NEA
NUCLEAR ENERGY AGENCY

Expert Group on Fuel Recycling and Waste Technology (EGFRW) - CRitical EvAluation of fuel Management during and after MSR operation (CREAMM)

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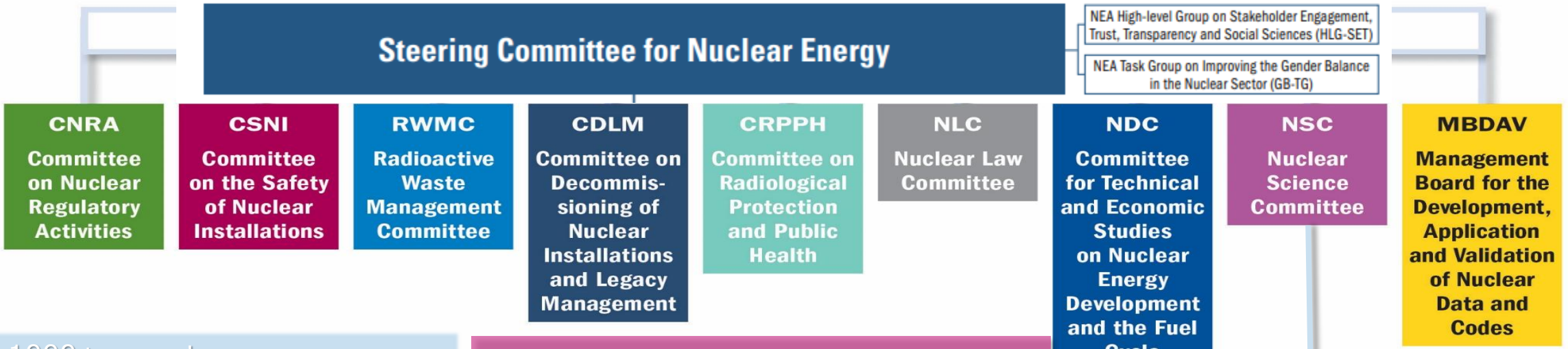
Joint IAEA/NEA/EC-JRC Workshop on the Taxonomy and Related Terminology of Fuel Cycles for Molten Salt Reactors, IAEA, 3-7 November 2025

Nuclear Science Committee activities

NSC helps member countries identify, collect, compile, develop, preserve and disseminate the basic scientific and technical knowledge required to ensure the safe, reliable and economic operation of current and next-generation nuclear systems and to promote innovation.



- 1000+ experts
- 5 Working Parties/ 20+ Groups
- 7 databases
- 20+ benchmark studies
- 10+ publications/year
- 10+ workshops/year
- 6 joint projects
- The Global Forum

- Reactor physics and transient studies
- Radiation shielding
- Fuel cycle physics and chemistry
- Fuel and material science
- Nuclear criticality safety
- Nuclear data
- Nuclear knowledge management, education and training

Division of Nuclear Science and Education

Working Party on Scientific Issues of Advanced Fuel Cycles (WPFC)

Chair:
Nathalie Chauvin (CEA)
Mandate:
2024-2026
Focus:
Metal and Oxide fuel properties and performance
Highlights:
- Fuel properties report sent for publication
- Phase-II fuel performance benchmark calculations completed
- Phase-II fuel properties launched

Chair:
Paul Schuurmans (SCK-CEN)
Mandate:
2024-2026
Focus:
HLM and Na : coolant properties and interactions with components
Highlights:
- SOAR draft progress – expected completion in 2025
- HLM handbook update launched
- Data base on Na and HLM properties launched

Chair:
Francesco Álvarez-Velarde (CIEMAT)
Mandate:
2024-2026
Focus:
Advanced fuel cycle scenarios
Highlights:
- TRU management report draft near completion – 2025
- Tripling nuclear capacity activity launched

Chair:
Pavel Souček (EC-JRC)
Vice-Chair:
Mike Edmondson (UKNNL)
Mandate:
2024-2026
Focus:
Advanced separation techniques and MSR chemistry
Highlights:
- Recycle & Reuse repot -Published
- Solvent extraction codes benchmark continuing
- **CREAMM activity** launched

