

Exchange Meeting

eurad

European Joint Programme
on Radioactive Waste Management

Welcome

Katrien Hendrix
Communication manager EURIDICE

26th Exchange Meeting

sck cen



ONDRAF/NIRAS

How does gas behave in the Boom Clay? 1 year of the NEMESIS experiment (NEon diffusion in the MEgas In Situ) has improved our understanding of dissolved gas transport. ...more



Caroline Poortmans and 39 others

5 comments • 4 reposts



Like

Comment

Repost

Send

Add a comment...



Most relevant ▾



Didier LEONARD

Director of the Sustainable Waste & Decommissioning Institute, SCK CEN

4d ***

Congratulations to all the team ! Again, collaboration between SCK CEN and ONDRAF/NIRAS results in an impressive success !

Like · 2 · Reply



Alexander Denisov

Passionate about making cross-functional engineering teams efficient

1d ***

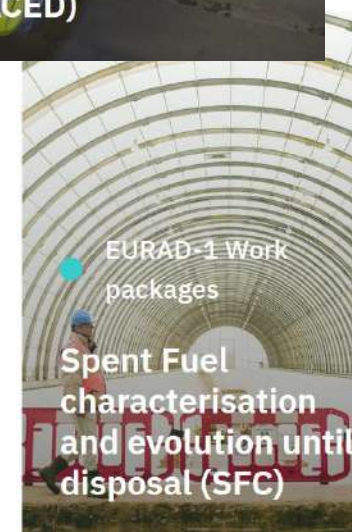
So let me get this straight, SCK CEN is the NEMESIS of ONDRAF?

Like · Reply



PREDIS eurad

European Joint Programme



Exchange Meeting

eurad

09:30	Welcome	Katrien Hendrix
09:40 – 10:00	Introduction to EURAD	Valéry Detilleux (BelV)
10:00 – 11:00	EURAD projects: 7-minute pitches	
	ROUTES	Chris De Bock (O/N)
	HITEC	Arnaud Dizier (EURIDICE)
	UMAN	Valéry Detilleux (BelV)
	SFC	Marc Verwerft (SCK CEN)
	MODATS	Guangjing Chen (SCK CEN)
	MAGIC	Suresh Seetharam (SCKCEN)
	DONUT	Diederik Jacques (SCK CEN)
11:00 – 11:30	<i>Coffee break</i>	

WiFi: Tabloo guest
Code: Tabloo2021

Exchange Meeting

eurad

13:40 – 14:30	<i>Lunch</i>	
14:30 – 14:50	Knowledge management	Niels Belmans (SCK CEN)
14:50 – 15:30	GAS	Séverine Levasseur (O/N)
15:30 – 16:10	ACED	Diederik Jacques (SCK CEN)
16:10 – 16:40	EURAD-2	Norbert Maes (SCK CEN)
16:40 – 16:50	Conclusions and outlook	Maarten Van Geet (SCK CEN)
	<i>Drink</i>	

WiFi: Tabloo guest
Code: Tabloo2021

EUROPEAN JOINT COLLABORATION TOWARDS SAFE RADIOACTIVE WASTE MANAGEMENT

Valéry Detilleux, Bel V

From a presentation prepared by ANDRA



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°847593

BACKGROUND – EUROPEAN RD&D

- Considerable knowledge in the field of radioactive waste management acquired over the past 40 years
- Collaborative RD&D projects supported by EC through EURATOM



BACKGROUND – EUROPEAN RD&D

- Considerable knowledge in the field of radioactive waste management acquired over the past 40 years
- Collaborative RD&D projects supported by EC through EURATOM
- Enhanced coordination supported by EC: IGD-TP platform and SITEX network



- Leap forward: EC Policy & Strategy for integration of EU Member-States R&D programmes
 - Replace EU competitive calls for projects by **inclusive European Joint Programmes** (EJP)
- In 2014, EC called for a feasibility study of creating such an EJP in RWM field: JOPRAD (2015-2017)
 - **identify the actors** with key responsibility for directing RD&D on safe RWM
 - engage them in the development of a **shared Vision** and a **shared Strategic Research Agenda**

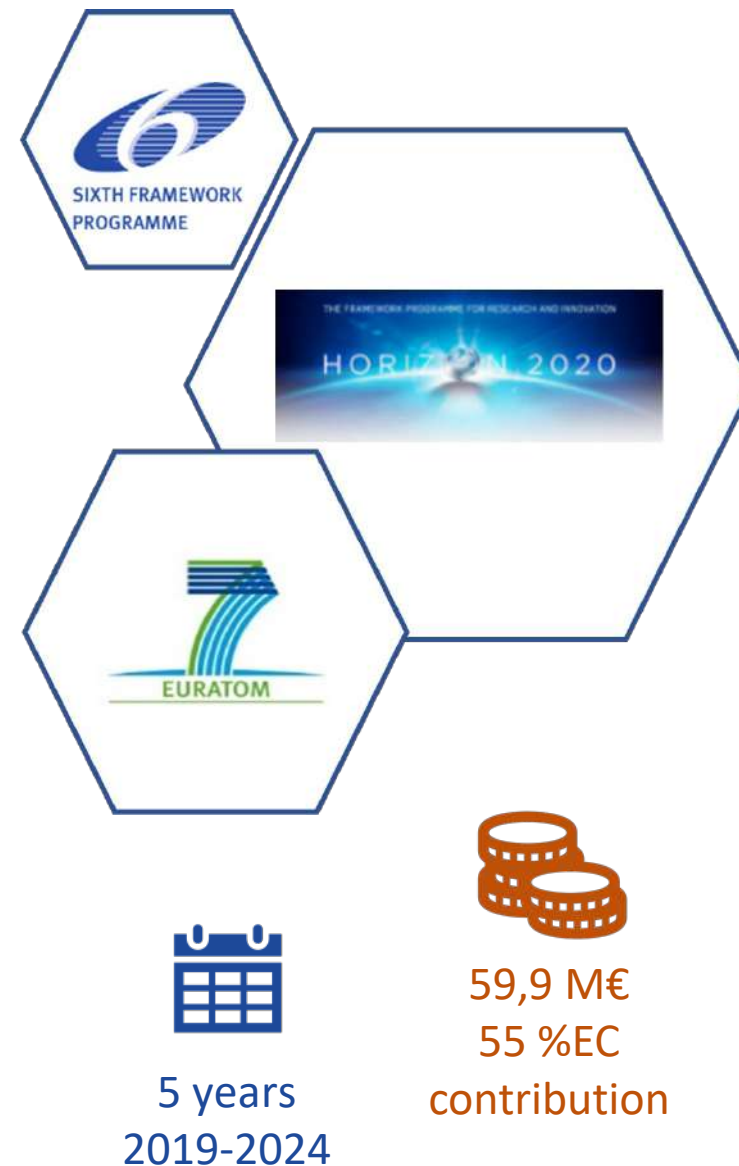
EURAD (2019-2024): A LEAP FORWARD

“A step change in European collaboration towards safe radioactive waste management (RWM), including disposal, through the development of a

- **robust and sustained science, technology and knowledge management programme that**
- **supports timely implementation of RWM activities and**
- **serves to foster mutual understanding and trust between participants.”**

Ambitions:

- **Complement the national Programmes**
- **Ensure the sustainability of the knowledge**
- **Act as a platform**



A COMMUNITY



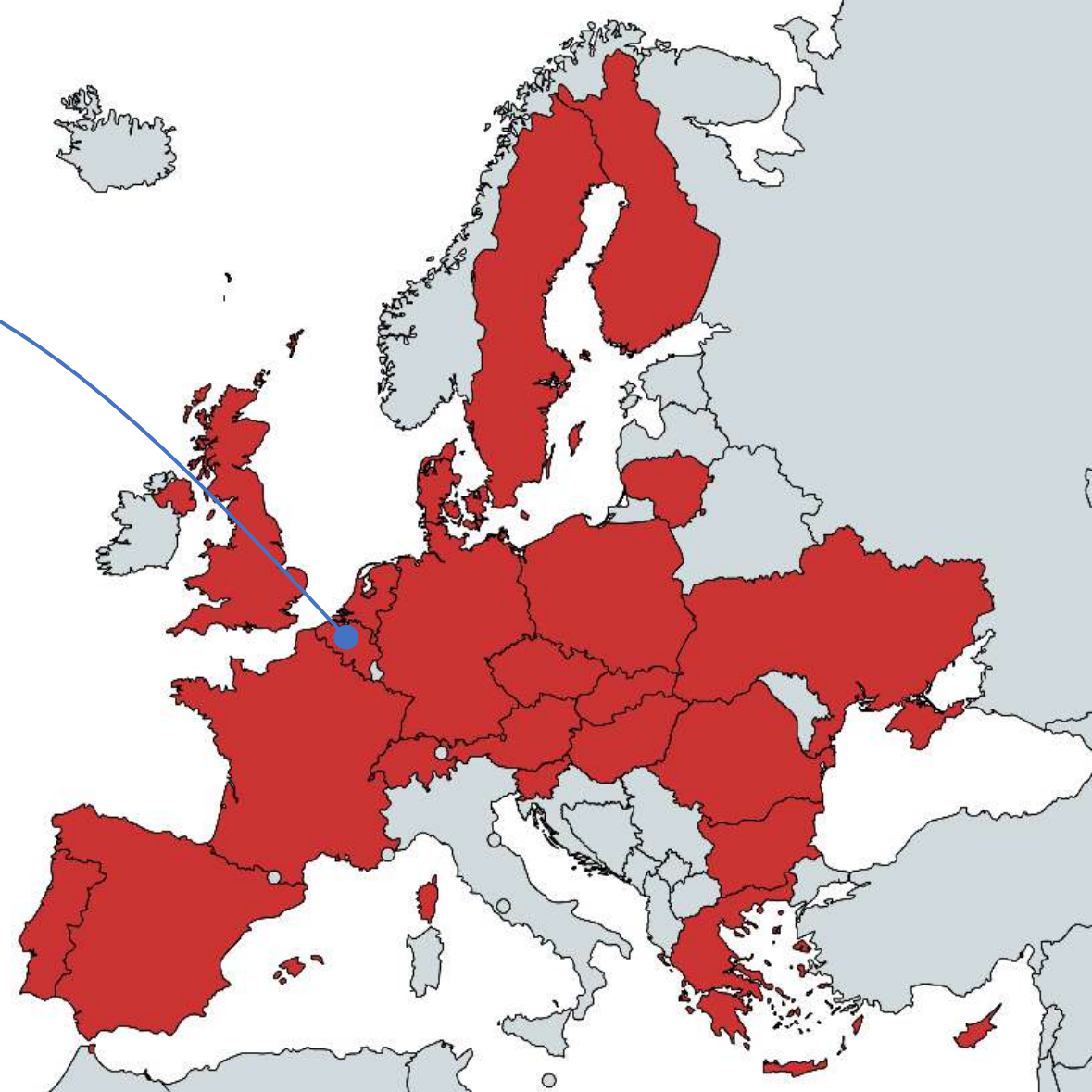
115
organisations

- 51 Mandated actors from 23 European countries representing the following Colleges :
 - Waste Management Organisation (WMO)
 - Technical Safety Organisation (TSO)
 - Research Entity (RE)
- 61 Linked Third Parties (mostly universities and research centres) and 3 International Partners (Canada, Australia and Japan)
- Groups of Civil Society organisations



BELGIAN ACTORS

- Mandated actors
 - ONDRAF/NIRAS (WMO)
 - Bel V (TSO)
 - SCK CEN (RE)
- Linked Third Parties (to ONDRAF/NIRAS)
 - Université de Liège
 - EURIDICE



GOVERNANCE

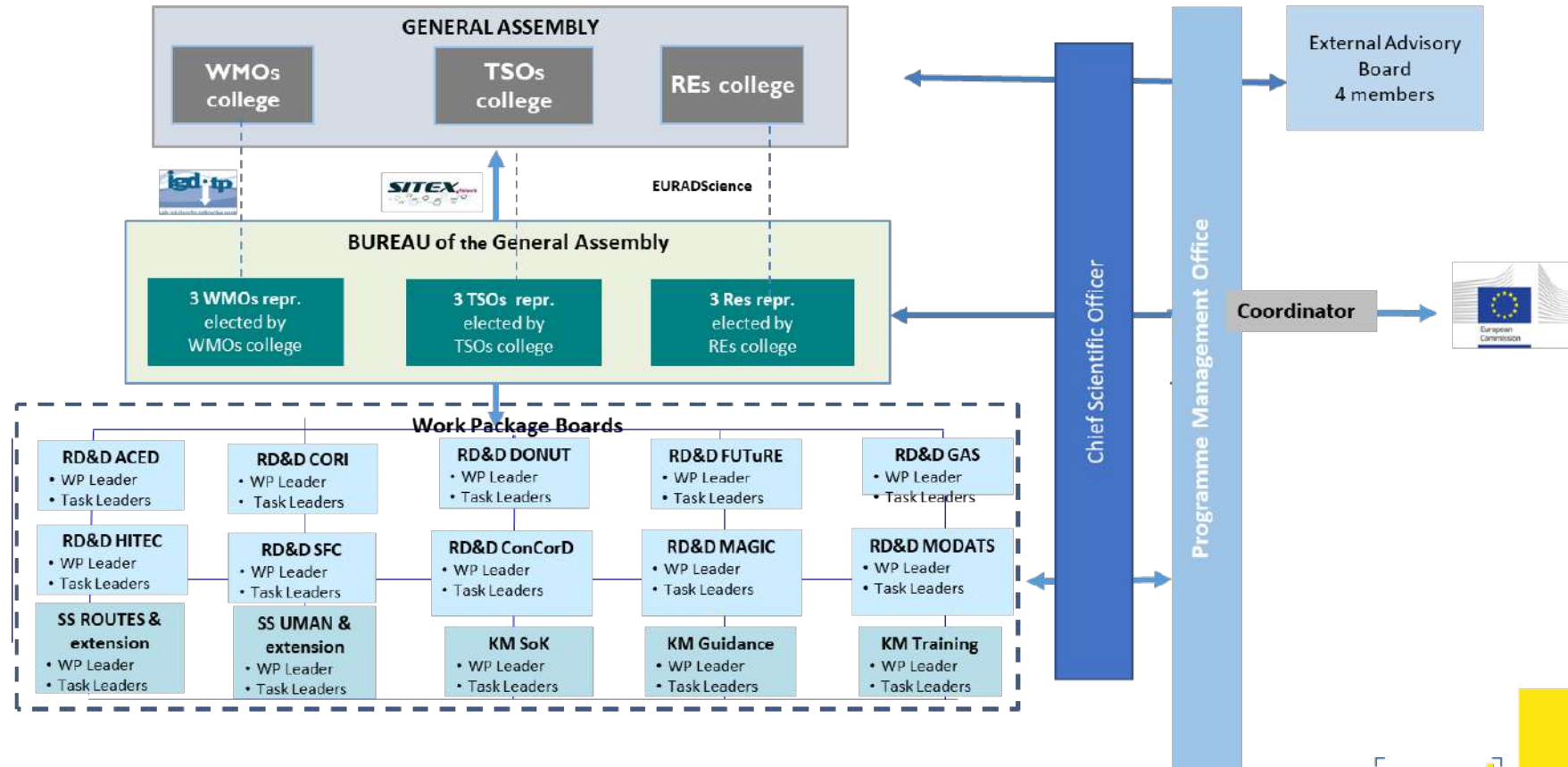
Governing principles:

- Positive participation
- Maintenance of independence
- Transparent governance
- Scientific excellence
- Balanced Programme
- Added value
- Inclusiveness
- Equitable Financing
- Complementary participation
- Tangible results

Bel V: Bureau member, WPL UMAN (interim)

SCK CEN: Bureau member, WPL ACED, WPL KM Training

ONDRAF/NIRAS: WPL Gas



DEPLOYMENT – EURAD WORKPACKAGES



17
work packages

- **Research and Development** (10 workpackages)
 - developing and consolidating scientific and technical knowledge
- **Strategic Studies** (2 workpackages)
 - enabling experts and specialists to network on methodological / strategical issues and advance significant challenges in direct link with scientific and technical issues
- **Knowledge Management** (3 workpackages)
 - developing State of Knowledge, developing descriptive methodological guidance and developing/delivering training modules and mobility measures
- **Coordination/Dissemination** (1 workpackage)

~82 % of the budget

SCIENCE & NETWORKING

- **Radioactive waste characterisation, processing and storage**
 - SFC- Spent Fuel Characterization and Evolution Until Disposal
 - ROUTES -Waste management routes in Europe from cradle to grave (with strong interface with PREDIS)
- **Engineered barrier system properties and long-term performance**
 - ACED -Assessment of Chemical Evolution of ILW and HLW Disposal cells
 - ConCorD - Container Corrosion under disposal conditions
 - MAGIC -Chemo-mechanical aging of cementitious materials
- **Geological disposal facility design and the practicalities of implementation**
 - MODATS - Monitoring equipment and data treatment for safe repository operation and staged closure
- **Geoscience to understand rock properties, radionuclide transport and long-term geological evolution**
 - FUTURE -Fundamental understanding of radionuclide retention
 - CORI -Cement-Organic-Radionuclide Interactions
 - GAS -Mechanistic understanding of gas transport in clay materials
 - HITEC - Influence of temperature on clay-based material behaviour
- **Performance assessment, safety case development and safety analyses**
 - DONUT -Development and improvement Of Numerical methods and Tools for modelling coupled processes
 - UMAN - Uncertainty Management multi-Actor Network

~7 % of the budget

KNOWLEDGE MANAGEMENT

1

Roadmap

What we want to achieve and how

2

State of Knowledge

What we know and why it is important

3

Guidance

How to achieve it

4

Mobility & Training

Transfer of experience and know-how

5

Networking & Tools

How to achieve it



INTERACTIONS WITH CIVIL SOCIETY (ICS)

- **Planned at the start of the programme**

- Involvement in the core group responsible for preparing EURAD
- Involvement through the Technical Safety Organisations (TSO) College
- Coordination of the activities within the PMO WP
 - Coordination, organisation, results integration
- Involvement in the two Strategic Studies
 - Waste Management routes in Europe from cradle to grave (ROUTES)
 - Understanding of uncertainty, risk and safety by different actor (UMAN)

- **Followed-up by new activities in the second wave**

- Involvement in one R&D WP
 - Monitoring equipment and Data Treatment for Safe repository operation and staged closure (MODATS)

A STEP CHANGE IN EUROPEAN COLLABORATION

- **Roadmap**
 - High-level guide for RWM activities
 - Draws on knowledge from advanced programmes, promoting knowledge across generations
- **Strategic Research Agenda**
 - Aligned with Roadmap
 - Central tool in addressing emerging challenges in RWM
 - Update introduced a set of drivers to define WPs, moving away from priority-based classifications
- **Effective and collaborative governance**
 - Foster interactions among Colleges
 - Effective representation of diverse points of view that enhanced credibility and results
- **Broad participation**
 - 23 European countries, over 110 organisations and international partners engaged
 - Cross-country collaboration: early-stage programmes accessed advanced knowledge, while advanced programmes shared critical insights
 - Interaction with Civil Society
 - Coordination with PREDIS project and international organisations to further strengthen synergies

KEY ACHIEVEMENTS

- **Scientific excellence**

Comprehensive integration across RWM lifecycle, including:

- Models and insights on nearfield evolution in deep geological repositories
- Significance of numerical models and tools, including DT and AI
- Key data on RN, cement and organics interactions
- Advanced mechanistic understanding of RN retention
- Developed methodologies and protocols for gas transport through clay materials



353 publications



191 deliverables

- **Trust and mutual understanding**

- Workshops with CS → public confidence and awareness
- Strategic Studies as think-tank activities that enabled comprehensive understanding of :
 - Key RWM issues for Small Inventory Member States
 - Uncertainty management, including CS involvement

- **Knowledge transfer**

- School of RWM promoting students
 - Over 150 trainings
 - 99 mobility actions fostering a skilled new generation
- Production of 3 guidance documents
- Production of 25 Domain Insights, 7 Theme Overviews and 2 State-of-Knowledge



EC FINAL REVIEW

Positive

- Clear governance
 - Coherent structure, less administrative workload for WP Leaders
- Colleges involvement
 - Shared vision, programme defined by actors not funding agency
- Roadmap and Strategic Research Agenda
 - 10 years vision, drivers implementation
- Dissemination
 - Annual events, cross fertilisation
 - Useful for member states
- Quality Assurance
 - Strict review process ensuring quality
- Creation of a community
 - Shared culture where people can debate

Recommendations

- End-users
 - Better definition needed
 - Involvement of regulators
- Executive Advisory Board role
 - Clarification of the terms of reference
- Civil society involvement
 - Open to wider community



THANK YOU FOR YOUR ATTENTION

Coordination : Andra (France)

For more information please contact :

secretariat@ejp-eurad.eu

Website : <https://www.ejp-eurad.eu/>



EURAD

@EJP_EURAD

EURAD UMAN WORK PACKAGE

Valéry Detilleux, Bel V



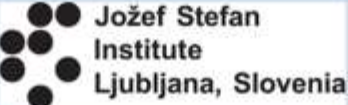
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°847593

UMAN: RATIONALE & OBJECTIVES



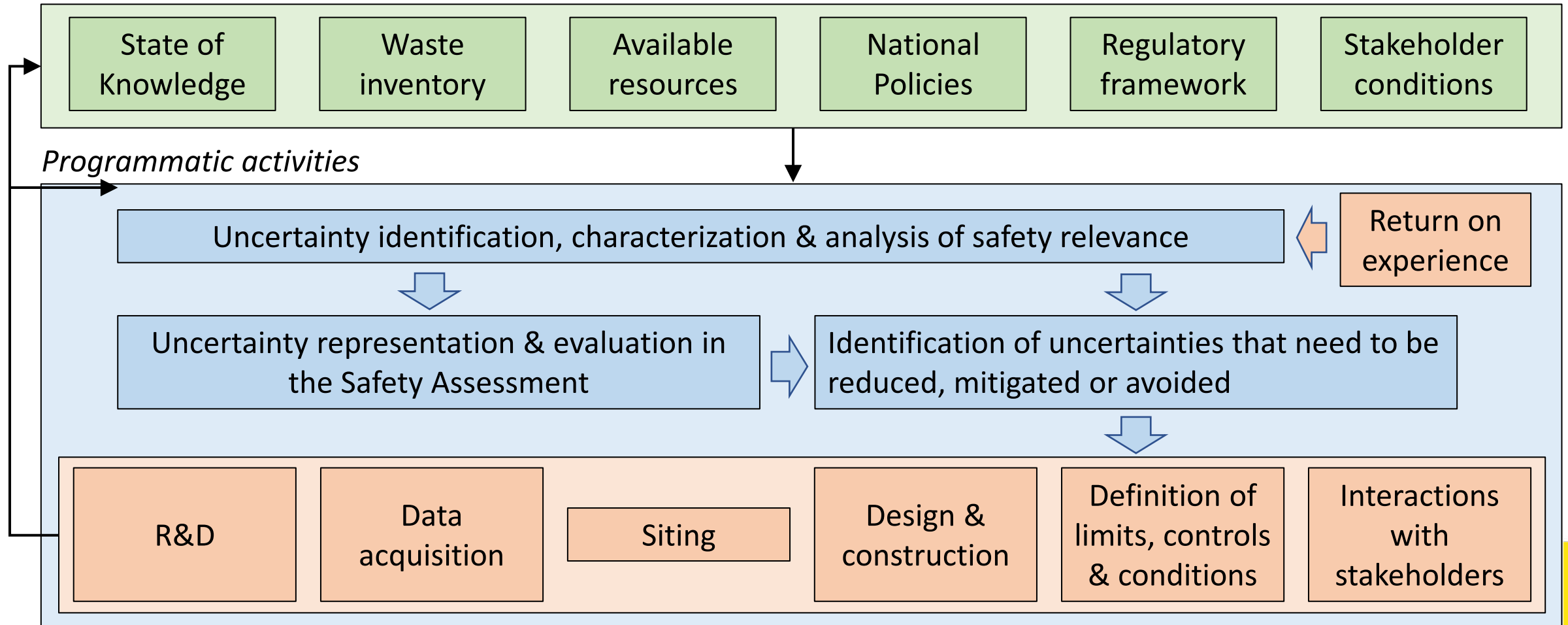
- **Decisions** associated with RWM programmes are made in the presence of **uncertainties**.
 - At the end of the process, uncertainties will inevitably remain and it should be demonstrated that these **uncertainties do not undermine safety arguments**.
 - Hence, the **management of uncertainties is a key element** of successful programme planning and of the safety case of waste management facilities (in particular disposal facilities).
-
- 
- Develop a **common understanding** among different categories of actors (WMOs, TSOs, REs & Civil Society) **on uncertainty management** and how it relates to risk & safety.
 - **Share knowledge/know-how** and discuss common methodological/strategical **challenging issues**.
 - Identify the **contribution of** past & on-going **R&D projects** to the overall management of uncertainties.
 - Identify **remaining and emerging issues and needs**.

