IAEA Coordinated Research Project on Challenges, Gaps and Opportunities for Managing Spent Fuel from SMRs

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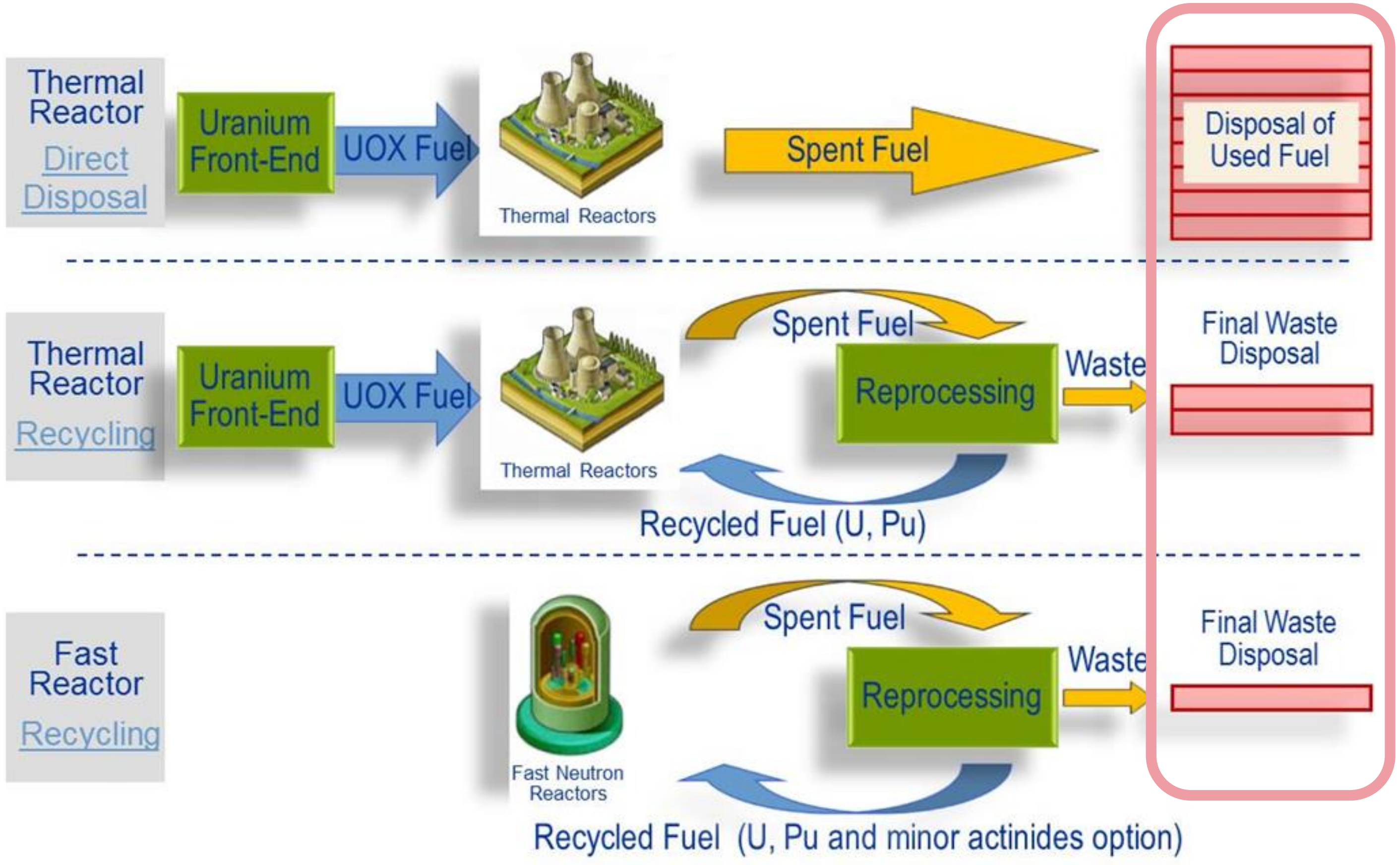
TM on the Management of Spent Fuel (Pebbles and Compacts) from HTGRs (7 – 11 Ju

Nuclear Fuel Cycle Options

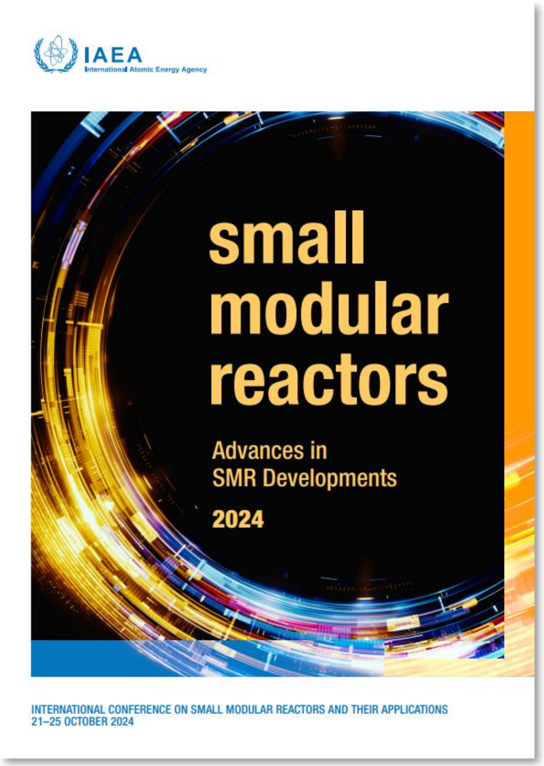
- For Nuclear power to be sustainable, the nuclear fuel cycle must remain **economically viable and competitive** through the optimization of the use of fissile materials in reactor cores or the **recycling of valuable materials**
- This results in different fuel **cycle options**, some already implemented and others may be deployed in the future
- Potential future synergies between LWR-SMRs and AMRs will bring new spectrum of Nuclear Fuel Cycle Options

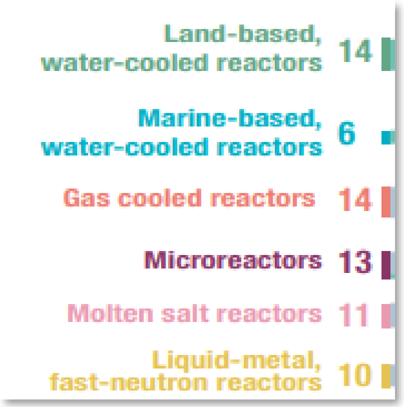


Each Type of Reactor has an Associated Nuclear Fuel Cycle

IAEA-ARIS SMR Booklet 2024

Type of reactor	Number of reactors	Fuel Type	Fuel enrichment < 5%	Fuel enrichment 5% - 15%	Fuel enrichment > 15%	Fuel enrichment TBD	Burnup < 50 (GWd/ton)	Burnup > 50 - 100 (GWd/ton	Burnpup > 100 (GWd/ton)	Burnup TBD
Water cooled SMRs (UO2)	17	17 UO2 pellet	15	0	2	0	10	4	0	3
Water cooled SMRs (Cermet)	3	3 Cermet	0	0	3	0	1	0	0	2
Microreactors.- Water cooled	3	2 Cermet 1 UO2 pellet	0	0	3	0	0	0	3	0
High Temperature Gas Cooled SMR (TRISO in **Pebble**)	5	UO2 TRISO in pebbles	0	2	3	0	0	4	1	0
High Temperature Gas Cooled SMR (TRISO in **Prismatic**)	7	UO2 TRISO in compacts	0	4	3	0	3	0	3	1
High Temperature Gas Cooled SMR (**Fast Neutron Spectrum**)	2	1 UC (not TRISO) 1 HALEU pellet	0	1	1	0	0	0	2	0
Microreactors.- High Temperature Gas Cooled	6	UO2 TRISO in compacts	0	1	5	0	1	3	2	0
Liquid Metal Cooled Thermal Neutron Spectrum SMR	1	UO2 TRISO in compacts	1	0	0	0	1	0	0	0
Liquid Metal Cooled Fast Neutron Spectrum SMR (Oxide) (2 Na, 2 Pb)	4	1 UO2 pellet 3 MOX pellet	0	0	4	0	0	3	1	0
Liquid Metal Cooled Fast Neutron Spectrum SMR (Metal) (3 Na)	3	3 U-Zr alloy	0	1	2	0	1	1	1	0
Liquid Metal Cooled Fast Neutron Spectrum SMR (Nitride) (2 Pb)	2	1 UN 1 PuN-UN	0	2	0	0	0	2	0	0
Microreactors- Liquid Metal cooled Fast	1	Metal fuel	0	0	0	1	0	0	0	1
Microreactors- Liquid Metal cooled Thermal	1	U-Zr Hydride	0	0	1	0	1	0	0	0
Molten Salt SMR (Thermal)	7	6 LEU in Fluoride molten salt 1 UO2 TRISO in pebbles	6	0	1	0	2	0	2	3
Molten Salt SMR (Fast)	4	Chloride molten salt	0	1	0	3	0	2	0	2
Microreactors.- Molten Salt cooled	1	TRISO in fuel compacts	0	0	1	0	0	1	0	0
Microreactors. Other. (eVinci+MoveluX)	2	1 Silicide 1 UO2 TRISO in	1	0	1	0	1	0	0	1
Total	**69**		**23**	**12**	**30**	**4**	21	20	15	13
			69				69			