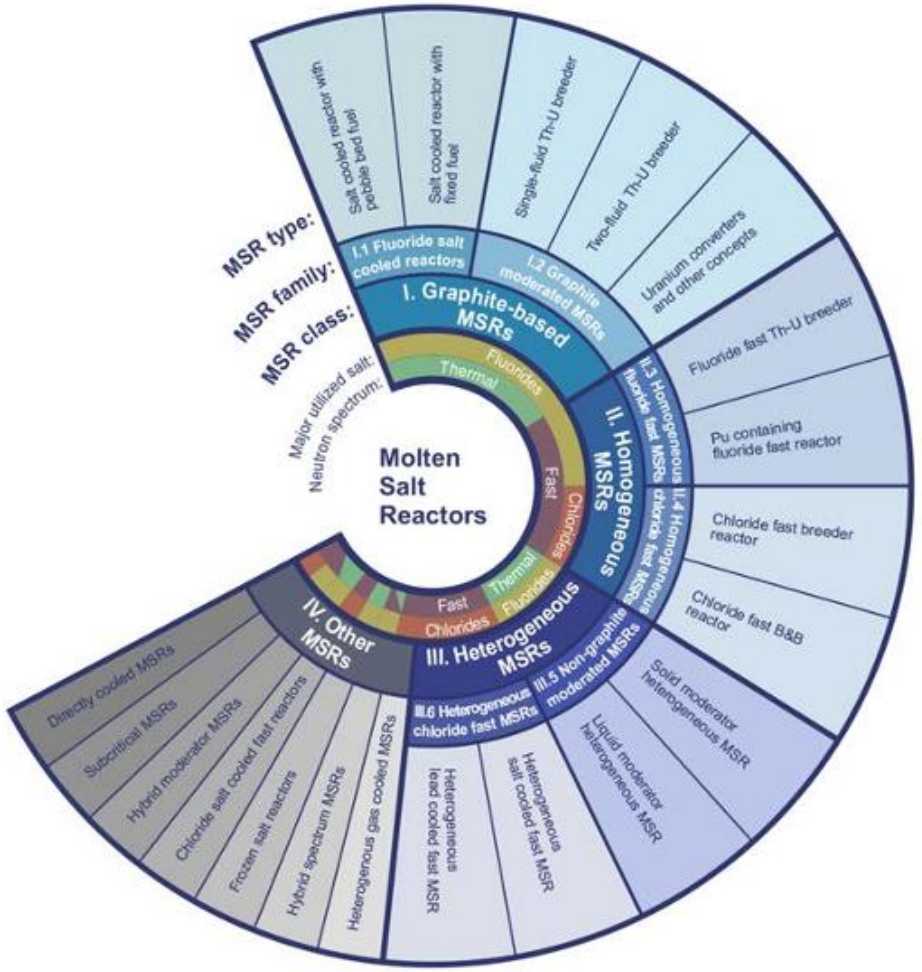
CREAMM - Overview

Background:

- Treatment of MSR fuel during and after irradiation is critical for MSR operation and licensing
- Area has seen limited development, requiring increased awareness and prioritization
- Activity officially launched in April 2025

Key Challenges

- **Terminology:** Align the current MSR fuel cycle terminology against standard set
- **Gaps in isotope removal and recycling (if considered) research:** Identifying gaps necessary to drive R&D in related to this field
- **Waste treatment:** Develop suitable waste treatment and waste products



Source: "Status of Molten Salt Reactor Technology" IAEA, Technical reports series no. 489

CREAMM - Scope

1. Terminology

- **Focus:**
- Define a consistent, robust language for the MSR fuel cycle

- **Timelines:**
  - Joint IAEA/NEA/EC-JRC workshop in **3-7 November 2025** on "Taxonomy and Terminology of MSR fuel cycles" – Hosted at the IAEA
  - Submission for publication by Q4 2026

2. Elements to be removed from the fuel

- **Focus:**
  - Identify which elements and isotopes have a detrimental effect on the salt neutronic and chemical properties and must be removed.
  - Identify rate of removal, as some elements and isotopes may only need removing after long periods of operation, some might need to be removed continuously.
- **Timelines**:
  - Report submission by Q3 2027

3. Separation techniques and their abilities and limitations

- **Focus:**
  - Evaluate separation methods and identify limitations and R&D needs
  - Will be using feedback and in coordination with phases 2 and 4

- **Timelines:**
  - Report submission by Q3 2027

4. Waste stream definitions and treatments

- **Focus:**
  - Define waste streams associated with different MSR fuel cycles, and develop suitable treatment methods based on removal processes
  - Will be using feedback and in coordination with phases 2 and 3

- **Timelines:**
  - Report submission by Q3 2027

CREAMM 1: Terminology – Overview

Objective:

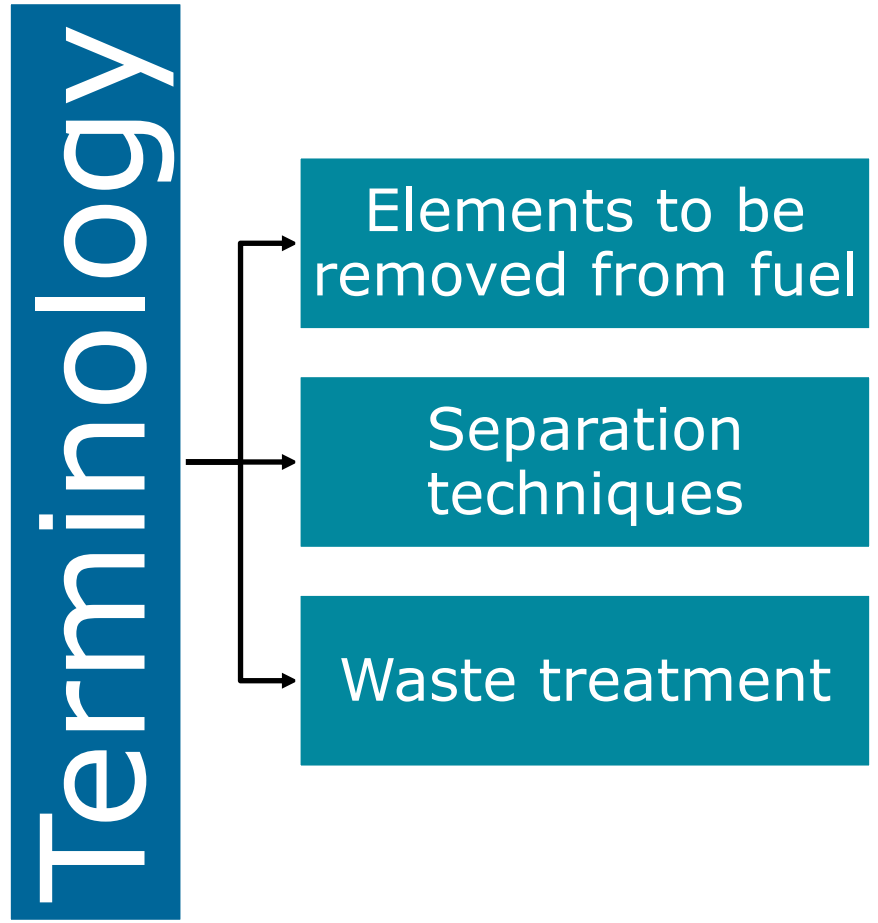
- Define a consistent and suitable terminology set for the MSR fuel cycle
- The terminology set will support all other phases by ensuring that participants are communicating with a common understanding of terms

Why terminology matters:

- Conventional terms (e.g. "spent fuel") may not be directly applicable to liquid fuels in MSRs
- Robust and consistent terminology set required to support R&D, regulation and international collaboration

Alignment with international efforts:

- Leverage outputs from the joint IAEA/NEA/EC-JRC workshop on the "Taxonomy and terminology of MSR fuel cycles" (3-7 Nov 2025)



CREAMM 1: Terminology – Actions and Integration

Current Activities:

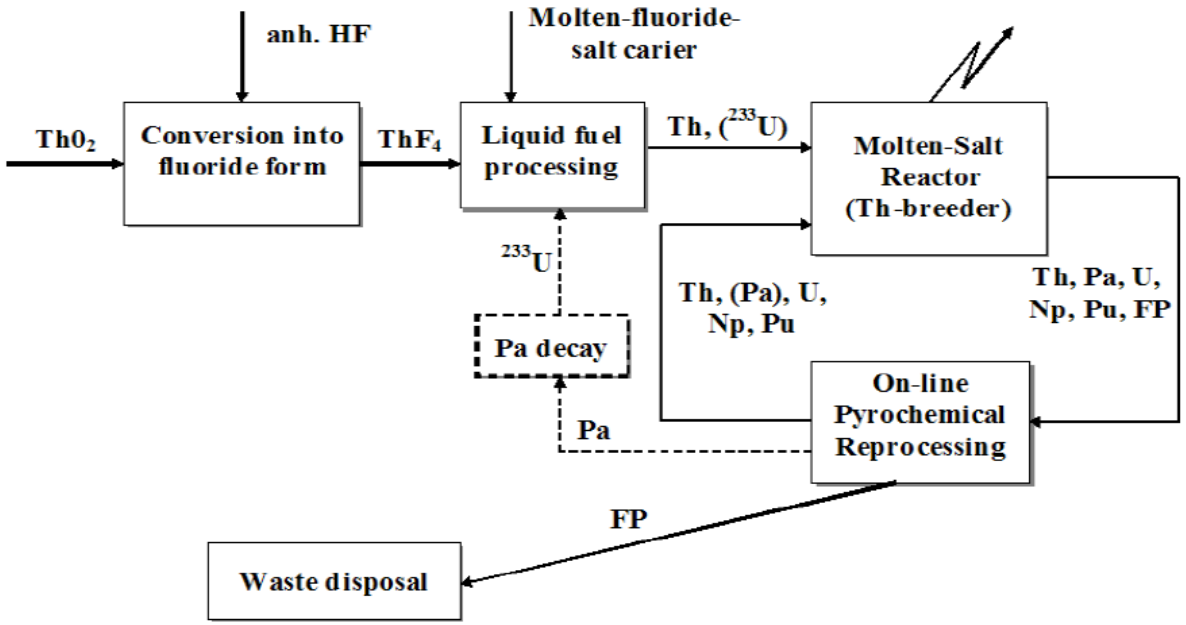
- Output from Joint MSR fuel cycle taxonomy and terminology workshop will be used as input for this phase of the activity
- Terminology will be structured around key MSR fuel cycle stages:
  - Fuel
  - Reprocessing
  - Reactor-linked recycling apparatuses
  - Online/inline/offline treatment
  - Separation of fission/corrosion/activation products
  - Recycling and disposal pathways
- In addition to highlighting and defining terms, there will also be a focus on synonyms and terms that are frequently used interchangeably in different national contexts (e.g. spent fuel vs. used fuel vs. irradiated fuel)

Consultancy meeting for the joint workshop held in Feb 2025

CREAMM 2: Elements to be removed from the fuel

Why element removal is essential

- CREAMM considers MSR concepts with liquid fuel – require continuous or periodic treatment to remove neutron poisons and maintain reactivity
- Removal is necessary for:
  - Sustaining neutron economy (especially in thermal spectrum)
  - Maintaining control and physio-chemical properties of the fuel salt
  - Extracting newly bred fissile material
- Optimal strategy is a compromise between:
  - Reactor physics requirements
  - Chemical separation capabilities
  - Economic feasibility



Source: J. UHLÍŘ presentation – EGFRW Meeting (April 2025)

CREAMM 2: Elements to be removed from the fuel

Sensitivity, Categorisation, and Timing of Removals

- Neutron spectrum matters:
  - Thermal-spectrum (e.g. MSBR) -> Highly sensitive to neutron poisons
  - Fast-spectrum -> Less sensitive, but still require targeted cleanup
- Cleanup time varies by isotope:
  - Noble gases and volatile FPs: Frequent (e.g. 30-second cycle)
  - Heavier fission products and actinides: Slower (e.g. 450-day cycle)
- Elements are categorized by:
  - Universality across reactor types
  - Reprocessing method (online vs. offline)
  - Recoverability (e.g. noble or rare metals)

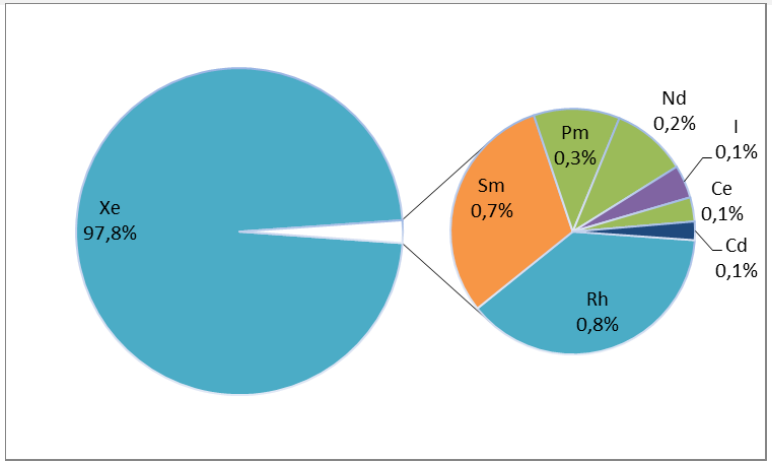
Processing group	Nuclides	Cycle time (at full power)
Rare earths	Y, La, Ce, Pr, Nd, Pm, Sm, Gd Eu	50 days 500 days
Noble metals	Se, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Sb, Te	20 s
Seminoble metals	Zr, Cd, In, Sn	200 days
Gases	Kr, Xe	20 s
Volatile fluorides	Br, I	60 days
Discard	Rb, Sr, Cs, Ba	3435 days
Protactinium	^{233}Pa	3 days
Higher nuclides	^{237}Np, ^{242}Pu	16 years

