EURAD-2 Annual Event

Topical Session 1 – pre-disposal
ICARUS – STREAM – L'OPERA

Speakers: ICARUS: Eros Mossini (POLIMI) – STREAM: Federica Pancotti (SOGIN) – L'OPERA: Thierry Mennecart (SCK CEN)

Rapporteur: Lander Frederickx (SCK CEN)

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

Topical Session 1 – pre-disposal ICARUS, STREAM, L'OPERA Agenda

14.00 – 14.30 _ The Journey of a Challenging Radioactive Waste: From Cradle to Grave

Introduction on the topical session and on the three WPs objectives, organisation and expected outcomes

14.30 – 15.10 _ 1st Interactive session

Introduction on the challenges faced in pre-disposal domain (Characterisation, Treatment, Conditioning and Long-term Performances)

Map how the different WPs deal with the identified challenges

15.10 – 15.50 _ 2nd Interactive session

Problem-solving session for a specific case to show how each WP can solve part of the problem

15.50 – 16.00 _ Wrap-up and closing of the Session

Rapporteur feedback

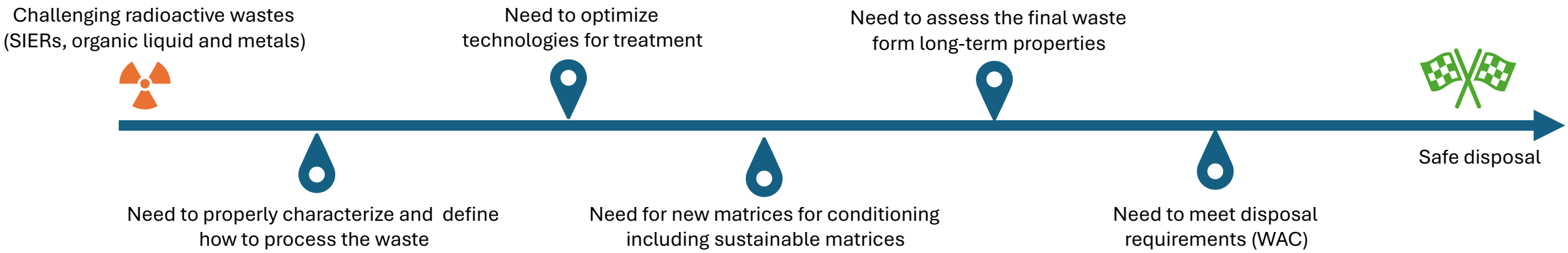
In person Participants will be asked to answer to some questions with the Event App

The Journey of a Challenging Radioactive Waste: From Cradle to Grave

In the European nuclear community, driven by technological advancements, certain problematic radioactive wastes, such as SIERs (Spent Ion Exchange Resins), organic liquids, and metals, have posed significant challenges for pre-disposal management.

*In the small country of **EURAD-2** within the EC kingdom, three heroes were chosen to strengthen an alliance on **pre-disposal topics**. Their mission is to tackle existing challenges and develop new solutions for managing these types of waste. Their journey has just begun and will continue over the next four years, involving Research and Development activities.*

The Journey of a Challenging Radioactive Waste: From Cradle to Grave



ICARUS will develop innovative solutions to advance characterization, providing essential data for developing processing routes and assessing the final waste package characteristics

STREAM will explore various processing methods, including new sustainable matrices for waste conditioning, improved performance and waste loadings. These new technologies will be optimised and integrated into existing systems to ensure compatibility with current infrastructure and scalability for industrial use

L'OPERA will focus on long-term performance and boundary conditions, ensuring that the final waste forms do not degrade or release harmful substances over time

All together will collaborate to ensure that the final waste forms meet WAC for disposal

THREE WORK PACKAGES ON PREDISPOSAL ACTIVITIES

Duration: 5 years

01.10.2024 – 31.09.2029

WP5 - ICARUS

Innovative characterisation techniques for large volume

Eros Mossini, POLIMI
Peter Ormai, PURAM

- **27** funded partners from **15** countries
- **2** Associated partners (NO, CH)

WP6 - STREAM

Sustainable treatment and immobilisation of challenging waste

Federica Pancotti, SOGIN
Marta Lopez, AMPHOS21

- **21** funded partners from **13** countries
- **3** Associated partners (UK, CH)

WP7 - L'OPERA

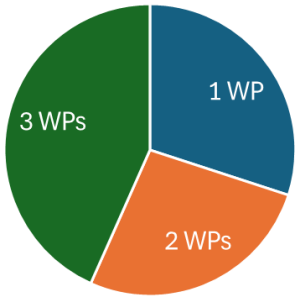
Long-term performance of waste matrices

Thierry Mennecart, SCK CEN
Marta Lopez, AMPHOS21

- **25** funded partners from **10** countries
- **2** Associated partners (CH)

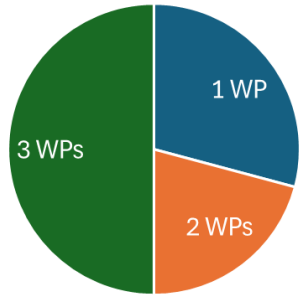
33 END USERS

- AB SVAFO (Sweden)
- ALARA (Estonia)
- Andra (France)
- ANVS (The Netherlands)
- ARWA (Australia)
- BASE (Germany)
- BGE (Germany)
- Campoverde (Italy)
- Cavendish (UK)
- DEKOM (Denmark)
- DSA (Norway)
- EDF (France)
- ENRESA (Spain)
- Environment Agency (UK)
- FOND NEK (Croatia)
- Fortum (Finland)
- IFIN-HH (Romania)
- IRE (Belgium)
- ISOTOPTECH ZRT (Hungary)
- KORAD (South Korea)
- NAAREA (France)
- NAGRA (Switzerland)
- NES (Austria)
- NWMO (Canada)
- NWS (UK)
- ONDRAF/NIRAS (Belgium)
- Polyeco (Greece)
- Sogin (Italy)
- TVO (Finland)
- Uniper Nuclear (Sweden)
- Veolia Nuclear Solutions (USA)
- Westinghouse (Spain)
- ZUOP (Poland)



26 STAKEHOLDERS

- AtkinsRéalis (UK)
- Canadian Nuclear Laboratories (Canada)
- Center for Ecotoxicological Research (CETI) (Montenegro)
- CNL (Canada)
- Comisión Nacional de Energía Atómica (CNEA) (Argentina)
- Cyclife engineering (France)
- Cyclife Germany GmbH (Germany)
- EDF (France)
- EPRI (USA)
- Frazer-Nash Consultancy Ltd (UK)
- IAEA (Austria)
- ININ (México)
- IRSN (France)
- ISIN (Italy)
- Korea Atomic Energy Research Institute (South Korea)
- Lucideon Ltd (UK)
- NDA (UK)
- NNL (UK)
- Nuclear Transport Solutions (UK)
- Platom Oy (Finland)
- PNNL (USA)
- RADCRE CO. Ltd (South Korea)
- Remondis (Switzerland)
- Tecnalia (Spain)
- U.S. Nuclear Waste Technical Review Board (USA)
- Waste2Glass (France)



