity
- Corrosion studies (ongoing)



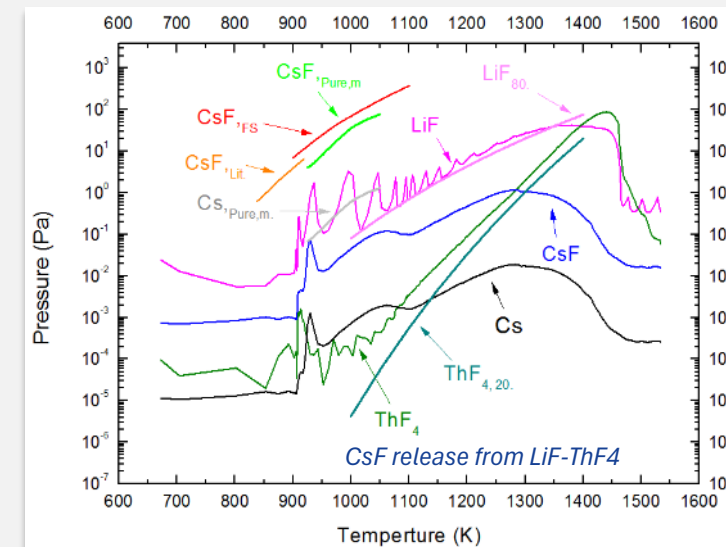
High temperature properties of MSR fuels

Highlights: Fission Product retention in the MSR fuel – KEMS measurements

- to demonstrate retention of FP in the fuel matrix
- to determine volatility of the fuel
- to determine thermodynamic stability
- to determine gas composition