UMAN: PARTICIPANTS

Belgium	  	Netherlands	 
Bulgaria		Romania	
Czech Republic	 	Slovakia	
Finland	 	Slovenia	 
France	    	Spain	 
Germany	    	Switzerland	 
Hungary		UK	 
Lithuania	 	Ukraine	

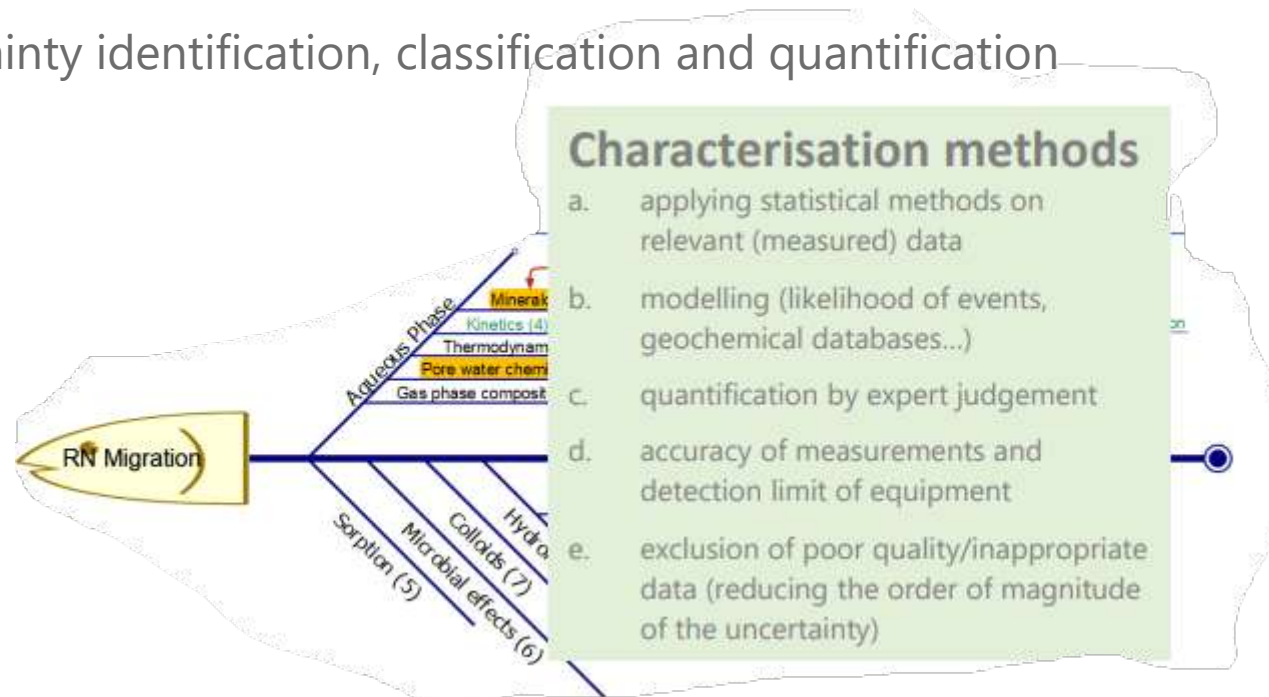
RESULTS: ELEMENTS OF UNCERTAINTY MANAGEMENT

Prevailing circumstances



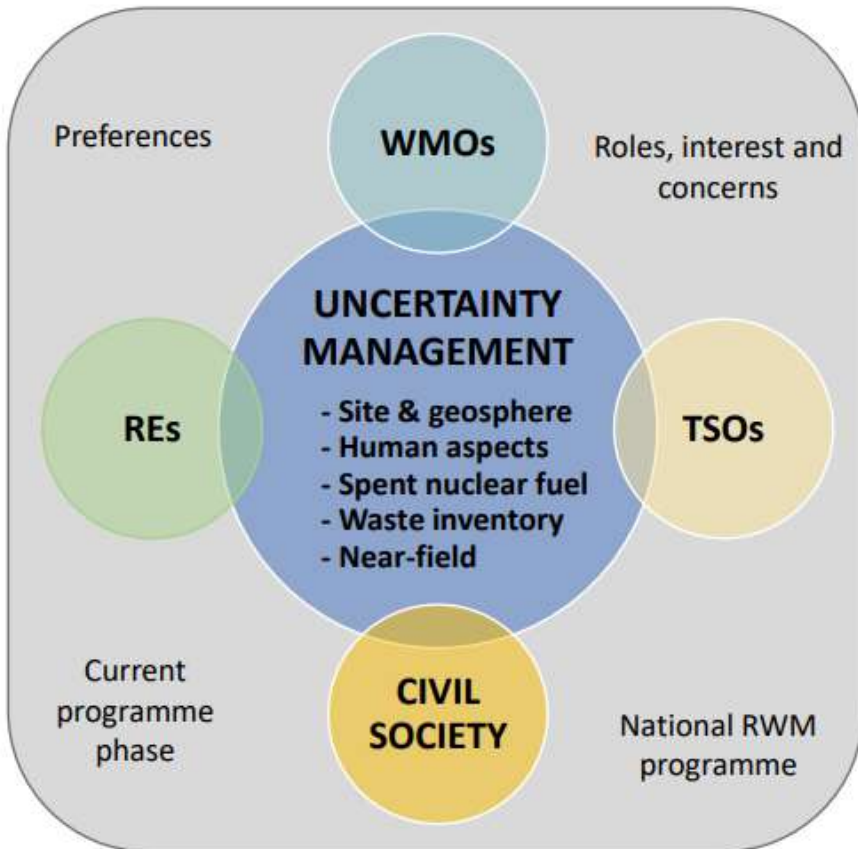
RESULTS: UNCERTAINTY IDENTIFICATION, CLASSIFICATION, QUANTIFICATION & ANALYSIS

- **D10.3** Uncertainty identification, classification and quantification



- **D10.4** Methodological approaches to uncertainty and sensitivity analysis

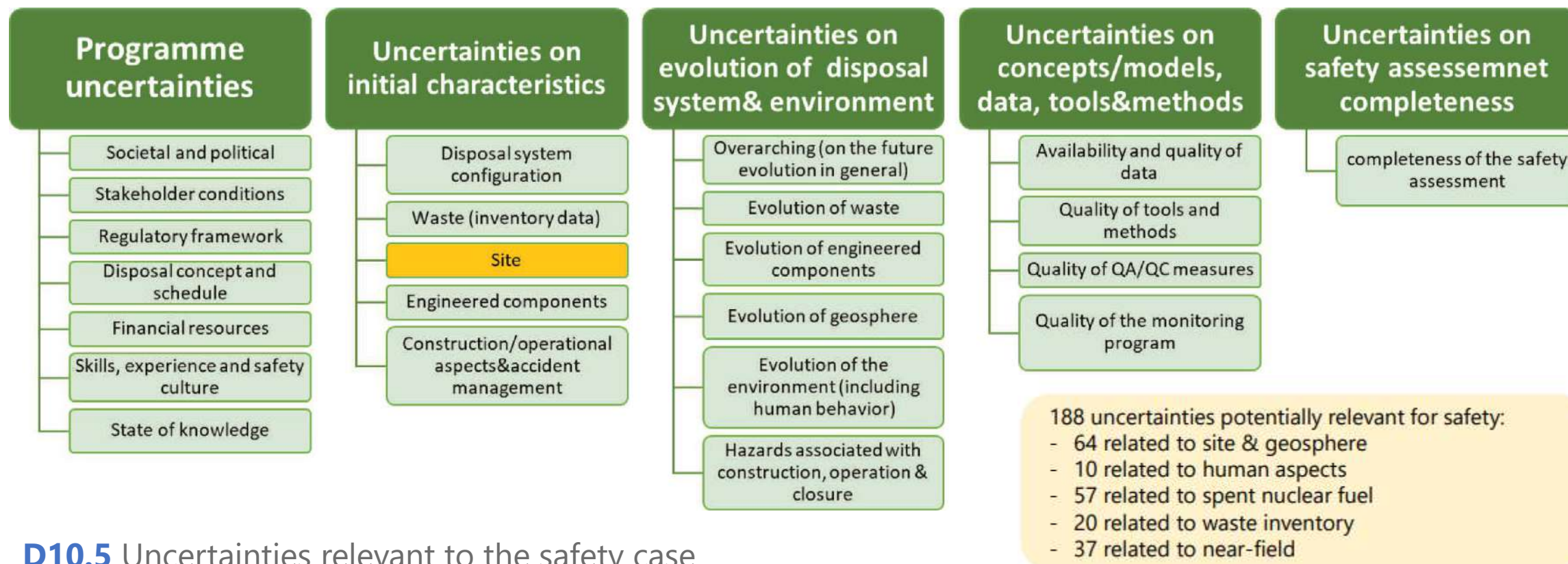
RESULTS: VIEW OF ACTORS ON IDENTIFICATION, CHARACTERISATION & POTENTIAL SAFETY SIGNIFICANCE OF UNCERTAINTIES



- **D10.6** Uncertainties related to waste inventory
- **D10.7** Uncertainties related to site and geosphere
- **D10.8** Uncertainties related to human aspects
- **D10.9** Uncertainties related to spent fuel
- **D10.18** Uncertainties related to near-field
- **D10.10** Analysis and description of groups of different actors

RESULTS: GLOBAL PICTURE OF UNCERTAINTIES (LEVELS 1 & 2)

- 5 types of uncertainties are considered (level 1)
- Each type of uncertainty is divided in topical groups of uncertainties (level 2).



D10.5 Uncertainties relevant to the safety case

D10.11 Study on management options for different types of uncertainties and programme phases

RESULTS: GLOBAL PICTURE OF UNCERTAINTIES (LEVELS 1 & 2)

		5. Uncertainties associated with FEP completeness		
<i>Knowledge is available</i>	<i>Lack of knowledge</i>	Known unknowns	Unknown/Ignored Knowns	Unknown Unknowns
Known Knowns <i>What is known & used</i>	Known Unknowns <i>What we know we don't know</i>	1. Programme uncertainties		
		2. Uncertainties associated with initial characteristics		
Unknown/Ignored Knowns <i>What is known but we are not aware of or do not consider</i>	Unknown Unknowns <i>What we don't know we don't know</i>	3. Uncertainties in the evolution of the disposal system & its environment		
		4. Uncertainties associated with data, tools & methods used in the safety case		

D10.5 Uncertainties relevant to the safety case

D10.11 Study on management options for different types of uncertainties and programme phases

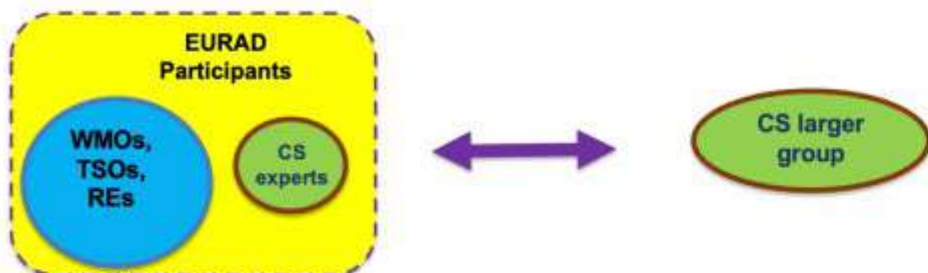
RESULTS: VIEW OF ACTORS ON MANAGEMENT OPTIONS FOR SELECTED UNCERTAINTIES

Waste Inventory	Spent nuclear fuel	Near-field	Site & geosphere	Human aspects
3 topical uncertainties: – Physico-chemical conditions in storage or disposal facility – Radionuclide activity (including scaling factor) – Chemical composition (focus: organic content)	3 topical uncertainties: – Fuel history data, reactor operation and irradiation conditions – Nuclear data – Performance of spent nuclear fuel during (dry) interim storage	3 topical uncertainties: – Hydraulic properties of bentonite – Metallic material behaviour in different barriers – Modelling of radionuclide transport	5 topical uncertainties: – Hydraulic conductivity – Sorption capacity... – Homogeneity... – Faults locations, detection and reactivation – Climatic evolution (focus: glaciations and permafrost)	4 topical uncertainties: – Public acceptance – Schedule for programme implementation – Adequacy of safety-related activities during construction – “New” knowledge

D10.12 & **D10.19** Identification, analysis and description of preferences of different actors on uncertainty management options

RESULTS: EXCHANGES WITH A LARGE GROUP OF STAKEHOLDERS

- **Double wing Model:** generic model of involvement in EURAD – two levels of involvement for civil society's members



1 → CS experts – direct involvement in UMAN work → review of results, prepared and facilitated the seminar together with the UMAN researchers

2 → CS larger group - collection of their views during ICS workshops (including UMAN session) to complete CS experts work, participation to UMAN seminars

Tools:

- **Discussions based on concrete cases**
 - a way to illustrate the issues linked to the uncertainties under discussion, enabling all actors to enter the discussion on the same footing
- **PEP tool –Pathway Evaluation Process**
 - tool of dialogue (designed as a serious game), enabling multi-actors' discussions in RWM

RESULTS: EXCHANGES WITH A LARGE GROUP OF STAKEHOLDERS

- **D10.13** Understanding of uncertainty management by the various stakeholders
- **D10.14** Pluralistic analysis of site and geosphere uncertainty
- **D10.15** Pluralistic analysis of uncertainty management related to human aspects
- **D10.16** How to manage uncertainties in a pluralistic way and in a long-term perspective
- **D10.17** Synthesis report of WP UMAN outcomes from a civil society point of view
- **D10.20** Application of the methods for a pluralistic assessment of uncertainties and their management to near-field uncertainties

RELEVANT INPUT FOR OUR BELGIAN PROGRAMME ?

- **UMAN: a framework for managing and exchanging about uncertainty management**
 - Could help Belgian actors to interact together about uncertainty management
 - Could support preparing and reviewing safety cases and safety evaluations
 - Could support the management of our R&D programmes
- **UMAN: a mine of information (literature, possible management options...) about specific uncertainties, in particular about:**
 - Near-field
 - Spent-fuel
 - Site and geosphere
 - Waste inventory
 - Human aspects
- **Uncertainty management: a « tool » to further interact with the Civil Society in Belgium ?**

DONUT

*Development and improvement of
NUmerical methods and **T**ools for
modelling coupled processes*

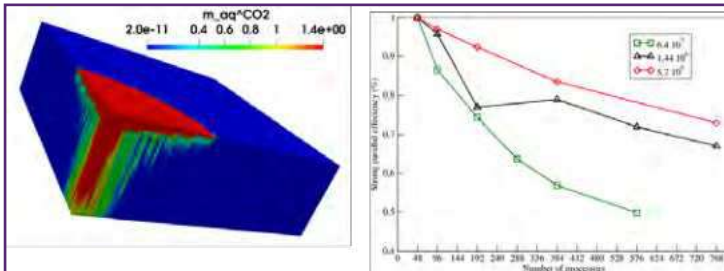
Eric Laloy & Diederik Jacques

Exchange meeting EURAD 25/10/2024

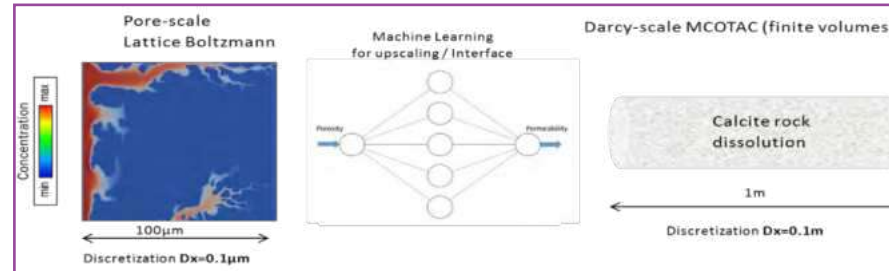


DONUT AT A GLANCE

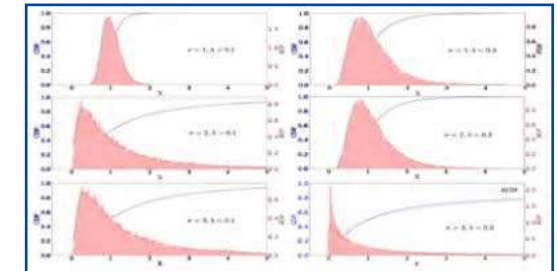
Task 1 Management (Leader F. Claret & G. Pepin)



Task 2 Numerical methods for high performance computing of coupled processes (Leader C. Cances)



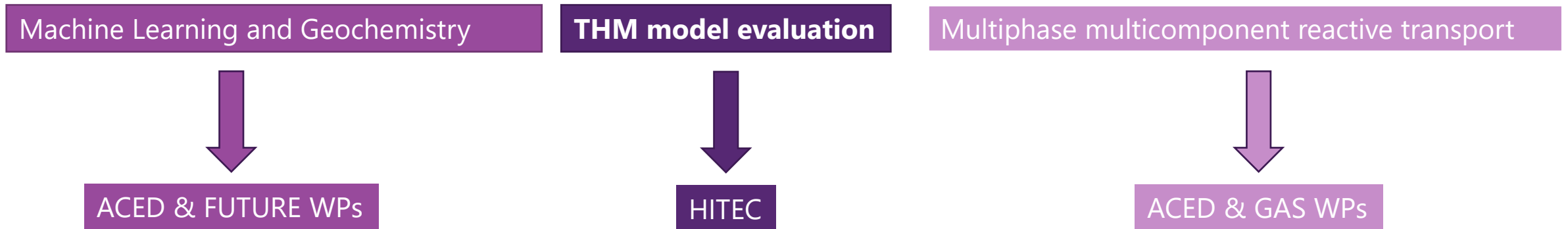
Task 3 Scale transition schemes for coupled processes (Leader O. Kolditz & N. Prasianakis)



Task 4 Tools and methods to quantify/derive uncertainties induce by coupled processes (Leader A. Baksay)

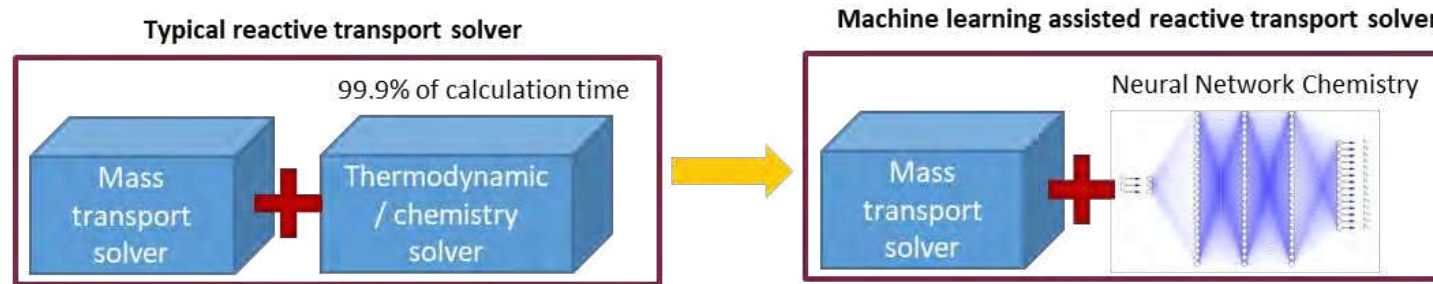
Task 5 Benchmarks of methods and tools for coupled processes (Leader D. Lukin)

Benchmarks of methods and tools for coupled processes



Machine learning & geochemistry

- RW disposal studies rely on reactive transport (RT) modelling to simulate, e.g.,
 - Cement and concrete degradation phenomena
 - The fate of radionuclides from drum matrix to the environment