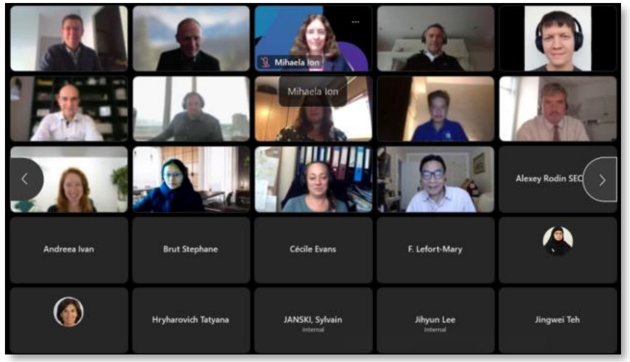


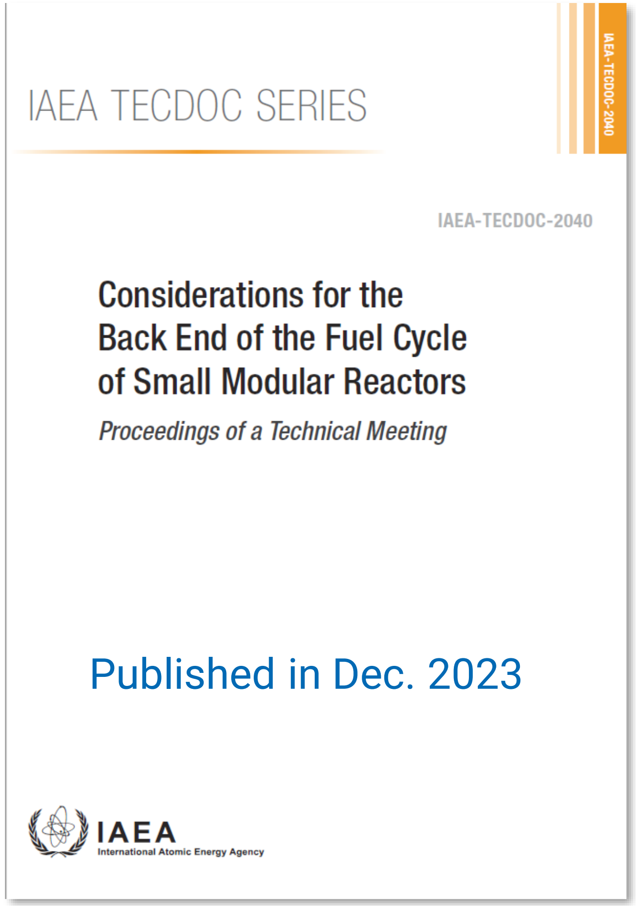


Technical Meeting on **Backend of the Fuel Cycle Considerations for SMRs**, 20-23 September 2022

107 Participating Experts from **32** Member States & **3** International Organizations

~ **40** Presentations and Extended Abstracts





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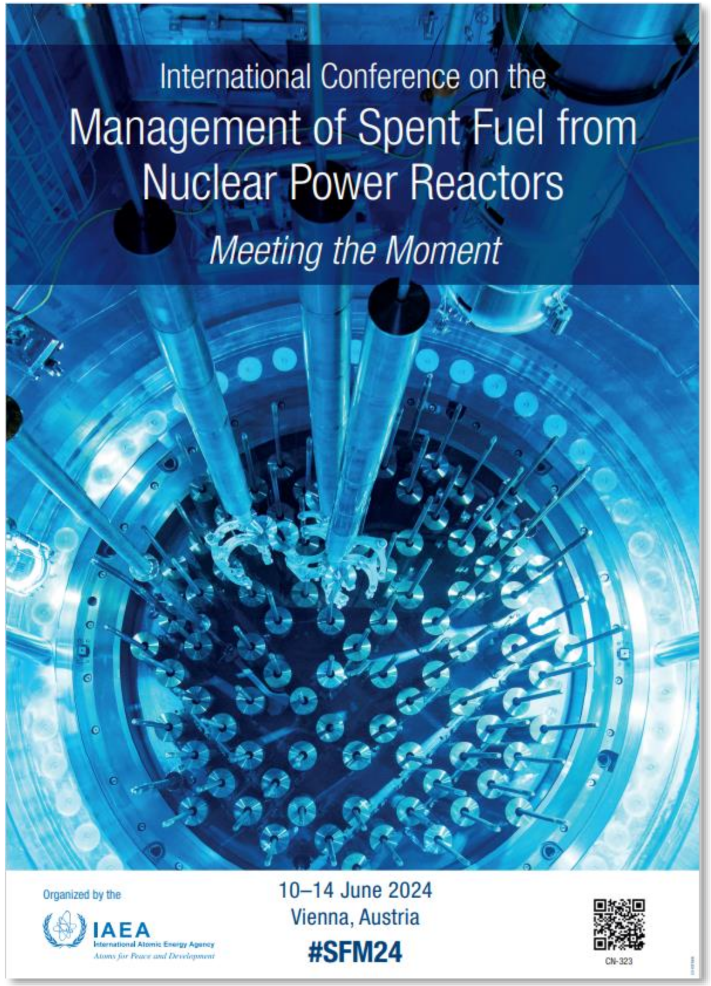
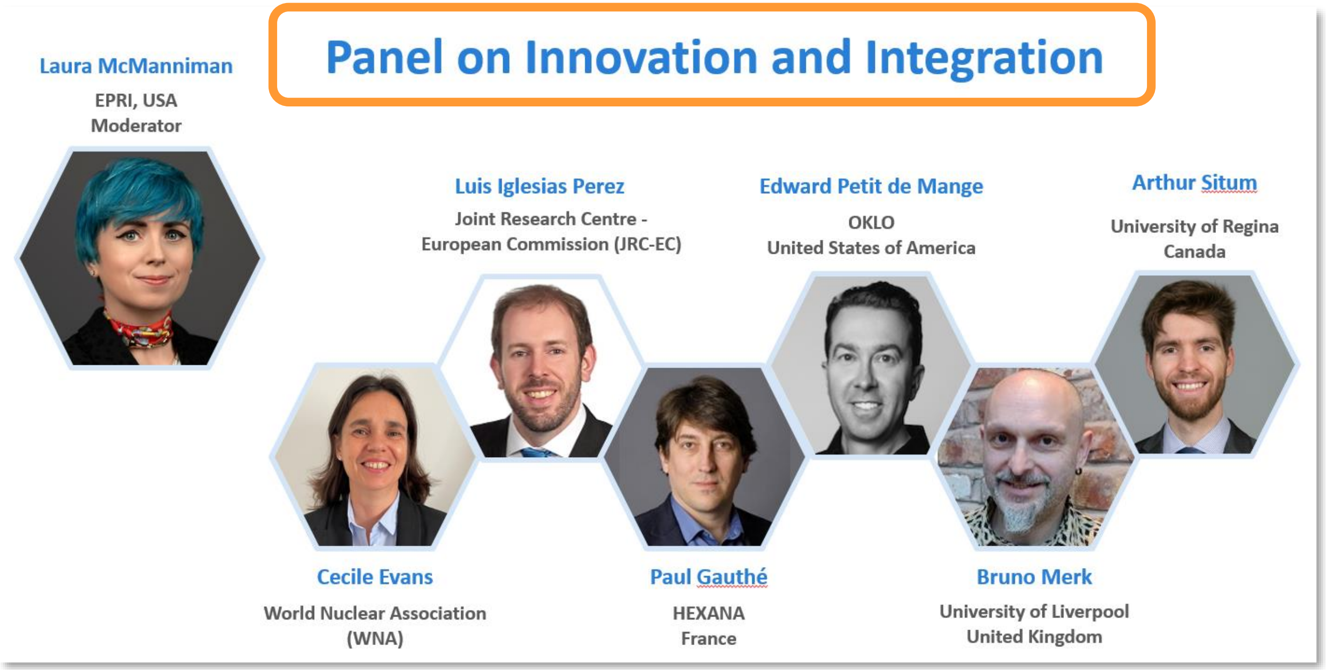
International Conference on Spent Fuel Management: Meeting the Moment, Panel Discussions on SMRs