26 COUNTRIES

INTERACTIONS WITH THE OTHER WPS

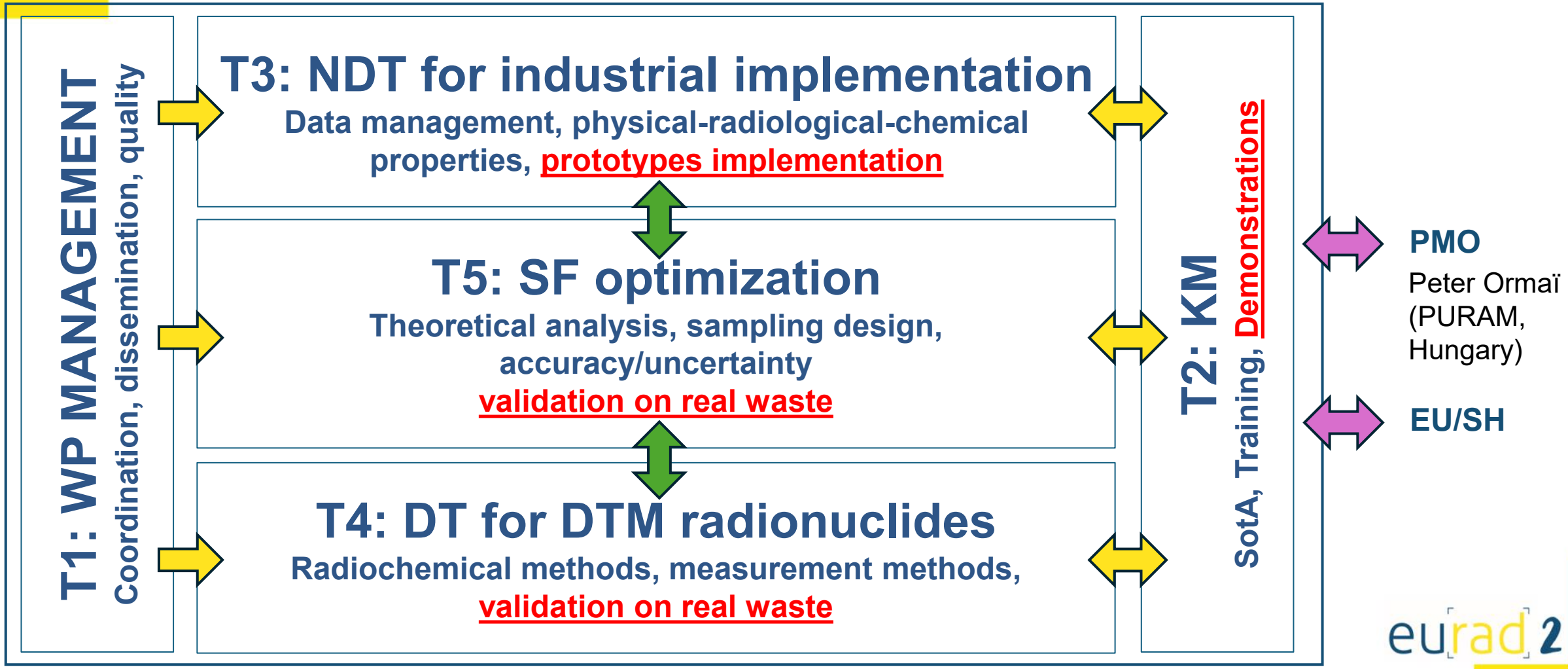
- WP2 – Knowledge Management
- WP3 – ASTRA: Exchange information for alternative RWM strategies and characterization of the waste forms from Small Inventory Member states (Non-destructive techniques and scaling factors)
- WP4 – FORSAFF: Waste management for SMR and future fuel and characterization
- WP12 – RAMPEC: Difficult-to-Measure radionuclides processes
- WP13 – OPTI: Optimization of buffer and backfilling composition
- WP14 – SUDOKU: Inputs / feedbacks related to the disposal facilities specifications in the development of the boundary conditions. Difficult-to-Measure radionuclides processes
- WP18 – DITUSC: Assess the application of thermodynamic understanding, and in particular the use of thermodynamic databases

WP5 ICARUS - Objectives

Further development, optimization and harmonization of innovative techniques for implementing the radiological, physical and chemical characterisation of LLW/ILW-mixed waste which could be critical for the safe implementation of radioactive waste management programmes, including destructive techniques (DT) on laboratory scale and its relation to non-destructive techniques (NDT) and scaling factors (SF) at the raw waste and package scale user cases.

- Identification of relevant **use cases** to develop cutting-edge techniques and methods for an industrial application.
- Development of characterization methodologies for **mixed wastes** as heterogeneous decommissioning, to acquire accurate radiological and chemical inventory necessary for defining pre-disposal management.
- Identification of most **relevant radionuclides**, including limitations and difficulties that remain for their proper characterisation.

WP5 ICARUS - Organisation



WP5 ICARUS - Expected Outcomes: the use-cases

•1st use case: to achieve fast and sufficiently accurate gamma activity distribution in large packages for industrial applications (decommissioning and ongoing operational processes, incl. mixed wastes as heterogeneous legacy waste) by **improved NDT methods**, incl. in-situ and remote characterization, gamma and neutron analyses;

•2nd use case: to improve/simplify the **NDT methods** for physical-chemical properties and alpha emitters inventory compared to current expensive DT and high uncertainty SF methods in relevant industrial scenarios to support waste segregation, treatment and conditioning;

•3rd use cases: to improve sensitivity, accuracy, uncertainty and cope with expensive and time-consuming conventional **radiochemical methods** for critical long-lived Difficult To Measure (DTM) radionuclides (C-14, Cl-36, Ca-41, Se-79, Zr-93, Mo-93, Tc-99, Pd-107, Cs-135, Cm-243, Cm-244) in relevant industrial scenarios (decommissioning/operational processes);

•4th use case: to lower the uncertainties and improve accuracy and reliability of **SF methods** to meet ever stringent requirements set by national regulators for raw mixed waste.