Recent experiment: Cs behaviour in molten LiF-ThF_4



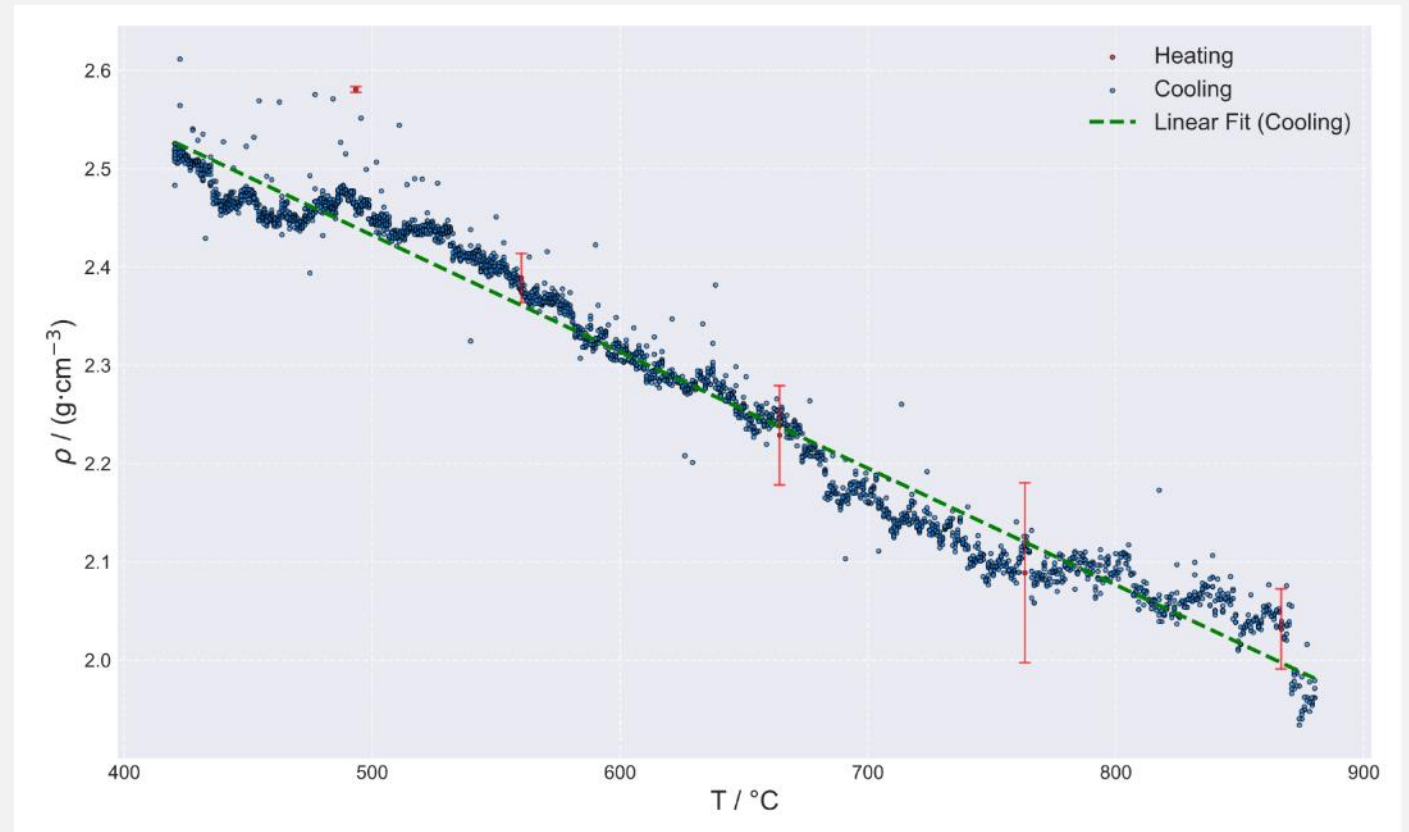
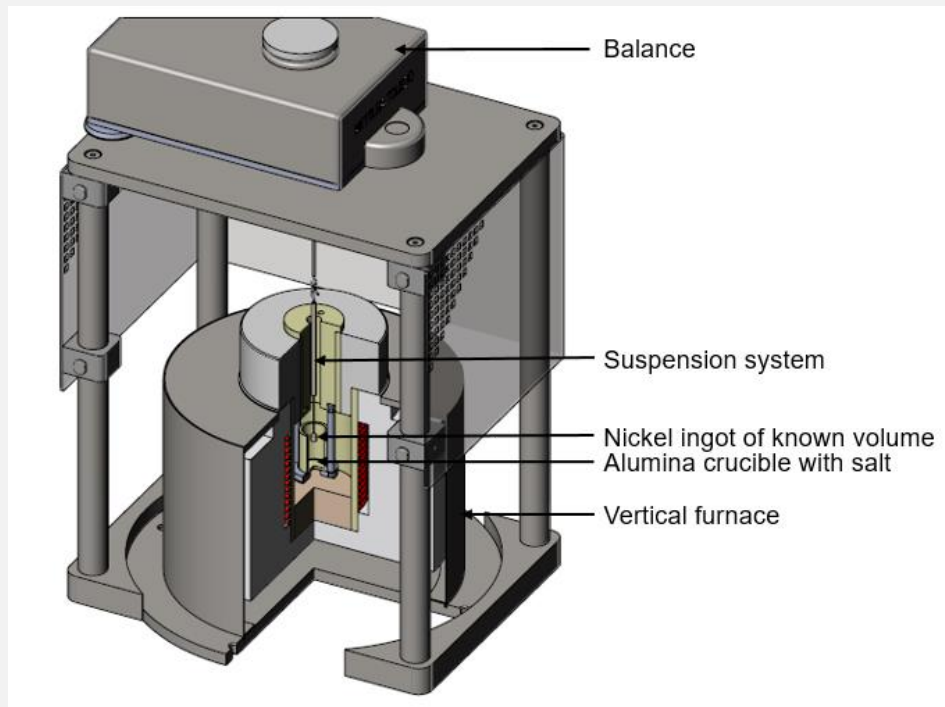
Conclusions:

- CsF dissolves and as consequence decreases volatility of Cs $>100000\times$ (ref. Elemental form)
- CsI is highly immiscible, but formation of CsI compound causes $\sim 3000\times$ lower volatility (ref. Elemental form)

High temperature properties of MSR fuels

Highlights: Density of molten $\text{NaCl-MgCl}_2\text{-PuCl}_3$

Composition: $\text{NaCl-MgCl}_2\text{-PuCl}_3$
(56.7-35.2-8.1) mol%



$$\rho_{\text{salt}} = (2.958 \pm 0.009) - (1.090 \pm 0.020) \cdot 10^{-3} \cdot T (^{\circ}\text{C})$$