Scientific Conference Programme from 8:30h to 18:30h

Monday, 10 June

09:00-10:30 — Opening Session
- *R. M. Grossi*, Director General International Atomic Energy Agency (IAEA)
- *W. D. Magwood*, Director General OECD Nuclear Energy Agency (OECD/NEA)
- *S. Bilbao y León*, Director General World Nuclear Association (WNA)
- *U. Engelmann*, Director for Nuclear Safety and Security Joint Research Centre - European Commission (JRC-EC)
- *P. Buchan*, Managing Director of Shipping Nuclear Transport Solutions (NTS), Board Member World Nuclear Transport Institute (WNTI)
- *J.A. Gago*, Conference Chairman, Spain

10:30-11:00 Coffee/Tea Break

11:00-13:15 — P1 — Panel on National Strategies for Spent Fuel Management (I)
- *T. Mannevile*, French General Directorate for Energy and Climate, FRA
- *T. Fukuda*, Nuclear Regulation Authority, JPN
- *T. Klomberg*, Ministry of Infrastructure and Water Management, NET
- *B. Sosnik*, Polskie Elektrownie Jadrowe, POL
- *H.-J. Park*, Institute for Korea Spent Nuclear Fuel, ROK
- *T. Jaurmas*, Nuclear Decommissioning Authority, UK (ID#81)
- *J. Lubinski*, Nuclear Regulatory Commission, USA

13:15-14:45 Lunch Break

14:45-16:00 — P2 — Panel on National Strategies for Spent Fuel Management (II)
- *B. Nős*, Public Limited Company for Radioactive Waste Management (PURAM), HUN
- *U. Dani*, Bhabha Atomic Research Centre (BARC), IND
- *M. Shoaib*, Pakistan Atomic Energy Commission (PAEC), PAK (ID#19)
- *A.I. Chicherin*, ROSATOM, RUS

16:00-16:30 Break

16:30-18:30 — S6.1 — ADV — Poster Session 1 NAT
- ID#26 Characterization of Spent Fuel for Selected Small Modular Reactors and Implications for the Back End Fuel Cycle, *X. Wang, CAN*
- ID#68 A Tool to Estimate Isotopic Evolution for Actinides Transmutation Dedicated to Fast Molten Salt Reactors: A Comparative Study of Evolving In-core Key Parameters for the Preliminary Design of a Fast Molten Salt Reactor (F-MSR), *P.-E. Dufour, FRA*
- ID#51 Assessing the Potential for Molten-Salt Reactor (MSR) Technology in EU's Sustainable Nuclear Energy Futures, *L. Van den Durpel, BEL*
- ID#37 The French R&D Collaborative Project ISAC on Fast MSR Dedicated to Actinides Transmutation, *M.-S. Chenaud, FRA*
- ID#142 NRC Research Activities in Spent Fuel Storage and Management of Advanced Fuels for Advanced Reactors, *T. Boyce, USA*
- ID#21 The Implementation of SMR and the Back End Issue of the Fuel Cycle in Ukraine, *B.P. Zlobenko, UKR*

18:30-20:00 — Official Reception

Tuesday, 11 June

08:30-10:30 — S6.2 — ADV
- ID#64 Challenges and Opportunities of Advanced Nuclear Reactors for the Back End of the Fuel Cycle, *C. Evans, FRA*
- ID#94 The WISARD Project - Starting with the End in Mind: Exploring How Innovative Nuclear Systems Require Innovative Waste Management Solutions, *L. McManniman, USA*
- ID#95 Potential Impacts of SMR Deployment on Multinational Cooperation at the Back End of the Fuel Cycle, *J. Kinghorn-Mills, UK*
- ID#119 Safeguards by Design: Supporting Sustainable Spent Fuel Management Strategies, *J.J. Whitlock, IAEA*
- ID#93 HTGR Spent Fuel Management Strategy in the UK, *L.E. Kissick, UK*
- ID#123 Assessment of Performance and Spent Fuel Characteristics of a Generic 100-MWe-Class SFR-SMR, *D.T. Wojtaszek, CAN*

10:30-11:00 Coffee/Tea Break

Poster Session 6 ADV

11:00-12:40 — S2.1 — STO
- ID#76 Characterization of the Swiss SNF Radionuclide Inventory for DGR Planning, *E. Vlassopoulos, SWI*
- ID#59 Computational Spent Fuel Characterization at VTT Finland, *S. Häkkinen, FIN*
- ID#127 EURAD - Spent Fuel Characterization - Report from a Recently Finished European Project, *E. Vlassopoulos, SWI*
- ID#132 Overview of Decay Heat Measurements at Clab Facility: Description of Decay Heat Measurements from 2003-2021 Under EPRI-SKB Collaboration, *H. Akkurt, USA*
- ID#144 New Calorimeter Concept for the Measurement of Decay Heat from Spent Fuel Assemblies: A Gösgen NPP Project, *S. Caruso, SWI*

12:40-14:00 Lunch Break

12:50-13:50 — Side Event 1: "The French Fuel Cycle: An Integrated System for a Sustainable Low-Carbon Energy", sponsored by France

14:00-15:40 — S2.3 — STO
- ID#72 Preparing for Extended Storage of SNF in Germany from the Point of View of the Licensing Authority, *J. Palmes, GFR*
- ID#87 Experience of Regulatory Oversight for the Construction, Commissioning and Operation of Spent Fuel Storage Facilities in Ukraine, *A. Shepitchak, UKR*
- ID#108 Regulatory Framework for Spent Fuel Management for Ghana's Nuclear Power Programme, *M. Asamoah, GHA*
- ID#65 Environmental Justice and Public Engagement in the US Consent-Based Siting Process, *M.Z. Bell, USA*
- ID#138 Spent Fuel Management in the Slovak Republic, *J. Václav, SLR*

15:40-16:00 Break

16:00-17:20 — S4.1 — REC — Poster Session 2.1 STO
- ID#106 Solvent Extraction Experiments for Uranium, Plutonium, and Neptunium Co-Recovery with Dissolver Solutions Derived from Irradiated Nuclear Fuels, *M. Nakahara, JPN*
- ID#43 Recycling of PWR Spent Fuel in a Fast Reactor, *C.-B. Lee, ROK*
- ID#112 MOX and UOX Fuel Recycling in Pressurized Water Reactors, *B. Vaast, FRA*
- ID#7 Fundamental Approaches to HTGR SNF Reprocessing Technology Development, *E.D. Filimonova, RUS*

17:20-18:40 — S4.2 — REC
- ID#9 Technological Approaches to Spent Accident Tolerant Nuclear Fuel Processing, *L.N. Podrezova, RUS*
- ID#61 Outlines for Building the Future of French Recycling Facilities, *H. Vincenti, FRA*
- ID#131 The ASOF Project - Advanced Separation for the Optimal Management of Spent Fuel, *K. Lemmens, BEL*
- ID#3 Sustainable Fuel Cycle as Basis for Successful Development of Nuclear Power Programmes for Embarking Countries, *T.A. Aleksandrova, RUS*

Wednesday, 12 June

08:30-10:30 — S2.2 — STO
- ID#36 Progression and Challenges in Technically Underpinning the United Kingdom's Strategy for the Management of Spent AGR Oxide Fuel, *R. Veazey, UK*
- ID#156 Assessment of the Effects of Long-Term Wet Storage on Canadian Spent Nuclear Fuel, *G. Cota-Sanchez, CAN*
- ID#17 Observation on Slow Cooling Rate Effect of Unirradiated Zircaloy-4 Hydride Reorientation Under Dry Storage Condition, *D.H. Kook, ROK*
- ID#57 Investigating Drying and Dry Storage Options for Stainless-Steel Clad Advanced Gas Reactor Spent Fuel, *C. Gallagher, UK*
- ID#90 Brittle Failure Limits of Spent Fuel Claddings Subjected to Long-Term Dry Interim Storage Conditions, *U. Zencker, GFR*
- ID#134 Re-Examining Spent Fuel Cladding Integrity Limits, *J. Faldowski, USA*