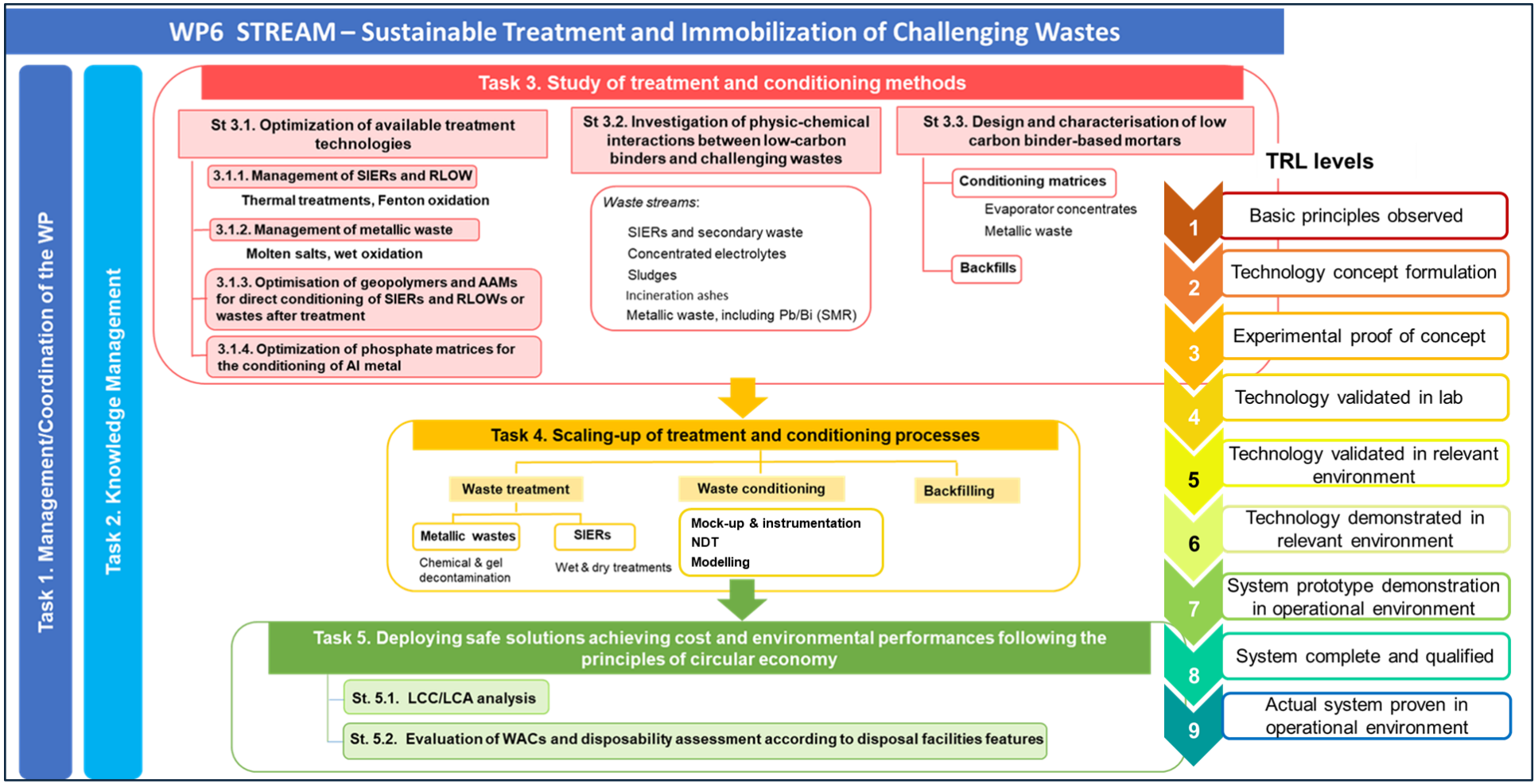
STREAM WP6 - Objectives

Sustainable TREAtment and iMmobilisation of challenging waste

Innovative and **sustainable design, optimization** and **upscaling** of treatments and conditioning materials for the predisposal of problematic waste

Development and **optimization of new or existing treatment** and **conditioning** methodologies for waste streams (metallic wastes, liquid organic wastes, SIERs, sludges or evaporator concentrates) without industrially implemented management routes (to increase TRLs)

STREAM WP6 - Organisation



WP7 L'OPERA
(Long-term performances)

WP5 ICARUS
(Characterisation)

WP3 ASTRA
(alternative RWM strategies)

WP4 FORSAFF
(WM for SMR and future fuel)

WP18 DITUSC
(thermodynamic database)

END-USERS

STREAM WP6 – Expected Outcomes

- **Improve chemical and physical treatment methods**, including decontamination solutions, to allow waste minimization and reduction of secondary waste streams
- **Design and optimization of alternative binders** (Geopolymer, AAM and MKPC) to increase waste loadings and/or improve waste form performance
- Assess the chemical compatibility and performances of **other low-carbon binders** (CEM II/C-M, CEM VI, LC3, belite-calcium sulfoaluminate cements) with existing waste streams to anticipate their implementation at an industrial level
- Design and characterization of **low-carbon binder-based mortars** incorporating recycled or secondary aggregates for conditioning matrices and backfill materials
- Demonstrating the **upscaling feasibility of treatment and conditioning** processes by a combination of large-scale testing and numerical modelling
- Identification and sharing of **most promising treatment and conditioning methods** considering technical, economic and environmental aspects (LCA/LCC)

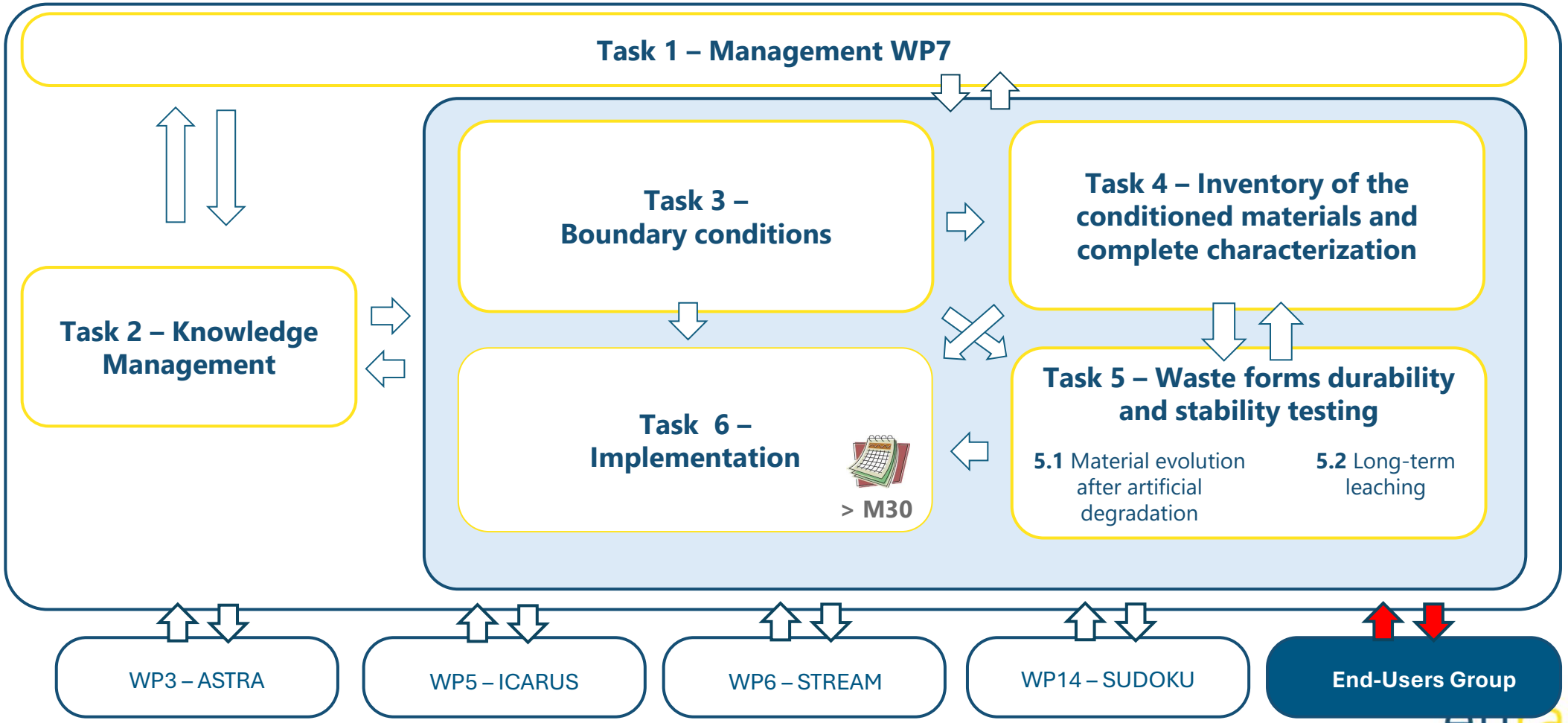
WP7 L'OPERA - Objectives

- **Increase the knowledge and understanding of matrices for the immobilization of Low and Intermediate Level Waste (LILW):**
  - Matrices : geopolymers, alkali-activated materials, magnesian potassium phosphate cements (MKPC), and Nochar
  - LILW: Radioactive Solid Organic Waste (RSOW), Metallics, Radioactive Liquid Organic Waste (RLOW).