- RT models can be computationally demanding
 - Transport component ~ 5-25% of CPU time
 - Geochemical component ~ 75 – 95% of CPU time
- RT model acceleration by replacing the geochemical solver by a trained ML regression algorithm → speedup of 4 to 20



GEOCHEMISTRY AND MACHINE LEARNING BENCHMARK WITHIN EURAD JOINT PROJECT



Participating teams

N.I. Prasianakis¹, E. Laloy², D. Jacques², J.C.L. Meeussen³, C. Tournassat⁴, G.D. Miron¹, D. A. Kulik¹, A. Idiat⁵, E. Demirer⁵, E. Coene⁵, B. Cochepin⁶, M. Leconte⁶, M. Savino^{6,7}, J. Samper II⁸, M. De Lucia⁹, C. Yang¹⁰, P. Sochala¹¹, S. V. Churakov^{1,12}, J. Samper⁸, O. Kolditz¹³, F. Claret¹⁴

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¹⁰Environmental Data Techniques, Inc, 4515 Gardendale, BLDG 902, San Antonio, TX 78240, USA

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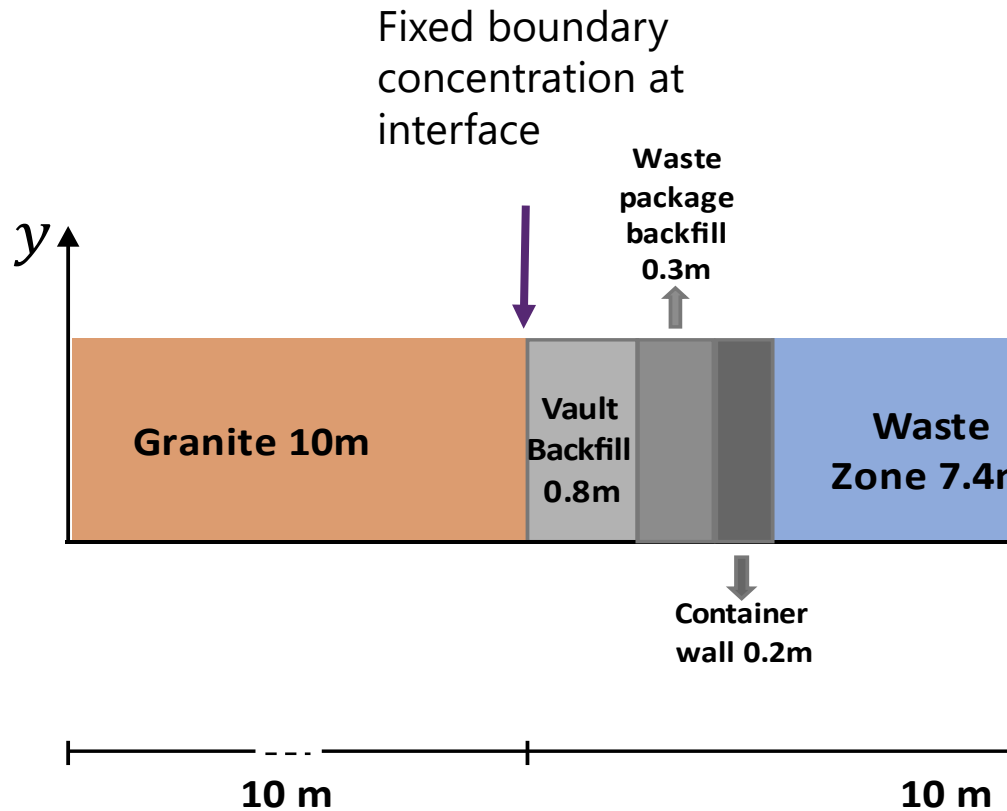
¹³Department of Environmental Informatics, Helmholtz Centre for Environmental Research, UFZ, Leipzig, Germany

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Contact: N. Prasianakis, nikolaos.prasianakis@psi.ch

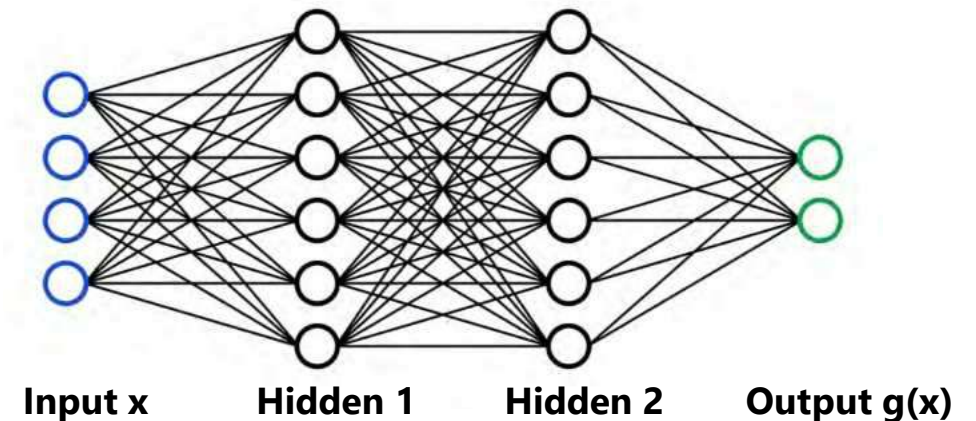


Application

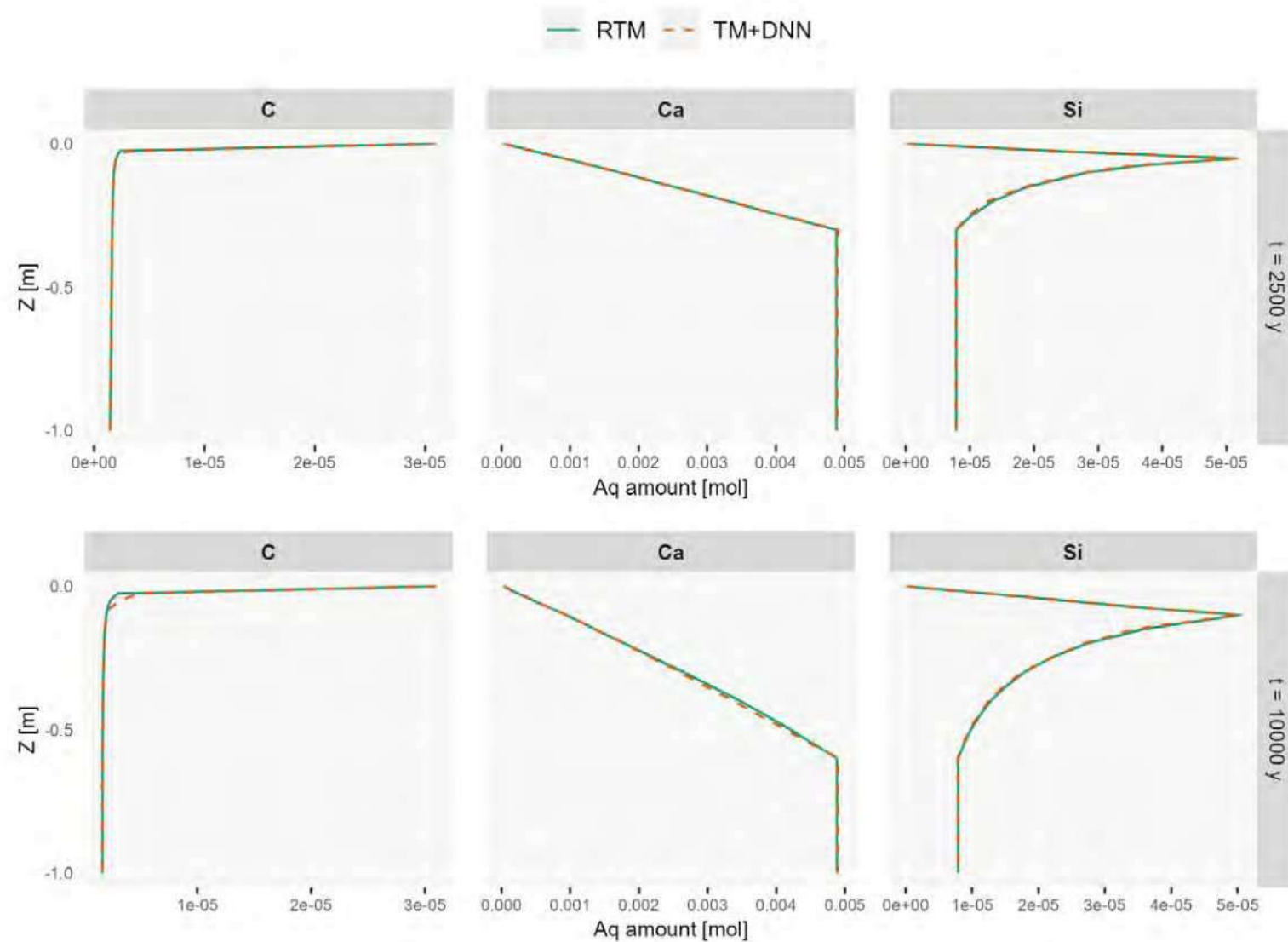


Simple cement: C, Ca, Si, O, H

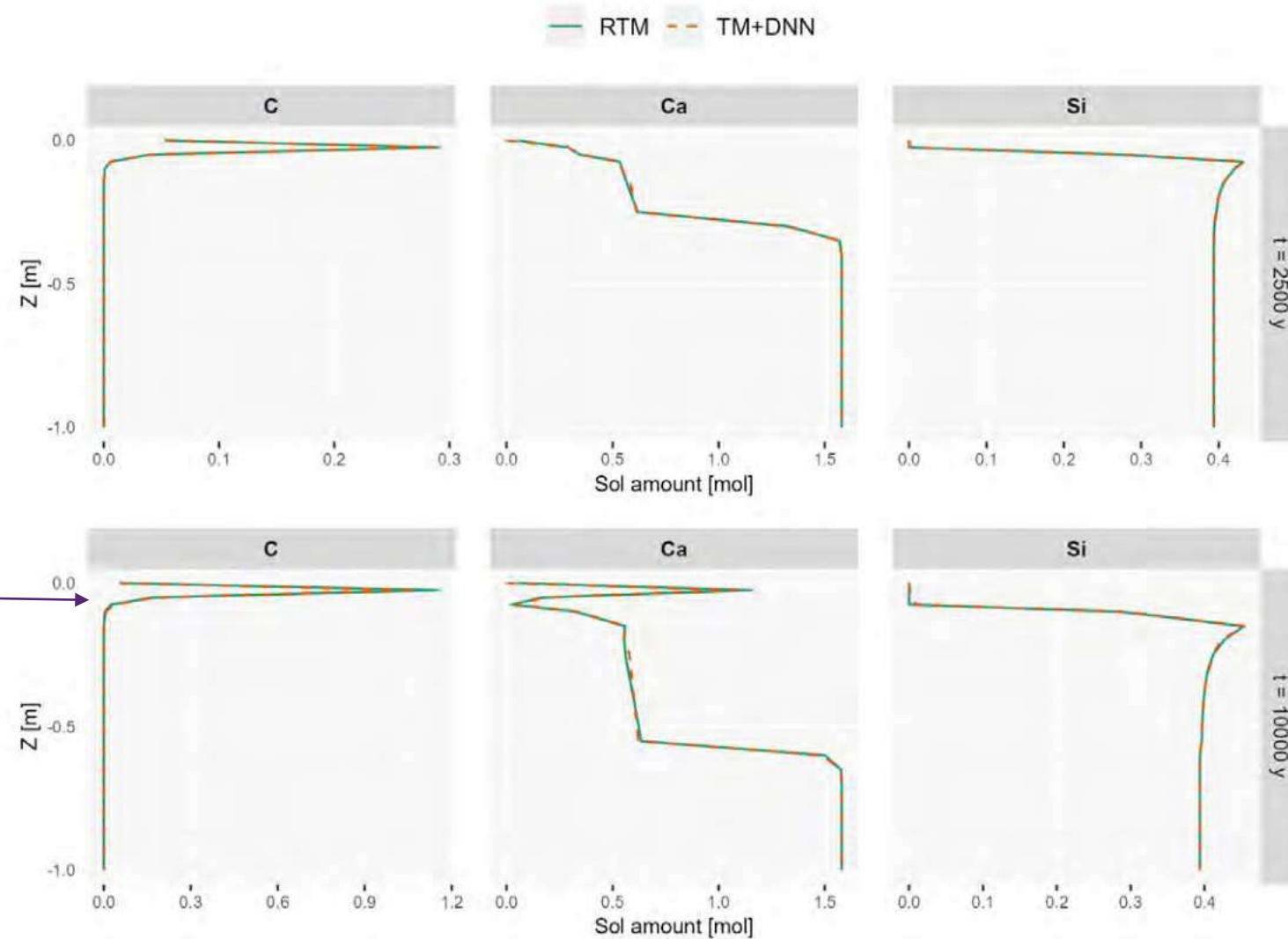
- Portlandite, C-S-H
- Boundary solution is in equilibrium with Calcite
- Triggers leaching + calcite precipitation



DNN, Case Pc (15) – Aqueous amount profiles at 2 times



DNN, Case Pc (15) – Solid amount profiles at 2 times



Conclusion

- Good accuracy and speedup of 5.5 (22) against HPx4C (HPx1C)
 - Close to “optimal” speedup ~ 85-90%
- Problem with more complex cement case (C-Ca-Si-Al-Cl-K-Na-Mg-S-O-H)
 - Limiting case for black-box DNNs?
- Follow-up in EURAD2 HERMES WP
 - Improve NN training set creation
 - Add physical constraints to NN training → physics-informed NNs (PINNs)
 - Accept/reject mechanism of ML predictions within the RT simulation
 - Apply to pore-scale RT simulation where geochemistry can take 99% of the CPU time

WP 7 : HITEC – INFLUENCE OF TEMPERATURE ON CLAY-BASED MATERIAL BEHAVIOUR

October 25, 2024 • Arnaud Dizier, Suresh Seetharam, Séverine Levasseur, Frédéric Collin, Hangbiao Song + HITEC Team (M. Olin, C. de Lesquen, M.V. Villar...)



The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 847593.

WP 7 : HITEC - Influence of Temperature on Clay-based Material Behaviour

Belgian contributors:

Arnaud Dizier (EURIDICE/ SCK CEN)

Suresh Seetharam (EGA/ SCK CEN)

Séverine Levasseur (ONDRAF/ NIRAS)

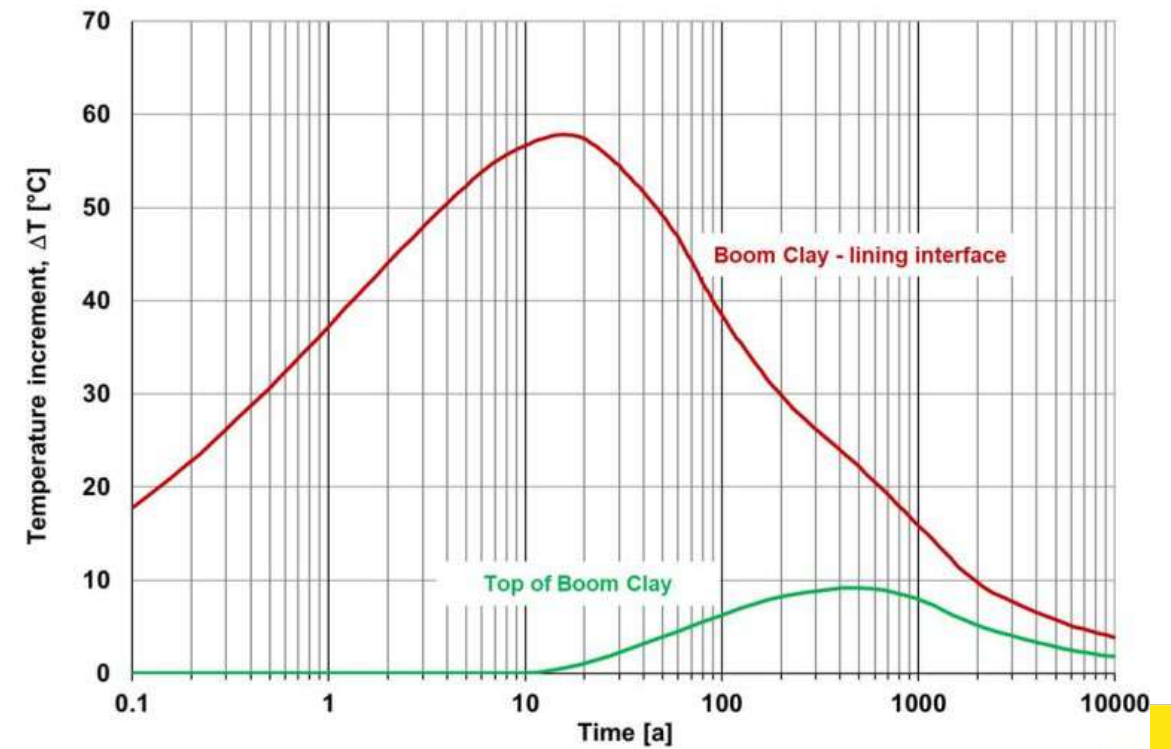
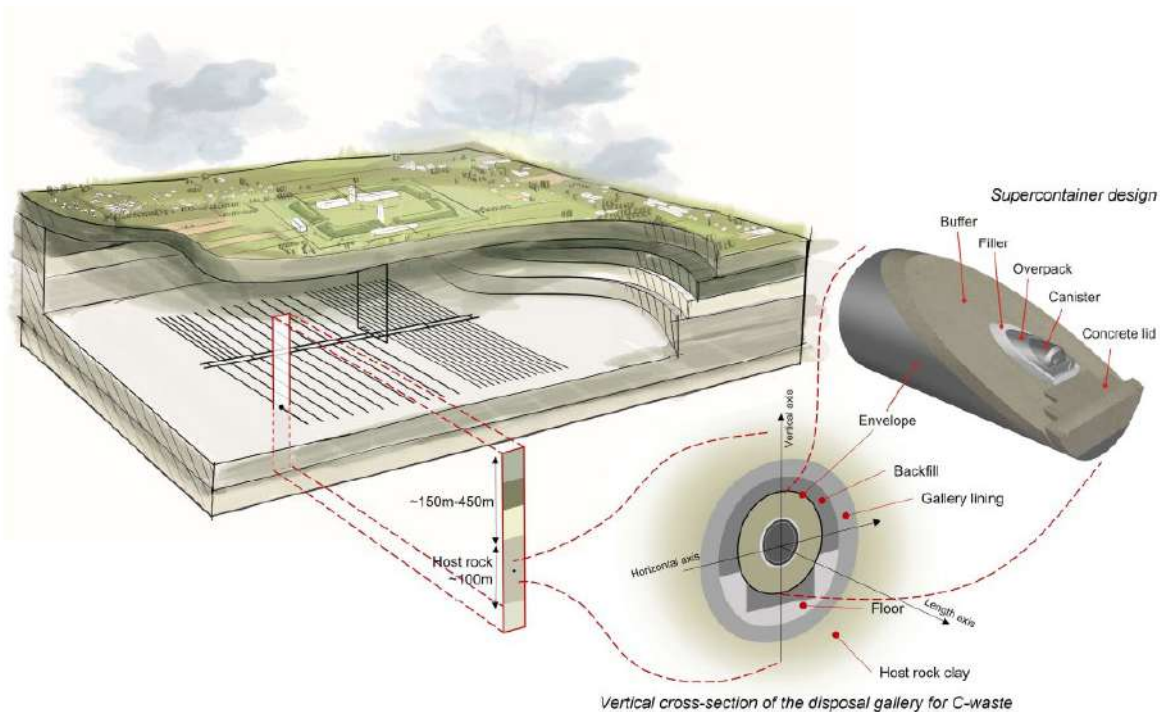
Frédéric Collin (ULiège)

Hangbiao Song (ULiège)



WP 7 : HITEC - Influence of Temperature on Clay-based Material Behaviour

Temperature variation around disposal galleries?



WP 7 : HITEC - Influence of Temperature on Clay-based Material Behaviour

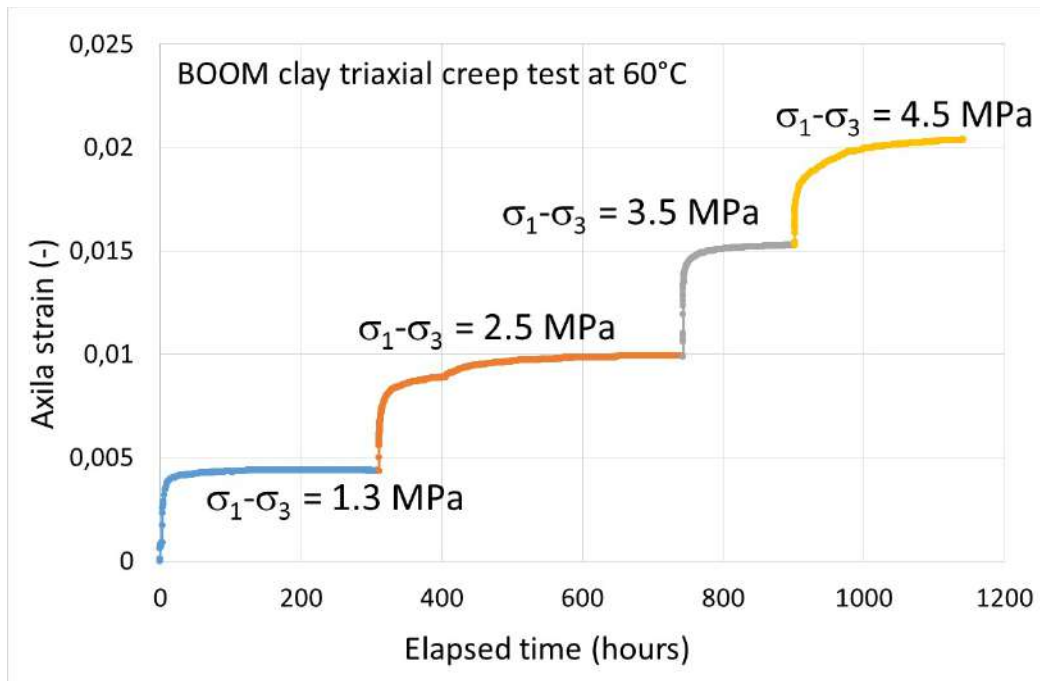
What are the consequences of the disposal of the category C waste (heat emitting waste) on the favourable properties of the host clay/ claystone formation?