High temperature properties of MSR fuels

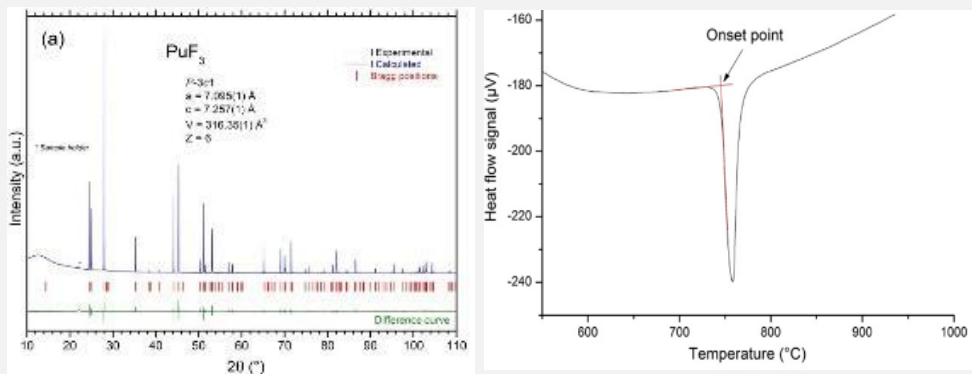
Highlights: Synthesis of fuel for irradiation experiments SALIENT-03

SALIENT-03 project (follow-up of SALIENT-01)

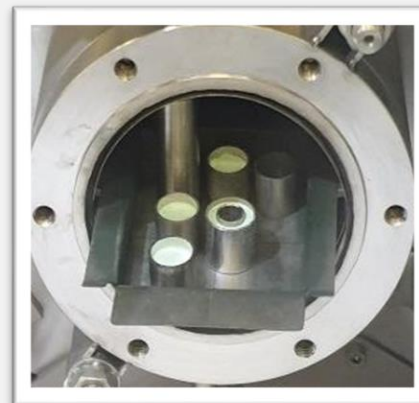
- 2nd European irradiation of molten salts at HFR, NRG, Petten (~5M€ project)
- Collaboration between JRC (KA, PT) and NRG
- ~100g of fuel mixture, encapsulation of plutonium fuel with no surface contamination)
- 4 different fuels (6 welded capsules) (${}^7\text{LiF}\text{-ThF}_4\text{-UF}_4\text{-UF}_3\text{-PuF}_3\text{-(CrF}_3\text{)}$ composition)

At JRC:

- Fuel synthesis and Encapsulation
- Safety analysis for HFR
- Post Irradiation Examination