- **Evaluation of the long-term performance of matrices:**
  - Increase of the TRL of processes developed within previous European projects (e.g. PREDIS)
  - Investigate final waste forms coming from innovative processes (collaboration with WP6 – STREAM)

- **Long-term behavior under disposal conditions:**
  - Degradation behavior and its consequences on the performance of the waste forms
  - Extrapolation to a few hundred years for surface disposal and to longer periods for geological disposal

WP7 L'OPERA - Organisation



WP7 L'OPERA – Expected Outcomes

- Better understanding of long-term behaviour of waste matrices/waste forms in **disposal conditions** (near surface disposal and deep geological disposal)
- Identifying **degradation processes** and their **elemental drivers**
- **Diffusion** and **leaching values** of new matrices/waste forms
- **Disposability assessment** and **demonstration** according to disposal facilities features (near-surface and/or intermediate-depth and/or geological)

1st Interactive session

Challenges/Gaps

Moderator: Federica Pancotti (SOGIN)

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

1st Interactive session – Challenges/Gaps

All the three WPs have completed the **initial State of the Art reports**:

- **D5.1** *State-of-the-art on innovative non-destructive techniques, destructive techniques, scaling factors for use cases*
- **D6.1** *Review of treatment and conditioning processes and materials available or under development for challenging wastes*
- **D7.1** *State of the Art on novel matrices for LILW immobilization*

They include:

- a comprehensive **review of the existing knowledge** on innovative characterization techniques, treatment and conditioning processes and long-term durability assessment of novel matrices
- the identification of the **challenges/gaps to be addressed** in the three WPs

Participants will be asked to collaborate to:

1) **Assign** the challenges/gaps to the work package (WP) that is best suited to address them and **identify overlapping** challenges/gaps that might involve two or three WPs
2) **Prioritise** challenges/gaps

1st Interactive session – Challenges/Gaps

1. **Waste Acceptance Criteria**
   Assess suitability of existing WAC, develop new criteria if necessary
2. **DTM Radionuclides Analysis**
   Workflow inefficiencies, specific DTM challenges, lack of validations
3. **Waste form durability**
   Long-term testing under various conditions: irradiation dosage, thermal cycling and combination of environmental actions / Long-term leaching (related degradation mechanisms in water and alkaline environment)
4. **Sustainability and Environmental Impact**
   Low-carbon cements, use of recycled materials, LCA/LCC methodologies
5. **Modelling**
   Models to extrapolate long-term performances
6. **New conditioning matrices**
   Alternative binders (GP-AAM, MKPC): enhance chemical resistance, increase waste loading, reduce environmental impact compared to traditional OPC
7. **NDT enhancement**
   Detection limits, processing speed, geometry handling, data analysis automation
8. **Nochar + RLOW**
   Assess bonding process, influence of ageing on polymer sorption / Effect of cement composition, mechanical strength and data on long-term durability
9. **MKPC + Metals**
   Short- and long-term H2 assessment changing environmental conditions / Impact of mineral admixtures, pore pH and M/P molar ratio on long-term durability
10. **Scaling-up**
    Demonstrate feasibility: pilot and large-scale tests, tests with real waste, assessment of technical and economic factors
11. **Physical-Chemical characterization**
    Limited real-time capabilities, high costs, low automation
12. **Monitoring and modelling**
    Non-destructive testing and monitoring tools, Advanced modelling to predict long-term performance under disposal conditions.
13. **SF Methodology**
    High uncertainty, Statistical reliability, data scarcity for validation
14. **Standardization**
    Testing protocols: facilitate scaling-up and industrial implementation, ensure regulatory compliance and approval
15. **GP-AAM + RLOW and RSOW**
    Assess influence of raw materials, gas release under irradiation
16. **Optimized treatment technologies**
    Thermal and chemical (improve efficiency, reduce secondary waste increase volume reduction)
17. **MKPC + SIERs**
    Encapsulation studies

1st Interactive session – Questions

Please assign the identified challenges/gaps to the work package (WP) that is best suited to address them – *Select all applicable*

Which challenges or gaps do you believe should be addressed by **ICARUS**?

1. Waste Acceptance Criteria
2. DTM Radionuclides Analysis
3. Waste Form Durability
4. Sustainability and Environmental Impact
5. Modelling
6. New Conditioning Matrices
7. NDT Enhancement
8. Nochar + RLOW
9. MKPC + Metals
10. Scaling-Up
11. Physical-Chemical Characterization
12. Monitoring and Modelling
13. SF Methodology
14. Standardization
15. GP-AAM + RLOW and RSOW
16. Optimized Treatment Technologies
17. MKPC + SIERs

Which challenges or gaps do you believe should be addressed by **STREAM**?

1. Waste Acceptance Criteria
2. DTM Radionuclides Analysis
3. Waste Form Durability
4. Sustainability and Environmental Impact
5. Modelling
6. New Conditioning Matrices
7. NDT Enhancement
8. Nochar + RLOW
9. MKPC + Metals
10. Scaling-Up
11. Physical-Chemical Characterization
12. Monitoring and Modelling
13. SF Methodology
14. Standardization
15. GP-AAM + RLOW and RSOW
16. Optimized Treatment Technologies
17. MKPC + SIERs

Which challenges or gaps do you believe should be addressed by **L'OPERA**?

1. Waste Acceptance Criteria
2. DTM Radionuclides Analysis
3. Waste Form Durability
4. Sustainability and Environmental Impact
5. Modelling
6. New Conditioning Matrices
7. NDT Enhancement
8. Nochar + RLOW
9. MKPC + Metals
10. Scaling-Up
11. Physical-Chemical Characterization
12. Monitoring and Modelling
13. SF Methodology
14. Standardization
15. GP-AAM + RLOW and RSOW
16. Optimized Treatment Technologies
17. MKPC + SIERs

1st Interactive session – Challenges/Gaps

Open discussion - Overlapping challenges/gaps that might involve two or three WPs

	Challenge/gap		ICARUS	STREAM	L'OPERA
1	**Waste Acceptance Criteria**	*Assess suitability of existing WAC, develop new criteria if necessary*			
2	**DTM Radionuclides Analys**	*Workflow inefficiencies, specific DTM challenges, lack of validations*			
3	**Waste form durability**	*Long-term testing under various conditions: irradiation dosage, thermal cycling and combination of environmental actions / Long-term leaching (related degradation mechanisms in water and alkaline environment)*			
4	**Sustainability and Environmental Impact**	*Low-carbon cements, use of recycled materials, LCA/LCC methodologies*			
5	**Modelling**	*Models to extrapolate long-term performances*			
6	**New conditioning matrices**	*Alternative binders (GP-AAM, MKPC): enhance chemical resistance, increase waste loading, reduce environmental impact compared to traditional OPC*			
7	**NDT enhancement**	*Detection limits, processing speed, geometry handling, data analysis automation*			
8	**Nochar + RLOW**	*Assess bonding process, influence of ageing on polymer sorption / Effect of cement composition, mechanical strength and data on long-term durability*			
9	**MKPC + Metals**	*Short- and long-term H2 assessment changing environmental conditions / Impact of mineral admixtures, pore pH and M/P molar ratio on long-term durability*			
10	**Scaling-up**	*Demonstrate feasibility: pilot and large-scale tests, tests with real waste, assessment of technical and economic factors*			
11	**Physical-Chemical characterization**	*Limited real-time capabilities, high costs, low automation*			
12	**Monitoring and modelling**	*Non-destructive testing and monitoring tools, Advanced modelling to predict long-term performance under disposal conditions.*			
13	**SF Methodology**	*High uncertainty, Statistical reliability, data scarcity for validation*			
14	**Standardization**	*Testing protocols: facilitate scaling-up and industrial implementation, ensure regulatory compliance and approval*			
15	**GP-AAM + RLOW and RSOW**	*Assess influence of raw materials, gas release under irradiation*			
16	**Optimized treatment technologies**	*Thermal and chemical (improve efficiency, reduce secondary waste increase volume reduction)*			
17	**MKPC + SIERs**	*Encapsulation studies*			

1st Interactive session – Challenges/Gaps

Open discussion – Where we see **clear possibilities for collaboration between WPs**

ICARUS

STREAM

L'OPERA

1 **Waste Acceptance Criteria**
Assess suitability of existing WAC, develop new criteria if necessary

2 **DTM Radionuclides Analysis**
Workflow inefficiencies, specific DTM challenges, lack of validations

3 **Waste form durability**
Long-term testing under various conditions: irradiation dosage, thermal cycling and combination of environmental actions / Long-term leaching (related degradation mechanisms in water and alkaline environment)

4 **Sustainability and Environmental Impact**
Low-carbon cements, use of recycled materials, LCA/LCC methodologies

5 **Modelling**
Models to extrapolate long-term performances

6 **New conditioning matrices**
Alternative binders (GP-AAM, MKPC): enhance chemical resistance, increase waste loading, reduce environmental impact compared to traditional OPC

7 **NDT enhancement**
Detection limits, processing speed, geometry handling, data analysis automation

8 **Nochar + RLOW**
Assess bonding process, influence of ageing on polymer sorption / Effect of cement composition, mechanical strength and data on long-term durability

9 **MKPC + Metals**
Short- and long-term H2 assessment changing environmental conditions / Impact of mineral admixtures, pore pH and M/P molar ratio on long-term durability

10 **Scaling-up**
Demonstrate feasibility: pilot and large-scale tests, tests with real waste, assessment of technical and economic factors

11 **Physical-Chemical characterization**
Limited real-time capabilities, high costs, low automation

12 **Monitoring and modelling**
Non-destructive testing and monitoring tools, Advanced modelling to predict long-term performance under disposal conditions.