10:30-11:00 Coffee/Tea Break

Poster Session 4 REC

11:00-12:40 — S2.4 — STO
- ID#6 New Dual-Purpose Casks for Spent Fuel of Foreign WWER NPPs and High Level Waste from Spent Fuel Reprocessing, *M.E. Budu, RUS*
- ID#33 Modifications of the Interim Spent Fuel Dry Storage Facility for the Storage of Fresh Fuel, *A. Smaižys, LIT*
- ID#109 Performance Enhancement of the NUHOMS EOS Dry Storage System and the TN EAGLE Transportation Cask for Used Fuel Management, *P. Narayanan, USA*
- ID#77 Complementary Facility for Cask Recovery at ISFSI, *F. Lentijo, SPA*
- ID#52 Spent Nuclear Fuel Management for Holtec International's SMR-300, *R. Marin, SPA*

12:40-14:00 Lunch Break

14:00-16:00 — P3 — Panel on Navigating Stakeholders Engagement
- *L. Frizzell*, Nuclear Waste Management Organization (NWMO), CAN
- *M. Kojo*, Lappeenranta-Lahti University of Technology (LUT), FIN (ID#79)
- *R. Zinovnik*, Association Nationale des Comités et Commissions Locales d'Information (ANCCLI), FRA
- *J. Boelen*, Centrale Organisatie Voor Radioactief Afval (COVRA), NET
- *M. Pérez Fernández*, Empresa Nacional de Residuos Radiactivos, S.A. (ENRESA), SPA
- *T. Weber*, Nationale Gesellschaft für die Lagerung radioaktiver Abfälle (NAGRA), SWI

16:00-16:30 Break

16:30-18:30 — S5.1 — DIS — Poster Session 2.2 STO
- ID#120 CIGEO, Readiness of the French DGR Project at the Construction Licence Examination Stage, *M. Maertens, FRA*
- ID#80 Recent Progress within the United Kingdom R&D Programme for the Geological Disposal of High Heat Generating Wastes, *J.J. Dunsford, UK*
- ID#124 Challenges in Collecting and Preserving Sufficient Spent Nuclear Fuel Information Before the Fuel is Placed in the Final Repository, *F. Johansson, SWE*
- ID#111 Cost Estimations for Disposal of Radioactive Waste in Switzerland: An Established Framework Takes the Next Step, *D. Mignone, SWI*
- ID#71 Adaptation of Current Final Disposal Strategy and Methods in Finland for Spent Fuel from SMRs, *P. Keto, FIN*
- ID#63 Spent Nuclear Fuel and the ConfinAR Geo Project, *L. Kniznik, ARG*

Thursday, 13 June

08:30-10:30 — S5.2 — DIS
- ID#85 An Overview of the United Kingdom Strategy for Management of Spent Nuclear Fuel, Focusing on Metallic Uranic Fuels and Challenges Presented for Geological Disposal, *M.J. Austin, UK*
- ID#16 Design and Evaluation of a Korean-Style High-Efficiency Disposal System for Domestic Waste, *K.-L. Lee, ROK*
- ID#40 Exploring Encapsulation Envelopes for Disposal of Spent Nuclear Fuel, *K.J. Robinson, UK*
- ID#38 Predicting Decay Heat by Combining Fuel Parameters with Gamma and Neutron Data Using Machine Learning, *V. Solans, SWE*
- ID#78 Developing Waste Acceptance Criteria for Advanced Reactor Waste Forms in the Universal Canister System, *J. Sloane, USA*
- ID#11 Effect of the Host Rock Thermal Properties on the Disposal Area Requirements for Spent Fuel and Vitrified High Level Waste in a Geological Repository, *B. B. Acar, TUR*

10:30-11:00 Coffee/Tea Break

Poster Session 5 DIS

11:00-13:00 — P4 — Panel on Innovation and Integration
- *C. Evans*, World Nuclear Association (WNA) (ID#53)
- *L. Iglesias Pérez*, Joint Research Centre - European Commission (JRC-EC)
- *P. Gauthé*, HEXANA, FRA
- *E. Petit de Mange*, OKLO, USA (ID#91)
- *B. Merk*, University of Liverpool, UK (ID#103)
- *A. Situm*, University of Regina, CAN

13:00-14:20 Lunch Break

13:10-14:10 — Side Event 2: "Meeting the Moment: Paving the Way for Tomorrow's SFM Workforce" (Co-organized by NEI, IYNC and IAEA-WiN, sponsored by NEI (USA))

14:20-15:40 — S7.1 — INT
- ID#34 Addressing Nuclear Spent Fuel Management Challenges: A Key to Alleviating Nigerian Skepticism Towards Nuclear Power Generation, *J. Simon, NIR*
- ID#73 An IRSN Augmented Expertise Tool Helping for Continuous Monitoring of the Consistency of the Fuel Cycle, *F. Ledroit, FRA*
- ID#151 Updated Status of Spent Fuel Removal at Fukushima Daiichi NPP, *Y. Ishii, JPN*
- ID#162 Findings from the RPV and PCV Internal Investigation for Fuel Debris Retrieval at the Fukushima Daiichi NPP, *K. Sawada, JPN*

15:40-16:10 Break

16:10-17:50 — S7.2 — INT — Poster Session 7 INT
- ID#45 About Spent Nuclear Fuel in Argentina: Should We Worry?, *L. Gringauz, ARG*
- ID#55 The Value of an Integrated View on Spent Nuclear Fuel and Radioactive Waste Management Strategies Reducing Financial Risks to Stakeholders, *L. Van den Durpel, BEL*
- ID#74 ROWO: A Holistic Approach to the Optimization of Deep Geological Disposal of High Level Waste, *E. Vlassopoulos, SWI*
- ID#113 Advances in Developing a LWR Multirecycling System, *C. Evans, FRA*
- ID#116 Study of Scenarios for Spent Fuel Management in Mexico, *J.L. François, MEX*

Friday, 14 June

08:30-10:10 — S3.1 — TRA
- ID#114 Preparing Safe and Efficient Loading and Transport Operations of Spent Nuclear Fuel, *Y. Solignac, FRA*
- ID#20 Experience and Perspectives of SNF Transportation in Russia: Organization of Shipments, Safety Requirements and Justification, Emergency Response, New Tasks, *V.N. Ershov, RUS*
- ID#110 Spent Nuclear Fuel Management at KKM Nuclear Power Plant: Spent Nuclear Fuel Storage Away from the Plant, *F. Hotzgrewe, SWI*
- ID#32 Transportation of Spent Nuclear Fuel Conducted in Poland - Lessons Learned, *L. Bak, POL*
- ID#141 Packaging Safety, Security, and Safeguards (3S) for Nuclear Fuel Cycle Materials in Storage, Transportation, and Disposal, *Y. Liu, USA*

10:10-10:35 Coffee/Tea Break

10:35-11:55 — S3.2 — TRA
- ID#42 Demonstration of a Risk-Informed Approach for Regulatory Approval for Shipping a Microreactor Transportation Package, *H.E. Adkins, USA*
- ID#41 Microreactor Transportation Emergency Planning Challenges, *S.J. Maheras, USA*
- ID#148 Transportation and/or Interim Storage of SMR/AMR Spent Fuel: Solutions and Challenges, *C. Allsten, FRA*
- ID#67 Development of a Functions and Requirements Document for a SNF Transportation Package Performance Demonstration, *L. Hay, USA*

12:00-13:00 — Closing Session
- *J. A. Gago*, Conference Chairman, Spain
- *L. Evrard*, Deputy Director General and Head of the Department of Nuclear Safety and Security, IAEA
- *M. Chudakov*, Deputy Director General and Head of the Department of Nuclear Energy, IAEA

Track titles
1. NAT - National Strategies for Spent Fuel Management
2. STO - Storage of SNF and Vitrified HLW and Subsequent Transportability
3. TRA - Transportation in the Back End of the Fuel Cycle
4. REC - Recycling of Spent Fuel
5. DIS - Disposal of SNF, HLW and Other Waste Forms in Deep Geological Repositories (DGR)
6. ADV - Impacts of Advanced Nuclear Energy Systems on the Back End of the Fuel Cycle
7. INT - Achieving Integrated Spent Fuel Management

