European Partnership
on Radioactive Waste Management

EURAD-2 WP4 FORSAFF Webinar

Key Challenges and Future Needs in Small and Advanced Modular Reactor (SMR/AMR) Waste Management

This webinar will be recorded for internal use only, to support follow-up activities.

Co-funded by the European Union under Grant Agreement n° 101166718

6 May 2025

Webinar Agenda

Time	Item	Speaker
13:00-13:15	Welcome/Introduction/ FORSAFF Overview	Tim Schatz (VTT)
13:15-13:40	Towards Safe and Sustainable Deployment of LW-SMRs and AMRs: Identifying Knowledge Gaps in Waste Management (FORASFF White Paper)	Anne Saturnin (CEA)
13:40-14:00	Mapping R&D Needs for SMR/AMR Deployment: A Backend Perspective (FORSAFF)	Jesus Martinez (Amphos 21)
14:00-14:20	Update from EU SMR Alliance: Focus on the Fuel Cycle	Hidde Baars (URENCO)
14:20-14:40	Progress on the NEA Project on Waste Integration for Small and Advanced Reactor Designs	Una Baker (NEA)
14:40-15:00	IAEA Project on Addressing Challenges, Gaps and Opportunities for Managing SNF from SMRs: IAEA CRP SMR-COGS	Amparo Gonzalez-Espartero (IAEA)
15:00-15:05	Breakout Room Arrangements	
15:05-15:50	Breakout Room Discussions • What do stakeholders want/need (in 5 years, in 10+ years)? • What project outputs are most useful? • What challenges still exist for SMR/AMR deployment? • How can project initiatives better support your decision making?	All
15:50-16:00	Feedback from Breakout Rooms	Breakout Room Moderators/Rapporteurs
16:00	Close of Webinar	Tim Schatz (VTT)

Webinar Purpose

This webinar will present key findings from FORSAFF. Guest speakers from the SMR Industrial Alliance, OECD/NEA and IAEA will provide context from other related ongoing international initiatives

It will offer an opportunity to:

- Gain up-to-date insights into SMR waste management challenges and research needs
- Consider how research, industry, and policy initiatives align
- Share your perspective on stakeholder priorities and expectations
- Contribute directly to shaping future research and collaboration agendas

Participants will join moderated breakout discussions to explore:

- Stakeholder needs
- Remaining challenges in SMR/AMR waste management
- Priorities for future research, guidance, and engagement

Your input will directly inform FORSAFF recommendations.

Breakout Rooms

The primary aim of the breakout discussions is to identify what impacts and outcomes stakeholders want to see from ongoing and future projects related to SMR deployment and radioactive waste management.

Framing Questions:

- What do stakeholders want/need (in 5 years, in 10+ years)?
- What project outputs are most useful?
- What challenges still exist for SMR/AMR deployment?
- How can such projects better support your decision making?

Please actively participate. The value of the breakout discussions depends on you openly sharing your perspectives, experiences, and concerns, as well as engaging with the views of others.

The breakout room sessions will be recorded for internal use only, to support follow-up activities.

What is FORSAFF?

FORSAFF (Waste Management for SMRs and Future Fuels) is a Strategic Study Work Package (WP4) in EURAD-2

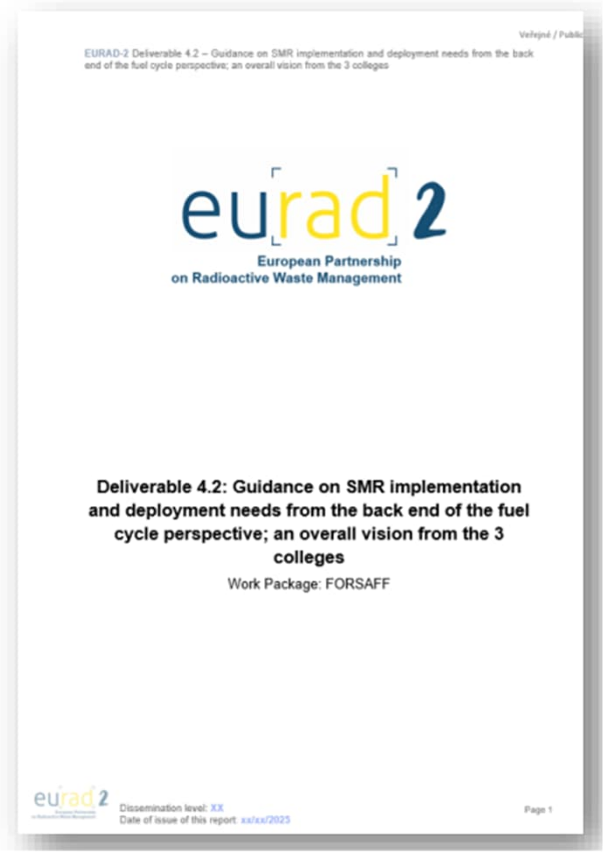
The main objective of FORSAFF is to identify knowledge gaps and provide recommendations for future research in SMR/AMR waste management

- Evaluate SMR/AMR waste inventories.
- Review management routes for SMR/AMR wastes.
- Examine national policies and regulatory frameworks in the context of SMR/AMR fuel cycle and waste management as well as stakeholder perceptions and concerns.

DELIVERABLE 4.2 - GUIDANCE ON SMR IMPLEMENTATION AND DEPLOYMENT NEEDS FROM THE BACK END OF THE FUEL CYCLE PERSPECTIVE

- Green Paper
  - What do we think should be done?
    - challenges
    - gaps
    - uncertainties

https://www.ejp-eurad.eu/publications/eurad-2-d42-green-paper-smr-implementation-and-deployment-needs



Veřejné / Public

EURAD-2 Deliverable 4.2 – Guidance on SMR implementation and deployment needs from the back end of the fuel cycle perspective; an overall vision from the 3 colleges

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Deliverable 4.2: Guidance on SMR implementation and deployment needs from the back end of the fuel cycle perspective; an overall vision from the 3 colleges

Work Package: FORSAFF

Dissemination level: XX
Date of issue of this report: xx/xx/2025

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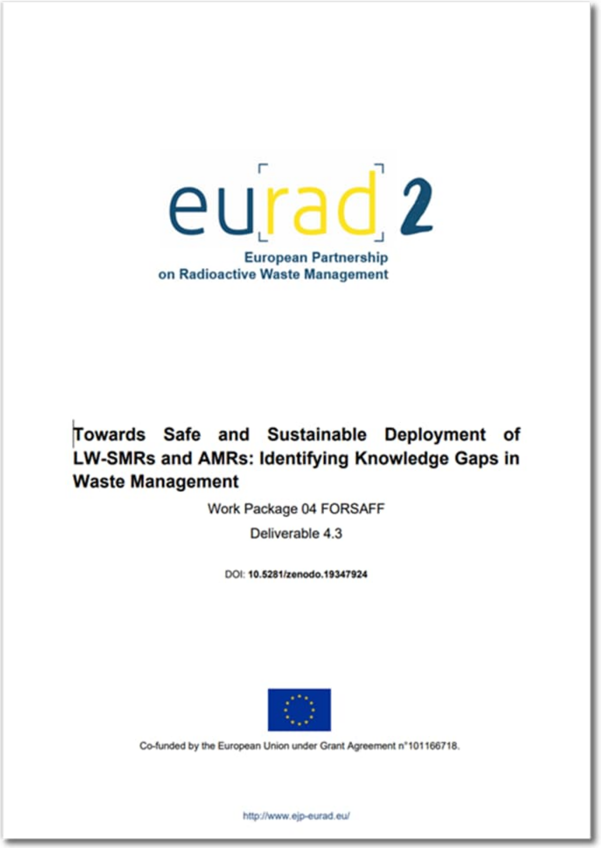
DELIVERABLE 4.3 – TOWARDS SAFE AND SUSTAINABLE DEPLOYMENT OF LW-SMRs AND AMRs

- White Paper
  - How do we think it should be done?
    - relative to addressing the challenges, gaps and uncertainties highlighted in the Green Paper.

https://www.ejp-eurad.eu/publications/eurad-2-d43-towards-safe-and-sustainable-deployment-lw-smrs-and-amrs-identifying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Towards Safe and Sustainable Deployment of LW-SMRs and AMRs: Identifying Knowledge Gaps in Waste Management

Work Package 04 FORSAFF

Deliverable 4.3

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TOWARDS SAFE AND SUSTAINABLE DEPLOYMENT OF LW-SMRS AND AMRS: IDENTIFYING KNOWLEDGE GAPS IN WASTE MANAGEMENT

White Paper - Deliverable 4.3 – March 2026 - https://ejp-eurad.eu/publications

Anne Saturnin (CEA), Gabriele Magugliani (POLIMI), David Garcia (Amphos 21), Jesus Martinez (Amphos 21), Virginie Wasselin (Andra), Bérengère Cordier (Andra), Robert Mandoki (Andra), Magaly Tribet (CEA), Timothy Schatz (VTT), Sami Naumer (VTT), Josef Brinek (UJV), Paula Keto (VTT), Nadja Zeleznik (EIMV), Alan Tkaczyk (UTARTU)

Co-funded by the European Union under Grant Agreement n° 101166718

INTRODUCTION

Large Development in the world of

LW-SMRs	small modular light water reactors
AMRs	advanced modular reactors *(3 concepts selected by FORSAFF)*
LMFR	Liquid Metal Fast Reactors
HTGR	High Temperature Gas-cooled Reactors
MSR	Molten Salt Reactors

Various applications (electricity, heat, cogeneration, hydrogen production)

Purpose of the White Paper

- Identify R&D challenges in Radioactive Waste Management (RWM)
- Propose solutions for safe and responsible deployment

KEY CHALLENGES IN RADIOACTIVE WASTE MANAGEMENT (RWM)

THE BACKGROUND

- Limited or not publicly available reactor design data
- Differences between LW-SMR/AMR waste streams and current ones
- Siting in populated or remote locations
- Centralised vs decentralised management and processing facilities

multiple and interacting uncertainties

Waste	radionuclides inventories, impurities, chemical forms, long-term behaviour?
Fuel cycle	advanced reprocessing and fuel conditioning technologies?
Compatibility	compatibility with existing storage/disposal concepts?
Regulatory	adaptability of current frameworks for LW-SMR & AMR specific waste streams?

Key Challenges in Radioactive Waste Management (RWM)

The Impacts

If LW-SMR/AMR waste issues are not resolved in a timely and effective manner

Delays in licensing, deployment schedules

Extension of storage periods / Series of delays in repository programs

Regulatory adaptations

Delays in deployment
Cost increases
Public distrust

But if LW-SMR/AMR waste management challenges are addressed effectively and as soon as possible

- Technical understanding improvement and uncertainty reduction in *waste characterisation*
- Development of optimised and cost-effective *conditioning, storage and disposal solutions*
- Enhancement of repository *readiness* and long-term *safety case* robustness
- Have clear *regulatory* and aligned approaches across LW-SMR/AMR waste management
- Increase of *societal* trust

Challenges to be addressed as soon as possible across multiple R&D areas

Proposed R&D Actions For Radioactive Waste Management

Waste characterisation studies

Nuclear fuel - fuel assemblies and core/components structures - coolant – discharges

- Depending on the reactor type and the specificities of the fuel cycle
- Identify waste sources, types, quantities, and physical/chemical forms
- Cornerstone for developing LW-SMR/AMR Radioactive Waste Management

Waste management studies throughout the fuel cycle

Waste Generation – Reprocessing - Treatment / Conditioning – Storage – Transportation - Disposal

- Address specific challenges for LW-SMRs, HTGRs, LMFRs and MSRs
- Develop treatment and stabilisation processes

All R&D actions concern LW-SMR/AMR Vendors, Research Entities, Technical Safety Organisations, Waste Management Organisations

Benefits of establishing international collaboration

Challenges to be addressed as soon as possible across multiple R&D areas

Proposed R&D Actions For Radioactive Waste Management

Regulatory and Policy issues

- Establish robust regulatory frameworks
- Harmonise waste transport regulations

Stakeholder engagement

- Develop engagement frameworks tailored to LW-SMR/AMR-specific waste challenges
- Test methods for communicating uncertainty and evidence in R&D contexts
- Co-produce RWM scenarios and decision points with stakeholders
- Develop and validate governance and fairness mechanisms

All R&D actions concern LW-SMR/AMR Vendors, Research Entities, Technical Safety Organisations, Regulators, Waste Management Organisations, civil society organisations and/or the public

Benefits of establishing international collaboration

Prioritising R&D For Safe Deployment

Light Water - SMRs

Near-Term priorities (3-5 years)

- Obtain access to input data for LW-SMR spent fuels and waste
- Assess the LW-SMR spent fuels specificities depending on the fuel cycle; adapt conditioning processes to modular assemblies; define safe and efficient transport solutions to storage or disposal facilities
- Characterise storage behaviour of LW-SMR waste
- Develop stakeholder engagement frameworks (LW-SMR/AMR); implement participatory decision-making, scenario-based planning, and transparent governance

Long-Term priorities (5-15 years)

- Develop comprehensive datasets on spent fuels and conditioned wastes
- Develop decommissioning/waste retrieval strategies considering modular core design and packaging
- Investigate long-term storage and disposal solutions
- Explore advanced partitioning and transmutation strategies to reduce long-lived radiotoxicity
- Assess integration of SMR-specific waste streams into national strategies
- Institutionalise stakeholder engagement in back-end R&D (LW-SMR/AMR); develop long-term trust monitoring with structured stakeholder involvement

Prioritising R&D For Safe Deployment

AMRs: HTGRs, LMFRs, MSRs

Near-Term priorities (3-5 years)

- Obtain access to input data in order to develop waste characterisation studies
- Expand knowledge base to a better understanding: chemistry, radiotoxicity, decay heat
- Integrate lessons from international collaborations and experimental facilities to guide back-end strategies
- Develop modelling tools for predicting radionuclide inventories, decay heat, and long-term behaviour of spent fuel and conditioned waste.
- Initiate R&D on high-level waste forms, including compatibility with geological disposal.

Long-Term priorities (5-15 years)

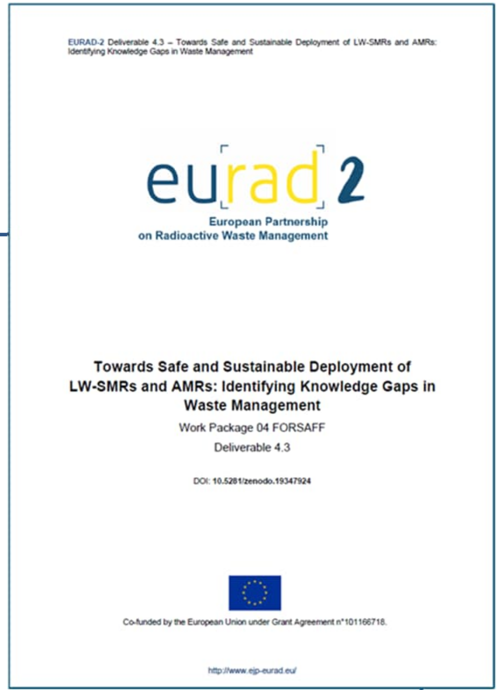
- Develop advanced monitoring, measurement, and analytical techniques (high-temperature, chemically complex waste)
- Study materials compatibility and corrosion in storage and disposal conditions for AMR-specific waste forms.
- Enhance modelling tools for predicting radionuclide inventories, decay heat, and long-term behaviour of spent fuel and conditioned waste.
- Advance R&D on high-level waste forms for AMRs, including compatibility with geological disposal.
- Explore novel fuel cycles to reduce waste volumes and radiotoxicity while maximising resource utilisation.
- Validate waste characterisation, conditioning, and storage methods through pilot-scale demonstrations.

Conclusions And Takeaways

Early and Integrated Planning / Collaborative Efforts

By addressing waste management challenges proactively

- Waste characterisation studies
- Waste management studies *(see next presentation)*
- Regulatory frameworks and international guidelines
- Stakeholder engagement


EURAD-2 Deliverable 4.3 – Towards Safe and Sustainable Deployment of LW-SMRs and AMRs: Identifying Knowledge Gaps in Waste Management

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Towards Safe and Sustainable Deployment of LW-SMRs and AMRs: Identifying Knowledge Gaps in Waste Management

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⇨Essential to mitigate risks, optimise costs, and ensure public confidence

⇨Ensuring Safe and Responsible Deployment of LW-SMRs and AMRs

THANK YOU FOR YOUR ATTENTION

WHITE PAPER STRUCTURE

Executive Summary

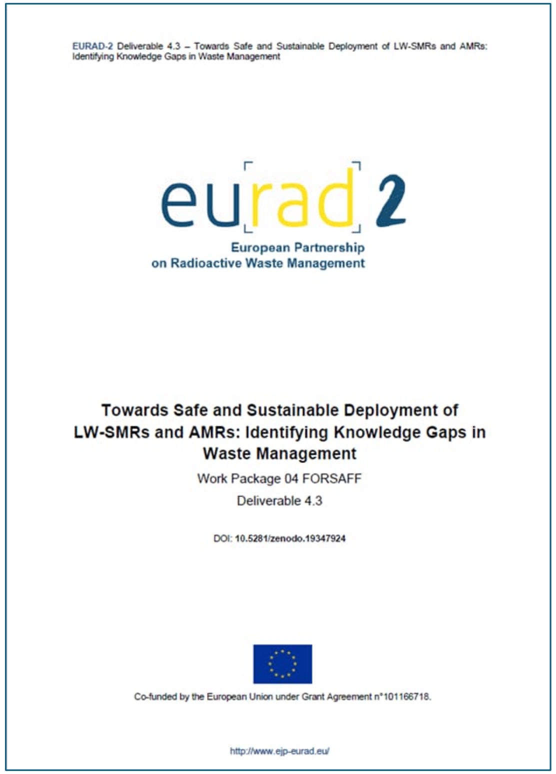
Introduction

Challenge

Proposed way forward

- Waste characterisation studies
- Waste management studies
- Regulatory and policy issues
- Stakeholder engagement issues

Call to Action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MAPPING R&D NEEDS FOR SMR/AMR DEPLOYMENT. A BACK-END PERSPECTIVE.