13 **SF Methodology**
High uncertainty, Statistical reliability, data scarcity for validation

14 **Standardization**
Testing protocols: facilitate scaling-up and industrial implementation, ensure regulatory compliance and approval

15 **GP-AAM + RLOW and RSOW**
Assess influence of raw materials, gas release under irradiation

16 **Optimized treatment technologies**
Thermal and chemical (improve efficiency, reduce secondary waste increase volume reduction)

17 **MKPC + SIERs**
Encapsulation studies

1st Interactive session – Challenges/Gaps

Standardization

Testing protocols: facilitate scaling-up and industrial implementation, ensure regulatory compliance and approval

Monitoring and modelling

Non-destructive testing and monitoring tools, Advanced modelling to predict long-term performance under disposal conditions.

Physical-Chemical characterization

Limited real-time capabilities, high costs, low automation

Modelling

Models to extrapolate long-term performances

Waste Acceptance Criteria

Assess suitability of existing WAC, develop new criteria if necessary

Scaling-up

Demonstrate feasibility: pilot and large-scale tests, tests with real waste, assessment of technical and economic factors

How can we build collaboration?

- Developing common protocols and methods for characterization and monitoring of waste and waste form
- Defining how to identify the relevance of the waste form characteristics and composition
- Defining minimum and common critical KPI
- WAC development and regulatory compliance: identify WP relationship, overlaps and workflow (*starting from the PREDIS outcomes*)
- Mechanism for integrating feedback from end-users, regulators, or stakeholders (*link with the morning breakout session 3*)

1st Interactive session – Questions

Please rate the priority (R&D needs) of the identified challenges and gaps for predisposal - *Use a scale from 1 (Lowest Priority) to 5 (Highest Priority)*

1. Waste Acceptance Criteria
2. DTM Radionuclides Analysis
3. Waste Form Durability
4. Sustainability and Environmental Impact
5. Modelling
6. New Conditioning Matrices
7. NDT Enhancement
8. Nochar + RLOW
9. MKPC + Metals
10. Scaling-Up
11. Physical-Chemical Characterization
12. Monitoring and Modelling
13. SF Methodology
14. Standardization
15. GP-AAM + RLOW and RSOW
16. Optimized Treatment Technologies
17. MKPC + SIERs

1st Interactive session – Challenges/Gaps

1. **Waste Acceptance Criteria**
   Assess suitability of existing WAC, develop new criteria if necessary
2. **DTM Radionuclides Analysis**
   Workflow inefficiencies, specific DTM challenges, lack of validations
3. **Waste form durability**
   Long-term testing under various conditions: irradiation dosage, thermal cycling and combination of environmental actions / Long-term leaching (related degradation mechanisms in water and alkaline environment)
4. **Sustainability and Environmental Impact**
   Low-carbon cements, use of recycled materials, LCA/LCC methodologies
5. **Modelling**
   Models to extrapolate long-term performances
6. **New conditioning matrices**
   Alternative binders (GP-AAM, MKPC): enhance chemical resistance, increase waste loading, reduce environmental impact compared to traditional OPC
7. **NDT enhancement**
   Detection limits, processing speed, geometry handling, data analysis automation
8. **Nochar + RLOW**
   Assess bonding process, influence of ageing on polymer sorption / Effect of cement composition, mechanical strength and data on long-term durability
9. **MKPC + Metals**
   Short- and long-term H2 assessment changing environmental conditions / Impact of mineral admixtures, pore pH and M/P molar ratio on long-term durability
10. **Scaling-up**
    Demonstrate feasibility: pilot and large-scale tests, tests with real waste, assessment of technical and economic factors
11. **Physical-Chemical characterization**
    Limited real-time capabilities, high costs, low automation
12. **Monitoring and modelling**
    Non-destructive testing and monitoring tools, Advanced modelling to predict long-term performance under disposal conditions.
13. **SF Methodology**
    High uncertainty, Statistical reliability, data scarcity for validation
14. **Standardization**
    Testing protocols: facilitate scaling-up and industrial implementation, ensure regulatory compliance and approval
15. **GP-AAM + RLOW and RSOW**
    Assess influence of raw materials, gas release under irradiation
16. **Optimized treatment technologies**
    Thermal and chemical (improve efficiency, reduce secondary waste increase volume reduction)
17. **MKPC + SIERs**
    Encapsulation studies

2nd Interactive session

Problem Solving

Moderator: Eros Mossini (POLIMI)

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

2nd Interactive session – problem solving

"address challenges for Spent Ion Exchange Resins (SIERs) pre-disposal management"

Problem Statement:

Ion exchange resins are widely used in NPPs and other facilities to purify liquids (e.g. water coolant, SNF pool).

The pre-disposal management of SIERs pose significant **challenges** addressing safety, characterization, treatment, conditioning and regulatory compliance to ensure the safe, cost-effective, and environmentally sound disposal of these radioactive wastes.

- Establishing a detailed Characterization of the waste properties is essential to inform subsequent steps
- Treatment and Conditioning processes to reduce volume, stabilize waste form, and prepare it for safe disposal are crucial
- Waste form properties and long-term durability need to be demonstrated to ensure the waste form remains stable over the required disposal period

Presentations will **show how the three WPs can contribute to solve these issues**

How can ICARUS contribute to solve the problem?

Characterisation of physical and chemical properties of SIER

What properties?

Density, amount of SIER in the package, water content, chemical composition

Why?

These properties are required to optimise SIER treatment and conditioning (link with STREAM)

How ICARUS will contribute?

By means of **Non-Destructive Techniques (NDT)**

- Investigate current practices for improvements
- Propose NDT alternatives for density inhomogeneity (sediment in water phase)
- If needed evaluate in-situ equipment as an alternative for laboratory samples

How STREAM and L'OPERA can contribute?

- STREAM should provide the list of technical needs and properties to be monitored
- END USERS could provide information or real samples

How can ICARUS contribute to solve the problem?

Characterisation of radiological properties of SIER

What properties?

Dose rate, gross alpha-beta, gamma-emitting and difficult-to-measure (DTM) radionuclides

Why?

These properties are required to optimise SIER treatment, conditioning, and long-term behaviour of the waste forms (link with STREAM and L'OPERA)

How ICARUS will contribute?

By means of **Non-Destructive Techniques (NDT)**, **Destructive Techniques (DT)** and **Scaling Factors (SF)**

How STREAM and L'OPERA can contribute?

- STREAM and L'OPERA should provide the list of radiological properties to be monitored
- END USERS could provide information or real samples

How can ICARUS contribute to solve the problem?

Characterisation of radiological properties of SIER

What properties?

Dose rate, gross alpha-beta, gamma-emitting radionuclides

How ICARUS will contribute?