Panel titles
P1 - Panel on National Strategies for Spent Fuel Management (I)
P2 - Panel on National Strategies for Spent Fuel Management (II)
P3 - Panel on Navigating Stakeholders Engagement: Sharing Insights and Lessons Learned in Spent Fuel Management Strategy Implementation in Member States
P4 - Panel on Innovation and Integration: Approaches for Managing Spent Fuel from Advanced Reactors (e.g. SMRs, …)

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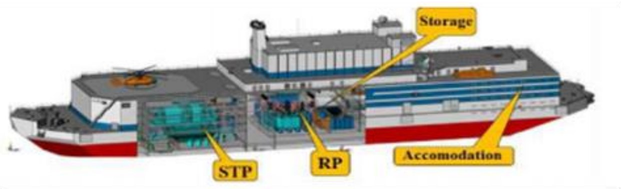
- **14** Sessions in **7** Tracks
- **77** contributed oral presentations **13** E-posters, **21** posters from **29** Member States and **2** international organizations

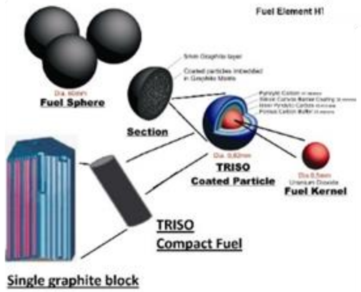
Identified Challenges for Spent Fuels from SMR Types

Short → Medium → Long Term

- LWR-type SMRs: Enrichment levels of below 5% are similar to conventional PWRs
- LWR-type SMRs: Enrichment levels up to 20% (HALEU)



- HTGR-type SMRs: Pebble Beds/Prismatic



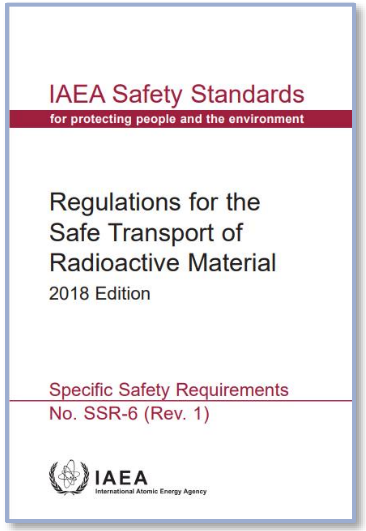
- Advanced Reactors (Fast Neutron SMRs): New fuel types introducing a new spent fuel characteristics/multirecycling processes

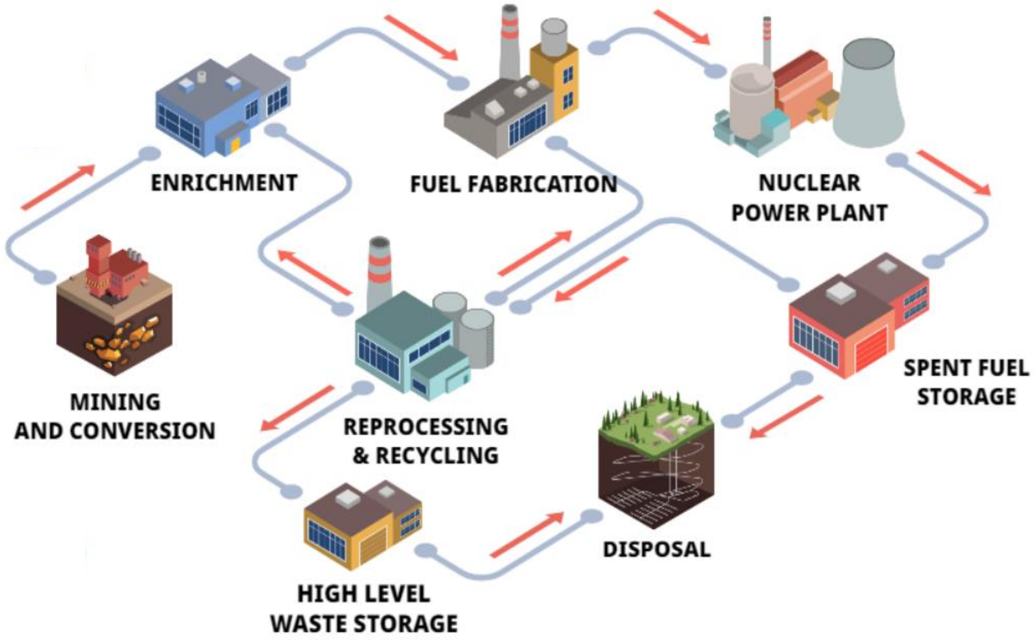
- Molten Salt SMRs: Nuclear fuel dissolved in melted chloride/fluoride fuel salts. Recycling of fissile material and managing salt mixtures containing all fission products is a challenge

Overview of Back End of the Fuel Cycle Implications for SMRs

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



Storage systems are optimized for current fuels

New spent fuels will require major changes and research

Reprocessing and recycling

Reprocessing is specialized on current fuels and capacities are limited

Ageing of available Rep&Rec facilities, specially in Europe

Accelerate implementation of Multi-recycling in LWRs as transition to AMRs

Disposal

Designs under development are based on current spent fuel and HLW

New spent fuels and wastes will require additional research

Integration of existing and new fuel cycles is key for sustainability

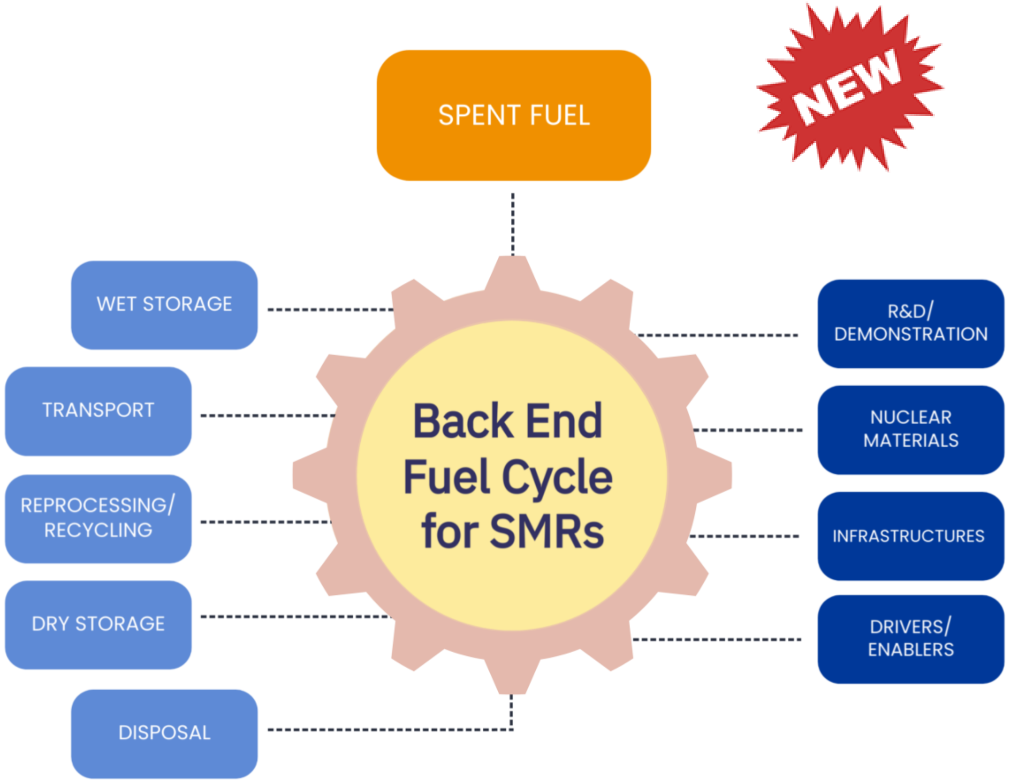
Coordinated Research Project on *Challenges, Gaps and Opportunities for Managing Spent Fuel from SMRs*

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

MAIN OBJECTIVES:

- To identify viable nuclear fuel cycle options for the different SMR technologies
- To identify common technologies/similarities for various reactor types and/or significant differences
- To prepare a list of generic key parameters for countries to perform their analysis incorporating their specific context