Purity analysis of all end-members and fuel mixtures

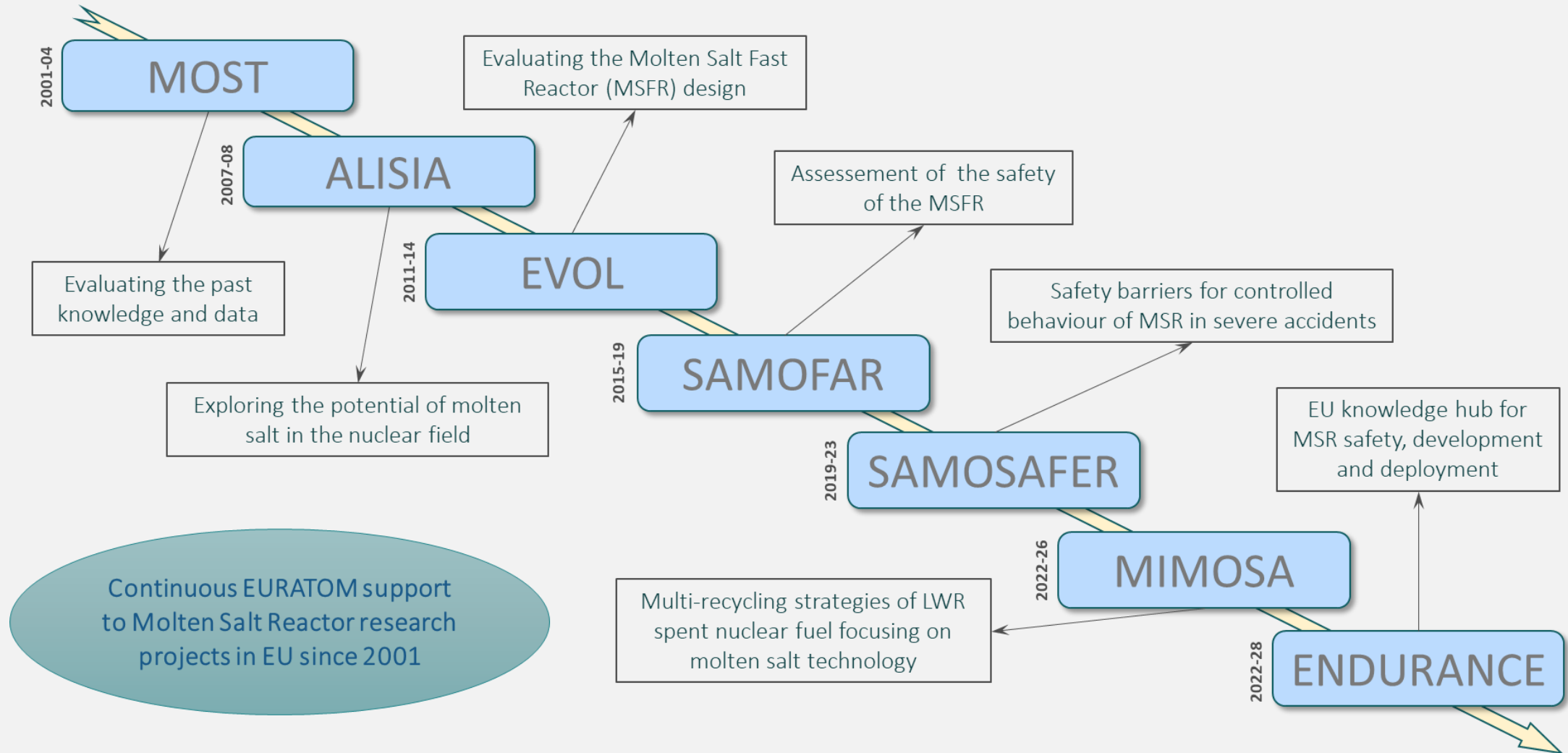


Densification of fuel by melting



Final ingots of fuel for SALIENT-03 irradiation experiment

EU Framework projects overview



MIMOSA

Multi-recycling strategies of LWR SNF focusing on MOlten SAlt technology

Project 101061142 – HORIZON-EURATOM-2021-NRT-01

Industrial multirecycling of Pu



Provision of innovative technologies



MSR research and innovation



MSR Fuel and Safety



Technical-economic assessment, scenario analysis, safety and security, non-proliferation