By means of **Non-Destructive Tecniques (NDT)**:

- **Data management**
  - For fingerprinting and grouping measurement results
  - Validating waste homogeneity for smart sampling
  - Collecting partners experiences on legacy drums
  - Correlating sample results and NDT drum results
- **NDT Methods** for contact dose rate to identify hotspots
- **In-Situ Methods** for sampling and on-site measurement of alpha-beta activity
- **NDT & Fingerprint Methods** for determining the content of gamma-emitting radionuclides

How can ICARUS contribute to solve the problem?

Characterisation of radiological properties of SIER

What properties?

Difficult-to-measure (DTM) radionuclides (e.g. C-14, Cl-36, Tc-99)

How ICARUS will contribute?

By means of **Destructive Techniques (DT)**:

- Development of **novel radiochemical methods** to enhance analytical capabilities, focus on SIER matrix.
  - Optimization of existing procedures by replacing conventional, time-consuming methods with more efficient alternatives.
  - Innovation in radionuclide analysis, focusing on isotopes for which current methods are limited or inadequate.
- Advancement of **measurement techniques** to improve accuracy, sensitivity, and reliability.
  - Application of novel radiometric techniques to enable efficient measurement.
  - Evaluation of mass spectrometric versus radiometric methods, comparing detection limits, analysis time, and cost-effectiveness.
- Coordination of **intercomparison exercises** to validate, demonstrate, and harmonize newly developed analytical methods across laboratories.

How can ICARUS contribute to solve the problem?

Characterisation of radiological properties of SIER

What properties?

Difficult-to-measure (DTM) radionuclides

How ICARUS will contribute?

By means of **Scaling Factors (SF)**:

- **Theoretical SF model**: production mechanisms of radioactive isotopes in a nuclear reactor from their origin in the reactor coolant to their transfer into the various waste streams (SIER);
- **Statistical SF model**: optimization of the sampling efforts and minimization of uncertainty and accuracy bias;
- **Combination** of adjusted theoretical models with sampling-based approaches.
- Parameters to be controlled:
  - ETM Activity Range / Targeted DTM.
  - Different systems and generation times.
  - Accuracy Improvement / Uncertainty Reduction.
  - Sampling Optimization: Composite Samples, Minimum number of samples, Sufficient Sample Size.

How can ICARUS contribute to solve the problem?

Monitoring of SIER or waste form properties

What properties?

Dose rate, gamma-emitting radionuclides, etc.

Why?

These properties are required to optimise SIER treatment, conditioning, and long-term behaviour of the waste forms (link with STREAM and L'OPERA)

How ICARUS will contribute?

By means of **Non-Destructive Techniques (NDT)**:

- **Sensor networks (NDT-Monitoring)**
  - During treatment (around plasma oven or other thermal treatment facilities)
  - During transport (on transport equipment, overpacks etc.)
  - During long-term interim storage / disposal (decrease uncertainty, monitor change, increase measurement time)

How STREAM and L'OPERA can contribute?

- STREAM and L'OPERA should provide the list of properties to be monitored

How can STREAM contribute to solve the problem?

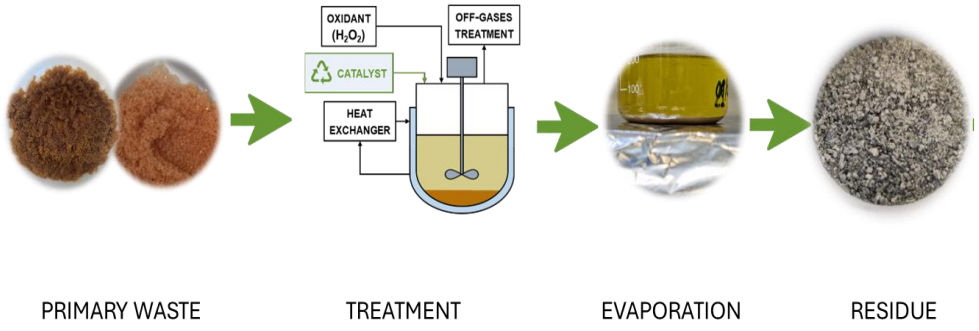
TREATMENT ISSUES

- Conventional thermal treatments help reduce the volume of SIERs but they can also increase specific radioactivity in the resulting ashes complicating disposal (use of alternative repository sites)
- Not all waste streams can undergo conventional thermal treatments due to their small volumes or their physic-chemical or radiological characteristics

STREAM will develop and optimise **new treatments** (low-gradient thermal treatment and heterogeneous Fenton wet oxidation processes) aiming at **improving performance, safety, waste minimization and cost-reduction**

How can STREAM contribute to optimise SIERs Treatment?

*Design of **low-gradient thermal treatment and heterogeneous Fenton wet oxidation** processes to limit potential loss of contaminants and minimize the footprint of the process*



- ✓ **Advanced oxidation tests** to liquefy samples of **fresh mixed bed** and **powdered IERs**, with **Fenton** (Fe^{2+} catalyst) and **Fenton-like** (Fe^{2+}/Cu^{2+} catalyst) **oxidation**
- ✓ Ongoing tests to **evaluate of sono-Fenton oxidation and to collect/analyze process gases**
- ✓ **Parameters to optimise:** reaction time, weight reduction ratio, usage of reagents (type/quantity of catalyst, concentration/quantity of H_2O_2), carbon removal
- ✓ **Representative loaded IERs** (**B**, **Fe**, Ni, Mn, Cr, **Cs**…) for treatment validation
- ✓ **Future tests on real radioactive SIERs** from TRIGA reactor

- ❑ The potential for **lower temperature processing**, with a significant reduction in resultant solid wastes, could provide **another technology in the toolbox** of treatment options
- ❑ The ability of Fenton wet oxidation to degrade material at lower temperatures is particularly **interesting for wastes containing volatile radioisotopes**, for which high-temperature processes may require extensive off-gas systems
- ❑ Opportunities exist for **optimising degradation reactions** with varied catalysts, optimising the quantity of H_2O_2 utilised to **reduce secondary wastes**

How can STREAM contribute to solve the problem?

CONDITIONING ISSUES

- Challenges regarding stability issues with cement matrix when immobilising SIERs
- Contaminants, particularly those from organic exchangers, can interfere with the cement hydration process, compromising the stability of the waste form. This can lead to issues such as swelling, gel formation, and reduced strength
- These challenges limit the full-scale practice of SIERs immobilization into conventional cementitious matrices to low waste loading

STREAM will **optimise GP and AAM** for the conditioning of **treated and untreated SIERs** and will investigate physico-chemical interactions between **low-carbon binders and SIERs**

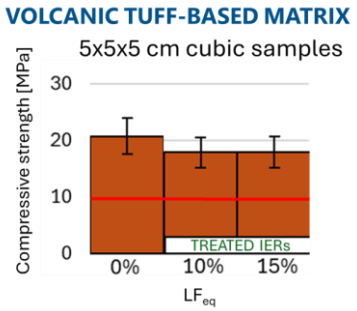
How can STREAM contribute to optimise the Conditioning of treated SIERs?

*Optimisation of **geopolymers and alkali activated materials** for the conditioning of **treated SIERs***

IERs Fenton treated

- **Binder:**
  - **Metakaolin and FA / alkali-activated GP** (tuff, FA, BFS, sand, sodium silicate) / **acid GP** (tuff, FA, MK, sand, H_3PO_4)
- **Parameters to optimise**:
  - loading factors, workability, and parameters linked to WAC (i.e. compression @28d, immersion, leaching, irradiation)

Italian WAC: $L_i(Cs) > 7,0$		
LF_{eq}	10%	15%
Cs	12,9 ± 0,1	12,7 ± 0,1



IERs incineration ashes

Incineration ashes

- Produced by Belgoprocess
- Inactive simulant: municipal waste incineration ashes
- Bottom ashes and fly ashes

- Preliminary processing (drying, sieving, homogenization and mixing) for bottom ashes to approach chemical composition of active ashes of Belgoprocess
- **Vitrified bauxite residue (VBR)** is used as either an SCM in a blended cementitious system, or as a precursor to an alkali-activated material

Bottom ashes – as received

Bottom ashes – dried and sieved at 2 mm

How can STREAM contribute to optimise the Conditioning of non-treated SIERs?