SMR-COGS, CRP T13021



Coordinated Research Project on *Challenges, Gaps and Opportunities for Managing Spent Fuel from SMRs*

MAIN 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
- To compare various SMR systems, in terms of efforts required to develop and implement an SFM strategy
    - Nuclear fuel cycle facilities
    - Technology readiness level
    - Nuclear materials involved
    - Infrastructures (e.g., human resources, financing)
    - R&D / Demonstrations
    - Enablers/Synergies

Building SMR-COGS Roadmaps: ROADMAP Exercise

- Roadmaps will be developed to support decision makers (e.g. government, industry, …) to develop plans for future SMR development and implementation
- Potential horizon for the Roadmaps: 2050 or 2070 or beyond??
- SMR-COGS Roadmaps are generic and should be adjusted and revisited to reflect countries' particularities and boundary conditions as well as changes with time in the policies and strategies

First Research Coordination Meeting of SMR-COGS CRP held on 11 to 15 November 2024 in Vienna

STATUS of the Coordinated Research Project SMR-COGS

- 14 Research Contracts from ARG, ARM, CPR, CZR, EGY, INS, LIT, MEX, POL, ROM(2), UKR(3)
- 18 Research Agreements from CAN(2), CPR, DEN, EGY, JOR, NOR, SIN, SPA, SWE, TUR, UK(2), USA(5)

Industry, Operators, Researchers, Regulators, etc.

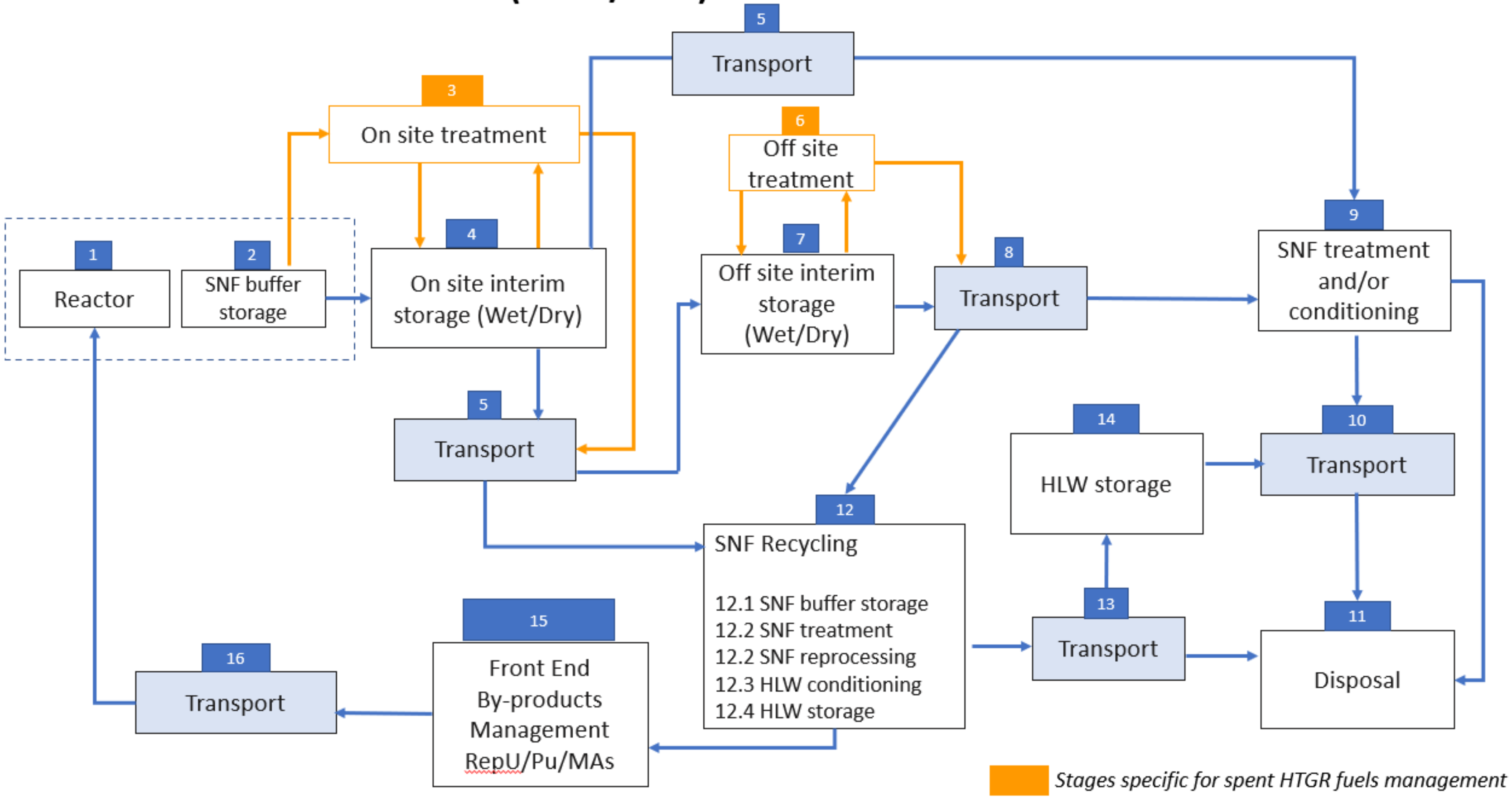
Nuclear Energy Programmes: Embarking (Phase 1, 2 and 3), Expanding, Mature and Not Nuclear (DEN and NOR)

Observers: OECD/NEA, FIN, FRA, NET, RUS

45+ participants from 25 countries

IAEA

GENERIC FUEL CYCLE SCHEME (HTGR/LWR)