- Current knowledge – state of the art ? (Task 1)
- Effects of the temperature (<120°C) on the permeability, self-sealing and mechanical properties at laboratory scale ? Can we model it? (Task 2)
- Characterisation of the buffer materials, determination of parameters, small scale experiments and modelling (Task 3)
- Impacts and deployment of results – guidance for safety case development – repository optimisation (Task 4)

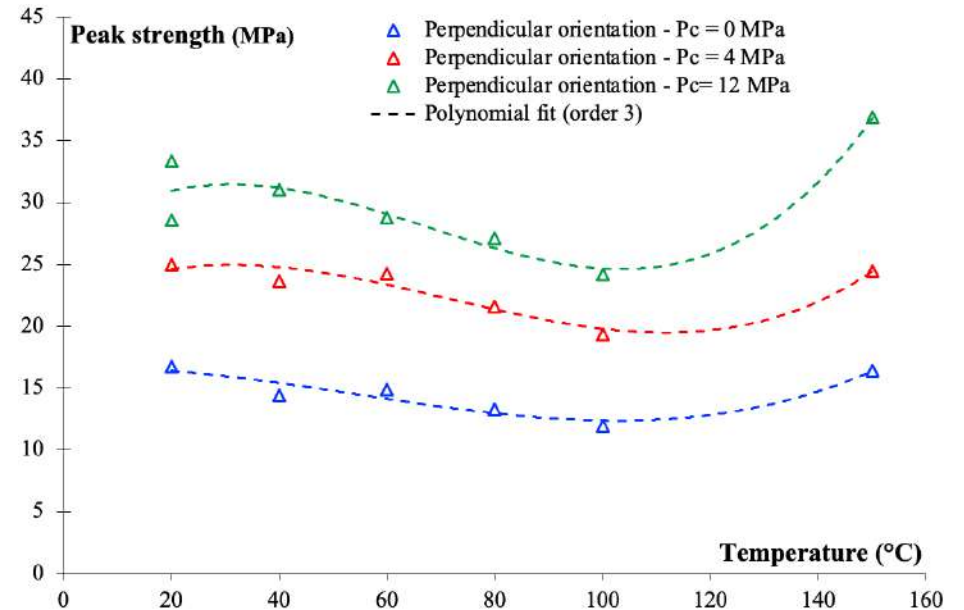
WP 7 : HITEC - Influence of Temperature on Clay-based Material Behaviour

Temperature effect on clay/ claystone at laboratory scale ?

Creep test on Boom Clay samples at 60°C (CEA)



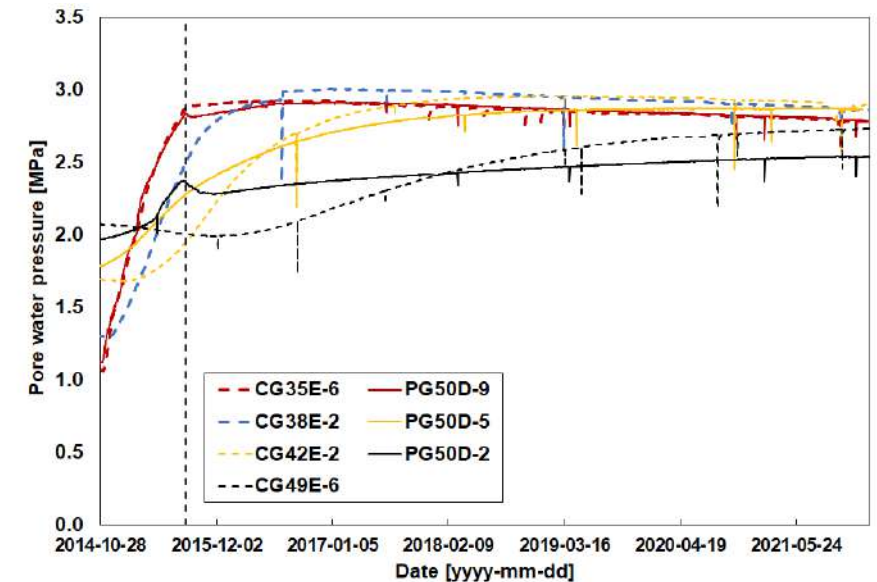
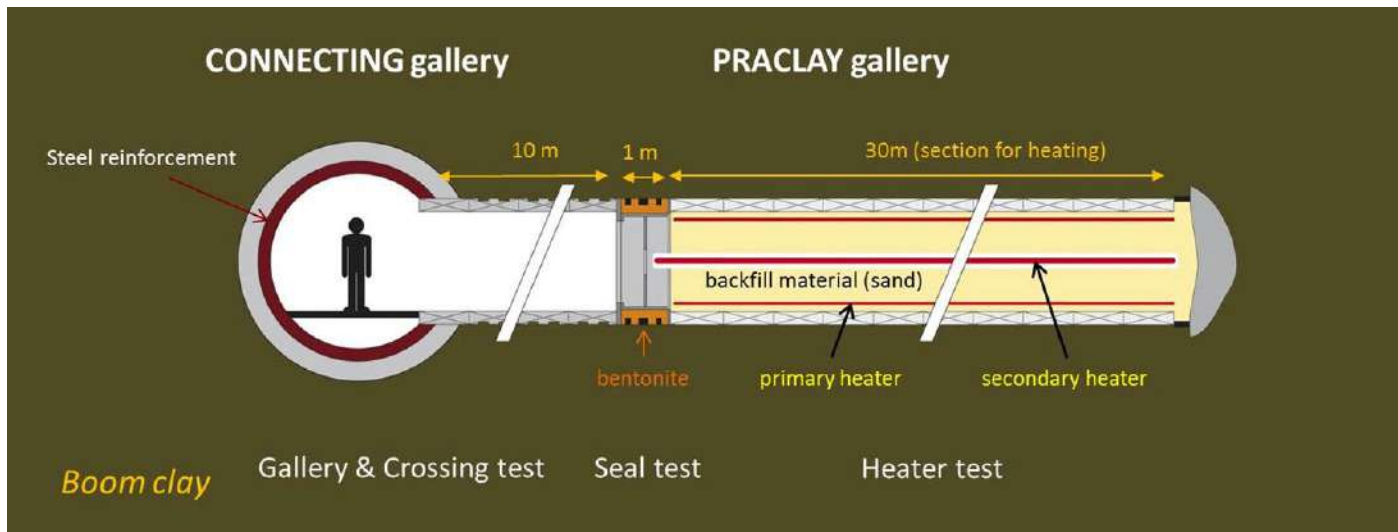
Variation of peak strength with temperature (COX, ULorraine)



WP 7 : HITEC - Influence of Temperature on Clay-based Material Behaviour

Temperature effect on Boom Clay at large scale (PRACLAY) ?

➔ Benchmark exercise with 4 teams (EURIDICE/ EGA (SCK CEN), ULiège, UPC, BGE)

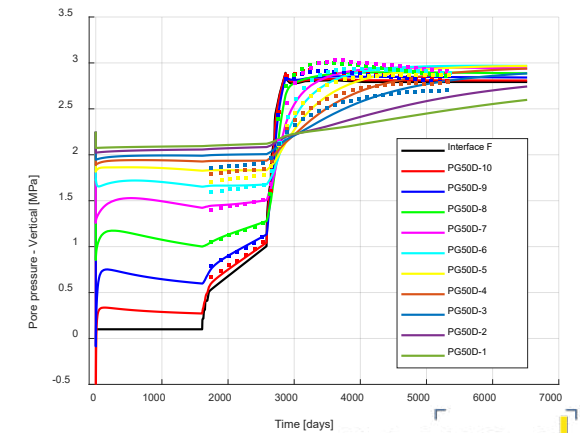
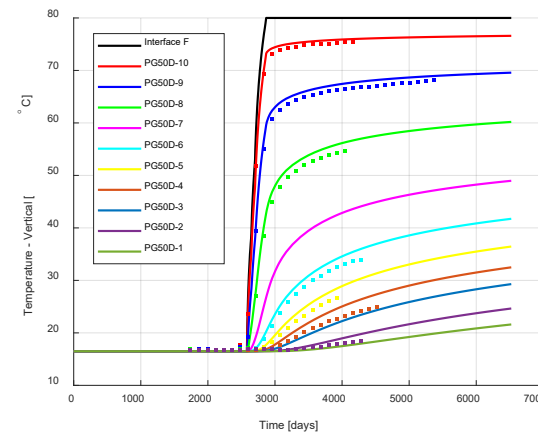
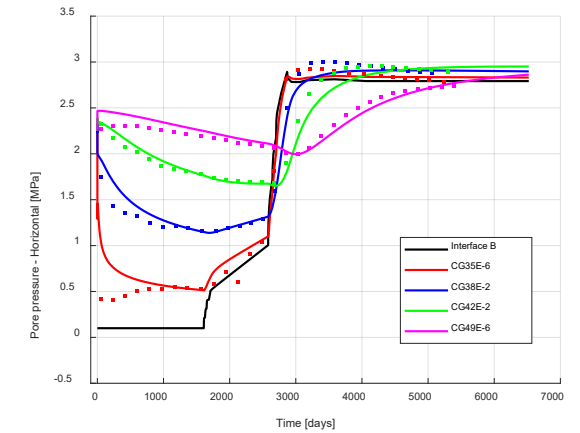
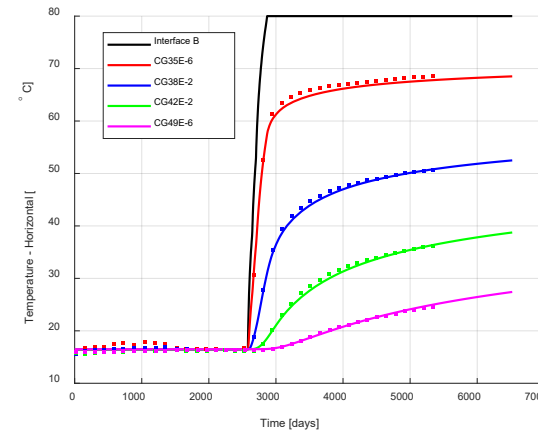
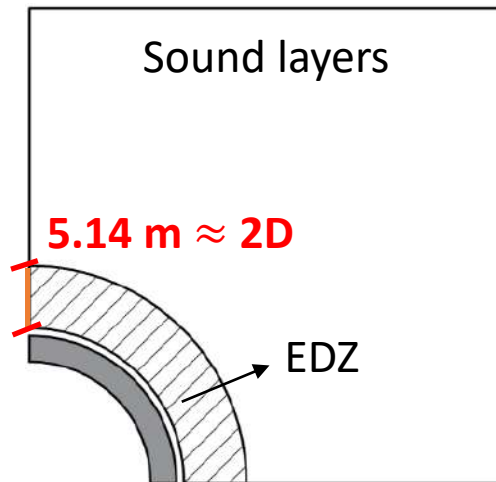


WP 7 : HITEC - Influence of Temperature on Clay-based Material Behaviour

Evolution of temperature and pore pressure

ULiège – new elements to model the experiment

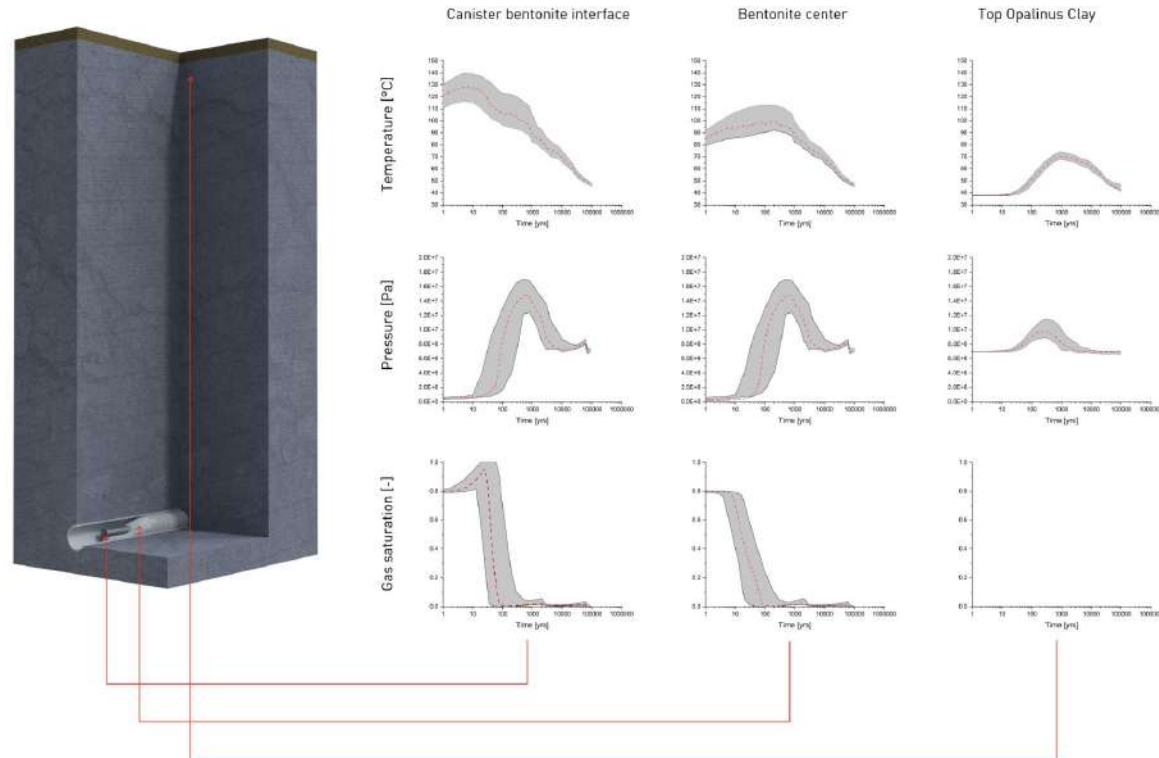
- Artificial creation of an EDZ
- Mechanical anisotropy (elasticity and plasticity)
- Small-strain stiffness behaviour
- Permeability – function of strain



WP 7 : HITEC - Influence of Temperature on Clay-based Material Behaviour

Task 4. Guidance for Safety Case Development with focus on **safety assessment and optimization**

- ➔ improve comprehensive understanding of the evolution of safety-related properties
- ➔ reduction of the unnecessary conservatisms
- ➔ optimizations for various aspects of the repository, from individual components to the layout of the entire facility





WP 7 : HITEC - Influence of Temperature on Clay-based Material Behaviour

Conclusions:

Task 1. Improvement of the state of the art on temperature effect on clay/ claystone materials

Task 2. Modelling benchmark of the large scale in situ heater test PRACLAY in HADES

➔ confirm and strengthen confidence in our understanding of the THM behaviour of the Boom Clay

Task 4. Reduction of uncertainties ➔ optimisation

HITEC DELIVERABLES (UP TO D7.10)

Del.#	Task #	Description	Key objectives
D7.1	1	Initial SoTA on THM behaviour of (i) buffer clay materials and of (ii) host clay materials	Present state-of-the-art and compile existing data
D7.2	1	Updated SoTA on THM behaviour of (i) buffer clay materials and of (ii) host clay materials	Update SoTA with HITEC results
D7.3	2	Technical report on thermal effects on nearfield properties	THM behaviour of clay host rocks at temperatures up to 120 degC; focus on self-sealing
D7.4	2	Specific GAS/HITEC technical report on self-sealing processes	Collaborative actions between HITEC and GAS to address self-sealing materials (successively) exposed to heat and gas
D7.5	2	Technical report on effect of temperature on far field properties	THM behaviour of clay host rocks due to thermal expansion; focus on thermally induced effects (damage/creep)
D7.6	2	Modelling report on effect of temperature on nearfield properties	THM modelling: improve understanding and models
D7.7	3	Technical report on material characterisation	Assess impact from prolonged temperature exposure, input for THM models
D7.8	3	Influence of high temperature on clay-based material behaviour	Bentonite HM properties at high temperatures, input for THM models
D7.9	3	Small- and mid-scale laboratory experiments	Buffer hydration under thermal gradients
D7.10	3	HITEC modelling	Buffer THM modelling

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European Underground Research Infrastructure for Disposal of Nuclear Waste in Clay Environment

Boeretang 200 – BE-2400 MOL





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Belgian Nuclear Research Centre

Mechanical properties of degraded concrete: micro-macro modelling

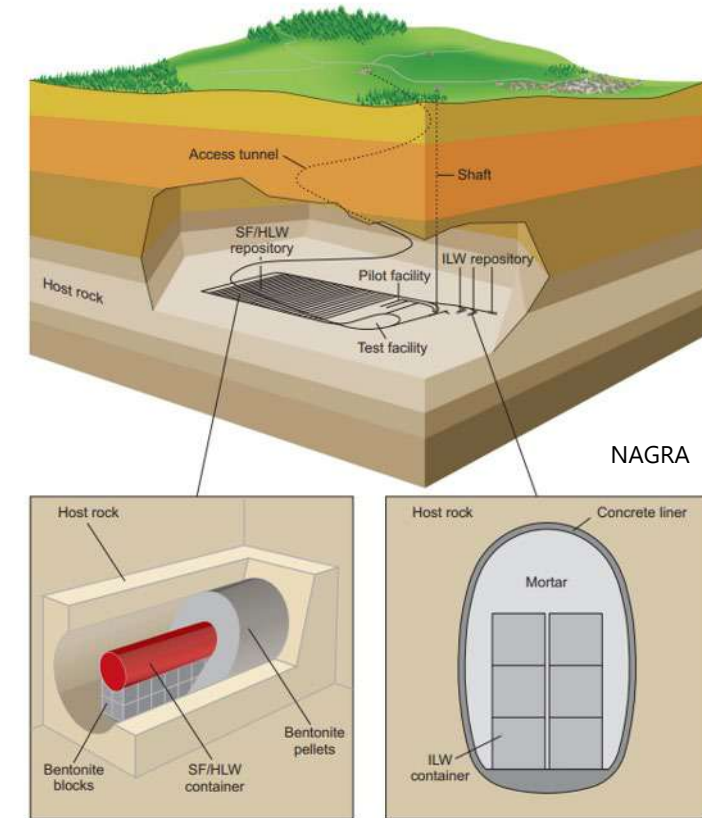
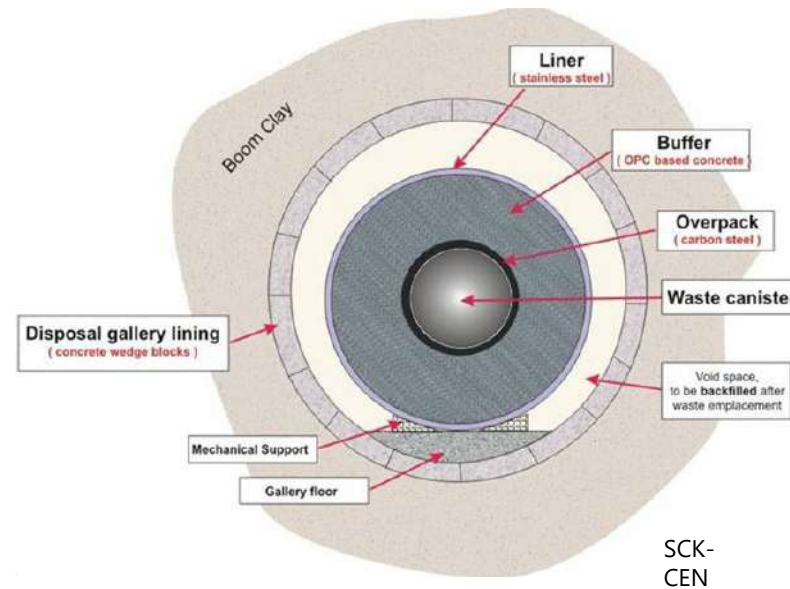
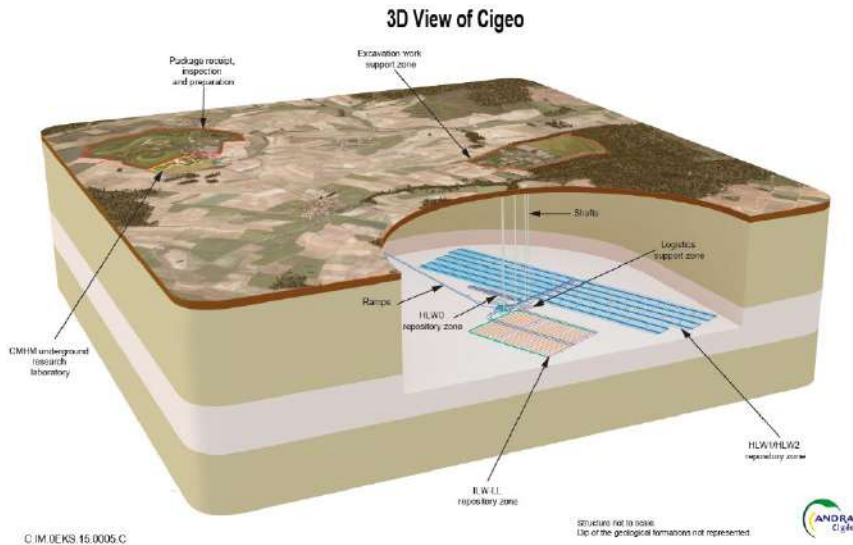
EURAD-MAGIC

Suresh Seetharam, Janez Perko, Tri Phung,
Kristel Mijndendonckx

European context

Cementitious materials widely used for :

- Backfill
- Barrier
- Buffer material
- Massive plugs in sealing area
- Container
- Vault/liner