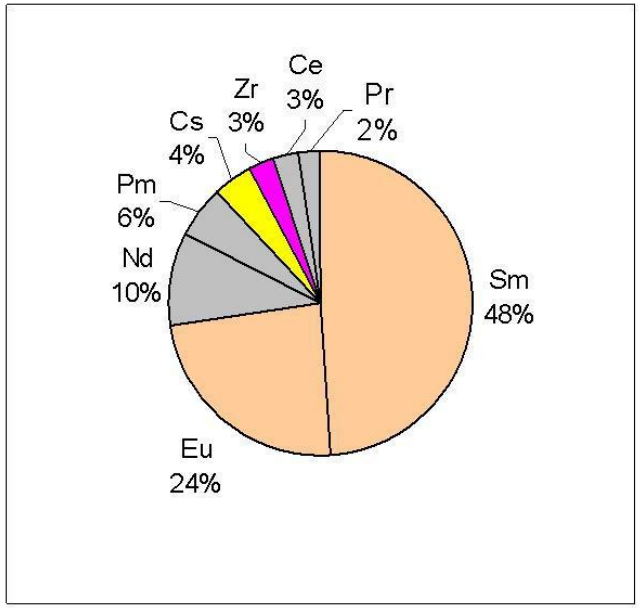
Source: Robertson, R. C, "Conceptual Design Study of Single-Fluid Molten-Salt Breeder Reactor", ORNL-4541

CREAMM 2: Elements to be removed from the fuel

Path Forward and Deliverables

- **Quantify neutron poison effects in fast-spectrum MSRs** 📊
  - Thermal systems (e.g. MSBR) are better characterized; fast systems are not
- **Compare poison sensitivity across spectra** ⚖️
  - Determine which isotopes require immediate vs. delayed removal
- **Define element-specific removal timing** 🎯
  - Support prioritisation for chemical R&D and system design
- Leverage expertise from chemists and reactor physicists participating in the activity to develop full picture
- Provide input and receive feedback from phases 3 and 4 of CREAMM, while containing consistent language defined by phase 1 of CREAMM





Source: J. UHLÍŘ presentation – EGFRW Meeting (April 2025)

CREAMM 3: Separation Techniques – Abilities and Limitations

Scope and Objective of Separation Techniques Phase

- Assess chemical separation techniques, their abilities and limitations, for MSR fuel processing by literature review of state-of-the-art MSR fuel treatment publications (e.g. ORNL reports, SAMOFAR/SAMOSAFER, EURATOM projects) -> working directly with phases 2 and 4
- Two major tasks:
  1. Identify suitable techniques for MSR fuel (fluoride, chloride, actinide-rich, etc.)
     - » Fluoride/ chloride volatility
     - » Molten salt liquid metal reductive extraction
     - » Electrochemical methods in molten salt media
     - » Oxide precipitation
     - » Zone melting
     - » …

2. Assess capability of these techniques to separate priority isotopes
   - » Available experimental data/ modelling and thermodynamic and ab-initio calculations
   - » Base on different chemical or physio-chemical properties of the separated elements according to the selected techniques (e.g. volatility, chemical/electrochemical potentials/ solubility …)
   - » Dependent on the fuel composition