*Optimisation of **geopolymers and alkali activated materials** and phosphate binders for the conditioning of **untreated SIERs***

- **Surrogated SIERs samples (doped or not with surrogated tracers)**
  - Different partners with alkaline GP/AAM (MK, BFS, FA, VT)
  - 1 partner with acid GP (H3PO3)
  - 1 partner with MKPC
- **Real SIERs**
  - 2 partners with MK, FA, BFS
- **Parameters to be studied and optimised**:

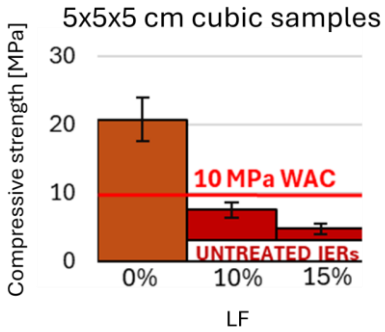
SIERs loading, L/B ratio, moisture and temperature curing influence, mechanical properties, porosity, fluidity, workability, homogeneity, short term leaching

Geopolymer paste (MK + sand + 10% IER)

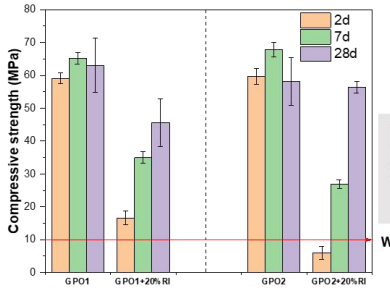
Sample structure (MK + sand + 10% IER)

MK(60°C,1d)

FA (60°C,7d)



GP and AAMs, still **need further optimization** (i.e. increase of waste loading)



Load: 20% SIERs (dry weigth)
CC: 21°C/99 %RH

Collaboration with L'OPERA: sharing samples and durability tests

How can STREAM contribute to develop novel matrices for SIERs Conditioning?

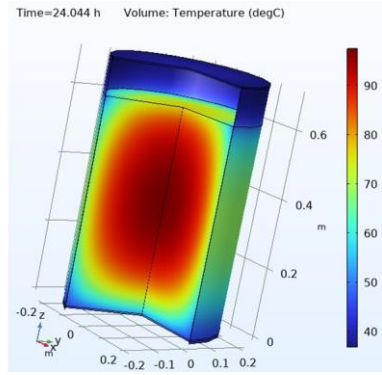
*Investigation of physico-chemical interactions between **low-carbon binders and SIERs***

- **Surrogated SIERs samples (doped or not with surrogated tracers)**
  - LC3 (limestone calcined clay cements) (CEM II/C-M (Clinker content up to 50%), Laboratory design and commercial cement
  - CSA
  - Clinker <40-50% +SCM

Other low-carbon binders can offer **new prospects** for waste immobilization whilst **minimizing environmental impact**. Their **immobilization capacity** and resulting w**aste form performances** still **need to be evaluated**

- **Parameters to be studied and optimised**:
  - mechanical performance, minimum porosity, adequate fluidity, good behavior at short and long-term (moisture and temperature)
  - immobilization, hydration, phase assemblage, crystallinity, short-term, mechanical properties
  - waste-matrix interactions, impact of soft inclusions on mechanical properties of wasteforms, minimization of hard aggregate content (for higher waste loading of direct immobilized IER)

How can STREAM contribute to demonstrate Scaling up feasibility and Disposability?



- Scale-up or standardization and qualification must be evaluated prior to an industrial implementation phase to increase TRL and support understanding of long-term performance of waste forms

STREAM will **scale-up wet (Fenton) treatment** processes for SIERs and will develop **conceptual design of mock-up and instrumentation** for treated or untreated SIERs **conditioning - *collaboration with ICARUS and L'OPERA***

STREAM will develop **monitoring techniques and simulation models** (*thermal excursion during hydration, stress development, expansion*) to support understanding package stability/performance through both long-term storage and final disposal - ***collaboration with ICARUS and L'OPERA***

- LCC/LCA analyses of the most promising processes/materials are needed to assess potential technologies for the implementation phase
- Disposability assessment, including the suitability of existing WAC for new waste forms or the need to develop new ones, is a key issue for increasing TRL.

STREAM will evaluate **treatment and immobilisation options** with dedicated **LCC/LCA studies** and **Disposability assessment** (*based on PREDIS knowledge and experience*) - ***collaboration with ICARUS and L'OPERA***

How can L'OPERA contribute to solve the problem?

Representativeness of long term conditions

- Common features for national disposal facilities and strategies for the management of LILW
  - (near-) surface or intermediate-depth disposal facilities for 300 years
  - Engineered barrier system based on a multibarrier approach (waste package, disposal vaults, …)

The durability of waste forms and matrices should be evaluated in **cementitious pore solutions**

Determination of the key parameters influencing the durability of the waste forms
- Chemical properties (leaching rates, chemical kinetics,…), physical properties (porosity, density,…) and mechanical properties (compressive strength,…)

Environmental conditions
- Irradiation, thermal cycles, carbonation,…

📖 EURAD-2 - D7.2: Representative conditions and identification of the key parameters influencing the long-term behaviour of LL-ILW

How can L'OPERA contribute to solve the problem?

LONG TERM ISSUES

- Evolution of "fresh materials" – baseline
  - ➢ Evaluation of the robustness and stability of the waste forms

- Long term using accelerated tests
  - ➢ Irradiation, temperature, redox, pH,…

- Long term performance by modelling
  - ➢ Several approaches will be considered

Establishment of protocols

How can L'OPERA contribute to solve the problem?

Investigated waste forms

Conditioned materials and waste forms developed in national projects or previous international (e.g. PREDIS). IERs are immobilized directly or after (thermal) treatment

Geopolymer & Alkali-Activated Materials: Metakaolin, Blast furnace slag } Direct /

Volcanic tuff — Direct /

> Y2

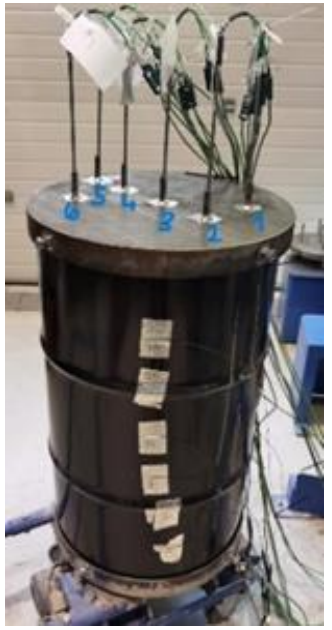
From WP6 STREAM

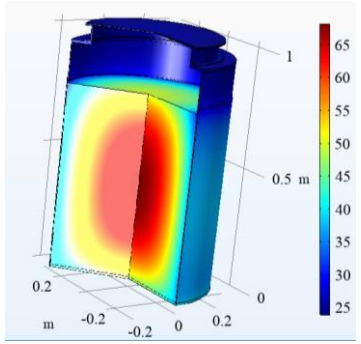
Magnesium potassium phosphate cement (MKPC)

How can L'OPERA contribute to solve the problem?