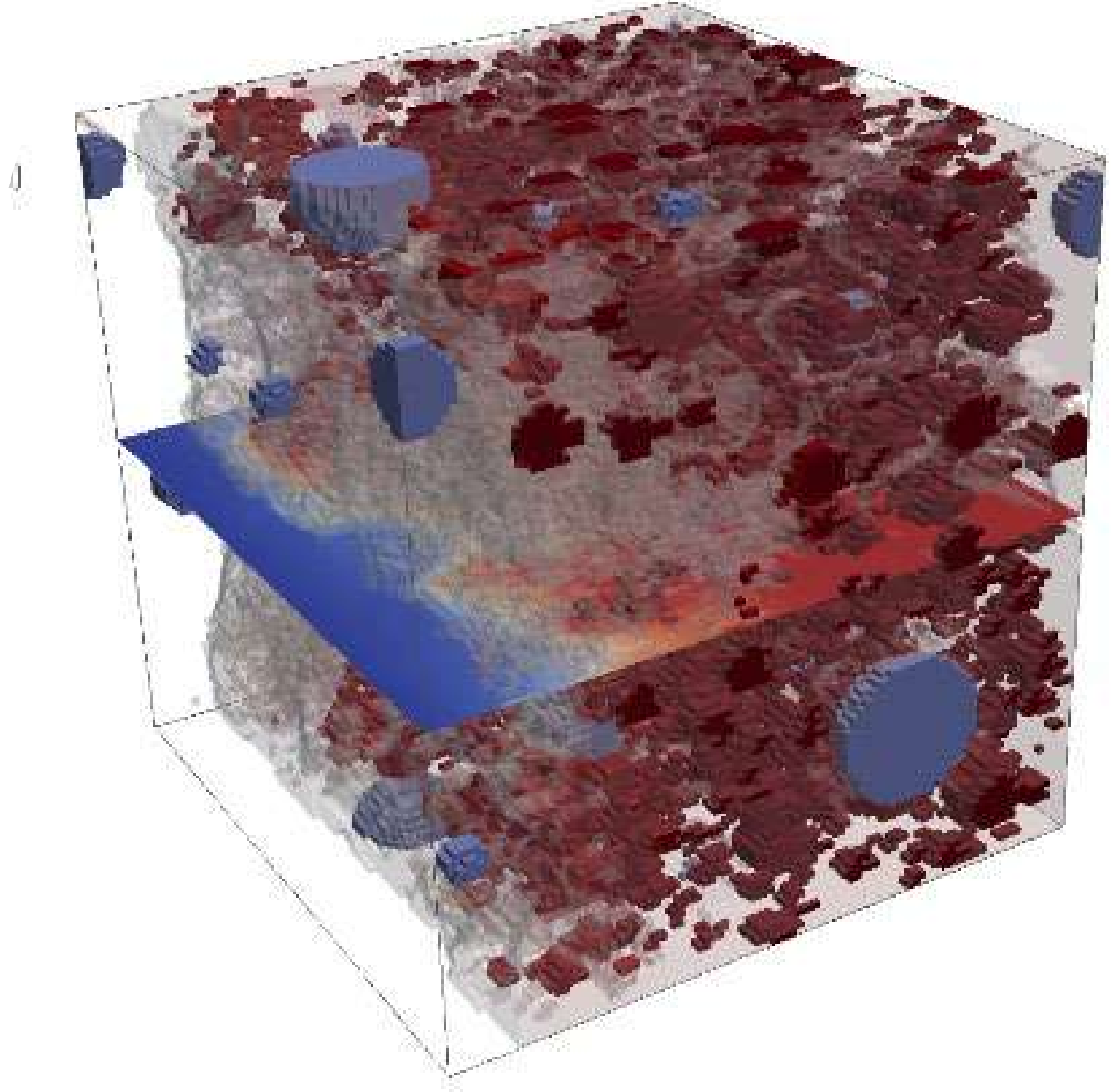


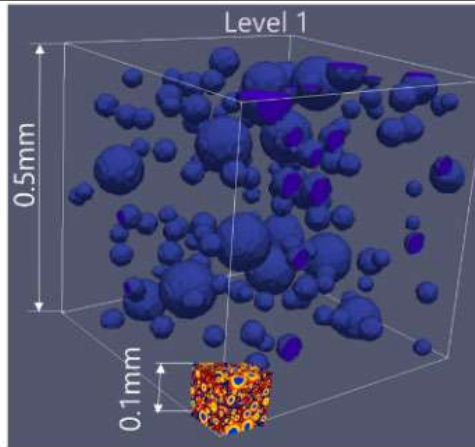
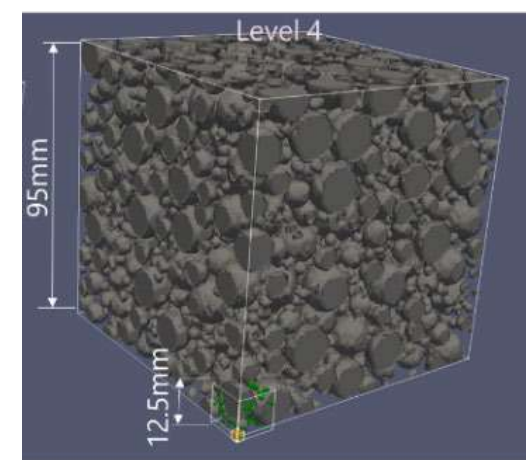
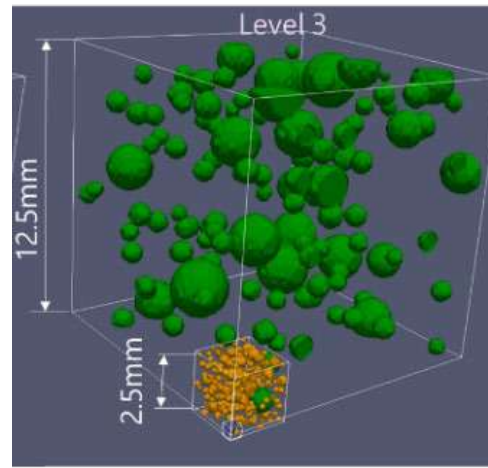
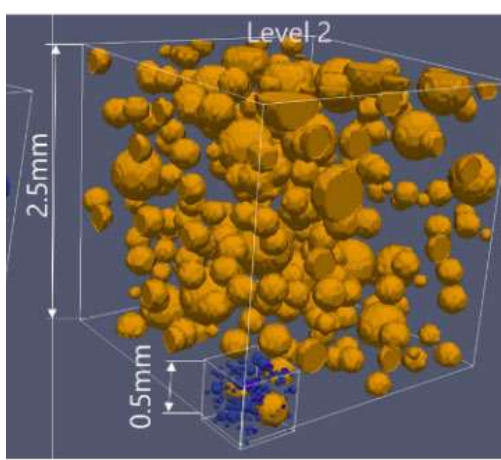
A use from the operating period to the long term

Material exposed to a set of disturbances

Scientific gaps

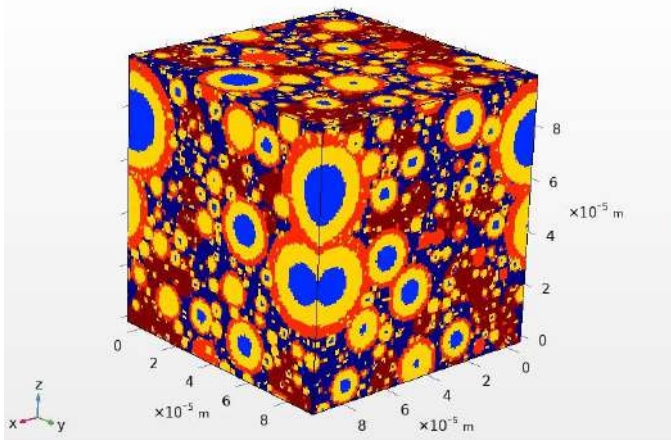
- Impact of various **chemical degradation** phenomena on the **mechanical behavior** of massive cementitious materials?
- Impact of **microbiologically** induced processes in the **chemo-mechanical** behavior of cementitious materials?
- **Reference model** for OPC and low pH concrete





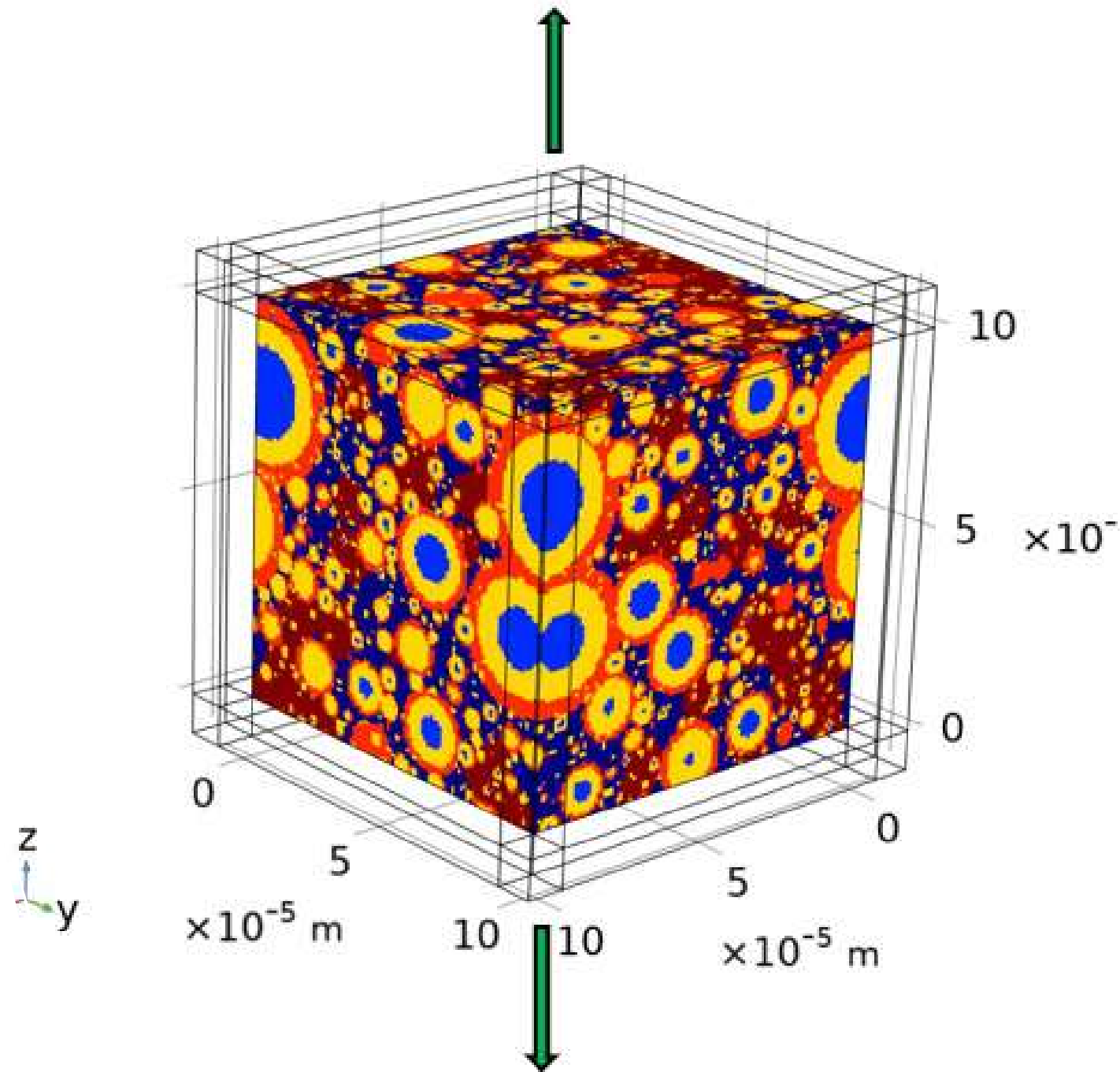
Micro-macro modelling using synthetic microstructures

- Microstructure obtained from HYMOSTRUC for real cement paste.
- Concrete aggregate distribution obtained from in house code, based on real data.

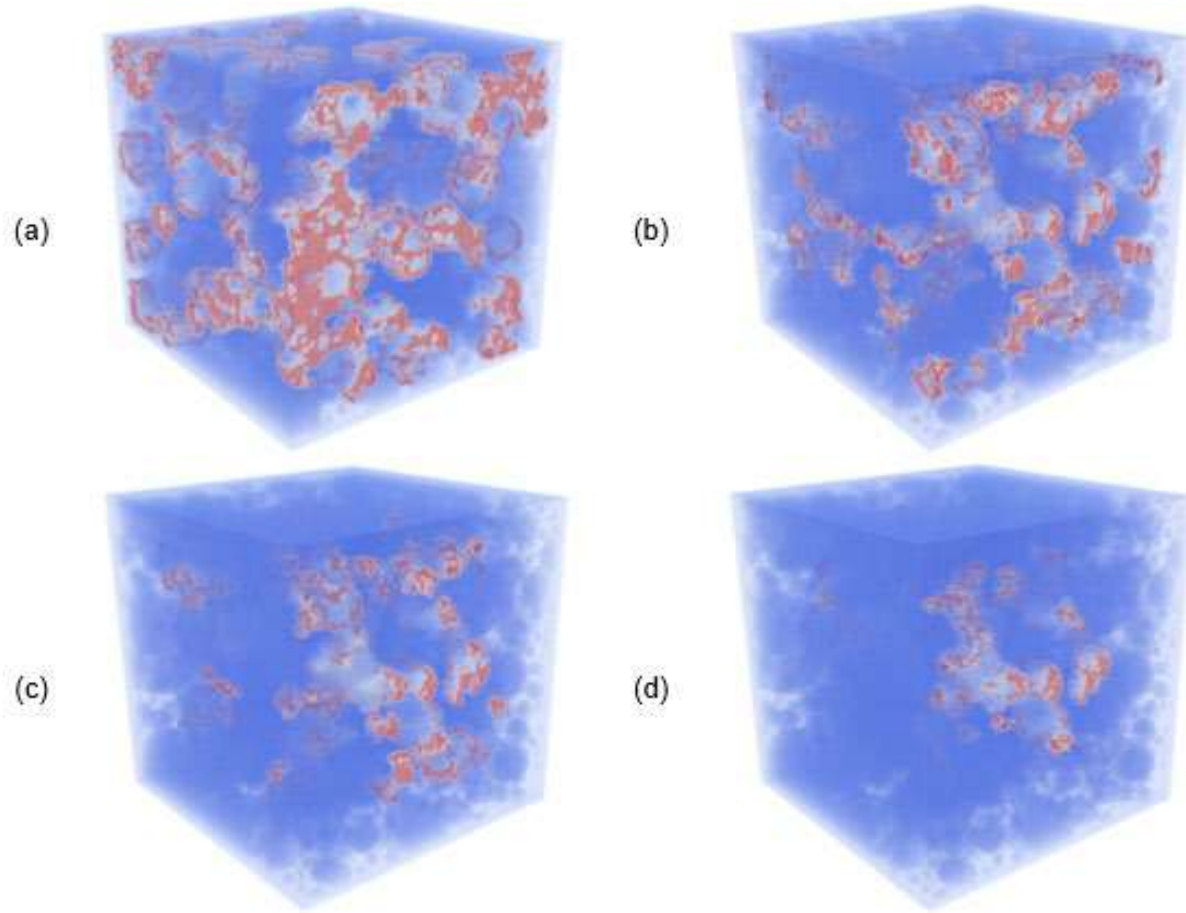


Modelling strategy

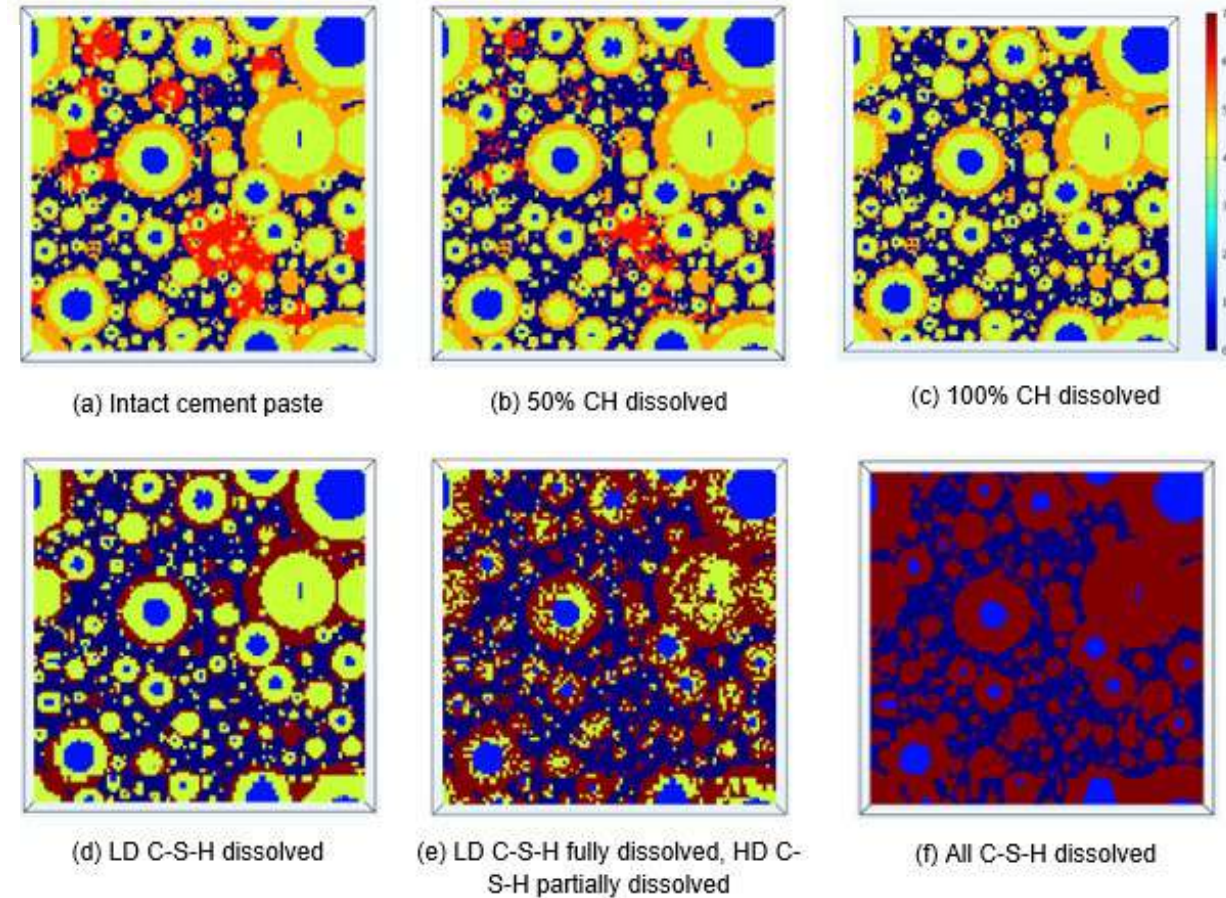
- Voxelized FE model.
- Numerical homogenization.
- Solve reactive transport model for leaching, also artificially generated leached random microstructure.
- Only artificially generated carbonated random microstructure.



Leached microstructures of cement paste



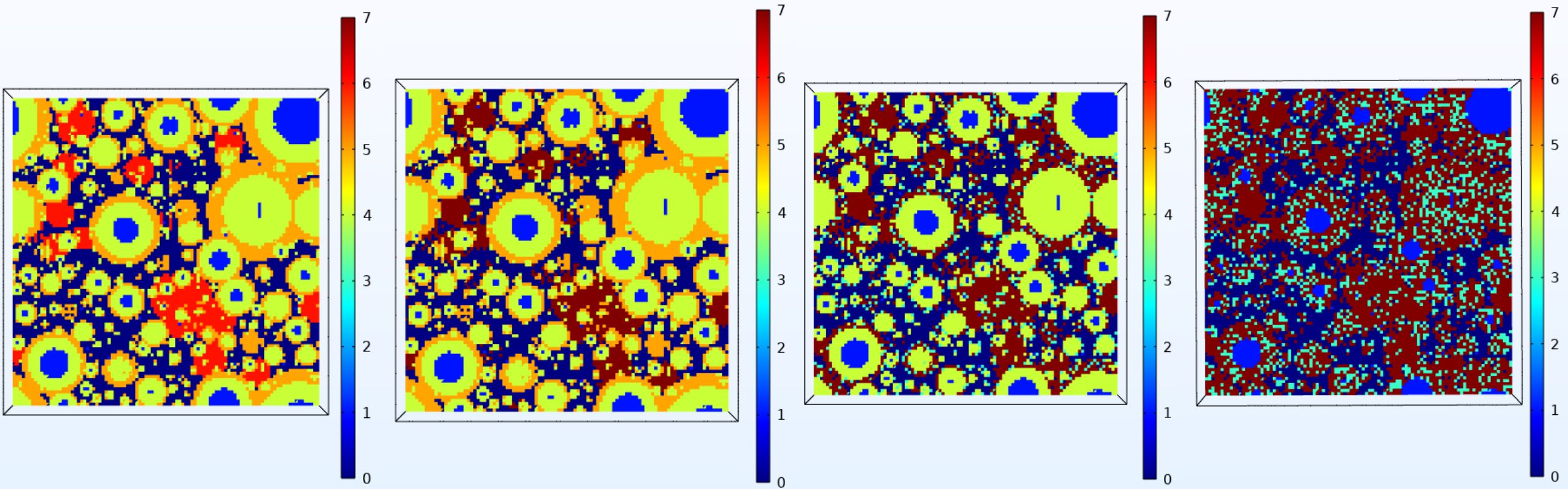
Lattice-Boltzmann simulations



0: water filled micropore; 1: Unhydrated clinkers; 4: HD C-S-H; 5: LD C-S-H; 6: CH; 7: Silica gel