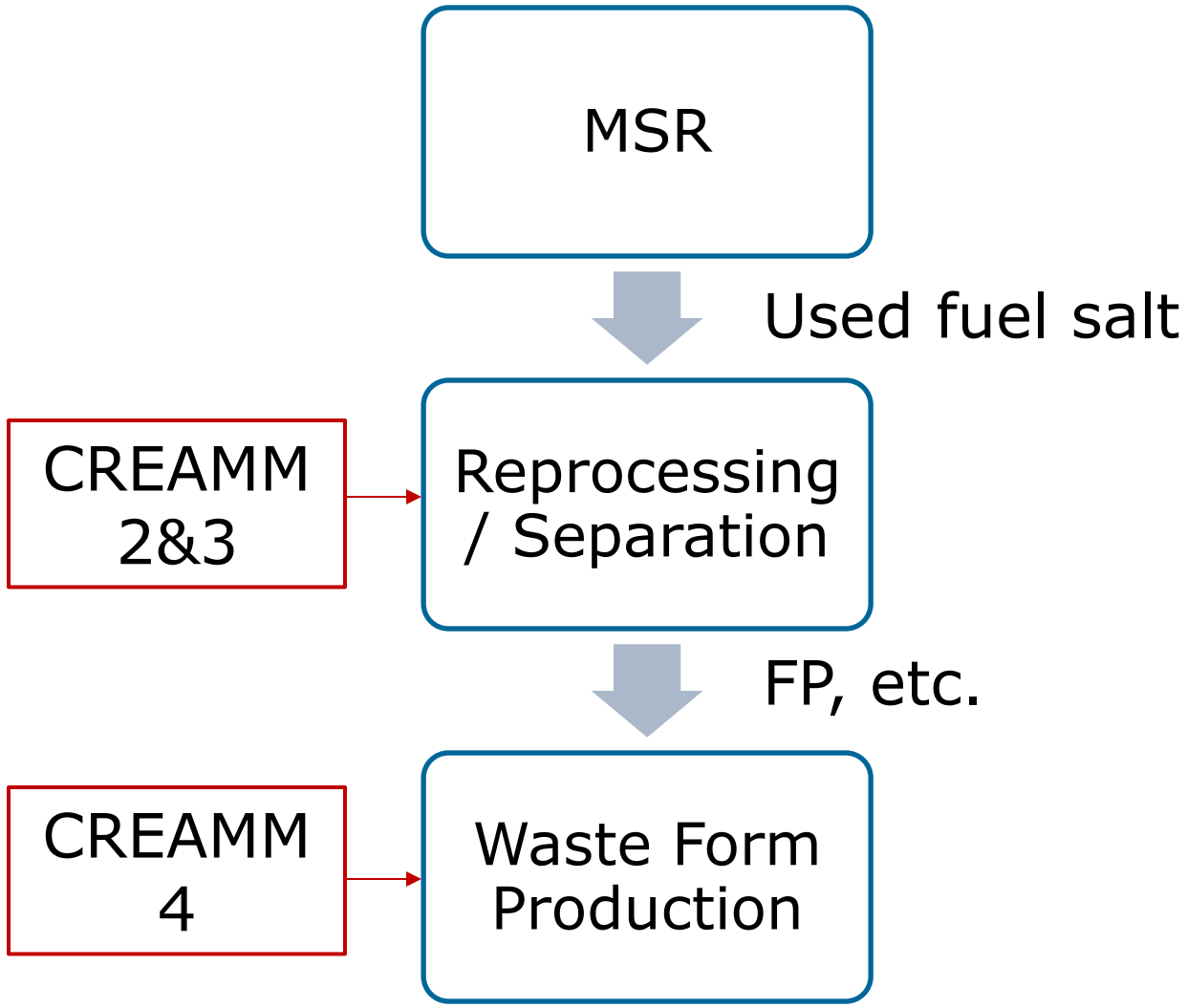
CREAMM 4: Waste Stream Definition and Treatment

Objectives

- Once elements are removed from MSR fuel, many become waste streams
- CREAMM 4 aims to:
  - Define these streams
  - Match them to suitable waste forms
  - Support overall MSR safety, sustainability, and feasibility
- Waste form selection depends on:
  - Origin (off-gas vs. used salt)
  - Separation process used
  - Chemical nature of the separated materials

Two main waste categories:

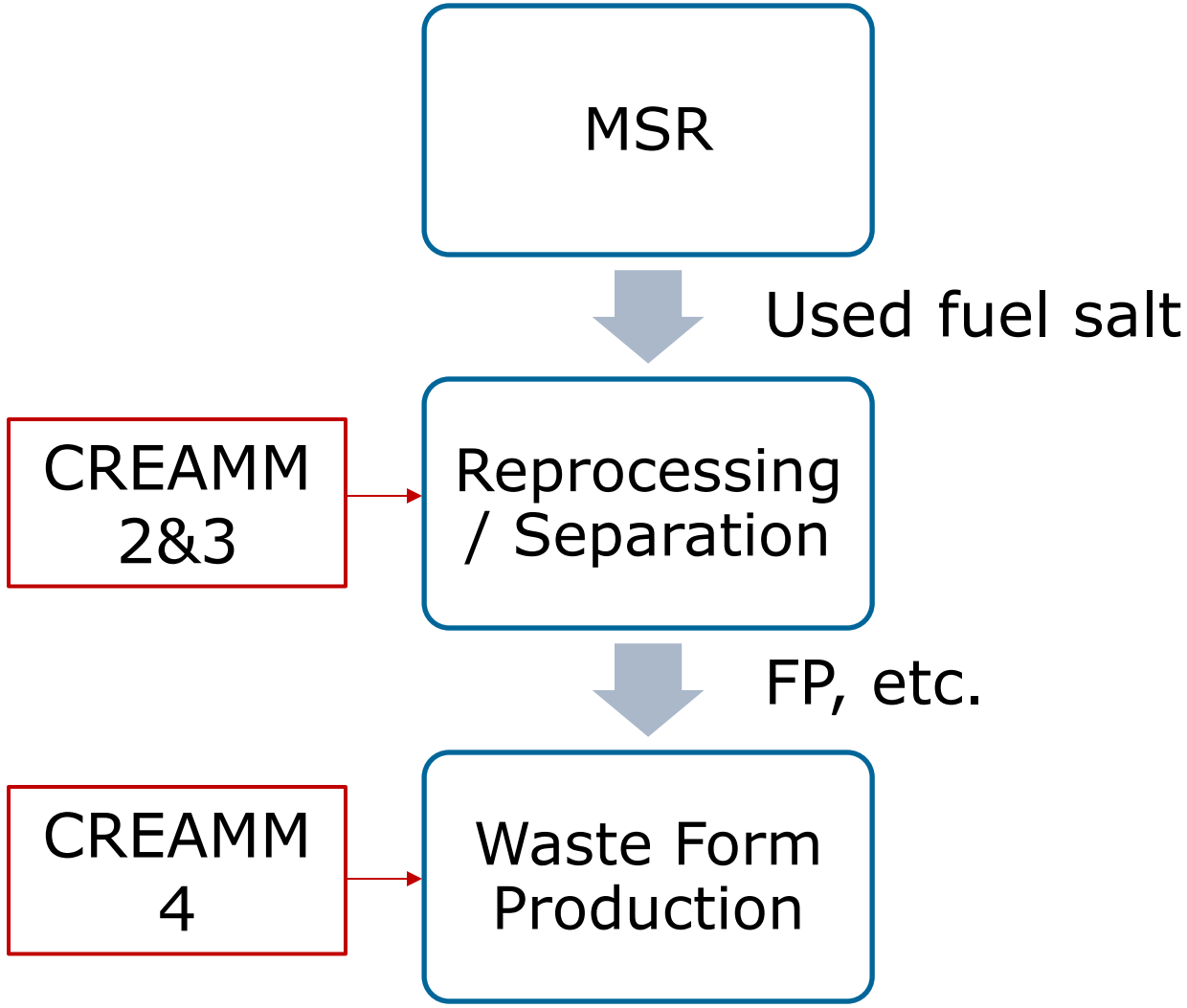
- **High-level Waste (HLW): Target for CREAMM 4**
  - Fission products and actinides removed by reprocessing/separation (on-, off-line) or those remaining after operation of MSR
- **Low-level Waste (LLW):**
  - Operating waste