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OUTLINE

1

FORSAFF
TASK 4

2

BACK-END
R&D NEEDS

3

KEY
TAKEAWAYS

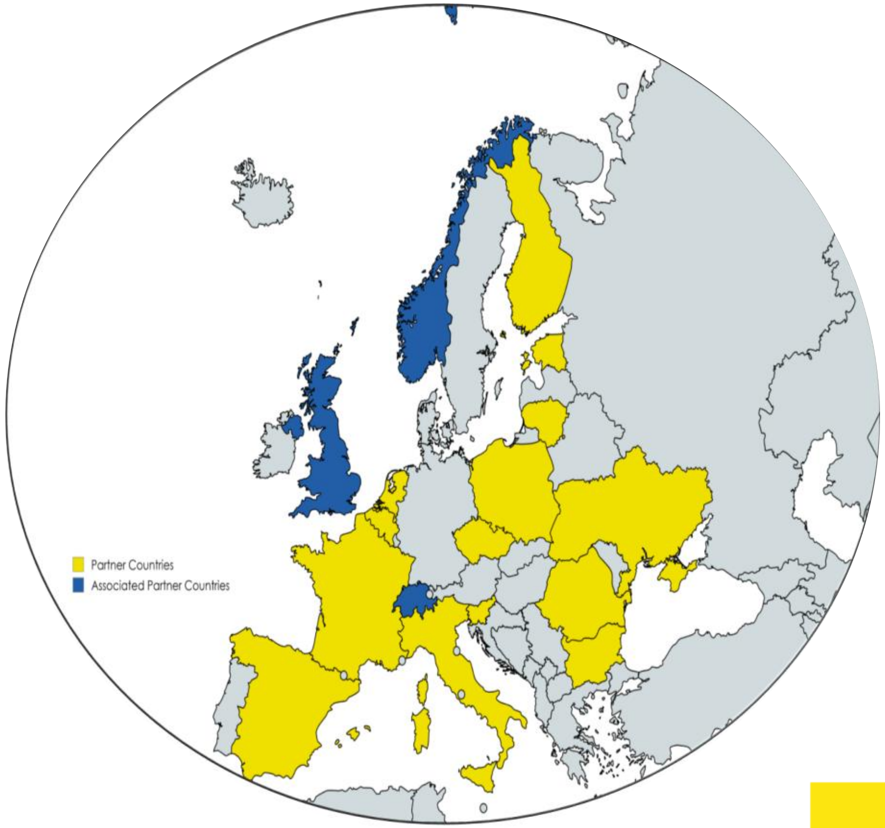
1

WP4 WASTE MANAGEMENT FOR SMRS AND FUTURE FUELS FORSAFF – OBJECTIVES

To develop understanding and provide recommendations on *SMR* deployment and supplier options with respect to nuclear waste management

- **Evaluate SMR waste inventories**, including those related to the back-end of the fuel cycle, and assess predisposal approaches and development needs in terms of anticipated waste generation across reactor designs and operating conditions.
- **Review management routes for SMR wastes** over a range of needs, considering both conventional as well as more recent concepts.
- **Examine national policies and regulatory frameworks** in the context of SMR fuel cycle and waste management as well as stakeholder perceptions and concerns.

FORSAFF aims to identify knowledge gaps and provide recommendations for future research in SMR waste generation and management



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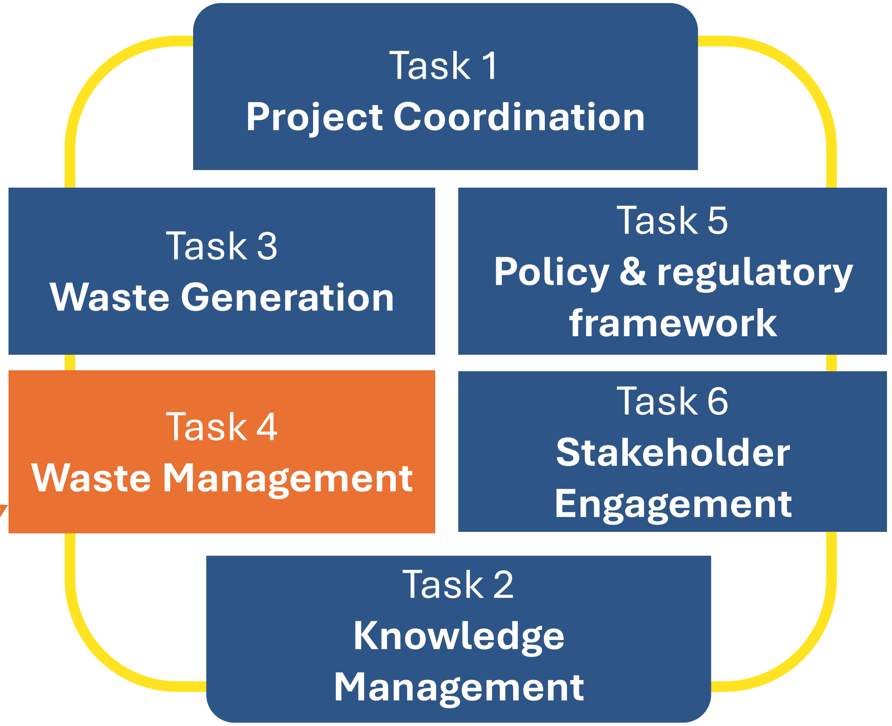
WP4 FORSAFF – TASK BREAKDOWN

Task 3: *What* ***waste inventories*** *will SMR/AMR concepts generate, with what properties and magnitudes, and how do these baseline characteristics shape downstream management* ***?***

Task 4: *Given the anticipated SMR/AMR waste streams, which* ***predisposal, reprocessing, and disposal strategies are feasible today? what R&D is needed ?***



Task 5: *Are today's* ***policies and regulatory frameworks*** *sufficient for SMR/AMR back-end management* ***?*** *what changes and harmonisation are required to license and implement it* ***?***

Task 6: *What do* ***stakeholders*** *need to understand and* ***trust SMR/AMR waste management decisions****, and how should we structure dialogue to address their concerns credibly* ***?***

FORSAFF TASK 4 – WASTE MANAGEMENT

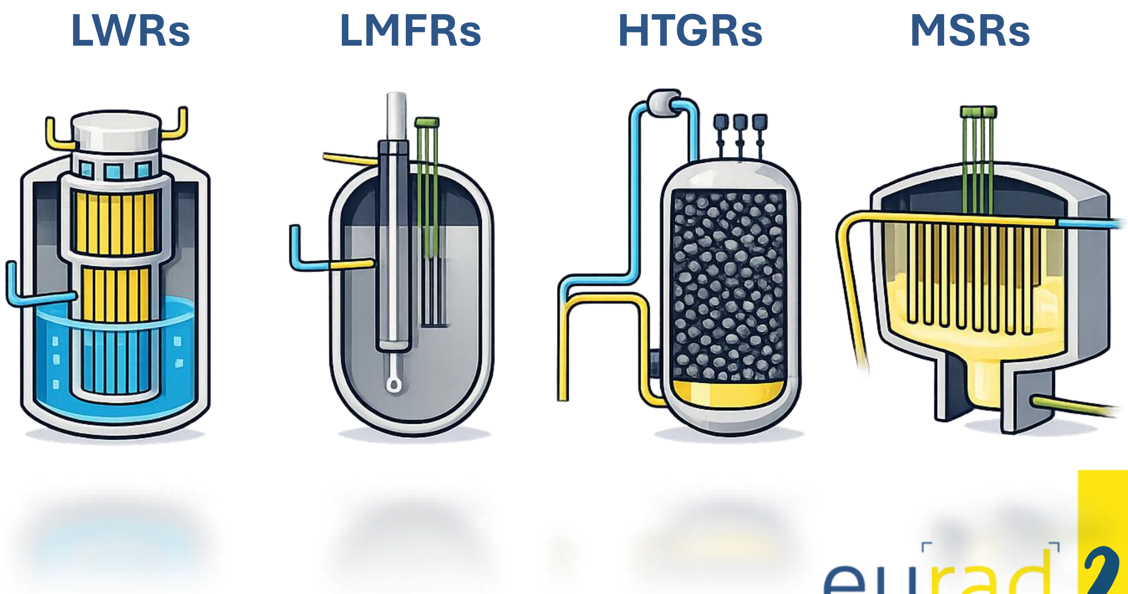
Lead (2): Amphos 21 and Andra | Partners (17): CEA, CIEMAT, CVR, GSL, IFE, INCT, LEI, NWS, POLIMI, TVO, PSI, RATEN, SCKCEN, SSTCNRS, SURO, VTT, UTARTU

Objective: Assess predisposal approaches and development needs in terms of anticipated waste generation across SMR designs and operating conditions including characterisation. Explore spent fuel reprocessing options. Examine disposal routes for SMR wastes across a range of deployment needs, disposability issues and waste acceptance criteria.

- **Subtask 4.1: SMR waste predisposal and disposal**
  Investigate predisposal and disposal management options for SMR wastes; identify pre-disposal / disposal route needs.

- **Subtask 4.2: SMR spent fuel reprocessing**
  Assess current reprocessing technologies with respect to SMR SNFs; identify reprocessing needs.

- **Subtask 4.3: Characterisation techniques and modelling**
  Evaluate waste characterisation methods and modelling tools for SMR wastes; identify characterisation needs (both experimental and modelling techniques)



FORSAFF TASK 4 – METHODOLOGY

Amphos 21 distributed a questionnaire to the partners

Objectives

- Investigate and describe **expected waste streams** per SMR family
- Identify **predisposal and disposal options**: treatment and conditioning, storage, transport, disposal (surface/near surface disposal, deep geological repositories, boreholes, regional or shared facilities)
- Identify **data gaps, research needs and uncertainties** to be considered
- Assess **infrastructure and R&D needs,** and **regulatory implications** where possible

Waste Stream	*Add as many columns as WS*	
Source Component (e.g. cladding, coolant, fuel salt)		
Operational or Decommissioni Waste		
Physical Form		
Chemical Compos		
Key Radionuclid		
Activity Level (LL/IL/HL)		
Volume per Unit En (e.g. m^3/TWh)		
Heat Generation R (W/m^3 or Bq/g)		
Notes		

Ranking	**Conditioning Option**	**References**	**Data gaps**	**Research needs**	**Uncertainties due to design parameters**
#1	*Immobilization cementitious matrix*		*Could be that there is knowledge gap on -the design and procedure on fixing a geometry -the number of TRISO particles per canister -the chemical interaction between graphite and cement (short-/long- term, during cement setting/casting, etc) -effect of Water/Cement ratio in criticality*	*-Criticality Safety Assessment accounting for different burnup grades, geometry and immobilization of cement. -Chemical behaviour of the interface cementitious matrix-graphite (accounting for potential microstructural fractures and behaviour during cement setting/casting)*	*-Uranium enrichment -Power distribution (burnup)*
#2	*Directly stored (no conditioning)*		*Might not be the most suitable option…?*	…	…
#3	*Vitrified*		*Could be that there is poor experience of TRISO particle vitrification*	…	…

FORSAFF TASK 4 – RESULTS

FORSAFF Publications

- **White Paper** (March 2026): EURAD-2 - D4.3 Towards Safe and Sustainable Deployment of LW-SMRs and AMRs: Identifying Knowledge Gaps in Waste Management, knowledge gaps and R&D needs.
- **Outcome/impacts report** (Q2/Q3 2026): to be published, summary of work conducted under Tasks 3, 4, 5 and 6.
- **Green Paper** (October 2025): EURAD-2 - D4.2 Green Paper on SMR implementation and deployment needs, an early-stage analysis of radioactive waste management challenges associated with SMR/AMRs with input from WMOs, TSOs, and Res.


EURAD-2 Deliverable 4.3 – Towards Safe and Sustainable Deployment of LW-SMRs and AMRs: Identifying Knowledge Gaps in Waste Management

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Appendix C. Challenges and R&D needs for LW-SMRs/AMRs

Table C-1 – LWR – Challenges and R&D needs

Technology	Back-end activity	Challenge	R&D Undertaking
LWR	Treatment and conditioning	In the vitrification process of HLW, glass-loading limits and behaviour need to be assessed, as well as the efficiency of off-gas capture of volatile radionuclides (e.g., ^{99}Tc, ^{137}Cs).	Launch pilot vitrification campaigns with high burnup UO_2, including volatile radionuclide capture systems tests.
	Treatment and conditioning	The long-term performance of cement, bitumen and advanced alternative materials (e.g., alkali-activated materials, geopolymers) for immobilisation of operational, decommissioning and end-state considerations, LLW and ILW waste needs to be better understood.	Perform experimental long-term retention, diffusion, and mechanical integrity studies on advanced waste forms (geopolymers, new cement mixes) for SMR representative L/ILW to demonstrate mechanical integrity and radionuclide retention under realistic waste loadings and temperatures.
			For dry storage, carry out cask long-term performance tests, assess degradation mechanisms across scenarios ...

Table C-3 – LMFR – Challenges and R&D needs

Technology	Back-end activity	Challenge	R&D Undertaking
LMFR	Treatment and conditioning	Vitrification of HLW requires better definition of waste composition, glass loadings, and heat tolerances. Alternative matrices such as Synroc have not yet been implemented at industrial scale.	Establish reference glass compositions, maximum waste loadings, and thermal limits. Evaluate Synroc/HIP performance and increase TRL.
	Treatment and conditioning	For ILW/LLW streams (especially lead, lead-bismuth, and sodium coolants, sodium-wetted components, and liquid effluents) treatment and conditioning practices remain technologically immature. Immobilisation of decontaminated lead coolant and structural waste in alkali-activated materials and geopolymers is promising but further research is required to demonstrate their performance. For sodium processing[1], batch conversion into carbonates and tritium removal require further research and industrial scale-up, especially regarding the effects of impurities and filtration systems. Practical experience is lacking for the water-vapor treatment of large, complex sodium-wetted components. Finally, cementation of liquid effluents requires formulations that ensure low leakage. Cs/Sr extraction technologies remain at an early development stage.	Develop and test AAM (Alkali-Activated Materials) and geopolymer formulations tailored to LMFR waste streams, including long-term durability and leaching studies. For sodium coolant, research batch processing into carbonates and tritium removal, focusing on impurity effects, filtration strategies, and overall process safety. Design and conduct large mock-up trials of water-vapor treatment for large sodium-wetted and geometrically complex components. Validate decontamination efficiency and operational safety. Design and qualify cement matrices for liquid effluents, assessing leakage and Cs/Sr extraction methods from concept to pilot scale.
	Storage and transportation	The suitability of existing storage or dual-purpose casks for LMFR spent fuel, activated core components, and conditioned waste must be assessed. Interim storage of metallic sodium poses safety challenges due to its high chemical reactivity, requiring robust containment and accident management provisions. Liquid effluents from sodium processing ...	Qualify existing storage and dual-purpose cask designs for representative LMFR fuel and waste forms through thermal, chemical, mechanical, criticality, shielding, and leakage analyses. Where necessary, develop tailored storage system designs.

EURAD-2 - D4.3 Towards Safe and Sustainable Deployment of LW-SMRs and AMRs: Identifying Knowledge Gaps in Waste Management | Eurad

Published **March 2026**

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BACK-END R&D NEEDS – SMR/AMR

- Treatment and Conditioning

- Storage

- Disposal

- Transport

→ Subtask 4.1 (Treatment and Conditioning, Storage, Disposal, Transport)

- Reprocessing

→ Subtasks 4.2

- Characterisation – experimental and computational

→ Subtasks 4.3

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BACK-END R&D NEEDS – LWRS

Subtask 4.1: Investigate predisposal and disposal options for SMR/AMR wastes

Treatment and conditioning ***HL**: vitrification | **LIL**: cements, bitumen, geopolymers, etc.*

- ***R&D needs:*** vitrification of high-burnup UO_2, evaluation of radionuclide mobility and long-term mechanical integrity in conventional vs. advanced waste forms (geopolymers), scalability of processes (crystalline ceramic immobilisation).

Storage ***HL:** wet and dry cask storage | **LIL:** interim dry (tanks, barrels/drums).*

These remain primary options. Challenges and R&D needs refer to SNF.

- ***R&D needs:*** severe accident phenomenology in pools, long-term safety assessments in changing environmental conditions, development of advanced monitoring systems.