Development and exploitation of MSRs



Collaborative research management

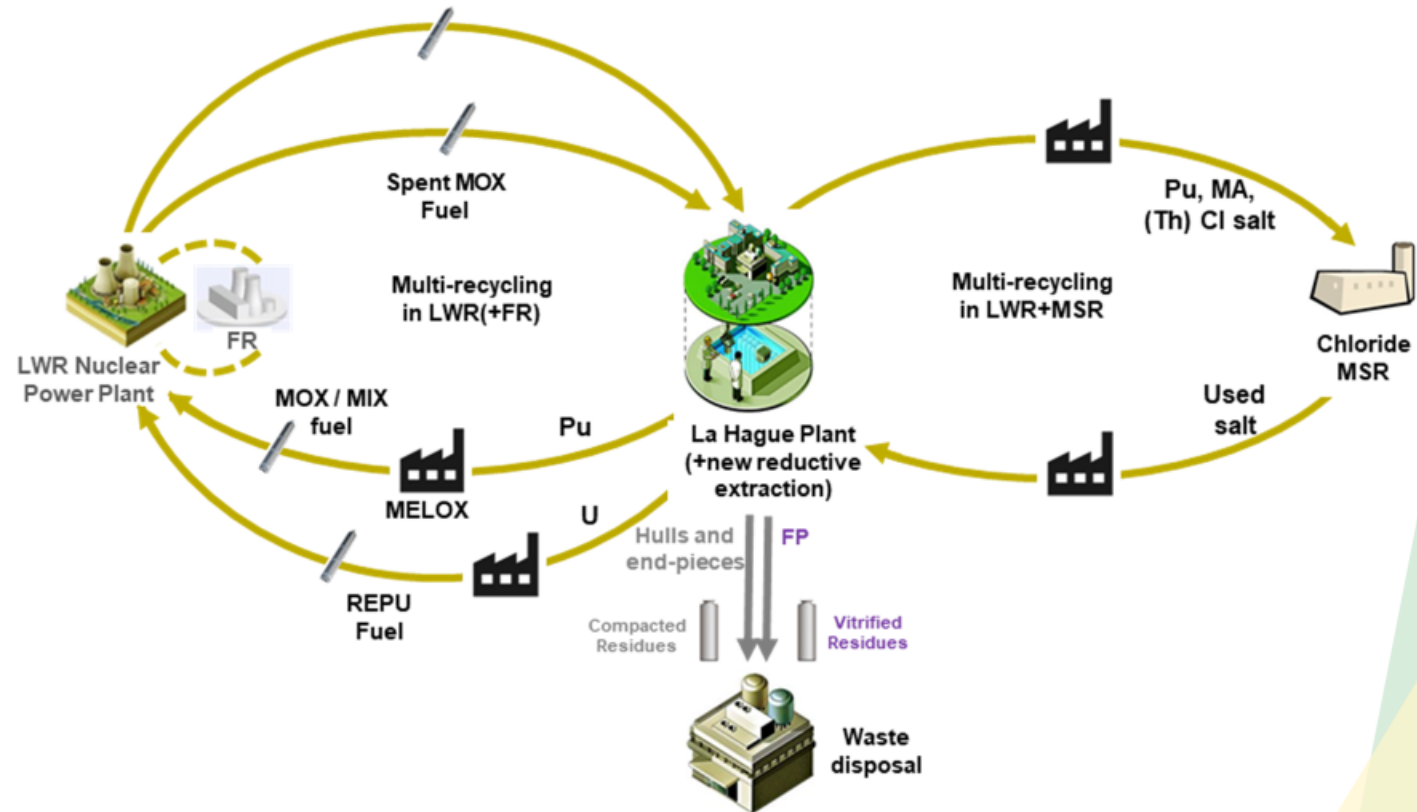




The objective of MIMOSA is to contribute to the development and deployment of MSR in the EU

MIMOSA aims to develop an **accessible and cost/risk optimized multi-recycling strategy of SNF from LWR in the EU** that:

- ✓ is based primarily on **multi-recycling of Pu and reprocessed U in LWRs**, combined with one of the most promising advanced nuclear energy systems, **Fast CI MSR**,
- ✓ **optimizes costs and risks** by using already available infrastructure in the EU such as the Orano reprocessing plant in La Hague (France),
- ✓ maintains and develops the EU's knowhow on the safe management of radioactive waste.



MIMOSA overall concept



Eu kNowleDge hUb foR enAbling molteN salt reaCtor safety development and dEployment

Grand objective of the ENDURANCE: “to support the safe operation and the technological development of Molten Salt Reactor (MSR) technology in Europe, through the knowledge advancement in different fields of MSR research and safety assessment, connecting the needs of reactor designers and industry with the university and research centre capabilities and the regulator requirements.”

Strengthen the European ENDURANCE on the MSR development

EU kNowleDge hUb

= involvement of EU stakeholders & connections among research, lab & industry to maintain EU leadership in MSR technology