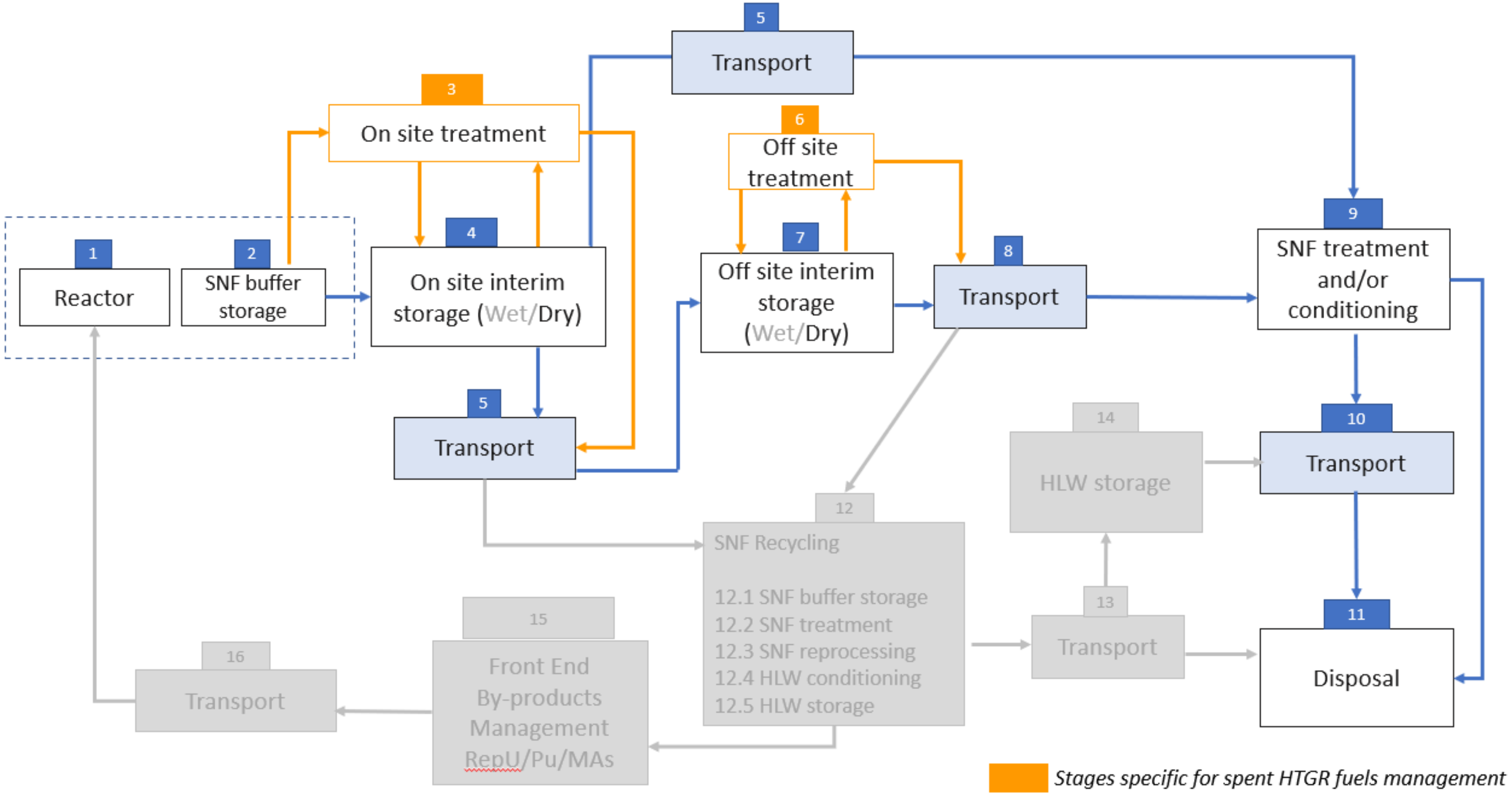


Reactor	Fuel Type
LWR	LEU (< 5%) (Open Cycle)
	LEU (< 5%) (Closed Cycle)
	LEU+ (5-10%) (Open Cycle)
	LEU+ (5-10%) (Closed Cycle)
	HALEU (10- 20%) (Open Cycle)
	HALEU (10 - 20%) (Closed Cycle)
HTGR	Pebble (Open Cycle)
	Prismatic (Open Cycle)
	Pebble/Prismatic (Closed Cycle)
LMFR	…..
	…..
MSR	…..
	…..

- High Level elements for the scenario
- Time scale for development and implementation
- Needs for development and implementation
- What is need and when
- Decision points

Time Horizon

SCENARIO A.- COMPACT/PRISMATIC FUEL OPEN CYCLE SCHEME

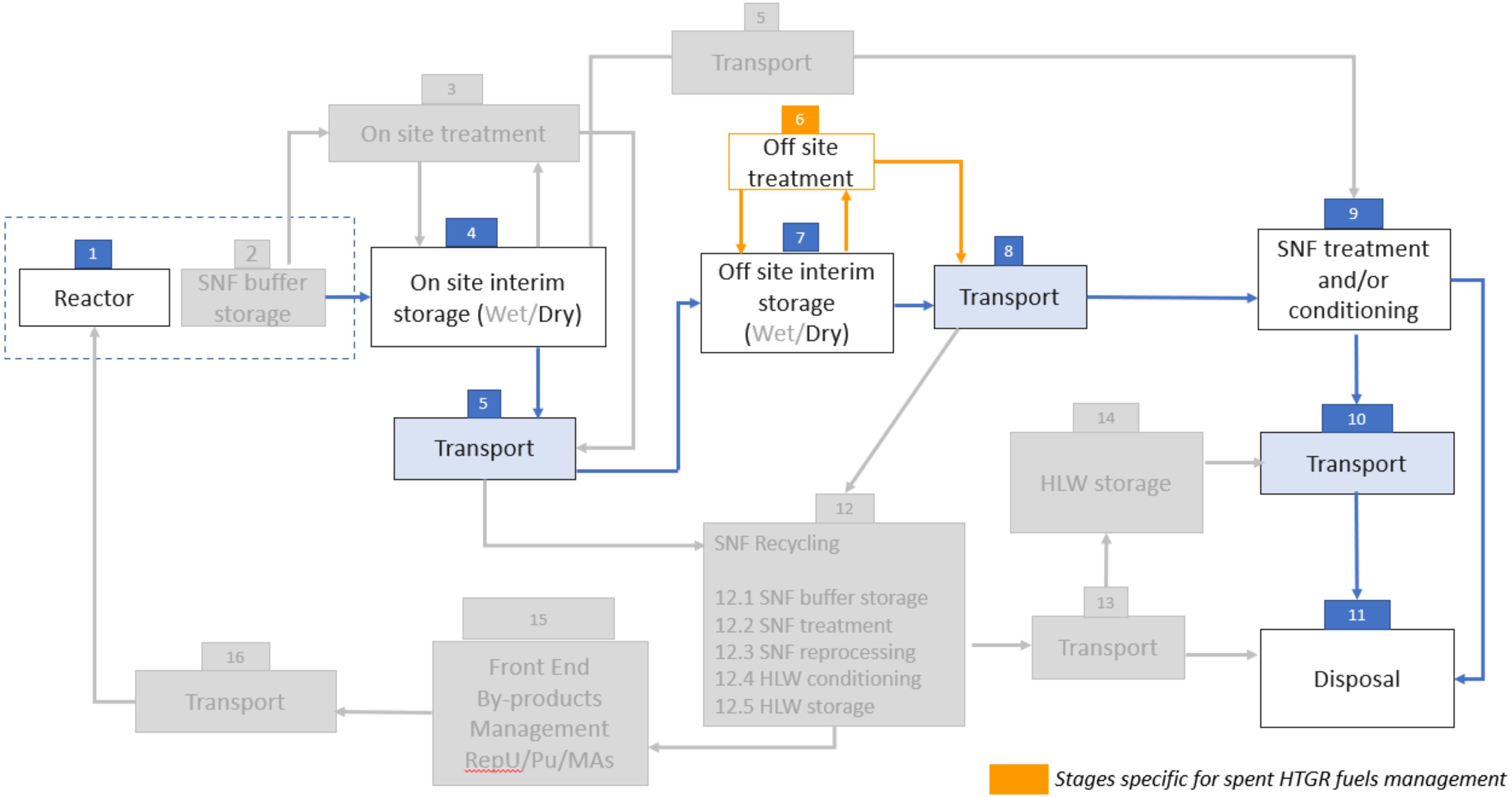


Reactor	Fuel Type
LWR	LEU (< 5%) (Open Cycle)
	LEU (< 5%) (Closed Cycle)
	LEU+ (5-10%) (Open Cycle)
	LEU+ (5-10%) (Closed Cycle)
	HALEU (10- 20%) (Open Cycle)
	HALEU (10 - 20%) (Closed Cycle)
HTGR	Pebble (Open Cycle)
	Prismatic (Open Cycle)
	Pebble/Prismatic (Closed Cycle)
LMFR	…..
	…..
MSR	…..
	…..

- High Level elements for the scenario
- Time scale for development and implementation
- Needs for development and implementation
- What is need and when
- Decision points

Time Horizon

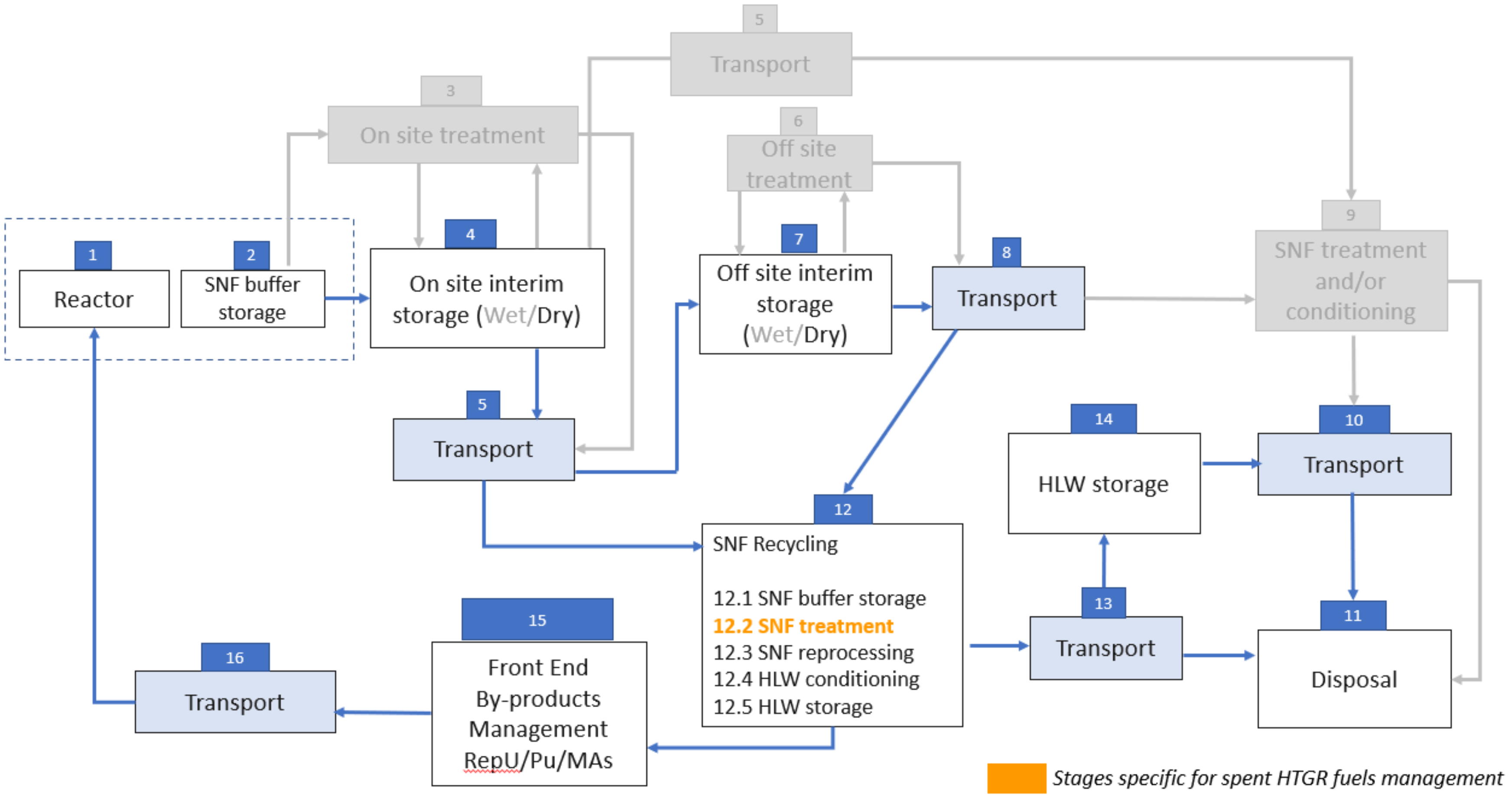
SCENARIO B.- PEBBLE FUEL OPEN CYCLE SCHEME