Disposal ***HL:** DGRs, DBD, shared facilities | **IL:** NSD, DGRs | **LL:** NSD.*

Waste inventory and regulatory compatibility for higher activity wastes.

- ***R&D needs:*** obtain reliable waste inventory data, improve real-time assay tools, assess radionuclide migration, criticality safety, bentonite-fuel interactions, decay-heat effects, and confirm whether existing repository concepts and waste acceptance criteria can accommodate SMR-specific fuel geometries, compositions and inventories…

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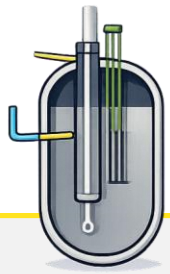
BACK-END R&D NEEDS – LMFRS



Subtask 4.1: Investigate predisposal and disposal options for SMR/AMR wastes

Treatment and conditioning ***HL**: vitrification, Synroc HIP | **LIL**: immo., decontamination (Pb, Na), wetted components*

Challenges arise from management of coolants, metal- wetted components, decontamination effluents…

- ***R&D needs:*** advancing HLW vitrification and immobilisation in Synroc-matrix through HIP; treatment of Pb, Pb-Bi, Na-bearing wastes and immobilisation in AAM/geopolymer/cement; Na processing (effect of impurities), decontamination of wetted components.

Storage ***HL/LIL:** short-term on site wet and dry cask storage*

Adaptability to be evaluated considering criticality, chemical reactivity and toxicity.

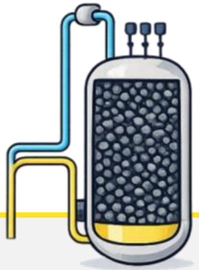
- ***R&D needs:*** development and licensing of suitable casks, with special focus on criticality safety and leakage minimisation.

Disposal ***HL:** DGRs, shared facilities | **LIL:** NSD, ID-DGRs (activated lead, sodium coolant, long-lived waste…)*

High Pu content, burnup histories and impact on DGR thermal loads and design costs, and risks of leakage in near-surface facilities.

- ***R&D needs:*** long-term evolution of fast-reactor HL in geological repositories, including fuel dissolution and degradation studies, criticality safety, and the cost implications of adapting disposal concepts. For LIL, especially bulk coolants and liquid effluents, research is needed to improve conditioning methods that minimise leakage in NSD.

BACK-END R&D NEEDS – HTGRS



Subtask 4.1: Investigate predisposal and disposal options for SMR/AMR wastes

Treatment and conditioning ***HL /LIL :*** *immobilisation (vitrification, cementation, bituminisation...)*

Complexity due to TRISO fuel and irradiated graphite

- ***R&D needs:*** criticality and long-term performance of cementitious or glass-based waste forms (including graphite-matrix interactions); optimisation of graphite decontamination and assessment of impact on activity reduction.

Storage ***HL /LIL :*** *short-term on site wet and dry cask storage*

Uncertainties regarding thermal, chemical, and mechanical behaviour of TRISO fuel and irradiated graphite.

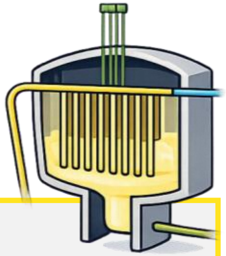
- ***R&D needs:*** thermo-mechanical and chemical testing of TRISO/graphite under wet and dry conditions, focusing on coating integrity and radionuclide leaching in varying conditions (temperature, humidity, mechanical stresses).

Disposal ***HL:*** *DGRs, DBD* | ***LIL:*** *NSD, ID-DGRs*

Low maturity of TRISO and irradiated graphite disposal; challenges in volume reduction, immobilisation techniques, and long-term stability in shallow disposal.

- ***R&D needs:*** pilot-scale testing of volume reduction and immobilisation (glass, ceramic, or bentonite); studies on long-term mechanical integrity and chemical compatibility of graphite waste forms.

BACK-END R&D NEEDS – MSRS



Subtask 4.1: Investigate predisposal and disposal options for SMR/AMR wastes

Treatment and conditioning *HL: salt immobilisation | LIL: immobilisation, decontamination*

High complexity due to molten salt fuels and coolant chemistry.

- ***R&D needs:*** development of effective decontamination methods to reduce residual activity in irradiated/corroded metallic components for waste re-classification.

Storage *HL/LIL: on-site interim storage*

Storage strategies for fuel salts are still being defined.

- ***R&D needs:*** definition of fuel salt storage requirements (e.g., optimised cooling times and container compatibility).

Disposal *HL/LIL: ID-DGRs, NSD*

Development of technologies for vitrification of fluoride- or chloride-based waste, either in the form of solidified melts or inorganic sorbents based on alkaline fluorides or chlorides

- ***R&D needs:*** develop methods for vitrifying fluoride- or chloride-based waste or verify the possibility of converting them into nitrates.

eurad 2

BACK-END R&D NEEDS – ALL – TRANSPORT

Subtask 4.1: Investigate predisposal and disposal options for SMR/AMR wastes

- Road (heavy-haul), rail, and barge remain viable transport modes for SMR/AMR spent fuels and wastes.

Cross-cutting considerations

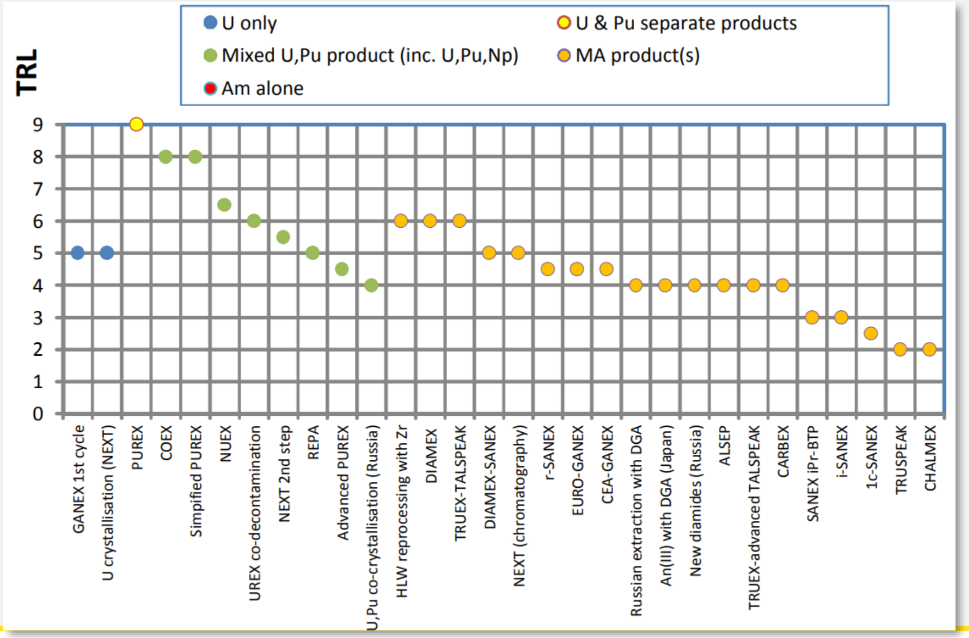
- ***Cask compatibility:*** assessing the suitability of existing dual-purpose casks versus the need for new, tailored designs, specifically for SMR/AMR geometries and material characteristics.
- ***Intermodal operations:*** reviewing transfer processes at intermodal facilities to enhance automation and contamination control, minimise handling risks and environmental exposures.
- ***Advanced modelling:*** improving transport simulations with high-fidelity data on transfer timing and transload-site conditions.

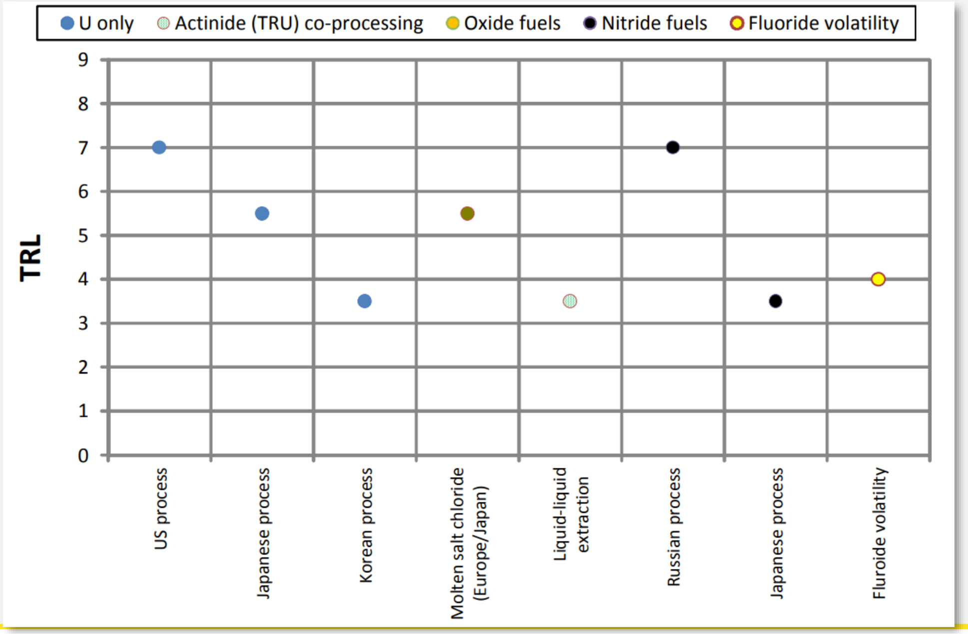
2

BACK-END R&D NEEDS – REPROCESSING

Subtask 4.2: Assess current reprocessing technologies with respect to SMR SNFs. Identify R&D needs.

- Existing reprocessing methods (**solvent extraction** and **pyroprocessing**) serve as a baseline: applicability depends on fuel chemistry and physical form, technical challenges remain, TRLs vary.





Technology Readiness Level for aqueous separation (left) and pyro processes (right)

Baron et al, A review of separation processes proposed for advanced fuel cycles based on technology readiness level assessments, Progress in Nuclear Energy, Volume 117, 2019, 103091, ISSN 0149-1970

eurad 2

BACK-END R&D NEEDS – REPROCESSING

Subtask 4.2: Assess current reprocessing technologies with respect to SMR SNFs. Identify R&D needs.

LW-SMRs: UO2 and MOX fuels, higher enrichment and burnups.

- PUREX is readily applicable. Advanced solvent extraction methods are in “proof of principle” TRL.

LMFRs: oxide, nitride, metallic fuels.

- ***Oxide fuels:*** PUREX/aqueous methods may require adaptation and extra criticality safety and regulatory considerations (higher Pu content) and pyro-processing with additional head-end steps. ***Metallic and Nitride fuels***: pyroprocessing remains at lower TRL than aqueous methods and requires significant scaling.

HTGRs: TRISO particles (UO2, UC, UN - kernels coated in PyC and SiC).

- Aqueous methods are applicable on exposed kernels.
- Challenges: low TRL of head-end processes, management of high volumes of graphite waste and secondary wastes.

MSRs: liquid salts of fissile and fertile isotopes in fluoride and chloride matrices.

- Pyroprocessing methods are at a conceptual and lab-scale stage.
- Challenges: corrosion, thermal gradients, behaviour of tritium and noble metals.

BACK-END R&D NEEDS – CHARACTERISATION

Subtask 4.3: Evaluate waste characterisation methods and modelling tools, identify needs

Experimental Methods	Modelling tools
• **Radiochemical analysis** (ICPMS, Radiochemical Separation with Beta Counting, Neutron Activation Analysis…) • **Spectroscopy and imaging** (Nuclear Resonance Fluorescence, Tomography, Gamma Imaging, X-rays Fluorescence, LIBS, Raman Spec…) • **Microstructural evaluation methods** (Scanning Electron Microscopy, Transmission Electron Microscopy, Electron Probe Microanalysis…).	• **Burnup codes** (ORIGEN, CESAR, SERPENT, KENO, MCNP, OpenMC, Tripoli, GEANT4…) • **Fuel cycle scenario simulators** (ANICCA, CLASS, COSAC, COSI, DYMOND, FAMILY, NFCSS, NMB, TR_EVOL, VISION…) • **Geochemical modelling tools** (PHREEQC, Geochemist WB, GEMS…) • **Thermomechanical modelling tools** (COMSOL, ANSYS…).

Method	***Laser-Induced Breakdown Spectroscopy (LIBS)***				*Destructive*
Description	*Laser pulse creates plasma emission lines that are element specific. Minimally destructive: ablates tiny material amounts (micrograms), destructive at microscopic level (µm craters).*				
Measured property	*Surface elemental composition (Li, Be, U, actinides)*				
Applicability	***LWR***	***LMFR***	***HTGR***	***MSR***	***Other***
	Surface analysis of debris.	*Surface of debris, Na-corroded components.*	*Fuel surface.*	*Salts.*	
Limitations	*Challenges in calibration due to matrix effects. Depth resolution is limited, which entails a limite for layered samples.*				
R&D Needs	*Salt matrix-specific calibration libraries.* *Depth-resolved LIBS (double-pulse systems).* *In-situ LIBS with minimal ablation craters (for deposits).*				
References	*(Salmon et al., 2008), (Campbell et al., 2017), (Ararat-Ibarguen et al., 2020), (Manard et al., 20 (US DoE, accessed 17.03.2026).*				

Method	***Neutron Activation Analysis (NAA)***				*Non-Destructive*
Description	*Samples are bombarded with neutrons which produces radioactive isotopes. Gamma emissions are analysed to determine elemental composition. Non-destructive (sample is irradiated, but remains intact).*				
Measured property	*Bulk elemental composition (trace to major elements).*				
Applicability	***LWR***	***LMFR***	***HTGR***	***MSR***	***Other***
	Fuel debris, resins	*Fuel and Na residues*	*Possible on TRISO or graphite bulk*	*Salts*	
Limitations	*Needs reactor or strong neutron sources. Sample becomes activated. No isotopic resolution.*				
R&D Needs	*Compact neutron sources. Automated systems for hot cell integration.*				
References	*(Pérot et al., 2018), (Abdel Rahman et al., 2024).*				

BACK-END R&D NEEDS – CHARACTERISATION

Subtask 4.3: Evaluate waste characterisation methods and modelling tools, identify needs

- Current experimental characterisation and modelling techniques are applicable but require additional developments, datasets, and validation for SMR/AMR spent fuels and waste forms.

Cross-cutting considerations

- ***Experimental techniques:*** adapt and validate preparation methods, calibration protocols, and measurement methods for complex matrices.
- ***Modelling tools:*** develop dedicated nuclear data libraries, datasets, and validation benchmarks to strengthen modelling reliability for SMR/AMR-specific fuels, coolants and waste forms. In addition, modelling circulating fuels remains a challenge.

KEY TAKEAWAYS

The SMR/AMR back-end is not a completely new challenge in nature, but the experience accumulated is not sufficient to support robust back-end planning for all SMR/AMR concepts at the same level.

- Further development is needed before existing **predisposal and disposal options** can be adequately transferred to the management of SMR/AMRs spent fuel and waste due to their new, specific radiological and chemical properties
- **Reprocessing options** can be mapped across SMR/AMR families, but significant R&D is required specifically for advanced aqueous and pyrochemical methods, as well as head-end treatments.
- **Characterisation and modelling techniques** remain relevant but for SMR/AMR further R&D is needed to advance experimental techniques, strengthen reliability of modelling tools, and develop validation datasets.