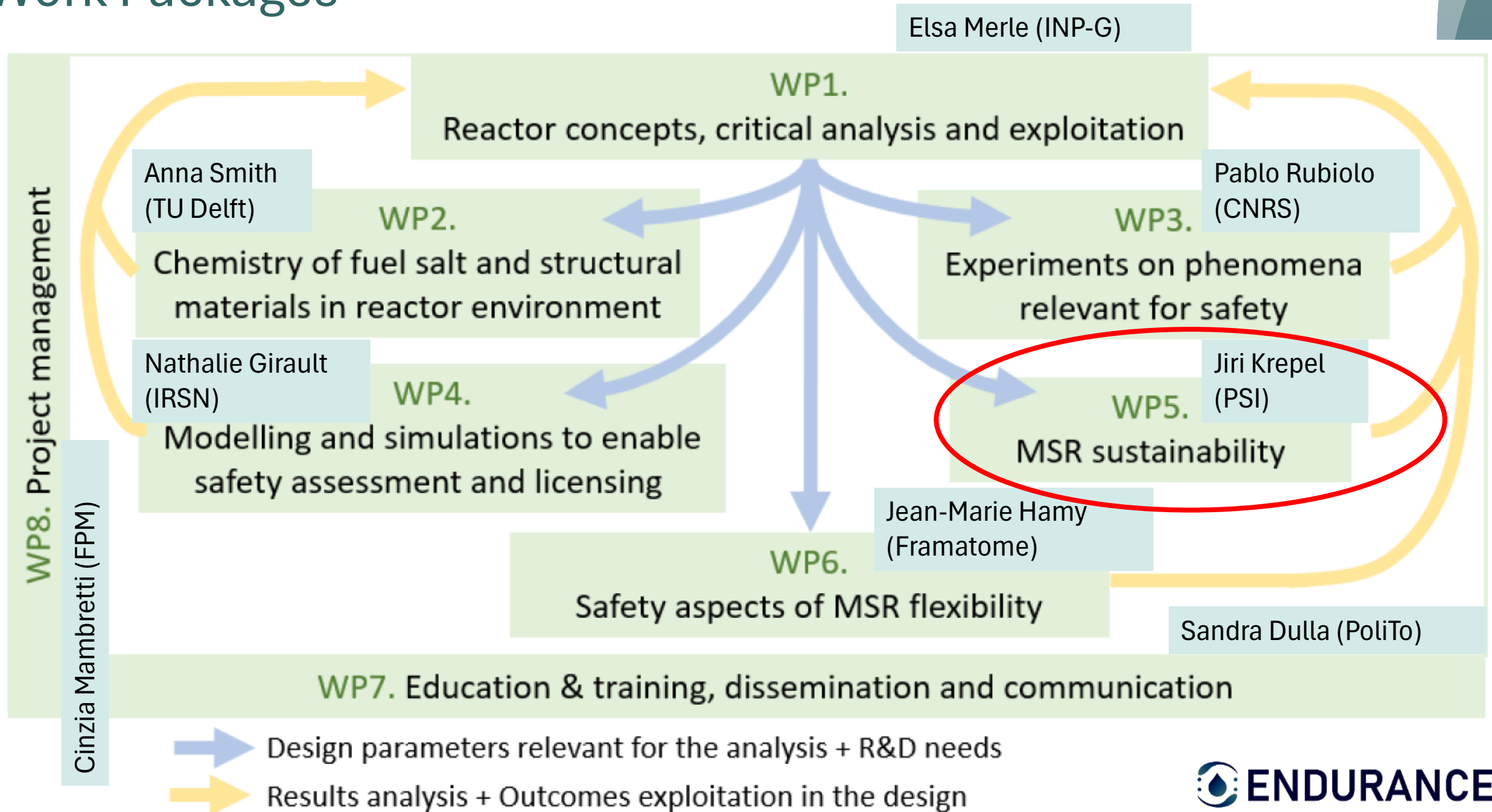
for enAbling MolteN Salt ReaCtor safety development and dEployment

= bring the MSR technology safety development from research (TRL 1-3) to development (TRL 4-6) and deployment (TRL 7-9)

Four years project. Starting date: October 1st 2024, **Budget:** ~4 mln €



Work Packages





WP5 “MSR sustainability”

The WP5 is aimed at contributing to the evaluation of the sustainability, proliferation resistance and safeguardability of the fuel cycle options and reprocessing schemes for MSR

WP5 Activities:

- providing standardized methods to preliminary assess sustainability of **fuel cycle performance** of MSR concept
- simulating the detailed **nuclides flow** inside the MSR system
- analysis of possible **salt clean-up and reprocessing techniques** to assess their efficiency, pace and proliferation resistance;
- assessing alternative **passive method for salt clean-up**;
- simulating the radionuclide releases from fuel salt during nominal condition and at elevated salt temperature
- evaluating the **proliferation resistance and safeguardability of different reprocessing schemes and fuel cycle options**



1st European Conference on MOLTEN SALT REACTOR TECHNOLOGY



Announcement

EUROMOST 26'

26.05. - 29.05.2026

Heidelberg, Germany

- 1st European Conference purely dedicated to MSR technology
- For all partners involved in the MSR field (researchers, industries, SMEs, regulators, standard organizations, government representatives, international organizations, etc.)
- Key topics include:
 - Reactor design and innovation
 - Materials science and fuel cycle technology
 - Thermal-hydraulics and safety analysis
 - Regulatory frameworks and deployment strategies



Thank you



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