Reactor	Fuel Type
LWR	LEU (< 5%) (Open Cycle)
	LEU (< 5%) (Closed Cycle)
	LEU+ (5-10%) (Open Cycle)
	LEU+ (5-10%) (Closed Cycle)
	HALEU (10- 20%) (Open Cycle)
	HALEU (10 - 20%) (Closed Cycle)
HTGR	Pebble (Open Cycle)
	Prismatic (Open Cycle)
	Pebble/Prismatic (Closed Cycle)
LMFR	…..
	…..
MSR	…..
	…..

- High Level elements for the scenario
- Time scale for development and implementation
- Needs for development and implementation
- What is need and when
- Decision points

SCENARIO C.- COMPACT/PRISMATIC and PEBBLE FUEL CLOSED CYCLE SCHEME



Reactor	Fuel Type
LWR	LEU (< 5%) (Open Cycle)
	LEU (< 5%) (Closed Cycle)
	LEU+ (5-10%) (Open Cycle)
	LEU+ (5-10%) (Closed Cycle)
	HALEU (10- 20%) (Open Cycle)
	HALEU (10 - 20%) (Closed Cycle)
HTGR	Pebble (Open Cycle)
	Prismatic (Open Cycle)
	Pebble/Prismatic (Closed Cycle)
LMFR	…..
	…..
MSR	…..
	…..

- High Level elements for the scenario
- Time scale for development and implementation
- Needs for development and implementation
- What is need and when
- Decision points

Time Horizon

Topics for Consideration during Break Out Sessions

1. Impact of characteristics of new SNF (e.g., decay-heat, criticality, radionuclide inventories, …) on:
   a. Storage duration to transition to next stage of the Fuel Cycle
   b. Transitioning from wet to dry storage
   c. Transitioning from buffer storage to reprocessing facility
   d. Reprocessing and Recycling
   e. Transportation
2. Impact of potential non-electrical applications (e.g. co-location with industrial areas or populated zones and the impact of having SNF storage facility, SNF transportation, …)
3. Which existing technologies can be adapted, optimized, …
4. Impact of ageing of existing facilities. Anticipating extension of life and/or new facilities needed
5. Additional or new capacity needed for the different stages
6. …

Thank You

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Technology Readiness Levels (TRLs)

The UK Advanced Fuel Cycle Programme (AFCP) (2016 – 2021)		TRL at start of AFCP	TRL at 2021
Accident tolerant fuels (ATF) or advanced technology fuels for light water reactors (LWRs)	High density fuels	1	3
	Coated cladding	2	6
	SiC cladding	2	3
Coated particle fuels (CPF) for high temperature reactors (HTRs)	Kernels	3	4
	Coating	3	3
Fast reactor fuels		3	3
Advanced aqueous fuel recycle technology		2	4
Pyro-processing fuel recycle technology		2	2

Table 1 Judgement on technology readiness level of advanced fuel and fuel cycle areas developed as part of AFCP in the UK (based on expert opinion from within AFCP)

Developing technology roadmaps

Trends and Drivers: These define the context within which opportunities will be realised. This theme encompasses the established vision, drivers of change and understanding of future energy system markets.

Opportunity/Application areas These arise from linking current capabilities with future needs. Each roadmap presents a unique advanced fuel cycle opportunity area, with specific applications within the area identified throughout.

Technologies and Capabilities: Realising the applications within each opportunity area will require certain technologies and capabilities to be developed. This theme includes both the existing and future concepts needed to achieve relevant applications.

Enablers: Key actions – which include strategic planning, industry collaboration and Government support – will enable the development of new and enhanced technologies and capabilities.

Scenarios or Roadmap with different levels of time

- LWR: near or short time (ATF: Enablers have been identified within the roadmap, including international partnering, access to irradiation and post-irradiation examination (PIE) facilities, and nuclear data requirements for new fuel qualification)
- **HTGR: Short and medium term** (Enablers have been identified within the roadmap, including securing a supply of high-assay low-enriched uranium, international partnering, access to irradiation and post-irradiation examination (PIE) facilities, and nuclear data requirements for new fuel qualification)
- FRs: long term
- MSRs: long term

Opportunity Areas

Short Term	2020 - 2025	**Coated cladding advanced technology fuel (ATF)** supplied to the domestic and international LWR markets	**Apply fuel cycle separations chemistry to recovery of commercially valuable isotopes** from reprocessed products: (eg for medical applications)		
Medium Term	2025 - 2035	**Revolutionary advanced technology fuel (ATF) concepts** supplied to the domestic and international LWR/ AMR markets	**UK developed coated particle fuel (CPF) product supplied to high temperature reactor (HTR)** demonstrator(s) (UK and international) CPF product supplied to emerging domestic and international commercial HTR markets with used fuel management options	**Advanced recycle technology to produce future fuels** credible and competitive technical options for advanced reprocessing of LWR (and MOX) used fuels	**Americium-241 supply** production of Am-241 for space power and other applications
Long Term	2035 - 2050	**Fast reactor fuel cycle** fuel fabrication and supply to a reactor demonstrator and technology demonstration for recycle of used fuels	**Advanced recycle of ATF to produce future fuels** credible and competitive technical options for reprocessing of used ATF	**Supply of molten salt fuels to reactor demonstrator** and technology demonstration for used fuel management	
Vision	2050+	**UK supplying the fuel cycle needs of Gen III(+) and advanced nuclear technologies (ANTs), enabling a significant nuclear contribution to achieving net zero in the UK and a sustainable future**	**UK industry has a strong domestic capability from fuel enrichment and manufacture to recycling and waste minimisation, storage and disposal**		

Table 2 Advanced fuel and fuel cycle opportunity areas

Understanding the Drivers

Drivers of Change

Social
- Alternate uses of nuclear
- Climate change awareness
- Public understanding of nuclear as low-carbon energy

Technological
- Delivery of new nuclear technology
- The rate of technological maturity of advanced reactors
- Innovation and delivery of other low-carbon technologies (low cost, rapid deployment)

Economic
- New nuclear build cost and schedule certainty
- Economics of advanced reactors (Gen IV) and fuel cycle
- Competitiveness of nuclear vs other low-carbon technology
- Cost to consumer bills driving demand
- Economic recovery as key focus following COVID-19

Environmental
- Net zero by 2050
- Sustainability through drive to reduce waste associated with energy production

Political
- Government policy position
- Clean growth policy to decarbonise while benefiting economy
- Net zero in legislation
- Energy security through support for homegrown energy