Randomly created leached microstructure

Artificially generated random microstructures of carbonated cement paste



Intact cement paste

CH fully carbonated

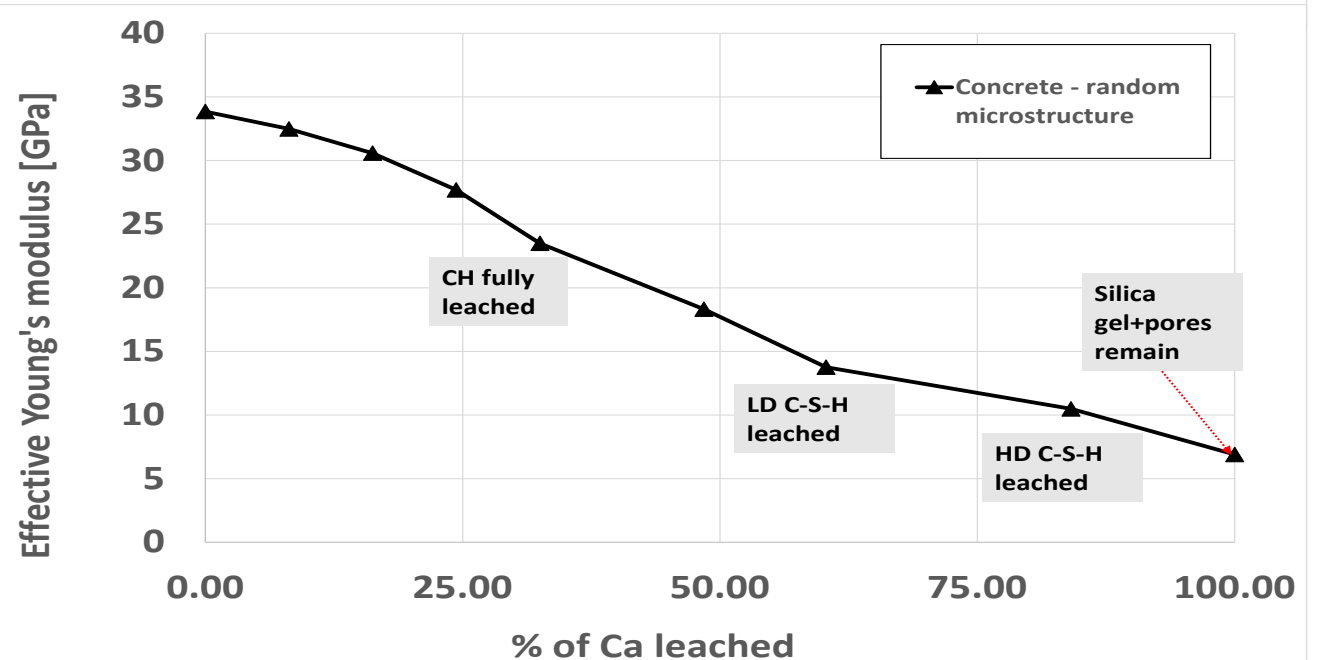
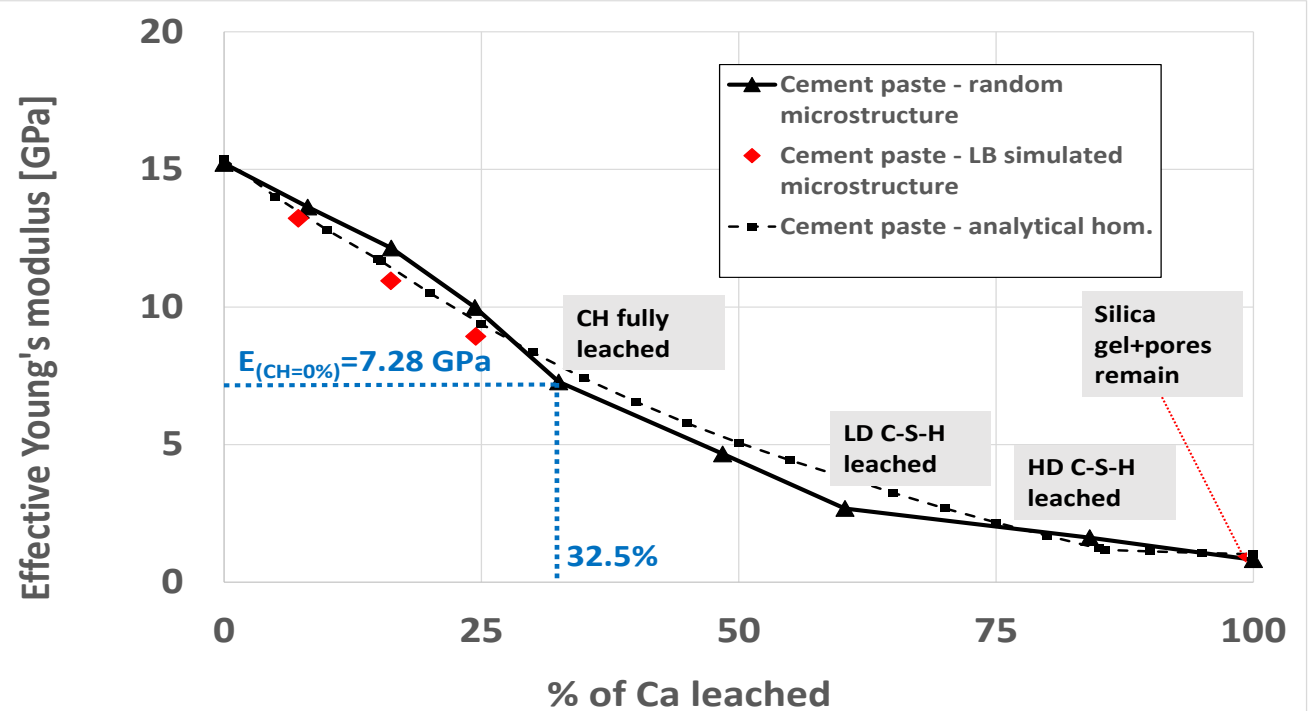
LD C-S-H fully carbonated

HD C-S-H fully carbonated

0: water filled micropore; 1: Unhydrated clinkers; 4: HD C-S-H; 5: LD C-S-H; 6: CH; 7: Calcite

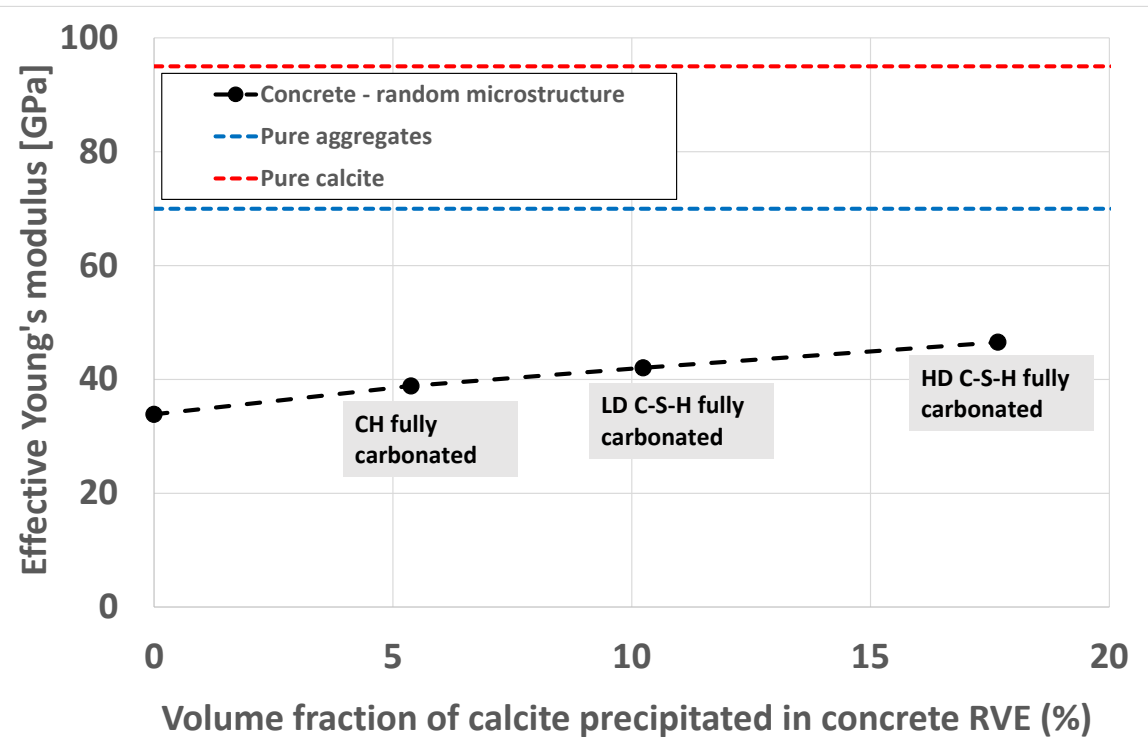
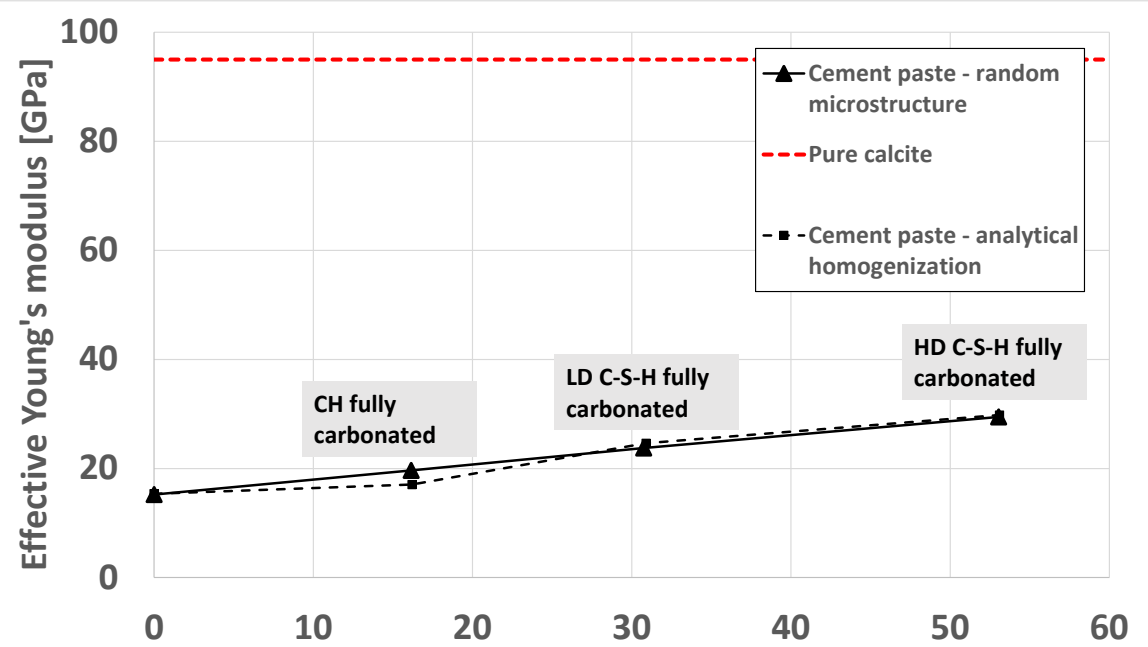
Young's modulus of leached cement/concrete

- Significant reduction in the stiffness even if all Portlandite is leached out.
- Not defined as a function of time, depends on the scenario.



Young's modulus of carbonated cement/concrete

- Maximum 30% increase in the stiffness.
- Not defined as a function of time, depends on the scenario.



Still ongoing experiments

■ Batch type experiments

- Concrete – clay slurry
- Bubbled by CO₂ 0.4% to mimic CO₂ concentration
- Follow up chemical, pH and transport properties evolution

■ Percolation type experiments

- Representative for the backfill concrete in the Belgian disposal concept
- The conditions in the HADES URF are mimicked:
 - Chemical compositions
 - Advective flow

Microbial: sterilized conditions (γ -irradiation + T)



Relevance to Belgian scenario

- Note: Leaching and carbonation are extremely **slow** process.
- Geological disposal - **Operational period**, e.g. tunnel lining – high carbonate, low pH water from BC.
- Near surface disposal - **Monolith** degradation in the long term. Infiltration over long term.

WP 17 MODATS

Exchange Meeting

25 October 2024

J. Verstricht, G. Chen

Jan.verstricht@euridice.be



ONDRAF/NIRAS



EURIDICE

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Content

- ❖ Context
- ❖ Project overview
- ❖ Technical tasks
- ❖ Methodology
- ❖ Main achievements

Context

- ❖ **MO**onitoring equipment and **DA**ta **T**reatment for **S**afe repository operation and staged closure
- ❖ Monitoring plays an essential role in development and operation of long-term safety of DGR, from siting to closure
 - Licensing requirements
 - Design optimization
 - Societal interest
 - etc.
- ❖ This project continues the work performed in previous monitoring projects:
 - EU stage: Thematic network, MoDeRn, Modern2020
 - Others (NEA, IAEA)

Project overview

- ❖ Three year duration: June 2021 – May 2024
- ❖ Coordinated by ANDRA
- ❖ A total of 21 organisations
 - 5 WMO: ANDRA, NAGRA, POSIVA, RWM, SKB
 - 12 RE: incl. Euridice through O/N as linked third party
 - 3 TSO (IRSN, SSTC NRS, VTT)
 - 1 civil stakeholder (Nuclear Transparency Watch)
- ❖ About 11 person months for EURIDICE

Technical tasks

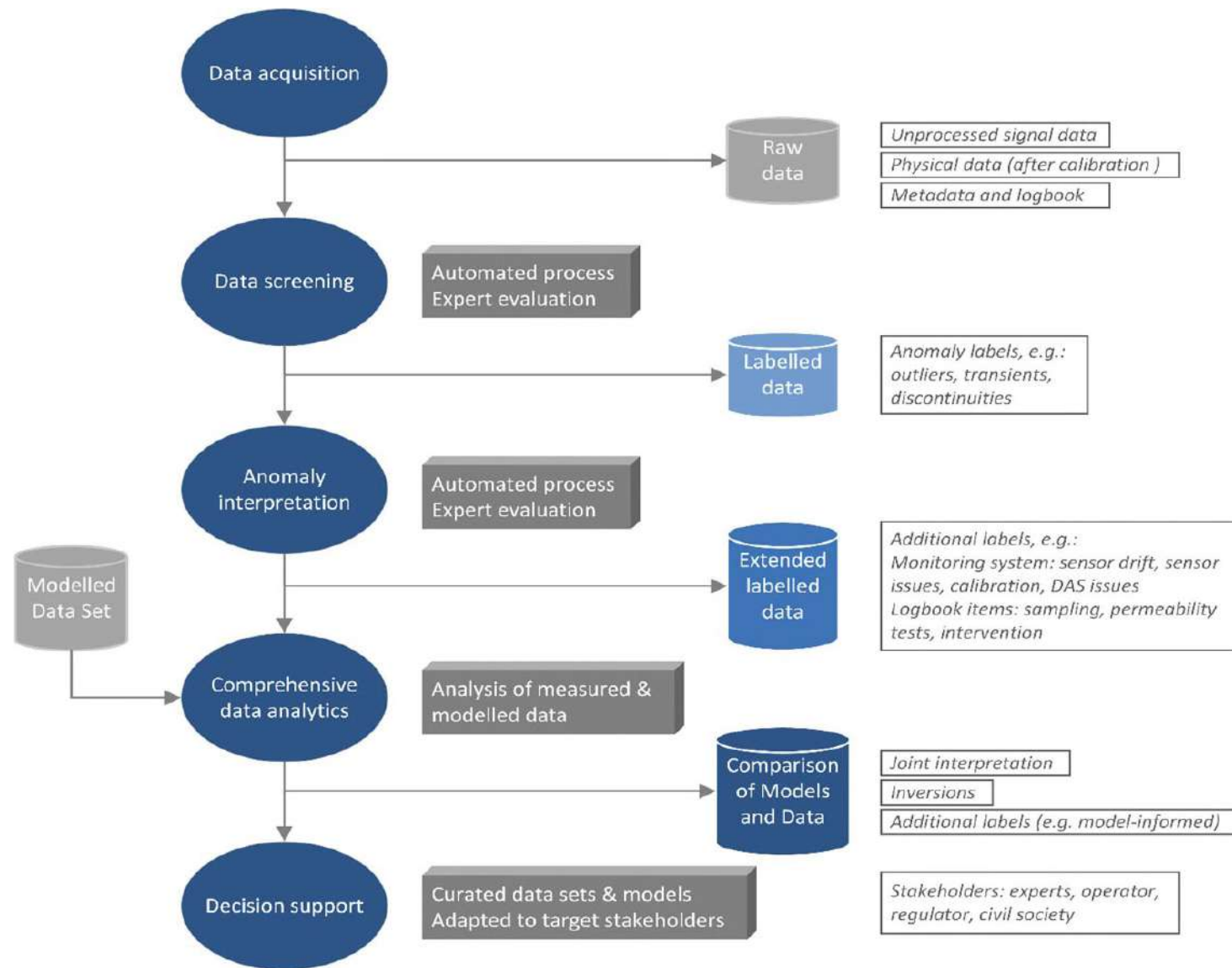
- ❖ Task 2: Data Treatment for Increased Confidence in Repository Monitoring
 - EURIDICE is only involved in Task 2
- ❖ Task 3: Novel and Optimised Monitoring Technology for Repository Monitoring
 - Continuation of monitoring technology developments focused on DGR
 - Non-invasive (wireless monitoring) or low-invasive techniques, such as Geophysical techniques, Fiber Optic technology (distributed sensing)

Methodology

- ❖ URL survey
 - Review of monitoring and data management practices at different URLs/organizations
 - Including those from the most advanced programs (POSIVA, ANDRA, NAGRA)
 - Including practices from PRACLAY, ATLAS tests in HADES URL
- ❖ Guidance for drafting a DGR monitoring QAPP (Quality Assurance Project Plan)
 - Formalization of “good practices”
 - With input from URL survey
- ❖ Using materials (operation & selected monitoring data sets) from Reference Experiments:
 - Our contribution: PRACLAY Heater test (HADES)
 - NAGRA: FE (Mont Terri)
 - ANDRA: HLW disposal cell (CMHM Bure)
 - POSIVA: Poplu Plug demo (Onkalo)
 - SKB: Prototype Repository (Aspo)

Main achievements (1)

- ❖ Data management practices at other partners
 - No formal standard approach
 - However common ideas on data processing
 - From sensor signal to final data for different end users: modellers, civil stakeholders, regulator, ...
 - Particular focus on data cleaning (QA labelling of monitoring data)
- ❖ Added value of digital twins, hybrid twins, PBM and DDM when analysing/interpreting monitoring data



Proposed workflow for data handling from acquisition to decision support.

Main achievements (2)

- ❖ Triggered developments at PPS
 - Data management strategy for all experimental data generated and used in the PPS projects
 - First applications to monitoring cases for the cAt waste (caissons and Test Cover)
 - Explore role of Machine Learning in data labelling process (through Master Thesis)
- ❖ Stay up-to-date with monitoring technology developments for DGRs
 - e.g. application of distributed monitoring for cAt caisson tests

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EURIDICE is a VOF
between SCK CEN and the Belgian nuclear waste management agency.

EURIDICE

Boeretang 200 - 2400 MOL - Belgium



ONDRAF/NIRAS

ROUTES Work Package

(characterisation, treatment, conditioning
and long-term waste management)

Chris De Bock

Presentation at EURIDICE EXCHANGE
October 25th 2024

PRESENTATION STRUCTURE

- **Context** of ROUTES
 - Objectives
 - List of wastes considered CHALLENGING
- **Structure** of ROUTES
 - Tasks, subtasks
 - Belgian partners involved
- **Methodology** followed
- **Results**
 - ROUTES recommendations for future R&D and collaboration
 - Applicability to the Belgian context
 - General
 - Overview of ROUTES Deliverable Reports
 - ROUTES recommendations for 'NO REGRET' waste management measures

CONTEXT OF ROUTES

- ROUTES is one of the two strategic studies as part of EURAD
- Subject of study: waste management routes ('from cradle to grave') in Europe, with focus on 'challenging' wastes (see next slide)
- Objectives of ROUTES
 1. Opportunity to **share experience and knowledge** on waste management routes between interested organisations (from different countries, with programmes at different stages of development, with different amounts and types of radioactive waste)
 2. Identify safety-relevant issues and their **R&D needs** associated with the waste management routes, including routes of legacy and historical waste, considering interdependencies between all stages of waste management
 3. **Describe and compare** the different approaches to characterisation, treatment and conditioning and to long-term waste management, and identify **opportunities for collaboration** between member-states.