CREAMM 4: Waste Stream Definition and Treatment

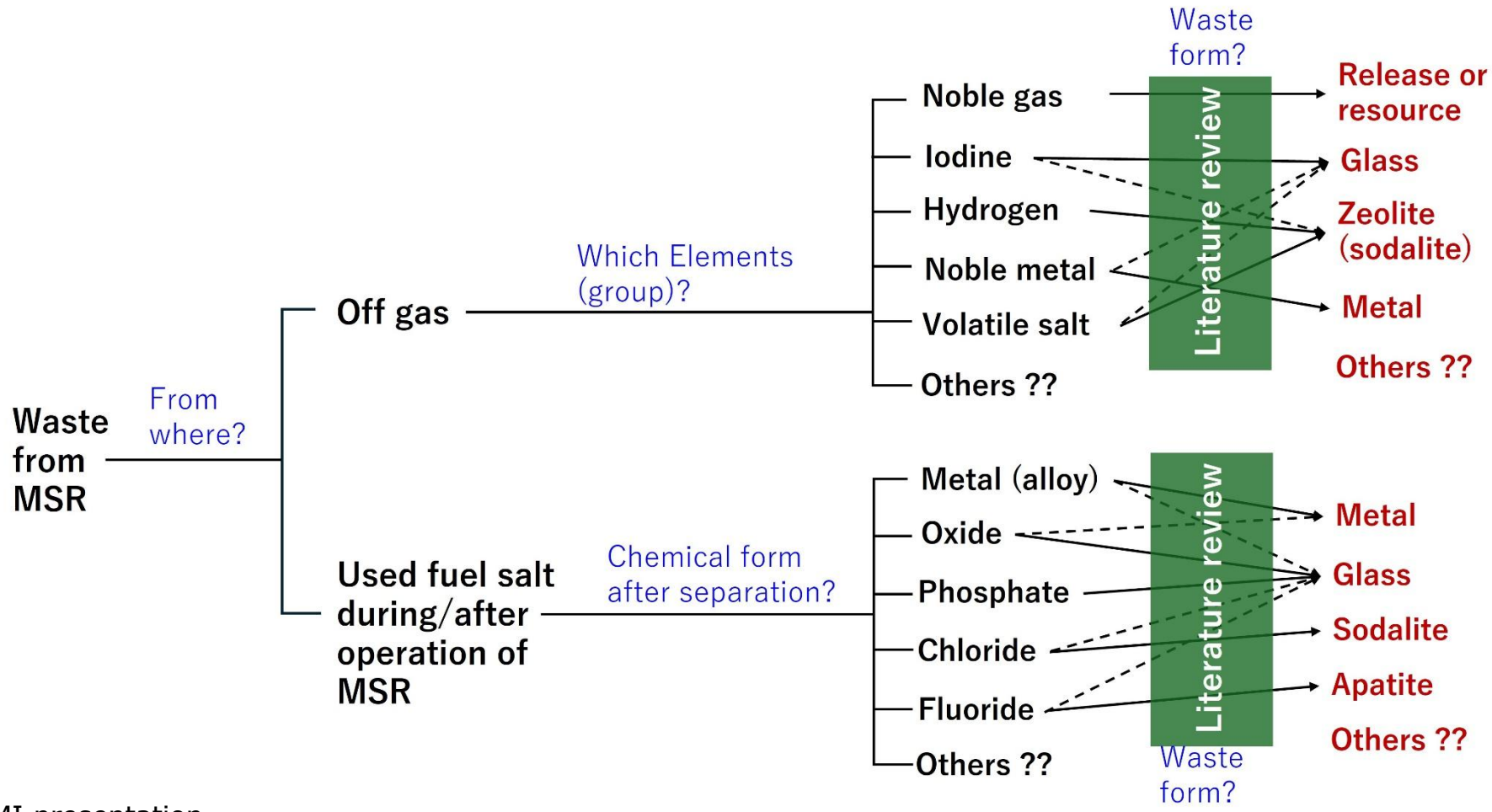
Waste Source Mapping and Waste Form Options

- Element groups to consider (input from CREAMM 2 & 3):
  - Rare earth, alkali, alkaline earth, actinides
  - Chlorine, fluorine
  - Nobel metals
  - Others
- Potential waste forms:
  - Glass (oxide, phosphate, etc)
  - Sodalite (chloride)
  - Apatite (fluoride)
  - Metallic waste (metal)
  - Others
- Literature review: how to produce above waste forms and identify which elements are problematic



CREAMM 4: Waste Stream Definition and Treatment

Classification of Waste from MSR:



Source: T. MURAKAMI presentation – EGFRW Meeting (April 2025)

CREAMM: State-of-the-Art Report

Systematic Integration of Multiphase Analysis	Link evolution of MSR fuel, from definition to disposal, into coherent operational framework, replacing LWR-based assumptions
Operational cleanup strategies	Embed time and neutron spectrum sensitivity (e.g. removal cycles for poisons in thermal vs. fast systems) into guidance for adaptive, design-specific strategies
Technology Readiness and Gaps Mapping	Cross-analyse chemical separation techniques and waste form technologies with isotope prioritisation needs, highlighting where R&D efforts will yield most impact
Terminology as an Enabler for Innovation	Reframe defining, categorising, and communicating fuel states and management in a liquid-fuel context by establishing a common MSR fuel language critical for collaboration and licensing
Not just a Review	The report would not only summarise the findings, but would suggest prioritisation and alignment of future efforts across fields in chemistry, reactor physics and engineering

Conclusion

- CREAMM addresses critical technical and terminological gaps in MSR fuel cycle understanding, essential for future reactor design, licensing, and waste strategies
- A phase-based analysis on terminology, elements to remove from the fuel, separation techniques, and waste treatment to culminate in a comprehensive state-of-the-art report
- The activity offers practical operational guidance to MSR developers, R&D communities, regulators, nuclear waste management and reprocessing organisations, decision makers and policy bodies, and international organisations for navigating the unique demands of liquid-fueled MSRs

Looking ahead

- Phases 1-4 working papers planned to be submitted for publication by Q3 2027
- State-of-the-art report planned to be submitted for publication by Q4 2028

Acknowledgments:

- Thank you to the leadership of the task leads: Jan Uhlíř, Pavel Souček, Michael Edmondson, and Tsuyoshi Murakami
- Thank you to the current and future participating experts to the EGFRW CREAMM activity

Thank you for your attention