THANK YOU FOR YOUR ATTENTION

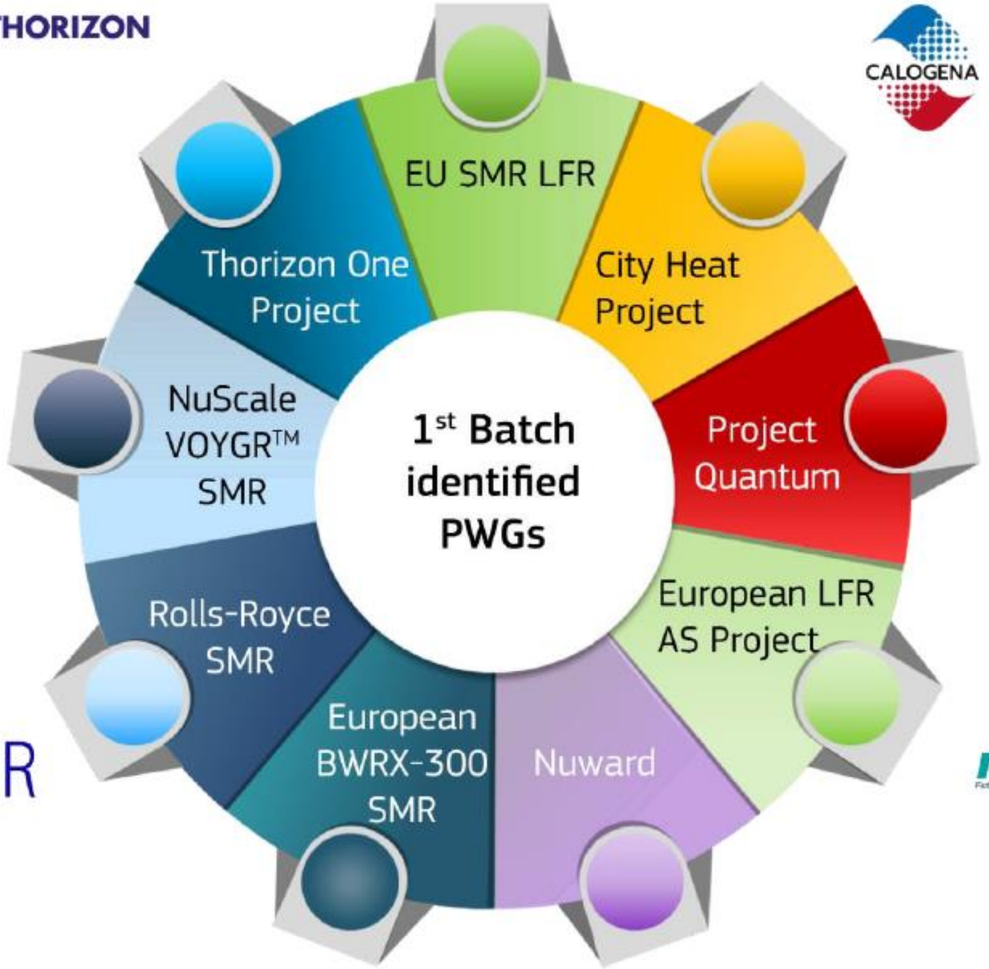
Technical Working Group 7

Nuclear Fuel Cycle and Radioactive Waste Management

Chair: Ureno Vice-chair: Orano

European Industrial Alliance on Small Modular Reactors - Internal Market, Industry, Entrepreneurship and SMEs

European IA on SMRs 1st batch PWGs*



*Announced on 11 October 2024
https://ec.europa.eu/docsroom/documents/62274

European IA on SMRs – TWGs

June 2024
October 2024

TWG1: Industrial Applications

Chair: N.Rega (CEFIC)
Vice Chair: A.Georgescu (Eurometaux)

TWG2: Technology and R&D&I

Chair: P.Baeten (SCK-CEN)
Vice Chair: M.Pasquet (Framatome)

TWG3: Supply Chain

Chair: V. Ramany (EDF)
Vice Chair: M.Tacconelli (Walter Tosto)

TWG4: Skills

Chair: M.E. Ricotti (POLIMI, CIRTEN)
Vice chair: O. Bard (GIFEN).

TWG5: Public Engagement

Chair: : M. Martell (GMF)
Vice Chair: M. Ilnicki (SGE)

TWG6: Nuclear Safety & Safeguard

Chair: O.Kymäläinen (FORTUM)
Vice Chair: R.Arsene (Nuclearelectrica)

TWG7: Fuel cycle & waste management

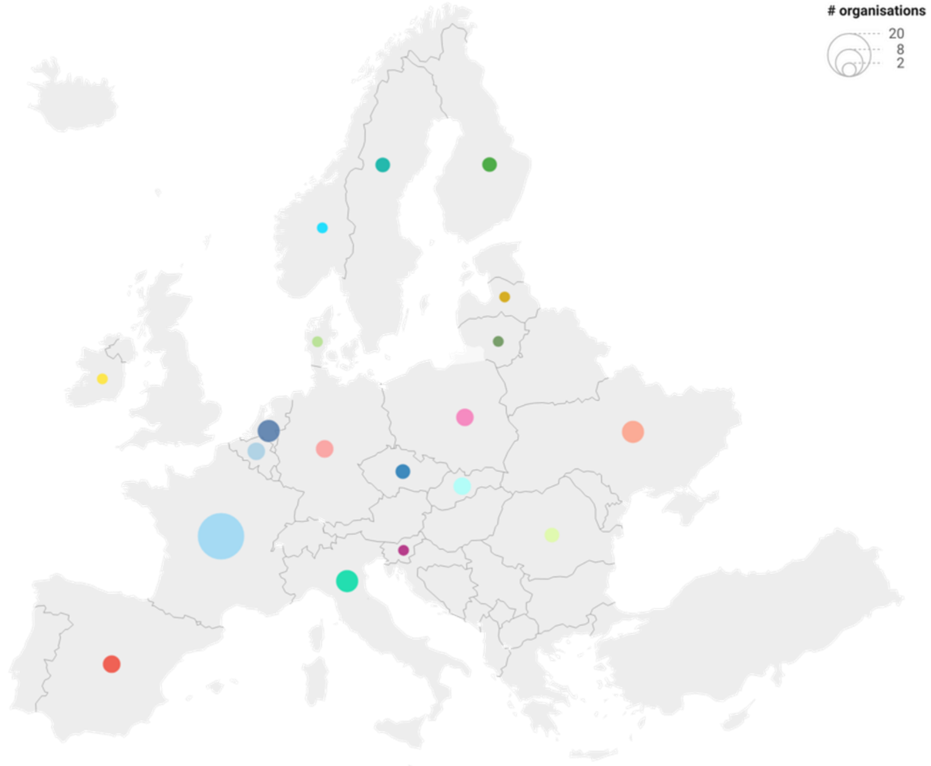
Chair: H.Baars (URENCO)
Vice Chair: T.Louvet (ORANO)

TWG8: Financing

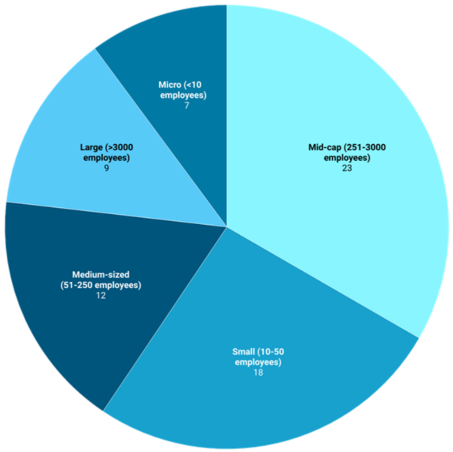
Chair: M.Jedlička (ČEZ)
Vice Chair: C.Töpfer (Vattenfall)

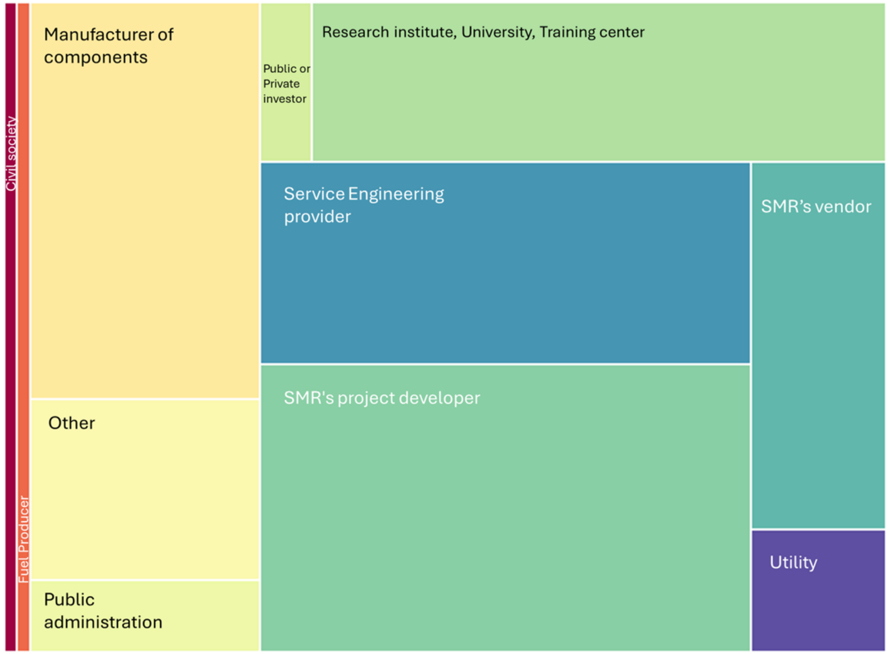
European Industrial Alliance on **SMALL MODULAR REACTORS**

[Country distribution, TWG7 members, Jan 2025]



[TWG7 Size of Organisation]

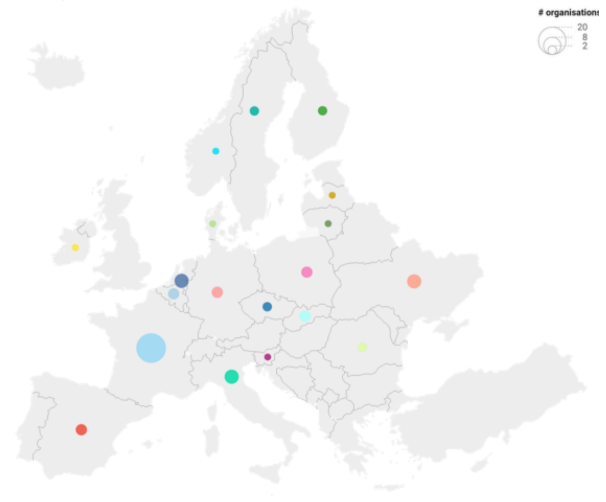




TWG7
Fuel & Waste Management

69 Organisations

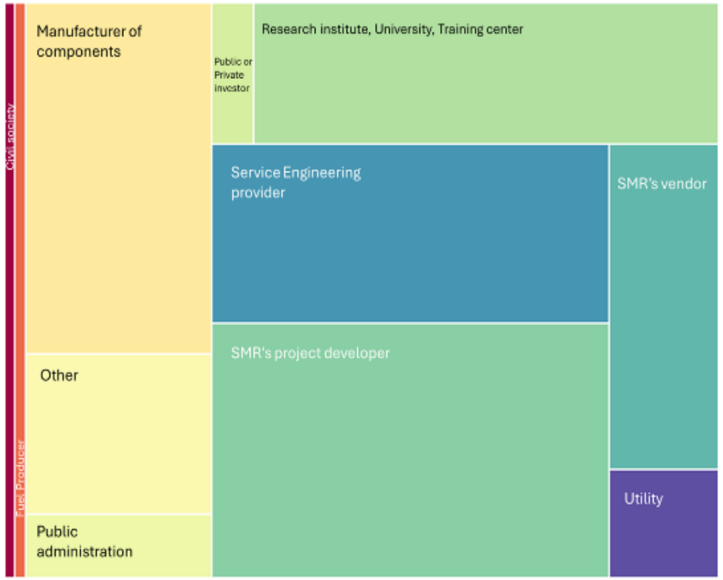
[Country distribution, TWG7 members, Jan 2025]



TWG 7

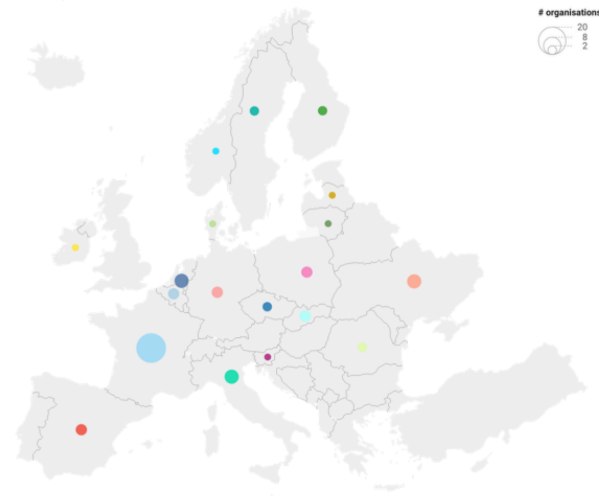
Overall goal as per the Strategic Action Plan

TWG7
Fuel & Waste Management
69 Organisations

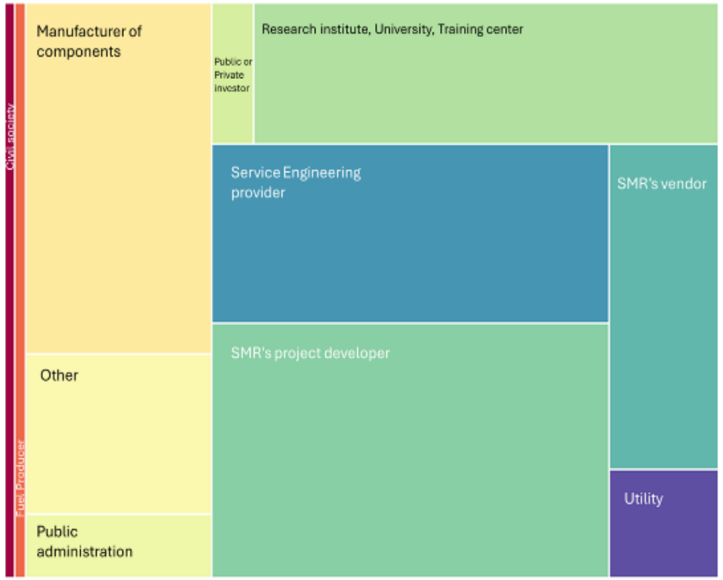


'Provide input to the development of standardised fuel design specifications for LWR SMRs and AMRs technologies in collaboration with PWGs'

[Country distribution, TWG7 members, Jan 2025]