CHALLENGING WASTES

Wastes considered 'challenging' within ROUTES

1. Sludges
2. SIERs (spent Ion exchange resins)
3. Organic waste
4. Bituminized waste
5. Graphite waste
6. Decommissioning waste
7. DSRs (disused sealed radiation sources)
8. Particular spent fuel
9. Radium/thorium/uranium-bearing waste
10. Waste containing reactive metals
11. Waste containing chemotoxic substances

ROUTES STRUCTURE (TASKS)

- Task 1 - **Coordination**
- Task 2 - Identification of **challenging wastes**
- Task 3 - **Characterization** approaches
- Task 4 - **WAC** ⁽¹⁾
- Task 5 - Waste management solutions for small amounts of wastes, focusing on **SIMS** ⁽²⁾
- Task 6 - **Shared solutions** for characterization, treatment, storage and disposal
- Task 7 - Interactions with **Civil Society**
- Task 8 - **ROUTES Extension** (Evaluation of possible waste management solutions in case of small inventory and absence of WAC)

(1) WAC = Waste Acceptance Criteria

(2) SIMS = Small-Inventory Member States

ROUTES STRUCTURE (SUBTASKS)

- Task 1 - Coordination
- Task 2 - Identification of challenging wastes
 - **Subtask 2.1** (Collection and analysis of existing work on categorization and classification of radioactive waste)
 - **Subtask 2.2** (Understanding at EU level of the practical issues on RWM routes for challenging waste)
- Task 3 - Characterization approaches
 - **Subtask 3.1** (Radioanalytical characterisation of radioactive waste and waste with complex/toxic properties)
 - **Subtask 3.2** (Characterization and segregation of legacy waste)
- Task 4 - WAC
 - **Subtask 4.1** (Current use of waste acceptance criteria)
 - **Subtask 4.2** (Sharing experience on waste management with/without WAC available)
 - **Subtask 4.3** (R&D needs and opportunities of collaboration)

ROUTES STRUCTURE (SUBTASKS)

- Task 5 - SIMS
 - **Subtask 5.1** (Collecting and analyzing actual existing knowledge about disposal options for SIMS)
 - **Subtask 5.2** (Describe the necessary predisposal routes for the disposal options of subtask 5.1)
- Task 6 – Shared Solutions
 - **Subtask 6.1** (State-of-the-art on shared development and use of technologies and facilities)
 - **Subtask 6.2** (Case studies on shared development and use of technologies and facilities)
 - **Subtask 6.3** (feasibility of developing further European shared solutions for cradle to grave waste management)
- Task 7- Civil Society
 - **Subtask 7.1** (Scoping and development of action plan for interaction with Civil Society)
 - **Subtask 7.2** (Implementing the action plan)
 - **Subtask 7.3** (Synthesis and dissemination)
- Task 8 – ROUTES extension
 - **Subtask 8.1** (qualitative analysis of predisposal routes)
 - **Subtask 8.2** (qualitative analysis of disposal options)

BELGIAN PARTNERS INVOLVED IN ROUTES

- Partners involved



sck cen



- Involved ROUTES Tasks

TASK 1	Coordination			 ONDRAF/NIRAS
TASK 2	Identification of challenging wastes		sck cen	 ONDRAF/NIRAS
TASK 3	Characterization approaches		sck cen	 ONDRAF/NIRAS
TASK 4	WAC			 = Task co-leader ONDRAF/NIRAS
TASK 5	SIMS			 ONDRAF/NIRAS
TASK 6	Shared solutions			
TASK 7	Civil Society			
TASK 8	ROUTES extension			 ONDRAF/NIRAS

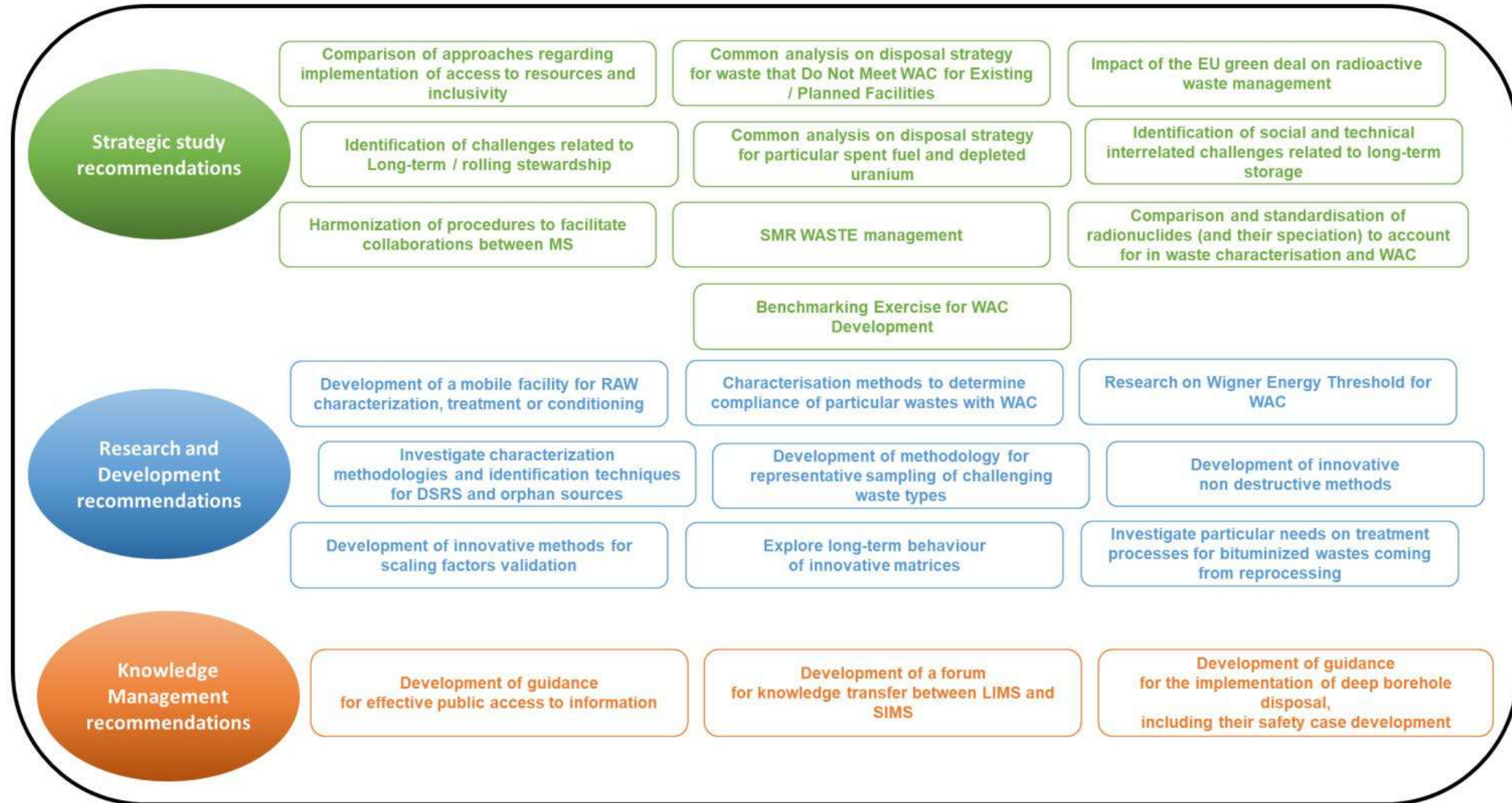
METHODOLOGY

- **Structured steps:** initial data gathering → inclusive workshops → detailed analysis
- Alle ROUTES tasks initiated with a **data gathering and analysis phase**

This phase entailed surveys, workshops, and case studies

- Collecting information on national waste classification, inventory, practices regarding predisposal steps and disposal facilities, and related aspects
- **Compilation of information and analysis results in milestones and deliverables**
- **Inclusive workshop approach**
 - Facilitating collaboration among a diverse array of stakeholders
 - Pivotal forums for partners with various backgrounds (SIMS and LIMS alike)
 - Diverse perspectives are comprehensively considered
 - **Holistic and inclusive recommendations that reflect the broader societal context**
 - A dedicated workshop, convened in December 2022, served as a focal point for deliberating and refining recommendations generated within the project
 - ROUTES recommendations fed into the **EURAD-2 Strategic Research Agenda**

R&D needs and opportunities for collaboration (ROUTES recommendations)



APPLICABILITY TO THE BELGIAN CONTEXT

- Recommendations for future R&D, strategic studies and KM
 - Offer opportunity for R&D and strategic studies in a **European collaborative context**
 - Scale benefits, benchmarking, networking
- Descriptions and comparative summaries of the different approaches to waste management in European countries (characterisation, treatment, conditioning, long-term management)
 - **State-of-the-art overview** of approaches to managing challenging wastes in EU
- Case analyses and treatment of specific cross-cutting topics
 - Examples of dealing with **specific** waste management challenges
- General recommendations
 - **Guidance/inspiration** in waste management dilemmas (e.g. early/late conditioning)
- Awareness of the importance of interaction with **Civil Society**

DELIVERABLE REPORTS

(available on the EURAD website <https://www.ejp-eurad.eu/publications>)

- **Task 1 – Coordination**



- **D9.3** “ROUTES Recommendations for R&D, strategic study and KM activities”

- **Task 2 – Challenging wastes**

- **D9.4** “Overview of existing work on categorization/classification of RWs in participating states”



- **D9.5** “Overview of issues related to challenging wastes”

- **Task 3 – Characterisation**

- **D9.7** “Review of radioanalytical characterisation of selected radioactive wastes and wastes with complex chemical and toxic properties”
- **D9.8** “Review of characterisation of legacy and historical wastes”

DELIVERABLE REPORTS

- **Task 4 – WAC**



- **D9.9** “Suggestions for the management of challenging wastes”
- **D9.1** “Training Materials” (on the joint ROUTES-PREDIS Summer School on WM, September 2023 in Prague)

- **Task 5 – SIMS**

- **D9.10** “Collection and analysis of actual existing knowledge about disposal options for SIMS”
- **D9.11** “Results of the workshop dealing with possible conditioning routes for SIMS”

- **Task 6 – Shared Solutions**



- **D9.12** “Studies and plans for developing shared solutions for radioactive waste management in Europe”
- **D9.13** “Case studies on shared solution between Member states”
- **D9.14** “Feasibility of developing further European shared solutions for waste management from cradle to grave”

DELIVERABLE REPORTS

- **Task 7 – Civil Society**



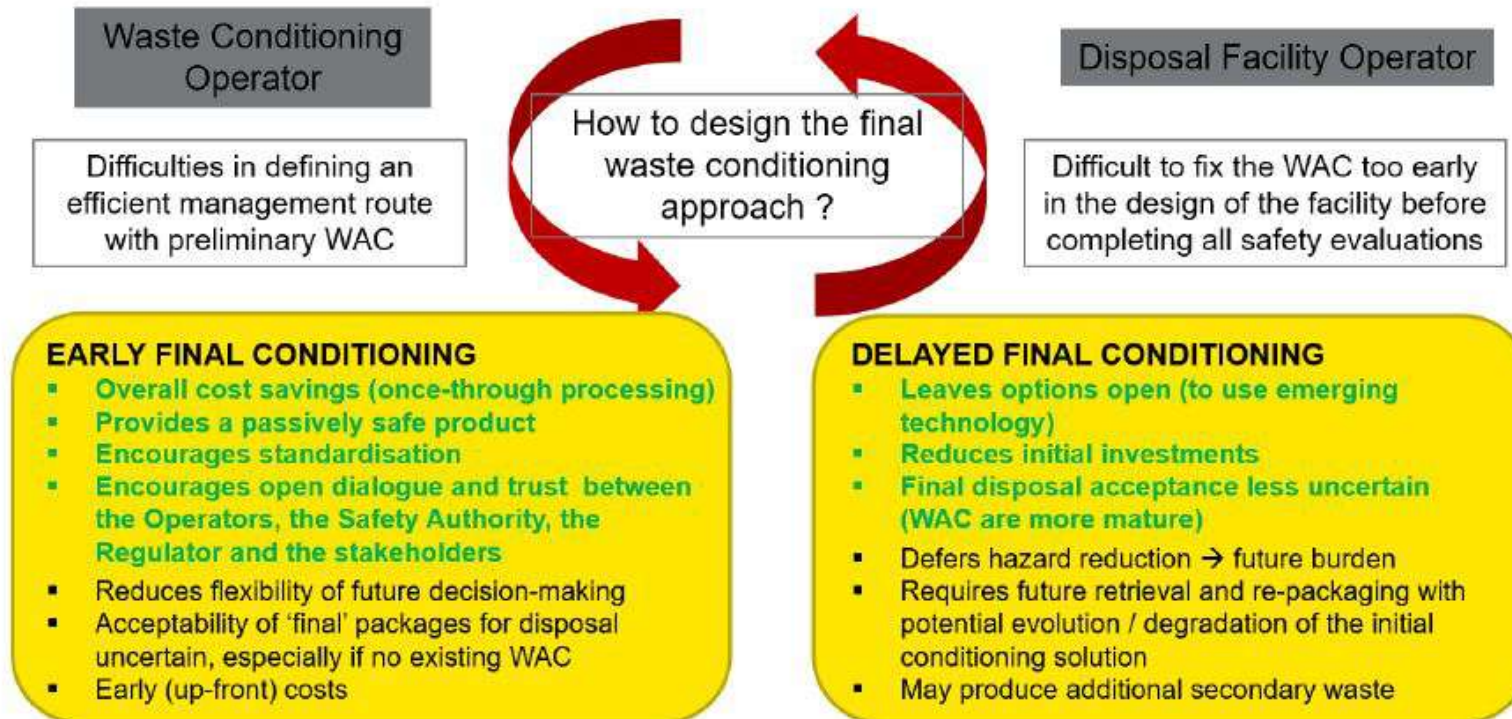
- **D9.19** “Synthesis of Task 7 activities” (encompasses D9.15, D9.16, D9.17 and D9.18)

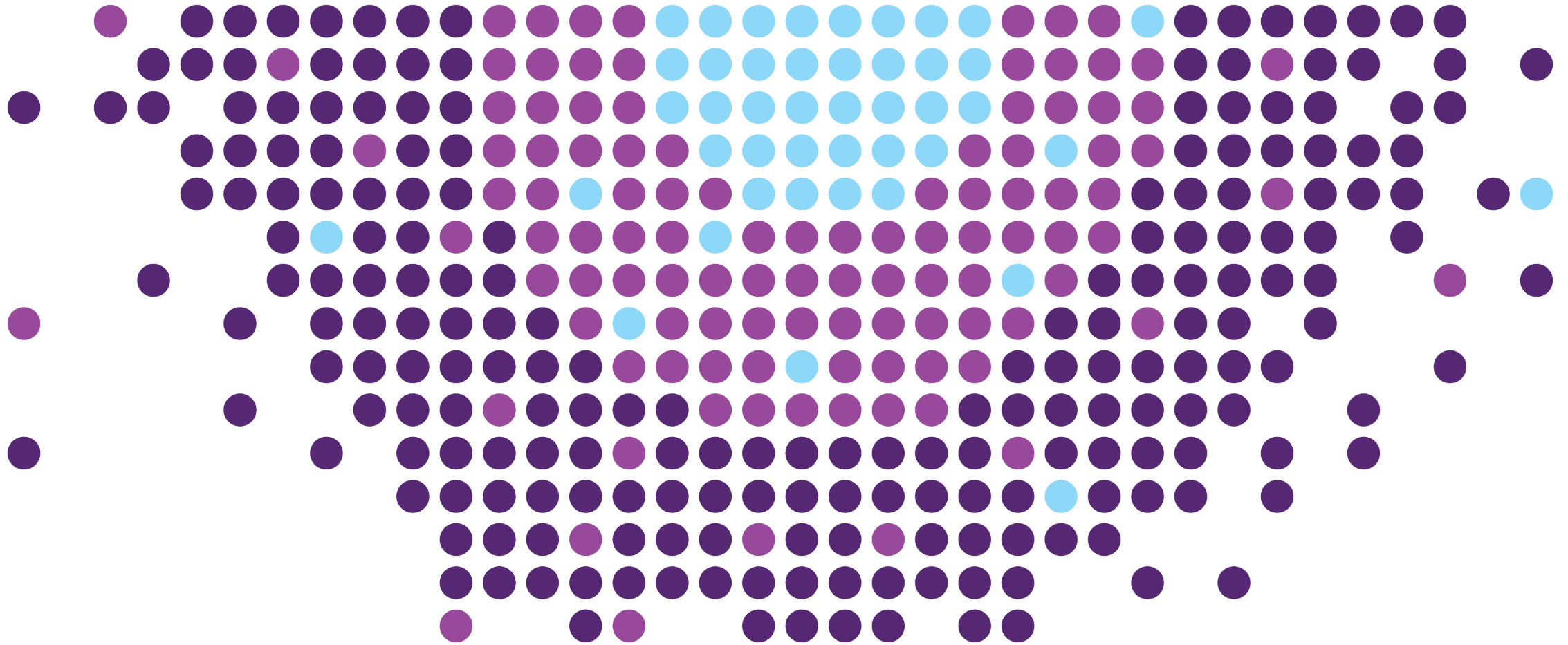
- **Task 8 – ROUTES extension**

- **D9.21** (Report on Evaluation of existing predisposal routes for SIMS with regard to disposal options)
- **D9.22** (Summary report on analysis, assessment and evaluation of disposal options for SIMS)

'NO REGRET' WASTE MANAGEMENT MEASURES

- **D9.9** (Task 4) contains recommendations for 'no regret' measures in all management route phases (characterisation, treatment, conditioning, storage, disposal)
 - Figure below summarizes pros & cons of **early versus delayed conditioning**
 - Repackaging without matrix conditioning can provide a flexible and reversible intermediate solution



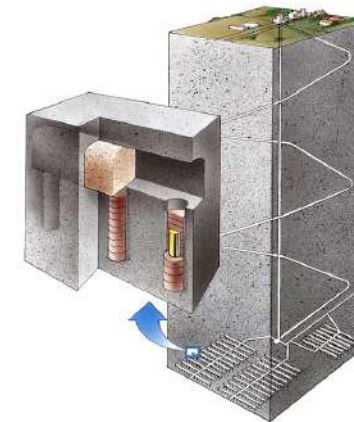


Spent Fuel Management and Characterization

BACK-END OF SPENT NUCLEAR FUEL

A **safe, secure, ecological** and **economic** transport, storage and disposal requires that **Spent Nuclear Fuel (SNF)** is **characterised** for the main observables of interest:

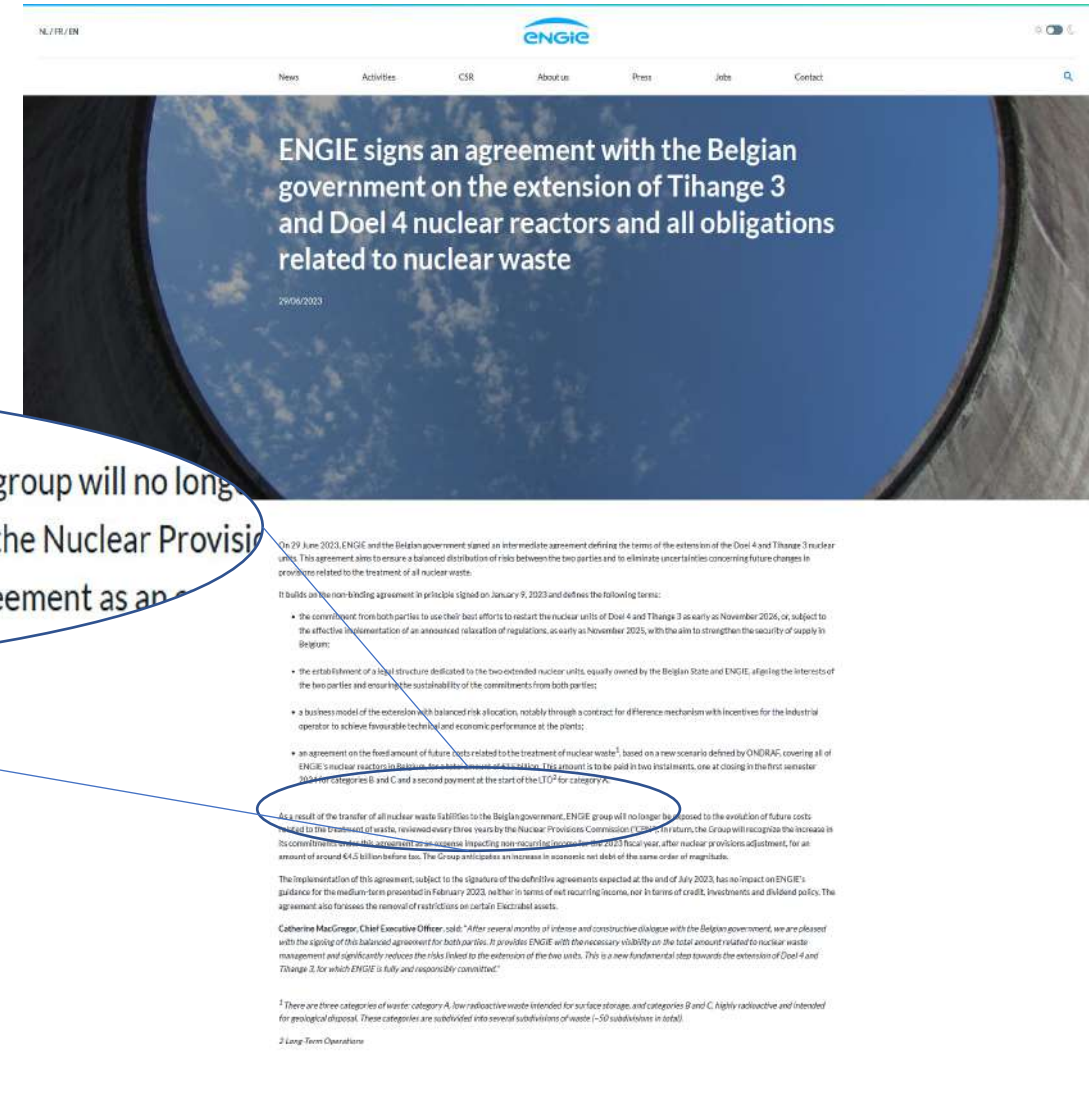
- Decay heat
 - Neutron emission
 - γ -ray emission
 - Reactivity (Burn Up Credit (BUC), i.e. Fission Product (FP), actinides)
 - Fissile material (Nuclear Safeguards, i.e. ^{235}U , ^{239}Pu)
 - Specific nuclides (Long term safety)
i.e. ^{14}C , ^{36}Cl , ^{79}Se , ^{94}Nb , ^{99}Tc , ^{129}I , ^{226}Ra , ^{237}Np
- ⇒ requires knowledge of a **complex nuclide inventory**
which can only be obtained by **theoretical calculations**



BACK-END OF SPENT NUCLEAR FUEL IN THE BELGIAN CONTEXT

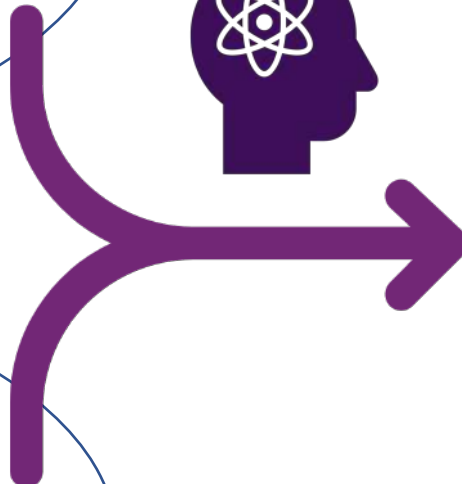
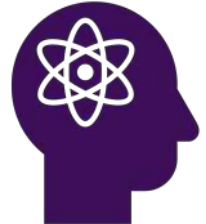
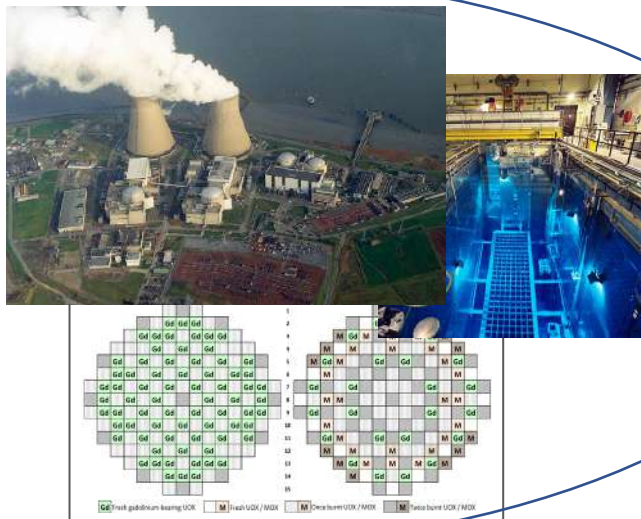
- 29th of June 2023

As a result of the transfer of all nuclear waste liabilities to the Belgian government, ENGIE group will no longer be exposed to the evolution of future costs related to the treatment of waste, reviewed every three years by the Nuclear Provisioning Commission (CPN¹). In return, the Group will recognize the increase in its commitments under this agreement as an expense for the 2023 fiscal year, after nuclear provisions adjustment for an amount of around €4.5 billion before tax. The Group anticipates an increase in economic net debt of the same order of magnitude.