'Old' geopolymer samples

Scale-up





Interaction WP5 ICARUS and WP6 STREAM

Questions

Do you believe ICARUS, STREAM, and L'OPERA can effectively help addressing the challenges in SIERs pre-disposal management? *(Please select the option that best reflects your view)*

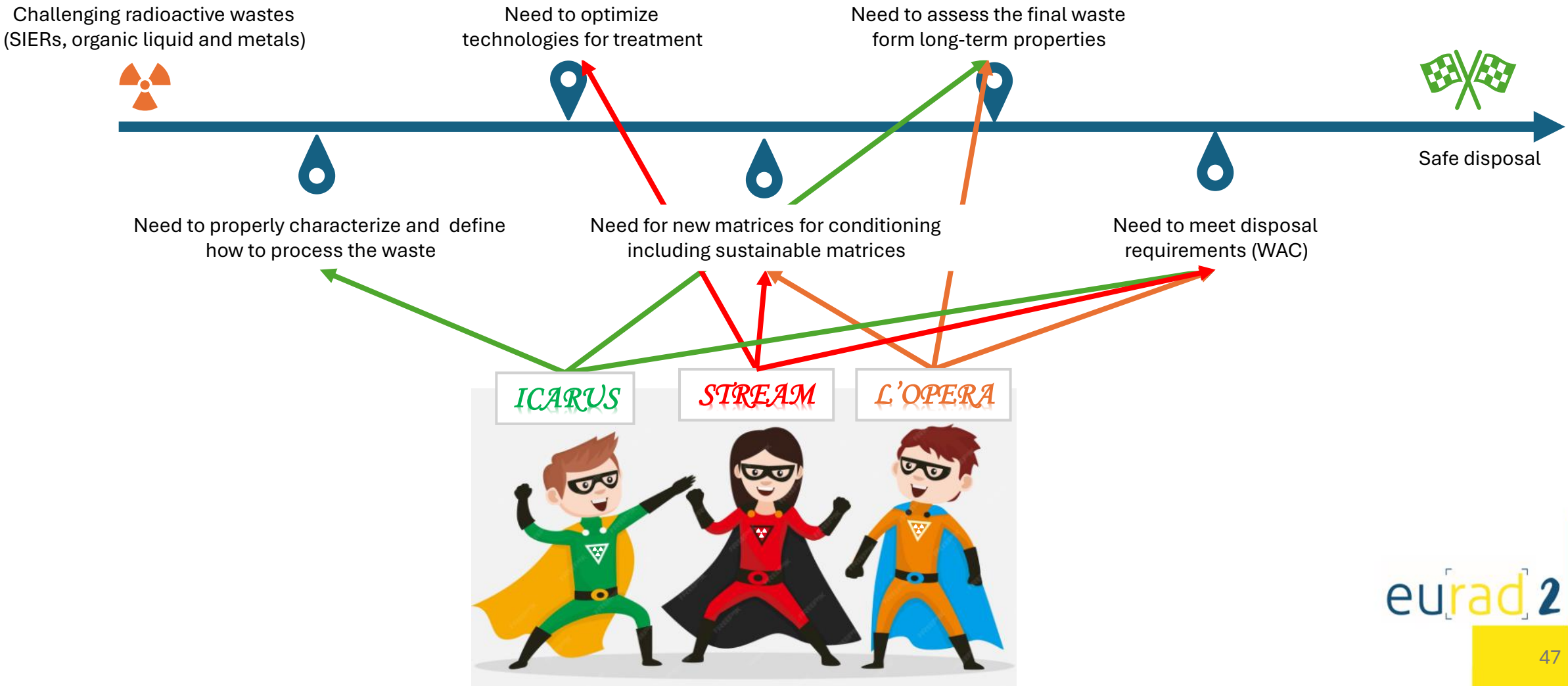
- **Strongly agree** – The proposed R&D activities comprehensively address all existing challenges and gaps
- **Moderately agree** – The proposed R&D activities address several key challenges and gaps, but not all
- **Slightly agree** – Only a limited portion of the challenges and gaps are addressed by the proposed R&D activities
- **Do not agree** – The proposed R&D activities do not address the existing challenges and gaps at all

Topical Session 1 – pre-disposal
ICARUS – STREAM – L'OPERA

Wrap-up and closing of the Session

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

The Journey of a Challenging Radioactive Waste: From Cradle to Grave



Questions (target End-Users and Stakeholders)

Questions will remain open even after the meeting to collect input from End-User and Stakeholders

1. **How would End-Users and Stakeholders prefer to contribute to our work?** *(Please select all that apply)*
   - 🧪 Supplying representative samples
   - 📊 Sharing real waste characteristics
   - 📝 Writing and/or reviewing technical documentation
   - 💬 Participating in technical discussions
   - 🧠 Contributing to research design
   - 🎓 Supporting knowledge capture and training initiatives

2. **How can we better engage with End-Users and Stakeholders?** *(Please select your preferred formats)*
   - 💻 Dedicated online sessions focused on specific Work Packages (WPs)
   - 🧵 Online sessions tailored to specific topics
   - 🤝 In-person meetings
   - 📅 Invitations to biannual technical WP meetings (with dedicated sessions for End-Users)

3. **Do you have any other suggestions?**
   - Open answer: *Let us know how we can make collaboration more effective and meaningful for you*

Rapporteur feedback

- A **brief summary** of the outcomes from *"Topical Session 1 – Pre-disposal: ICARUS, STREAM, and L'OPERA"* will be presented during the **Plenary Session tomorrow**, Thursday, 11 September (11:15–12:00)
- Additionally, a **summary report** will be prepared and used to draft the Annual Event Summary, which will be made available as a **public document**

Thank you for your attention

Contacts:

Eros Mossini (ICARUS) eros.mossini@polimi.it
Federica Pancotti (STREAM) pancotti@sogin.it
Thierry Mennecart (L'OPERA) thierry.mennecart@sckcen.be

1st Interactive session – Challenges/Gaps

ICARUS

- 7 • **NDT enhancement** *Detection limits, processing speed, geometry handling, data analysis automation*
- 2 • **DTM Radionuclides Analysis** *workflow inefficiencies, specific DTM challenges, lack of validations*
- 11 • **Physical-Chemical characterization** *Limited real-time capabilities, high costs, low automation*
- 13 • **SF Methodology** *High uncertainty, Statistical reliability, data scarcity for validation*

SREAM

- 16 • **Optimized treatment technologies** *Thermal and chemical (improve efficiency, reduce secondary waste increase volume reduction)*
- 6 • **New conditioning matrices** *Alternative binders (GP-AAM, MKPC): enhance chemical resistance, increase waste loading, reduce environmental impact compared to traditional OPC*
- 4 • **Sustainability and Environmental Impact** *Low-carbon cements, use of recycled materials, LCA/LCC methodologies*
- 10 • **Scaling-up** *Demonstrate feasibility: pilot and large-scale tests, tests with real waste, assessment of technical and economic factors*
- 14 • **Standardization** *Testing protocols: facilitate scaling-up and industrial implementation, ensure regulatory compliance and approval*
- 12 • **Monitoring and modelling** *Non-destructive testing and monitoring tools, Advanced modelling to predict long-term performance under disposal conditions.*
- 1 • **Waste Acceptance Criteria** *Assess suitability of existing WAC, develop new criteria if necessary*

L'OPERA

- 15 • **GP-AAM + RLOW and RSOW** *Assess influence of raw materials, gas release under irradiation*
- 9 • **MKPC + Metals** *Short- and long-term H2 assessment changing environmental conditions / impact of mineral admixtures, pore pH and M/P molar ratio on long-term durability*
- 17 • **MKPC + SIERs** *Encapsulation studies*
- 8 • **Nochar + RLOW** *Assess bonding process, influence of ageing on polymer sorption / Effect of cement composition, mechanical strength and data on long-term durability*
- 3 • **Waste form durability** *Long-term testing under various conditions: irradiation dosage, thermal cycling and combination of environmental actions / Long-term leaching (related degradation mechanisms in water and alkaline environment)*
- 5 • **Modelling** *Models to extrapolate long-term performances*