TWG7
Fuel & Waste Management
69 Organisations



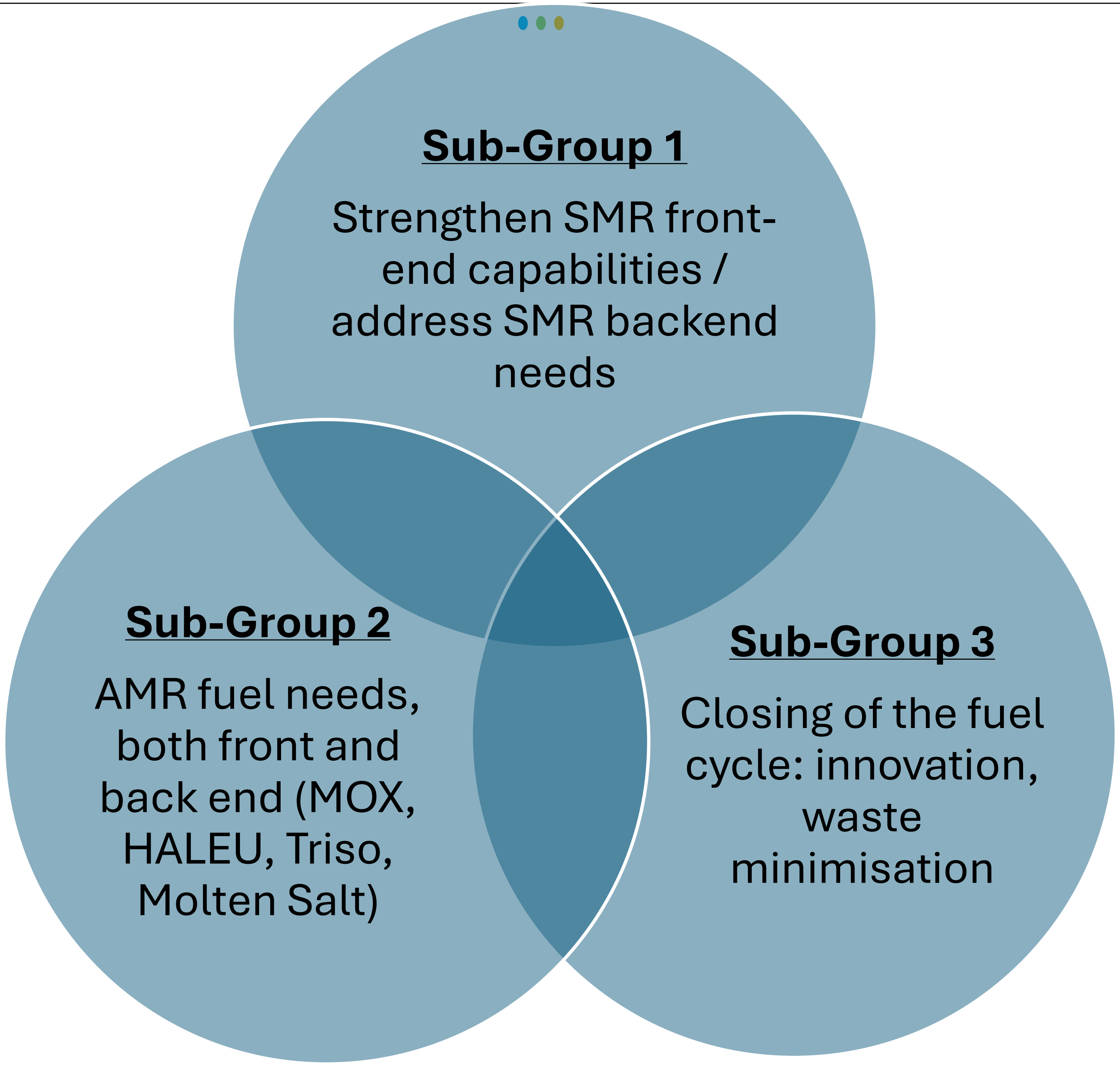
TWG 7

Objectives

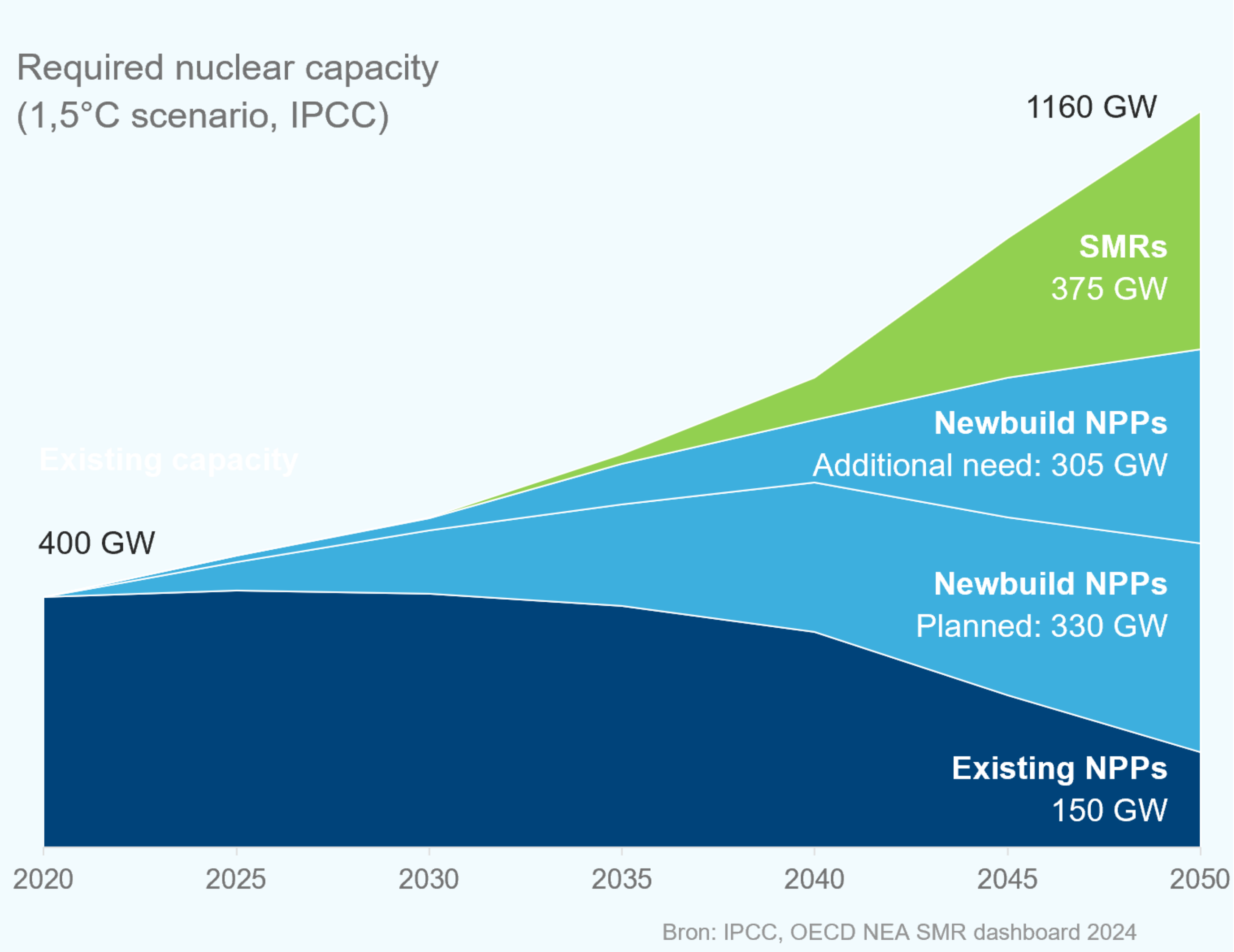
1. Ensure availability of nuclear fuel
2. Explore and propose ways to enhance industrial capabilities
3. Advance innovation and development of next gen fuels
4. Consider fuel transport and storage solutions
5. Define and support the back-end of the fuel cycle
6. Identify regulatory gaps and harmonisation needs

nucleareurope SNETP Sustainable Nuclear Energy Technology Platform

TWG 7 Sub-Group Structure



Context – growth of nuclear

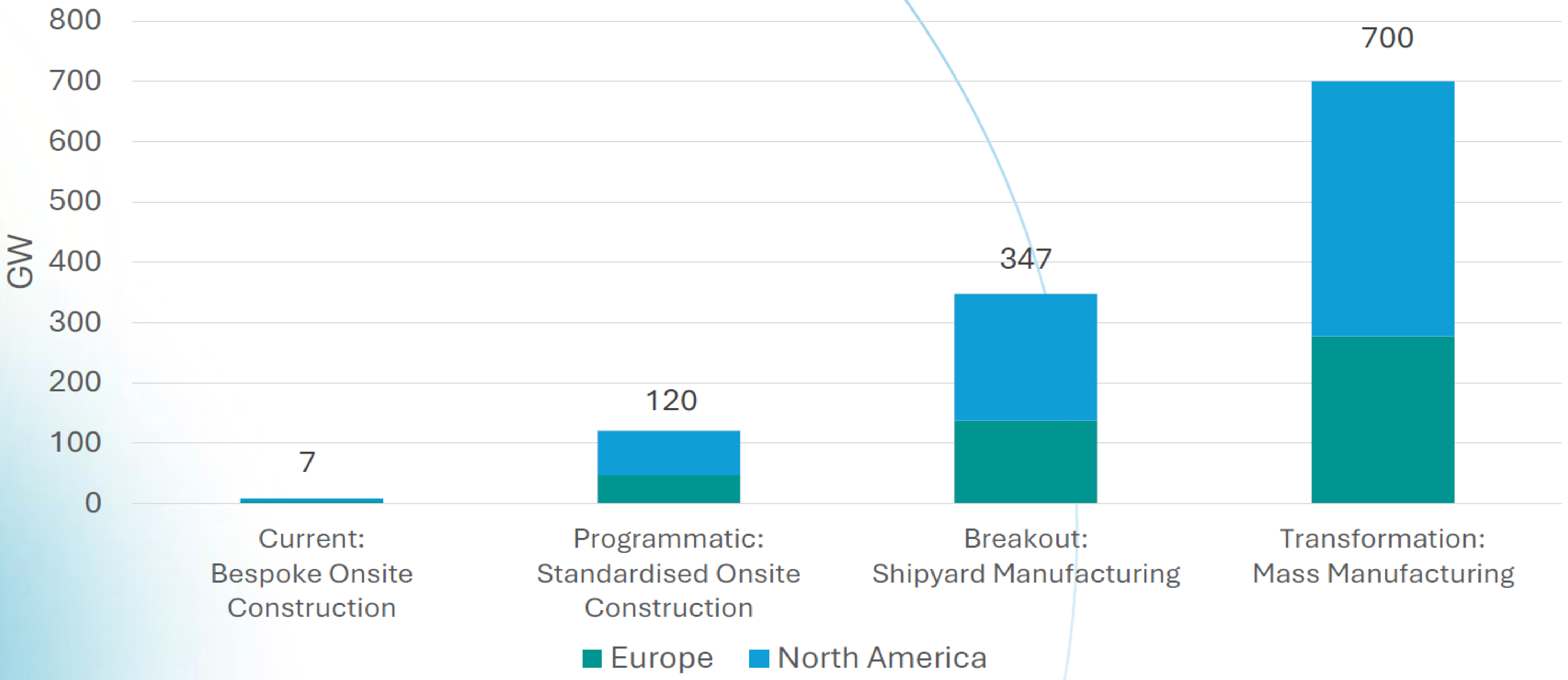


- Tripling of installed nuclear capacity – COP28
- IEA states that 1160GW installed nuclear capacity is need for 1,5°C scenario

Context – growth of nuclear

Market potential: positive insecurity

SMR scenario's per region in 2050



- Urenco Propriety -

Concluding remarks

- Existing nuclear fuel cycle is well established. It is crucial to **limit Russian nuclear fuels in the EU**. Allow no market distortion. The EU (France, Netherlands, Germany) is a dominant player in parts of the global fuel cycle, yet international collaboration is key.

- A stable and **agile regulatory framework** is needed, and **political long-term policy** is critical for enabling investment in new fuel cycle capabilities. **Harmonisation of regulations** would greatly help.

- To minimise lead times for licensing of ‘new’ fuels a **Common Framework for Technological Readiness Levels** (TRL) could be envisaged.

- With more nuclear deployment we need to focus on back-end **solutions for spent fuel** (minimisation, recycling, reprocessing and final storage).

- There are clear challenges which need to be addressed but with coherent policies and support, the **European Nuclear fuel supply chain will support the EU’s decarbonisation and energy independence ambitions** whilst driving the bloc’s **industrial competitiveness**.

NEA
NUCLEAR ENERGY AGENCY

Progress on the NEA Project on Waste Integration for Small and Advanced Reactor Designs (WISARD)

Una Baker

NEA Division of Radioactive Waste Management and Decommissioning

NEA WISARD Joint Project – Objectives

Waste Integration for Small and Advanced Reactor Designs

Project duration: 2025-2028

Innovative solutions for innovative systems

WISARD project objectives:

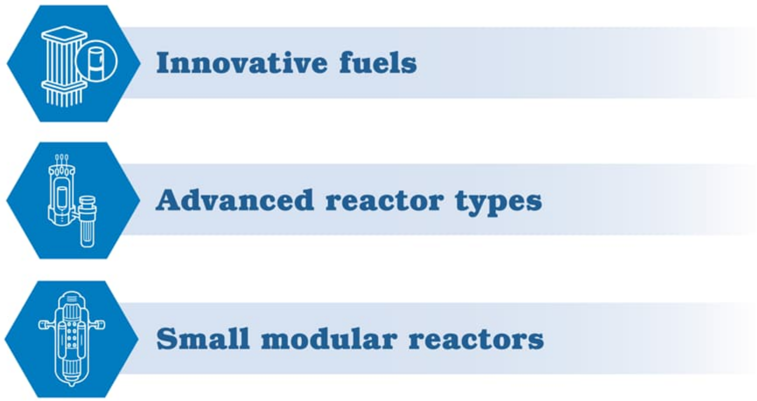
- *Understand* effects of fuel cycle options & new technology choices
- *Include* waste management perspective in design decisions
- *Improve* design optimisation & robustness by creating opportunities to address future issues early.

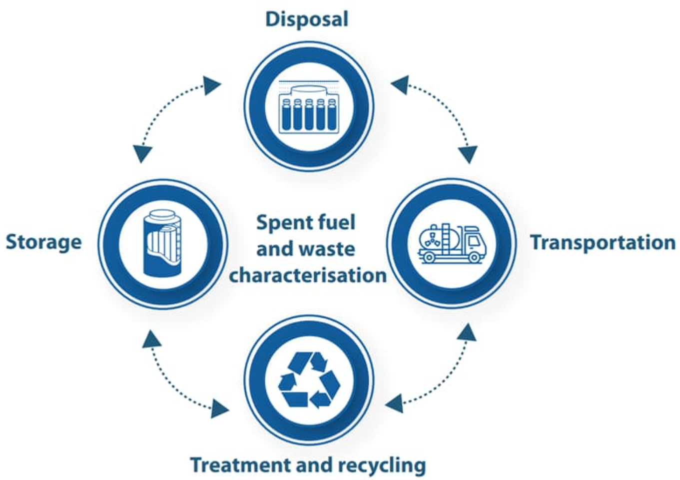
WISARD will investigate:

1. Is waste from these innovative systems compatible with current waste management solutions?
2. If not, what are the technology needs for a sustainable future back-end strategy?
3. How will these innovative systems require innovative solutions?

NEA WISARD Joint Project – Focus Topics

Waste Integration for Small and Advanced Reactor Designs





Front-end & design-phase decisions will have an impact on back-end waste management strategies:

- Increased fuel enrichment (e.g. HALEU)
- Irradiated graphite-matrix TRISO fuel management
- Activated coolant disposal (e.g. liquid metal, salt)
- Liquid fuel waste management strategies
- Location limitations (e.g. waste transport for remote SMRs)

WISARD Task focus areas:

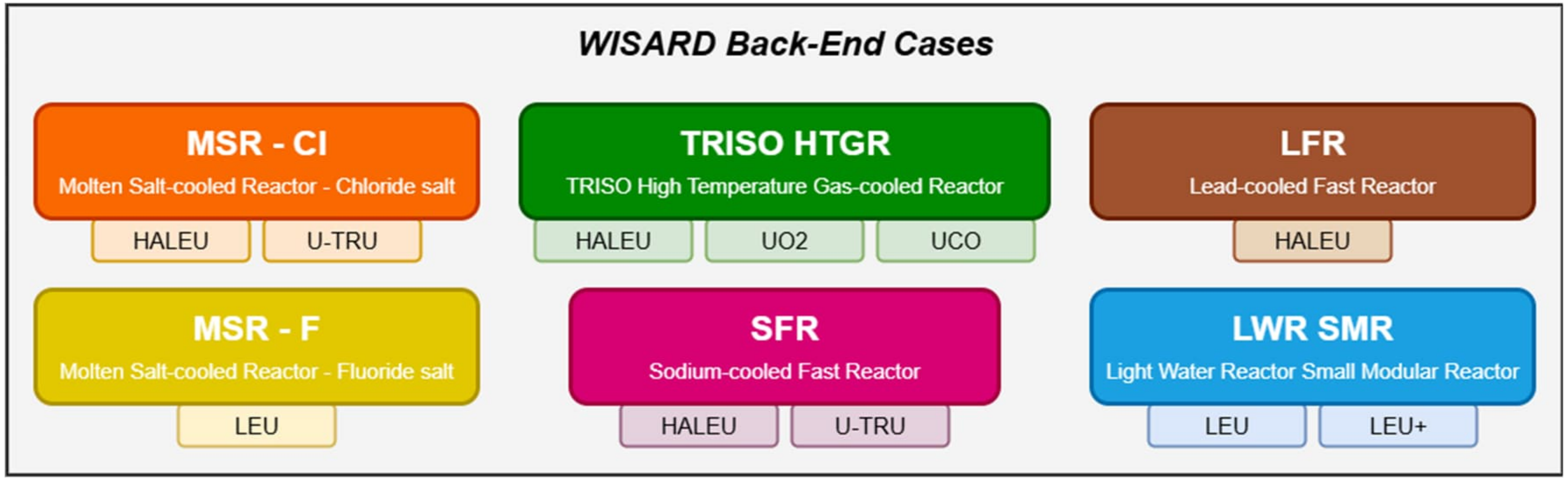
1. Irradiated fuel & coolant characterisation
2. Treatment & reprocessing
3. Storage
4. Transportation
5. Disposal (DGR & borehole)
6. Cross-cutting integration and interdependencies

NEA WISARD Joint Project – SMR/AR Systems

Waste Integration for Small and Advanced Reactor Designs

Engaging with developers to provide the most accurate back-end information

- WISARD focuses on selected systems and fuels of interest to project participants
- SMR/AR designers and vendors participating in WISARD will provide the most up-to-date information, allowing detailed characterisation of used fuel and waste materials
- WISARD is a closed project and all participants retain ownership of IP shared within the activities
- Used fuel and waste characterisation data will be collected into Back-End Cases (BECs) and assessed for compatibility with different waste management strategies under the Task focus topics



NEA WISARD Joint Project – Participants

Waste Integration for Small and Advanced Reactor Designs

Signatories

Canadian Nuclear Laboratories

SALTFOSS

VTT

GRS

Korea Atomic Energy Research Institute KAERI Since 1959 한국원자력연구원

KOREA HYDRO & NUCLEAR POWER CO., LTD KHNP 한국수력원자력(주)

Blykalla

NATIONAL NUCLEAR LABORATORY

Nuclear Waste Services

DEEP ISOLATION®

EPRI

NEI NUCLEAR ENERGY INSTITUTE

Third parties

Énergie NB Power

moltex clean energy

GNS

KINGS

Environment Agency

HOLTEC INTERNATIONAL

NAC INTERNATIONAL

orano

wnti

NEA WISARD Joint Project – Tasks

Waste Integration for Small and Advanced Reactor Designs

TASK 1
Irradiated fuel & coolant characterisation

TASK 2
Treatment & reprocessing

TASK 3
Storage

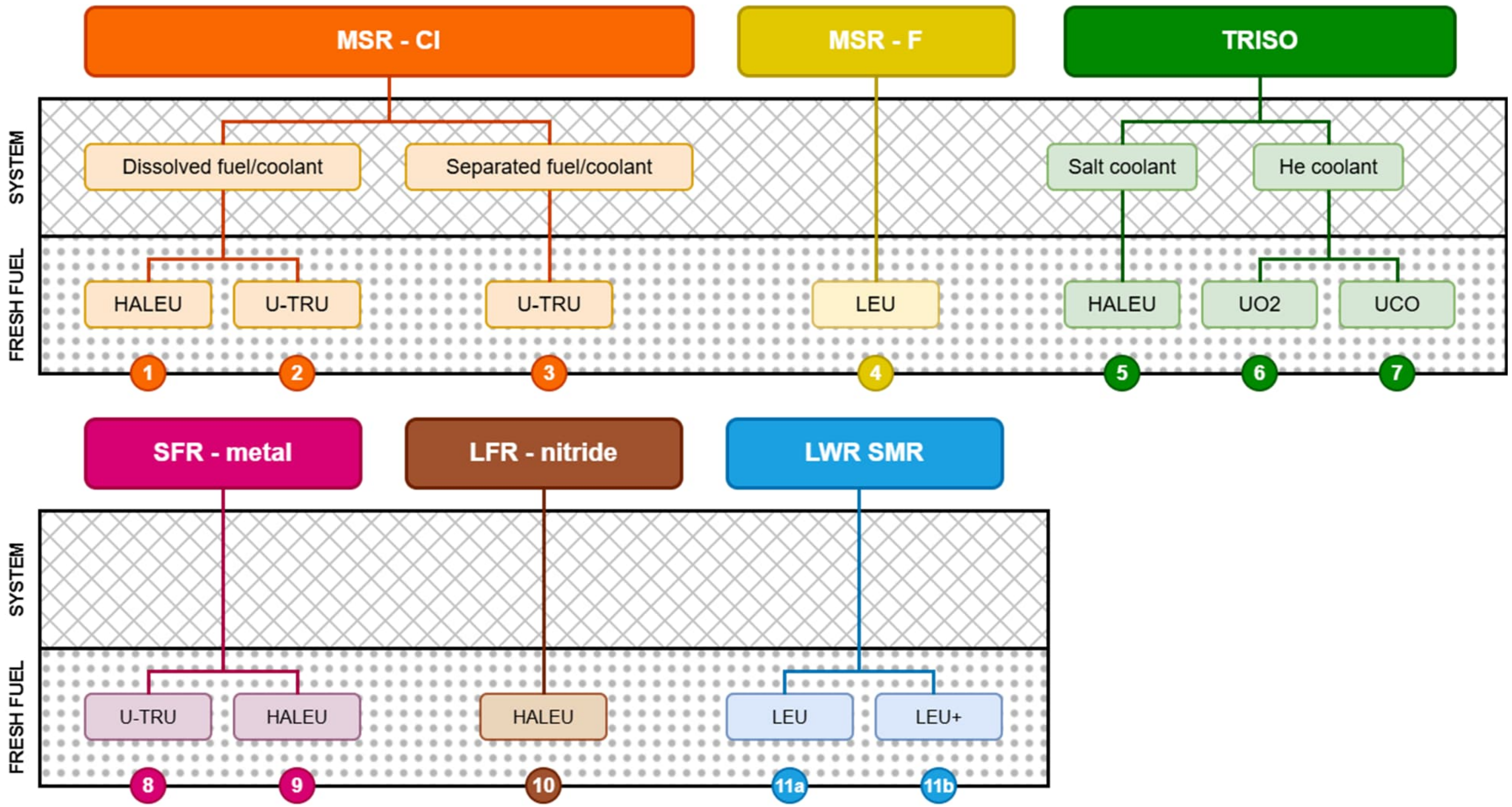
TASK 4
Transportation

TASK 5
Disposal

TASK 6
Cross-cutting issues & interdependencies

NEA WISARD Joint Project – Task 1

Waste Integration for Small and Advanced Reactor Designs



NEA WISARD Joint Project – Tasks 2-5

Waste Integration for Small and Advanced Reactor Designs

NEA NUCLEAR ENERGY AGENCY

TASK 2
Treatment & Reprocessing

- Assessment of the need for treatment and evaluation of the compatibility with existing treatment processes
- Re-characterisation of waste destined for final disposal after treatment/reprocessing
- Assessment of additional waste streams generated by treatment or reprocessing
- Identification of cost drivers and regulatory challenges

TASK 3
Storage

- Assessment of technological challenges
- Comparison of wet storage densities (LWR-SMR BEC-11 only)
- Feasibility study and gap analysis for dry storage
- Identification of cost drivers and regulatory challenges

TASK 4
Transportation

- Assessment of novel fuel forms/waste streams under accident conditions
- Cask compatibility assessments
- Assessment of global transport capacity and suitability of current transport infrastructure
- Identification of cost drivers and regulatory challenges

TASK 5
Disposal

- Systems analysis of disposal system performance for novel waste
- UQ/SA to identify key impacts on repository design and operation
- Assessment of waste suitability for direct disposal
- Identification of cost drivers and regulatory challenges

NEA WISARD Joint Project – Task 6

Waste Integration for Small and Advanced Reactor Designs

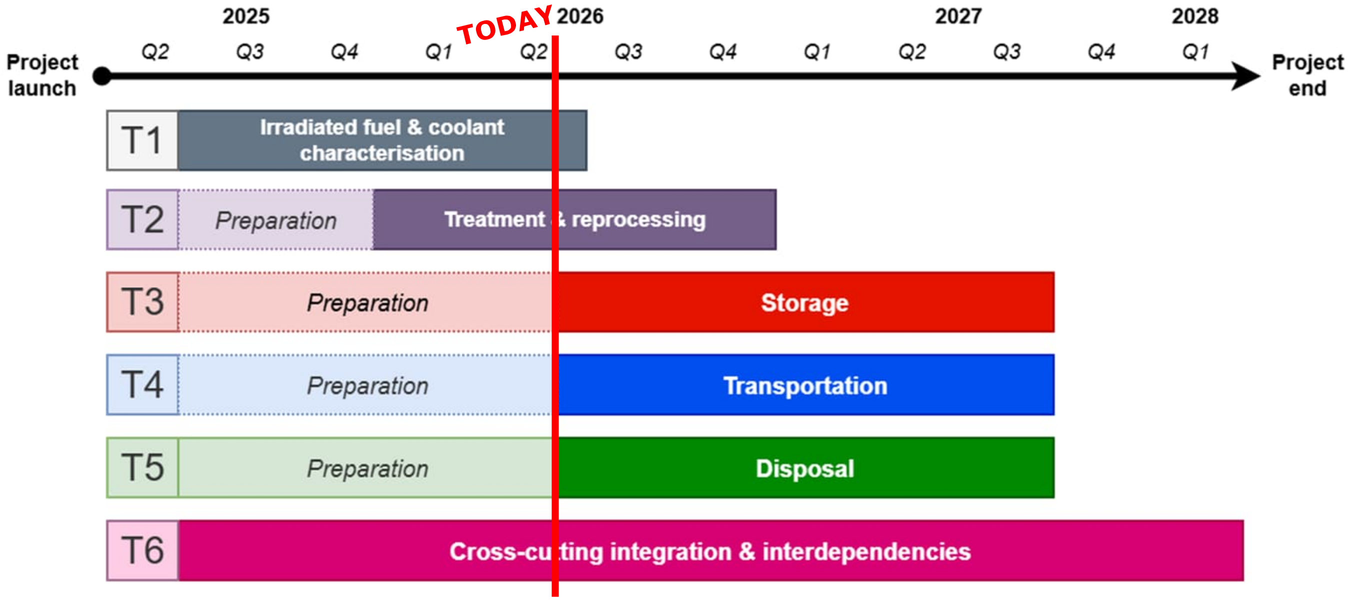
Task 6 Overview

Task focus topic:	Continuous assessment of interdependencies between Tasks to allow integrated consideration of waste management strategies.
Assessment method:	Review of Task findings and other assessments as defined using methods employed in other Tasks.
Key results:	Additional calculations, where needed in other Tasks. High-level cost estimation analysis.

- As WISARD is an integration-focused project, it is crucial to capture the interdependencies between Tasks to provide a full assessment of different waste management strategies for SMRs/ARs.
- Task 6 will:
  - Review results from all Tasks continuously throughout the Project, ensuring cohesion between different working groups through periodic meetings.
  - Provide recommendations for additional calculations where needed to address interdependencies between Task results.
  - Collect high-level cost drivers from Tasks and co-ordinate with NEA expert groups to provide cost estimation analysis.

NEA WISARD Joint Project – Progress

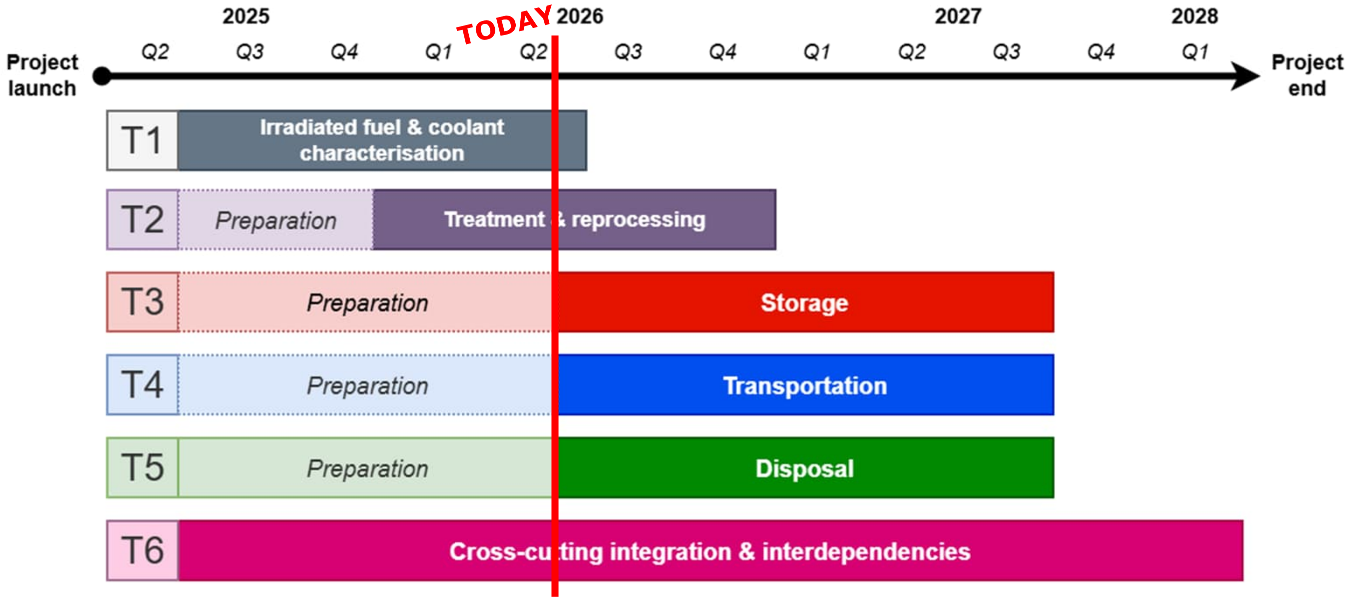
Waste Integration for Small and Advanced Reactor Designs



- Programmes of Work for all Tasks have been developed by participants and agreed by MB
- First results provided in Q1 2026: Task 1 waste characterisation data
  - Radionuclide inventories & source term data
- Preparation for compatibility assessments in next Tasks:
  - Definition of storage/transport canisters & DGR/borehole scenarios for evaluation

NEA WISARD Joint Project – Next Steps

Waste Integration for Small and Advanced Reactor Designs



- Provision of material properties data for Task 1 BECs
- Re-characterisation of waste after treatment/reprocessing activities
- Beginning of compatibility assessments for storage, transportation, and disposal
- Identification of high-level cost drivers for different strategies
- Planning for limited collaborations and open workshops with other groups

NEA Workshop on Reprocessing for Advanced Fuel Cycles

Supporting Sustainable Waste Management Solutions

- Dates: 11-13 November 2026
- Location: Daejeon, Korea
- Hosts: KAERI and KHNP
- Technical programme: Under development but expected to include:
  - *Strategic drivers:*
    - Policies, regulations, & economics to create favourable conditions for reprocessing activities
  - *Enabling actions:*
    - Technologies, infrastructure, & alignment of decision-makers to support reprocessing implementation
  - *Back-end impacts:*
    - Integration of waste management & decommissioning perspectives

Site visits:

- PRIDE pyroprocessing facility
- KURT, underground research tunnel for geological disposal
- SMR Simulator Center

Image source: visitkorea.or.kr

Thank you for your attention!

Visit the WISARD website or contact WISARD@oecd-nea.org for more information

Title page image: ShutterStock

IAEA Coordinated Research Project on Challenges, Opportunities and Gaps for Managing Spent Fuel from SMRs (CRP SMR-COGS)

Ms Amparo González-Espartero, PhD
Technical Lead Spent Fuel Management
Nuclear Fuel Cycle and Materials Section
Department of Nuclear Energy, IAEA
a.g.espartero@iaea.org

SMR Fundamentals: Advances in Technology Development and Applications

Definition, Rationale for Development

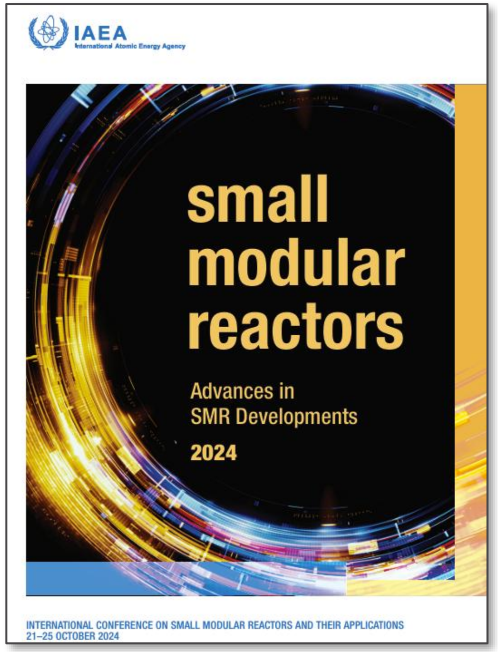
- SMRs: Advanced reactors to generate typically **up to 300 MWe**, built with modularity in factory setting, transportable as modules to shorten construction schedule thus reduce cost
- Designed for lower capital cost, flexible siting & operation, scalability and non-power applications

Categorization by **Technology, Siting & Size**

- ❖ Water-cooled reactors (land based, stationary)
- ❖ Marine-based reactors (WCRs and Non-WCRs)
- ❖ High Temperature Gas-cooled Reactors
- ❖ Liquid-metal cooled reactors, with fast neutron spectrum
- ❖ Molten salt fuelled and cooled reactors
- ❖ Microreactors (≤ 10 MWe) of diverse technologies

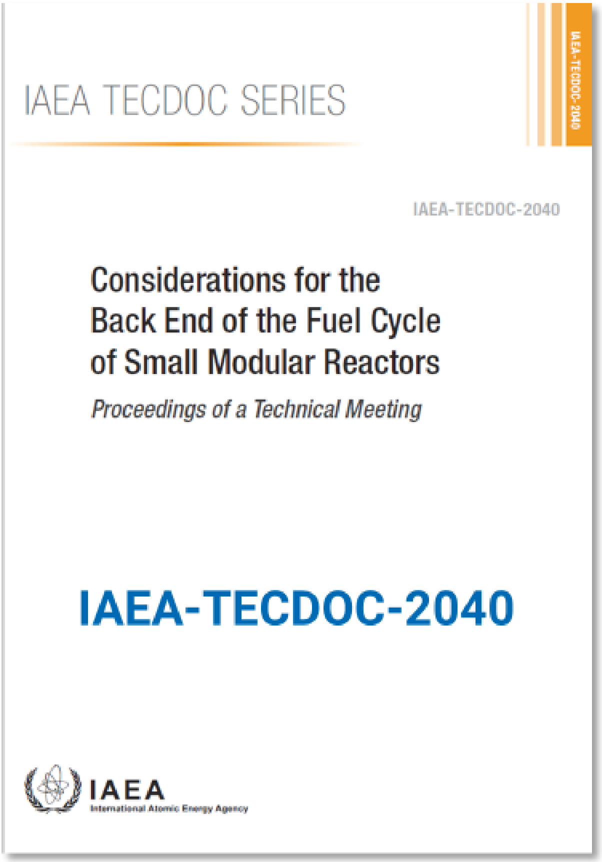
Advances in Design Development

- ~ **68 designs** of major lines technology with active development projects in **18 Member States**
- **Four (4) units in operation: 2 PWR units (70 MWe) in Floating NPP, 2 HTGR units for 200 MWe) NPP**
- Four (4) units under construction. > 50 designs in conceptual, basic and detail design stages



IAEA TECDOC 2040 on Considerations for the Back End of the Fuel Cycle of Small Modular Reactors

From a Technical Meeting held on 20 – 23 September 2022 in Vienna


IAEA TECDOC SERIES

IAEA-TECDOC-2040

Considerations for the Back End of the Fuel Cycle of Small Modular Reactors

Proceedings of a Technical Meeting

IAEA-TECDOC-2040

IAEA

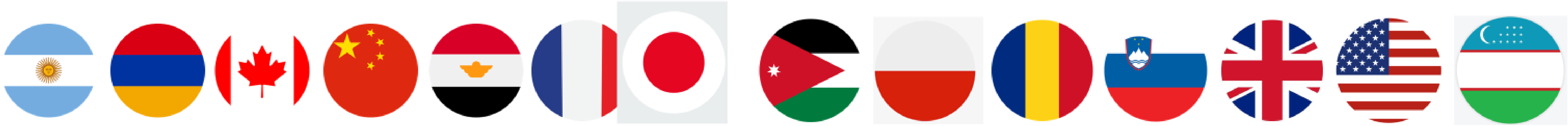
International Atomic Energy Agency

107 Participating Experts from **32** Member States

3 International Organizations: EC/JRC, OECD/NEA and ERDO

TECDOC Content: Summary of Presentations and Discussions during the Technical Sessions on:

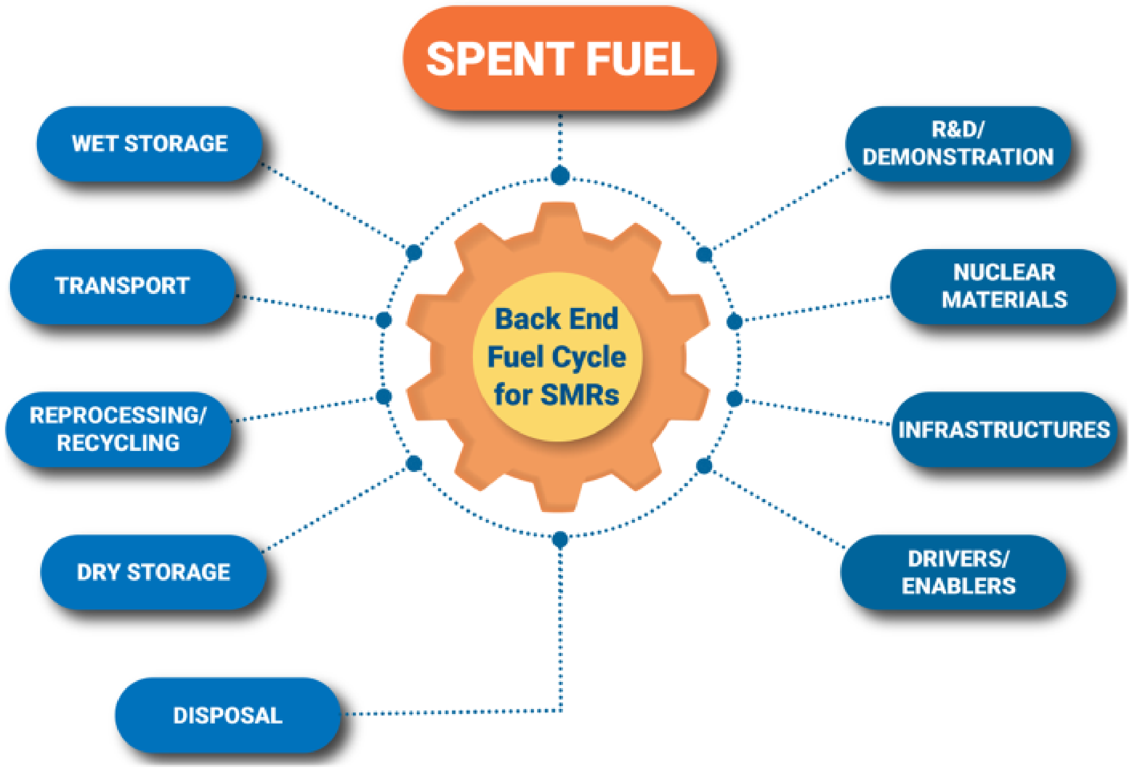
- **IAEA Activities:** SMR Developments and Associated Nuclear Fuel Cycle Options, Fuel Designs, Safety, Security, Safeguards, Economics, Transportation
- **International Organization's Activities and Perspectives:** EC/JRC, OECD/NEA and ERDO
- **Member States' Activities and Perspectives:** Argentina, Armenia, Canada, China, Egypt, France, Japan, Jordan, Poland, Romania, Slovenia, UK, USA, Uzbekistan
- **Breakout Sessions on SFM** (Storage, Reprocessing&Recycling, Transport, Disposal)
  - LWR type; HTGR type; AMRs type (FRs and Molten Salt Reactor)
- **Conclusions and Future Areas of Work**



Coordinated Research Project on Challenges, Gaps and Opportunities for Managing Spent Fuel from SMRs (SMR-COGS) 2024-2028

Understanding the implications of the management of new spent fuels is paramount to make informed decisions

IAEA SMR-COGS Project



MAIN OBJECTIVES and OUTPUTS

Development of **specific roadmaps** for managing spent fuel from the different SMR technologies, identifying **what can be derived, optimized or adapted from existing practices, or what needs to be fully developed**

- **All SMR technologies included**: LWRs (LEU, LEU+, HALEU), HTGR (TRISO (compact, pebbles)), FRs (Metallic, Oxide, Nitrides, …), MSRs
- **To compare various SMR systems**, in terms of efforts required to develop and implement an SFM strategy

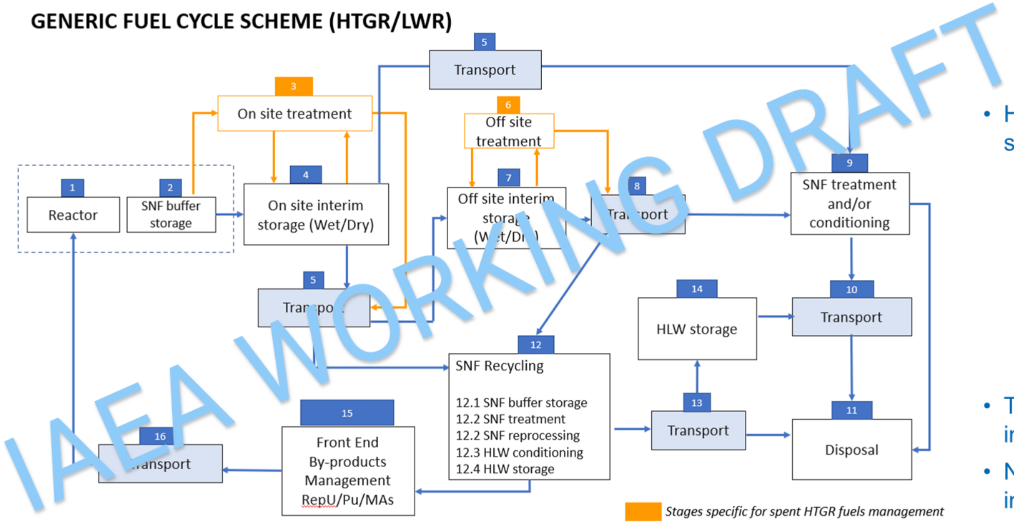
First Research Coordination Meeting of SMR-COGS CRP, 11-15 November 2024

- ***27 Research Agreements and Contracts*** from **20 countries** ARG, ARM, CAN(2), CPR(2), CZR, EGY(2), INS, JOR, LIT, MEX, POL, ROM(2), RUS, SIN, SPA, SWE, TUR, UK(2), UKR(3), USA

- **Observers:** FIN, FRA, NET
- Industry, Operators, Researchers, Regulators, …
- Embarking, Expanding, and Mature Nuclear Power Countries

45+ participants from 25 countries

2[nd] RCM scheduled on 6 – 10 July 2026



Timeline: Short, Medium, Long Term

- High Level elements for the scenario
  - NFC facilities
  - Nuclear materials involved
  - RW generated
  - Gaps/Challenges/Opportunities/ R&D/ Demonstrators
  - Technology readiness level
  - Infrastructures needed
  - Potential enablers
  - …
- Time scale for development and implementation
- Needs for development and implementation
- What is needed and when
- Decision points

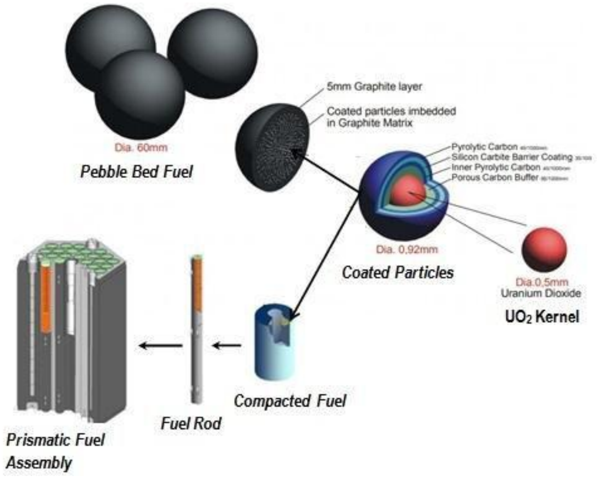
Technical Meeting on Managing SNF (Pebbles and Compacts) from HTGRs, 7-11 July 2025

47 participants from **22** Member States

https://conferences.iaea.org/event/414/

Scope

- Management of spent HTGR fuels (TRISO particles in graphite matrix (pebbles and compacts)



Discussions on

- **Country experiences** on managing spent fuel from HTGR (e.g, China, Germany, Japan, Kazahastan, Russia, UK, USA, EC on-going Projects)
- **Newcomer's perspectives** on HTGR spent fuel management (e.g., Egypt, Jordan, Pakistan, Poland)
- **Work on HTGR Fuel Cycle Options**: Open and Closed Cycle for managing spent Pebble and Compact fuels

IAEA Document in progress on

Comparison of the Management of Spent HTGR and LWR Fuels

Joint IAEA-NEA Workshop on the Chemistry of Fuel Cycles for Molten Salt Reactor Technologies, October 2023

44 participants including **4 developers of MSRs** (Copenhagen Atomics, Seaborg Technologies, Naarea and Terrapower)**,** R&D organisations, regulators and industry experts from **13 countries** and the EC/JRC

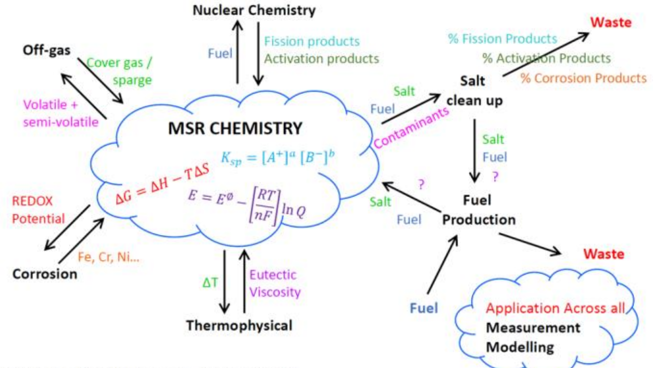
A harmonized set of related **terminology** and **taxonomy** of MSR fuel cycles is required to enhance discussion and communications cross the different stakeholders (e.g., developers, researchers, implementors, regulators and decision makers) on this complex topic

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

32 participants from **12** countries

- **Main elements** to develop a **taxonomy** for the fuel cycle options associated to MSRs were identified.
- **List of terms related to MSR fuel cycles** and potential similarities (synonymous) identified.

Joint Publication under preparation



Note: No relevance to the colours chosen – purely arbitrary!

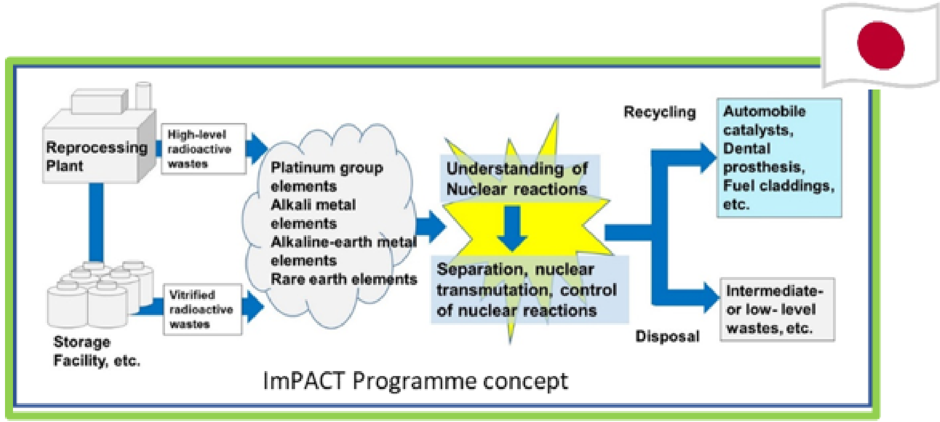
Courtesy Dr. Mike Edmondson, NNL (UK)

On-Going IAEA Report on Advanced Fuel Cycles

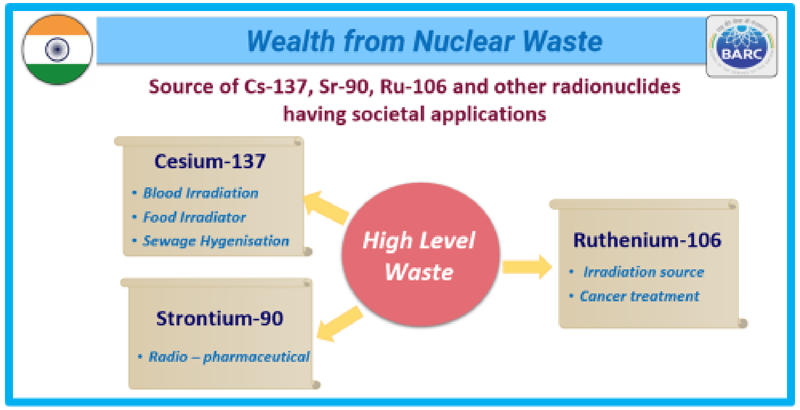
IAEA Guidebook for Decision Makers on

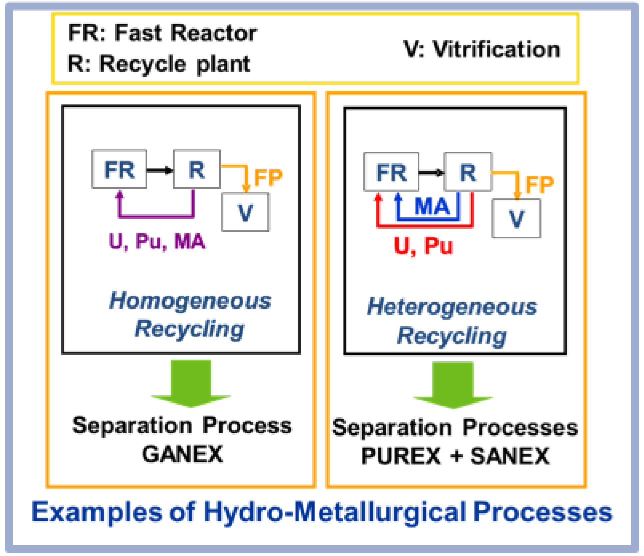
Advanced Nuclear Fuel Cycle Options for Waste Burden Minimization and Natural Resources Preservation

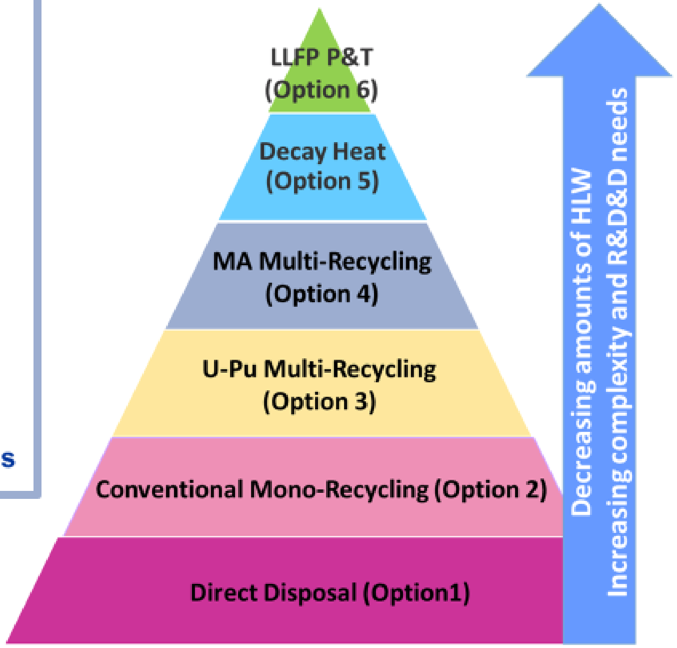
Describes relevant information on nuclear materials, generated wastes, nuclear facilities, infrastructures required, etc.

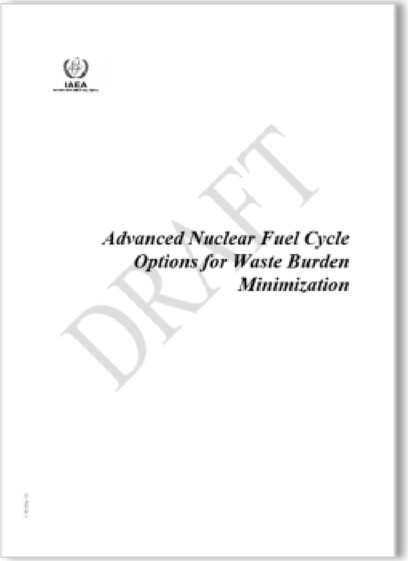


LLFP impacting GDF: ^{79}Se, ^{99}Tc, ^{129}I, ^{135}Cs, …







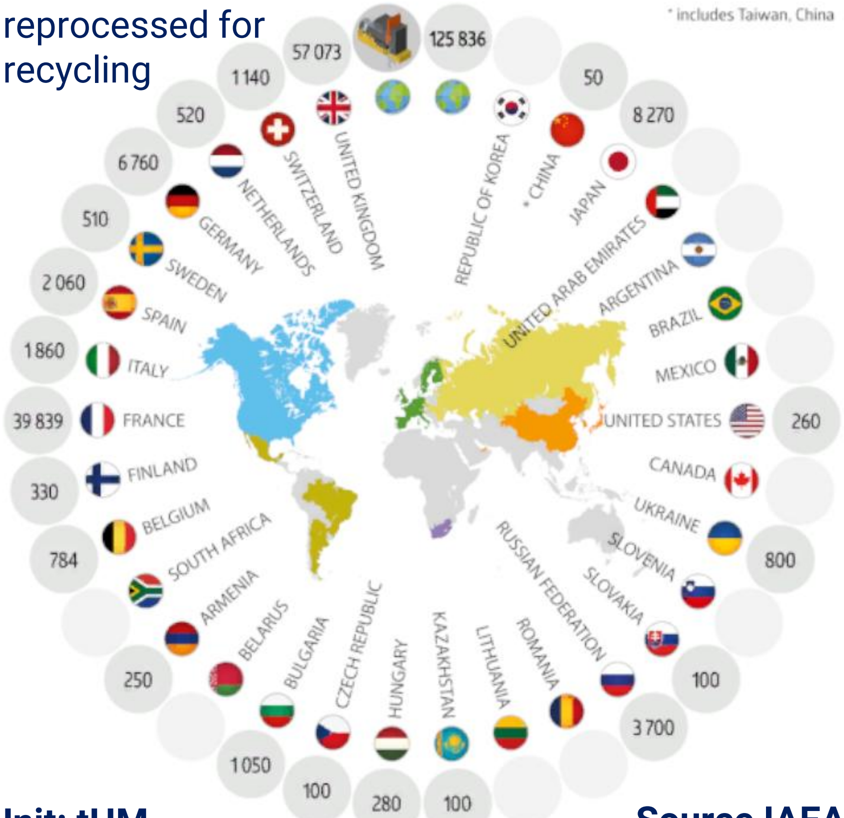


- **LWRs multirecycling**
  - MIX and MOX-MR processes (France)
  - REMIX process (Russian Federation)
- **FRs multirecycling**

Status of Spent Fuel Recycling

≈ **448000 tHM** discharged from NPPs

≈ **30%** has been reprocessed for recycling



*** Unit: tHM**

Source IAEA

- **Rep-Pu as MOX in Light Water Reactors**
  - More than **40 years** of experience worldwide
  - Recent reactor designs can accommodate 100% MOX cores
- **Rep-Pu as MOX in Fast Reactors**: implemented in Russia in BN-800
- **Rep-U** as **Enriched Reprocessed U (ERU)** in Thermal Reactors (PWRs, VVERs, RBMKs, AGRs, PHWRs)
  - More than **30 years** of experience worldwide
  - Thermal Reactors can accommodate 100% Rep-U cores
- **Mono-Recycling is a mature technology,** reference process worldwide (PUREX)
- Reprocessing capacities exist in France, Russia, India, Japan and China

Recycling Spent Fuel is a **mature technology**
PUREX reference industrial reprocessing process

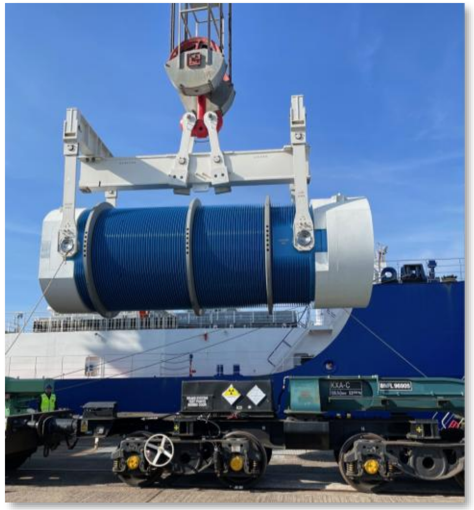
Advanced (hydro and pyrometallurgical) processes have been researched for decades aiming at Reducing the Burden of High-Level Waste and Preserving Natural Resources

TECDOC on Operational Experiences on Spent Fuel and High-Level Waste Transport

- Transport is a key enabler of the nuclear fuel cycle
- Spent fuel has been regularly transported for decades in certified casks
- Different modes of transport are routinely used (railway, waterways, roads)

Swedish transport routes and modes. Courtesy of SKB

Courtesy of Orano



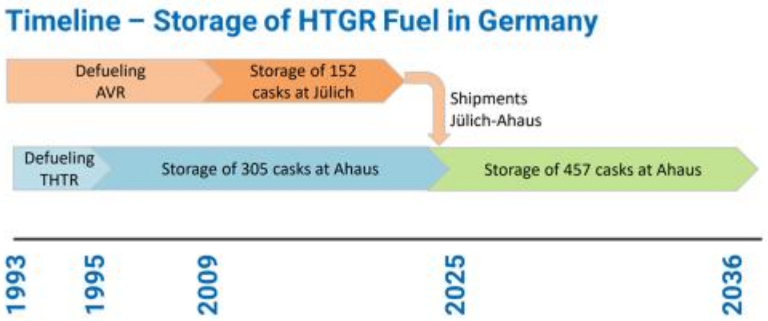
Shipment from UK to Germany. Courtesy of NTS Courtesy of Orano Daher

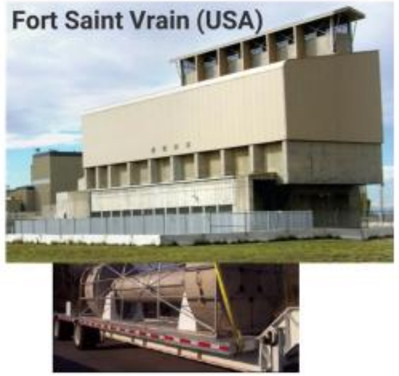
Management of SNF from SMRs, Learning from the Past, Enabling the Future

SHORT TERM — **MID TERM** — **LONG TERM**

Based on UOx with enrichments up to 5% and beyond (up to 20%)
Existing technologies could be adapted

Based on HTGR with TRISO particles in pebbles/compacts

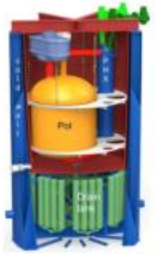




- Fort Saint Vrain (USA)
- Additional experiences in UK and Japan

- Studies on coated particle spent fuel disposal have been conducted (e.g. USA 2014)

FRs (Oxide, Metallic, Nitride)
MSRs (U, Pu, Th, MA in fluoride/chloride molten salts)

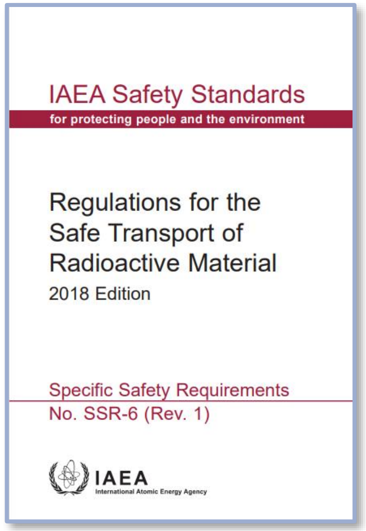


- Most of these fuels have been tested in research reactors, PIE and at R&D level
- Advanced Fuel Cycles are at demonstration scale and need scale up for industrial implementation

Overview of Implications for Managing SNF from SMR/AMRs

Transport packages are content specific

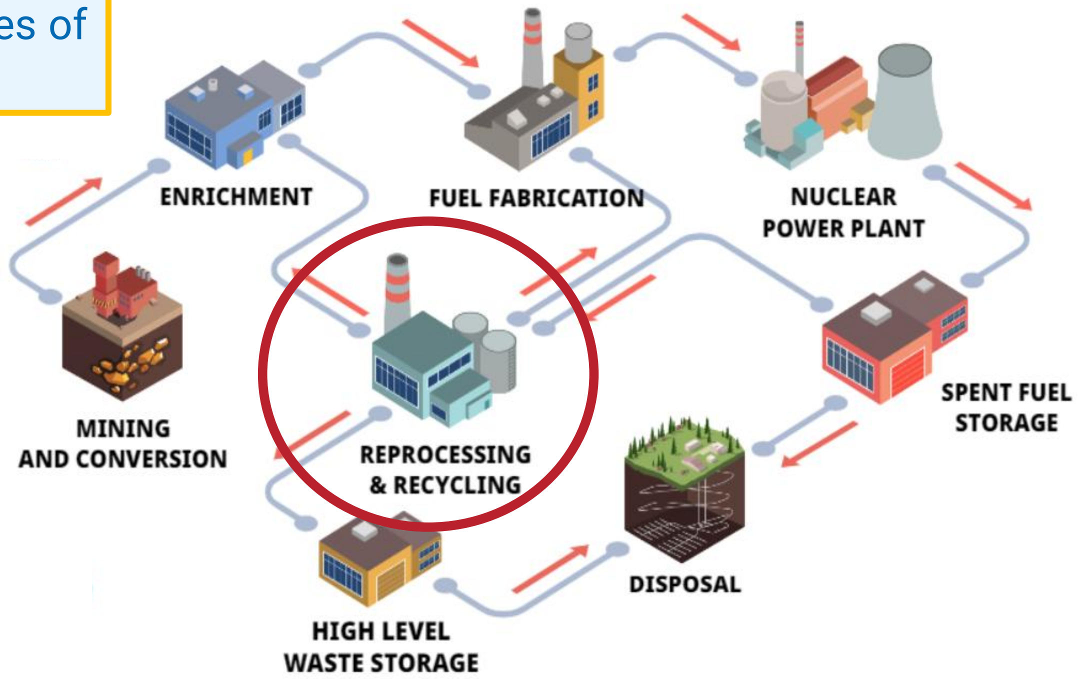
Needed at all stages of the Fuel Cycle


IAEA Safety Standards
for protecting people and the environment

Regulations for the Safe Transport of Radioactive Material
2018 Edition

Specific Safety Requirements
No. SSR-6 (Rev. 1)

IAEA
International Atomic Energy Agency



Storage systems are optimized for current fuel

New spent fuels will require major changes and research

Recycling

Reprocessing is specialized on current fuel and capacities are limited

France and Russia offer services

Higher enrichment and higher burnup are challenging

Multi-recycling is a challenge

Safeguards implications for AMR's SNF (e.g., compacts/pebbles, MSRs' fuels, …)

SFM impact on public support of SMRs/AMRs for non-electrical applications

Disposal, Waste Acceptance Criteria for disposal are based on current fuel designs

New Spent Fuels will require additional research

How to keep flexibility in a DGR Programme that lasts decades

Upcoming Related IAEA Events on Spent Fuel Management

1. International Conference on Fast Reactors and Related Fuel Cycles (FR26), **18-21 May 2026, Beijing, China**

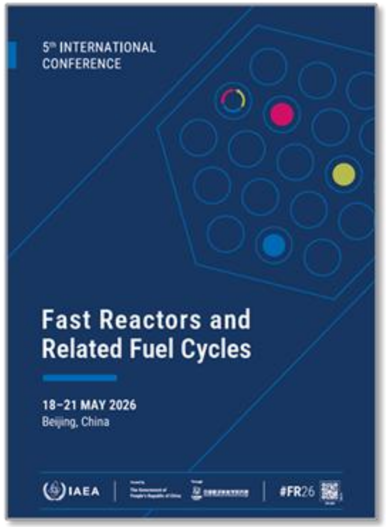
2. International Conference on Fuel Supply Chain for Sustainable Nuclear Power Development, **13-15 October 2026, Vienna**

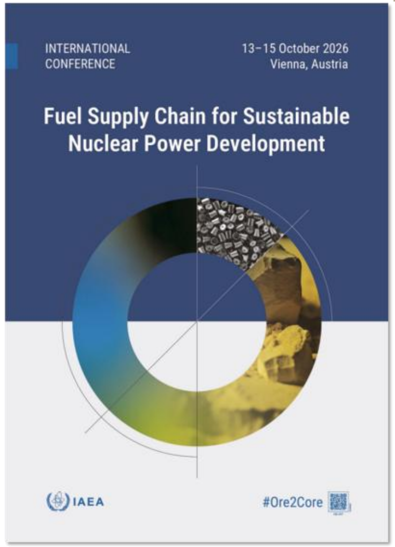
3. Technical Meeting on Spent Fuel Characterization: Techniques, Results, and Experience, **31 August – 4 September 2026, Vienna**

4. Workshop on the Challenges in Managing Spent Evolutionary Advanced Technology Fuels, **19-23 October 2026, Vienna, Austria**

5. Technical Meeting on Policy and Strategies for Spent Fuel and Radioactive Waste Management, **16 – 20 November 2026, Vienna (In collaboration with Waste Technology Section)**

6. Workshop on Nuclear Fuel Cycle Options for Current and Advanced Reactors, **08-11 December 2026, Vienna, Austria**





IAEA SMR Schools

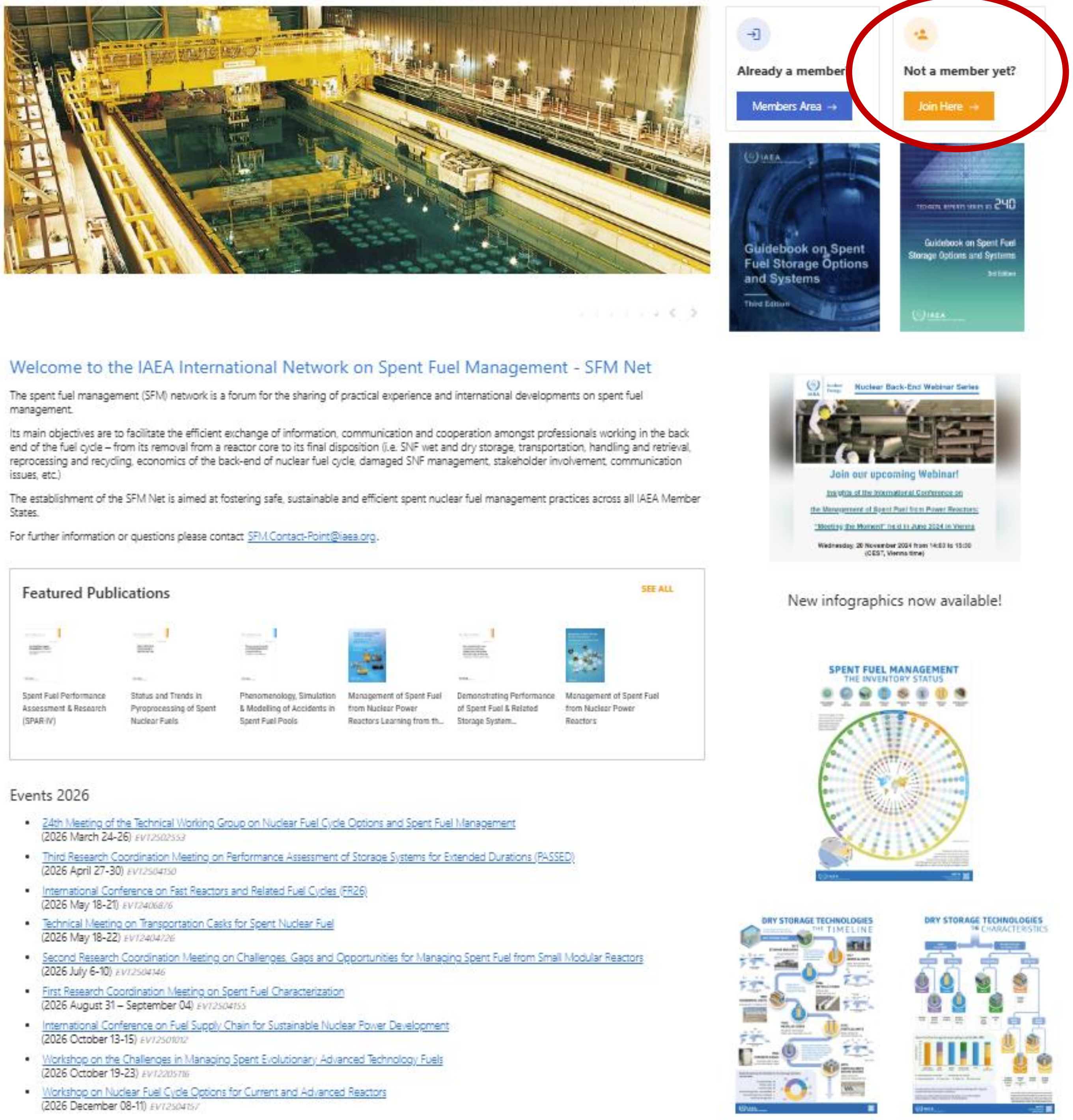
- To raise awareness about **key aspects of SMR development and deployment** among **high-level participants** from governments, policy making organizations, NEPIOs, regulatory bodies, and industries of potential user Member States
- Three schools in **2025** in **Kenya, Thailand** and **Argentina** and one in **2026** in **IAEA HQ (Vienna)** for over 100 participants from 28 countries interested in SMRs

Topics

1. Energy planning and systems analysis for sustainable development
2. Strategic planning and assessments for long-term sustainable deployment of nuclear energy systems
3. Economics and financing of SMRs
4. Nuclear infrastructure considerations for SMRs
5. Fundamentals of SMR: technologies, advances in design development, reactor engineering, and industrial applications of SMRs
6. **Nuclear fuel cycles, radioactive waste management and decommissioning of SMRs**
7. Human resource development for SMR programmes
8. Supply Chain, Industrial Involvement and Procurement
9. Stakeholder engagement for nuclear power programs
10. International and national legal frameworks and SMRs
11. Introduction to SMR safety: design, assessment, regulation and licensing
12. **Safe transport of radioactive material and fueled SMRs and NPPs**
13. Optimized siting and external event protection for safe SMR
14. Nuclear security of SMRs
15. Emergency preparedness and response for SMRs
16. Safeguards for SMRs

Spent Fuel Management Network

SFM.Contact-Point@iaea.org



Thank You

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