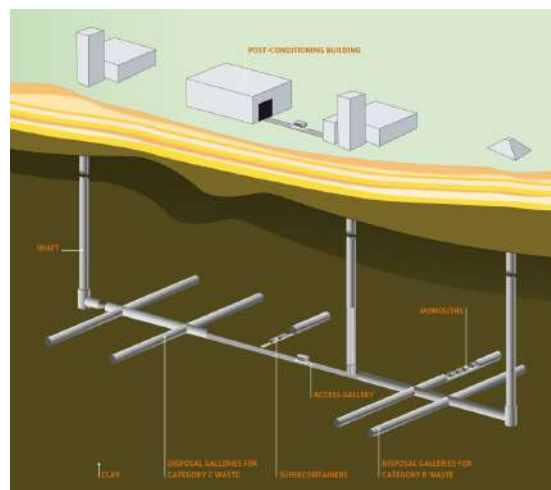
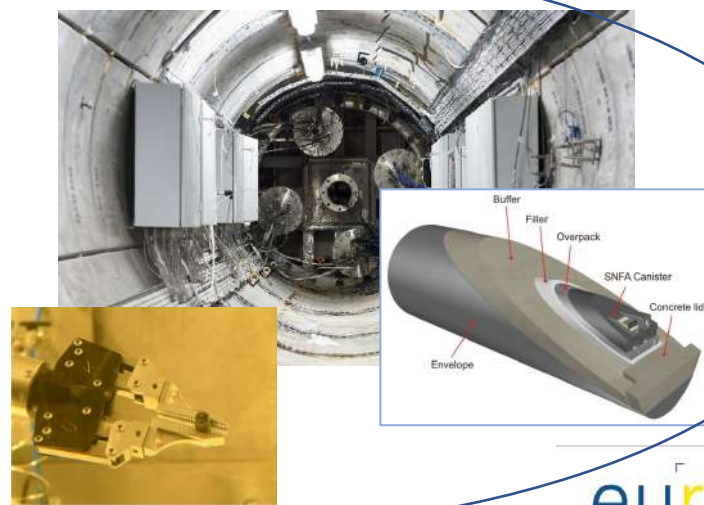


BACK-END OF SPENT NUCLEAR FUEL IN THE BELGIAN CONTEXT: KNOWLEDGE MERGING

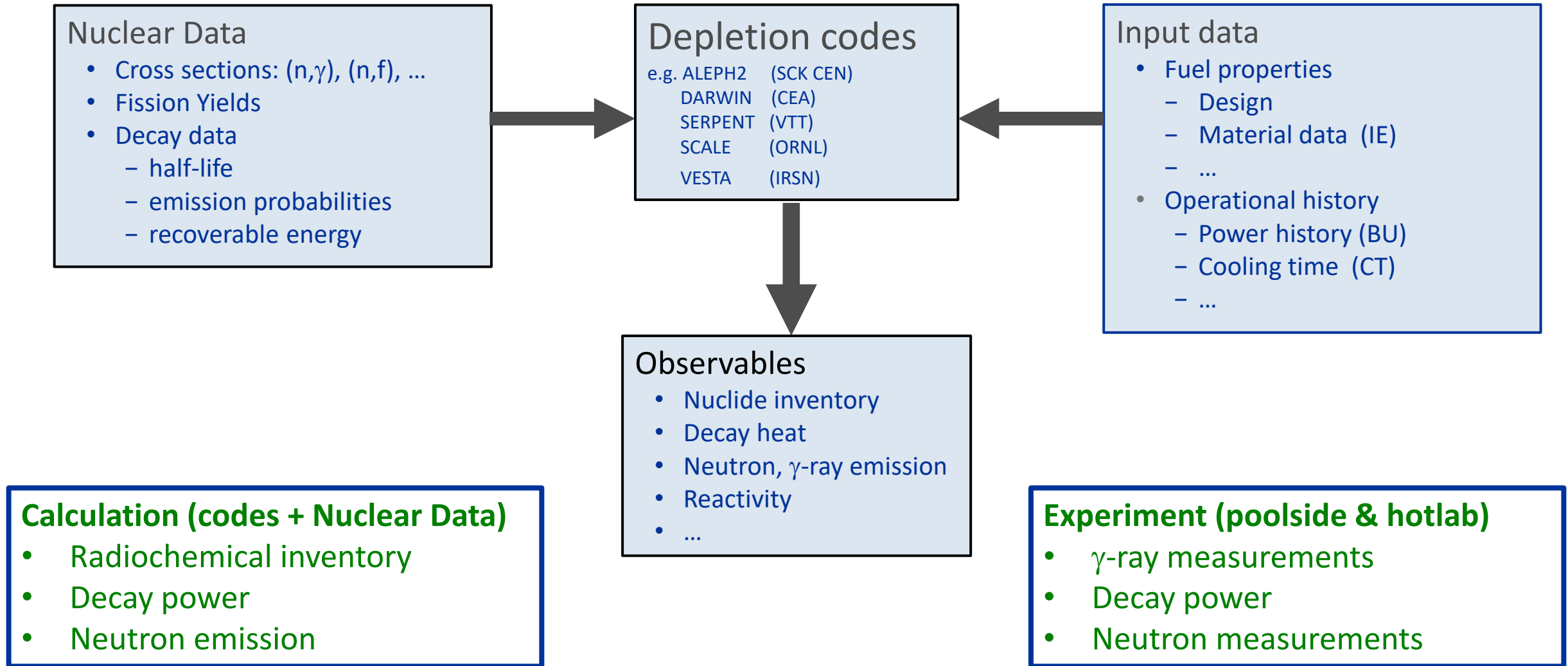
ELECTRABEL
TRACTEBEL
SYNATOM



NIRAS/ONDRAF
SCK CEN



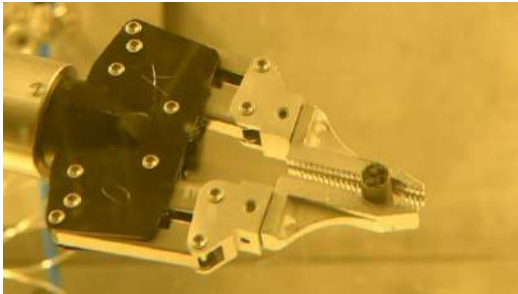
EURAD: WP8 (SPENT FUEL CHARACTERIZATION) - TASK 2 (TOWARDS VALIDATED DEPLETION CALCULATIONS WITH REALISTIC UNCERTAINTIES)



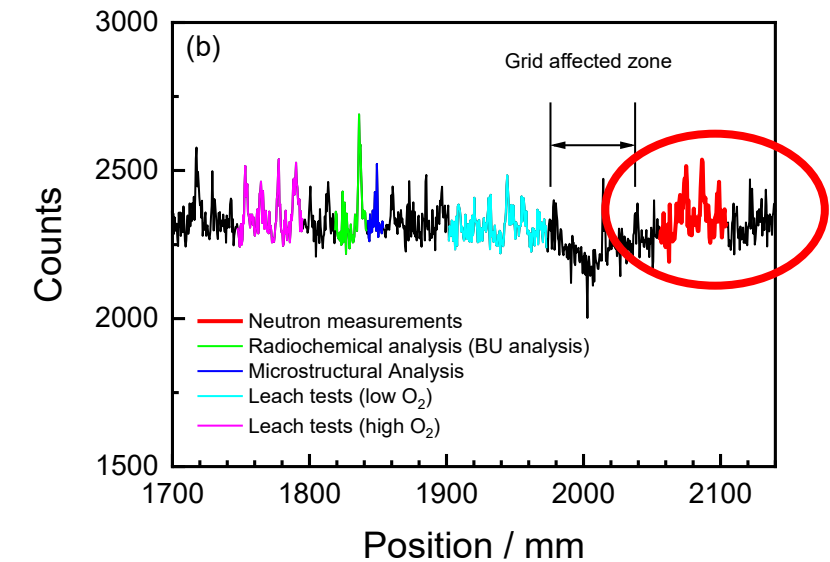
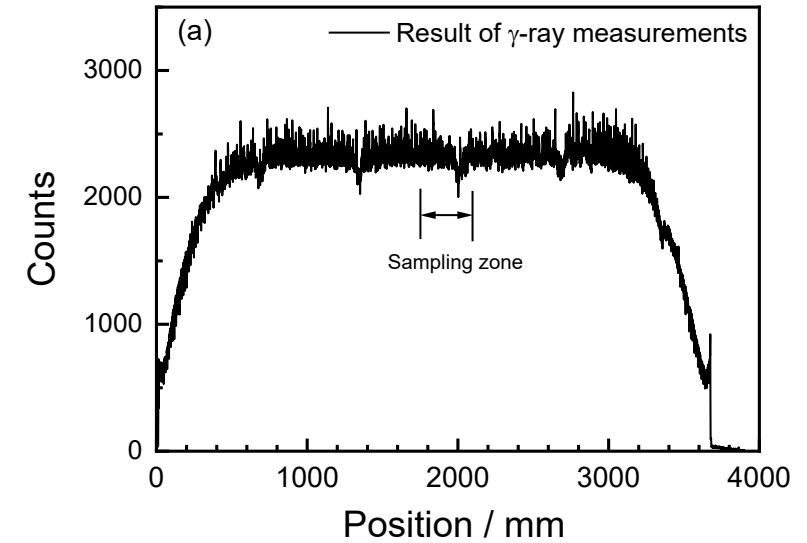
NEUTRON EMISSION: ABSOLUTE MEASUREMENTS OF SNF SEGMENT SAMPLE

Non Destructive Assay method to determine the neutron output of a **SNF** segment

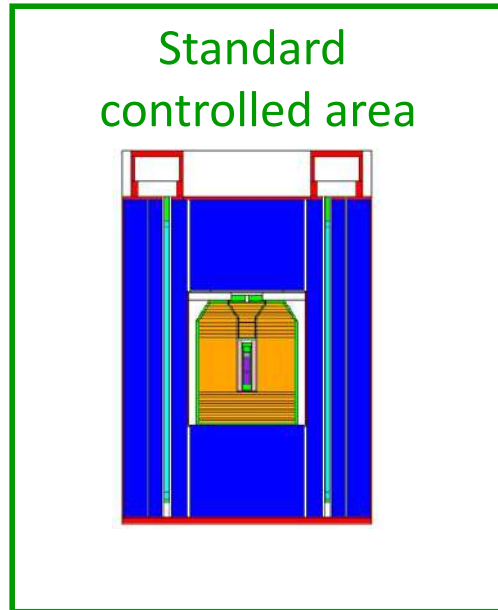
?



SNF SEGMENT SAMPLE: REGAL PROJECT



NEUTRON MEASUREMENTS: FIRST-OF-A KIND RESULTS



Direct neutron measurement

$$S_{sf} = 678 (12) \text{ s}^{-1} \text{ g}^{-1} \quad (U_{rel} = 1.8\%)$$

Calculated from radiochemical analysis of ^{244}Cm content:

$$S_{sf} = 699 (28) \text{ s}^{-1} \text{ g}^{-1} \quad (U_{rel} = 4.0\%)$$

The direct method improved the uncertainty
on ^{244}Cm by a factor of two!

NEUTRON MEASUREMENTS: CODE VALIDATION

Experimental result
 $S_{sf} = 678 \pm 12 \text{ s}^{-1} \text{ g}^{-1}$

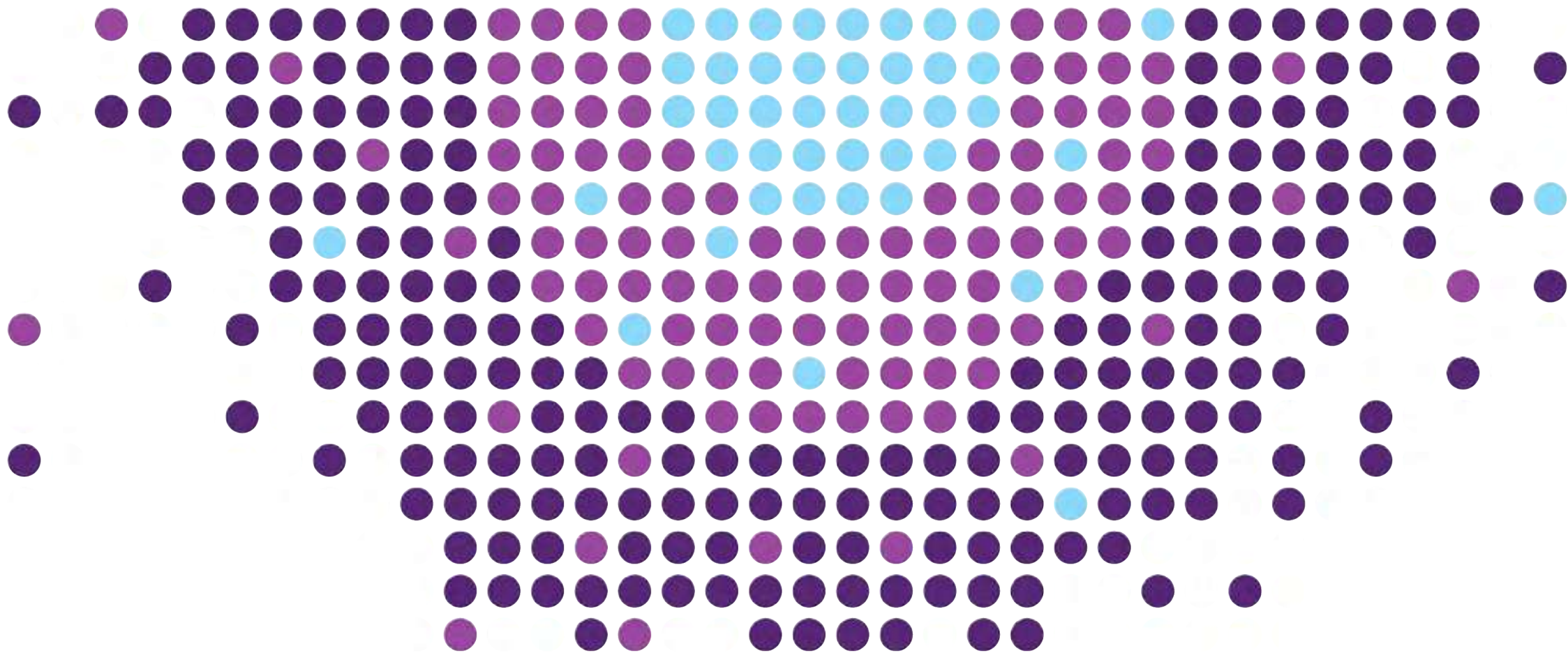
All calculations normalized to ^{148}Nd inventory

Code	Library	N _x /N _U				BU (MWd/kg)		S _{sf} (1/s)		C/E
		¹⁴⁸ Nd	¹³⁷ Cs	²⁴⁴ Cm						
		(x 10 ⁻⁴)	(x 10 ⁻³)	(x 10 ⁻⁵)						
Serpent2	JEFF-3.3	9.740	2.225	6.354	1	53.57	1	656.8	1	0.969
	ENDF/B-VII.1	9.740	2.274	6.710	1.056	54.39	1.015	689.4	1.050	1.017
	ENDF/B-VIII.0	9.740	2.274	6.701	1.055	54.38	1.015	688.5	1.048	1.015
DARWIN	JEFF-3.3	9.743	2.210	6.070	0.955	52.69	0.984	627.4	0.955	0.925
	ENDF/B-VII.1	9.742	2.271	6.420	1.010	53.93	1.007	660.6	1.006	0.974
	ENDF/B-VIII.0	9.742	2.271	6.460	1.017	53.69	1.002	664.1	1.011	0.979
ALEPH2	JEFF-3.3	9.740	2.225	6.290	0.990	53.25	0.994	640.1	0.975	0.944

- ⇒ Substantial differences same code with different Nuclear Data (ND) libraries
- ⇒ Substantial differences same Nuclear Data (BD) Library with different codes
- ⇒ Root cause still under investigation
 - Interpretation of the input data?
 - Depletion code?
 - Normalization?

TAKEAWAY MESSAGE AND OUTLOOK

- Findings
 - Neutron emission rate of SNF is an excellent observable for burnup
 - Nuclear Data have margin for improvement
 - Depletion Codes have margin for improvement
- Outlook
 - Findings (both code calculations and experiments) are directly relevant for Belgian's back-end programs (PHOENIX) but also reach beyond Belgium
 - Poolside observations followed by hot laboratory investigations are scheduled (PHOENIX)
 - Calculation efforts using reactor core and fabrication data are scheduled in (PHOENIX)



sck cen
Belgian Nuclear Research Centre

Thierry Mennecart

PREDIS: Pre-disposal management of radioactive waste

26th Exchange Meeting – EURAD (25.10.2024 – Tabloo)



PREDIS overview

Work packages description

Outcomes

PRE-DISPOSAL MANAGEMENT OF RADIOACTIVE WASTE



47 partners
17 countries
25 End User Group members



Total budget 23.7 M€
EC contribution of 14 M€



**Aim: Identify, develop and improve
innovative technologies in pre-
disposal radioactive waste
management**



4 years
Started Sept 2020



Endorsement and close interaction
with SNETP-Nugenia, IGD-TP,
IAEA, NEA, EURAD



Detailed info:
<https://predis-h2020.eu/>

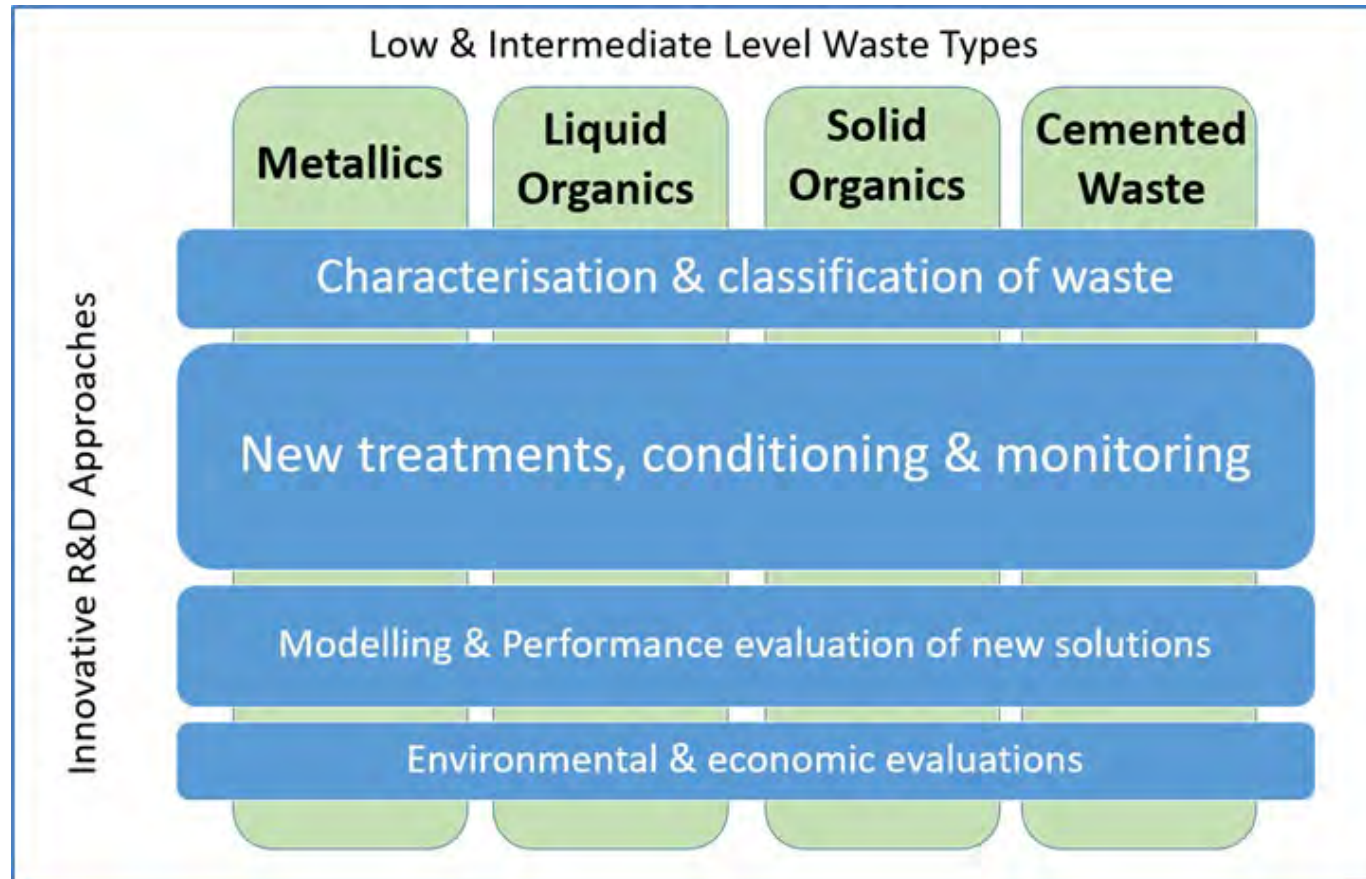
PREDIS high-level, overall objectives

- **Develop solutions** (*methods, processes, technologies and demonstrators*) for **future treatment and conditioning** of waste across a number of MSs (Member States) for which **no industrially mature or inadequate solutions** are currently available, improving **safety** during next waste management steps;
- or **improve existing solutions with safer, cheaper or more effective alternative** processes where they bring measurable benefits to several MSs.
- **Analyse criteria, parameters and specifications** for materials and packages with associated **Waste Acceptance Criteria (WAC)** for pre-disposal and disposal activities, supporting homogenisation of waste management processes across Europe.

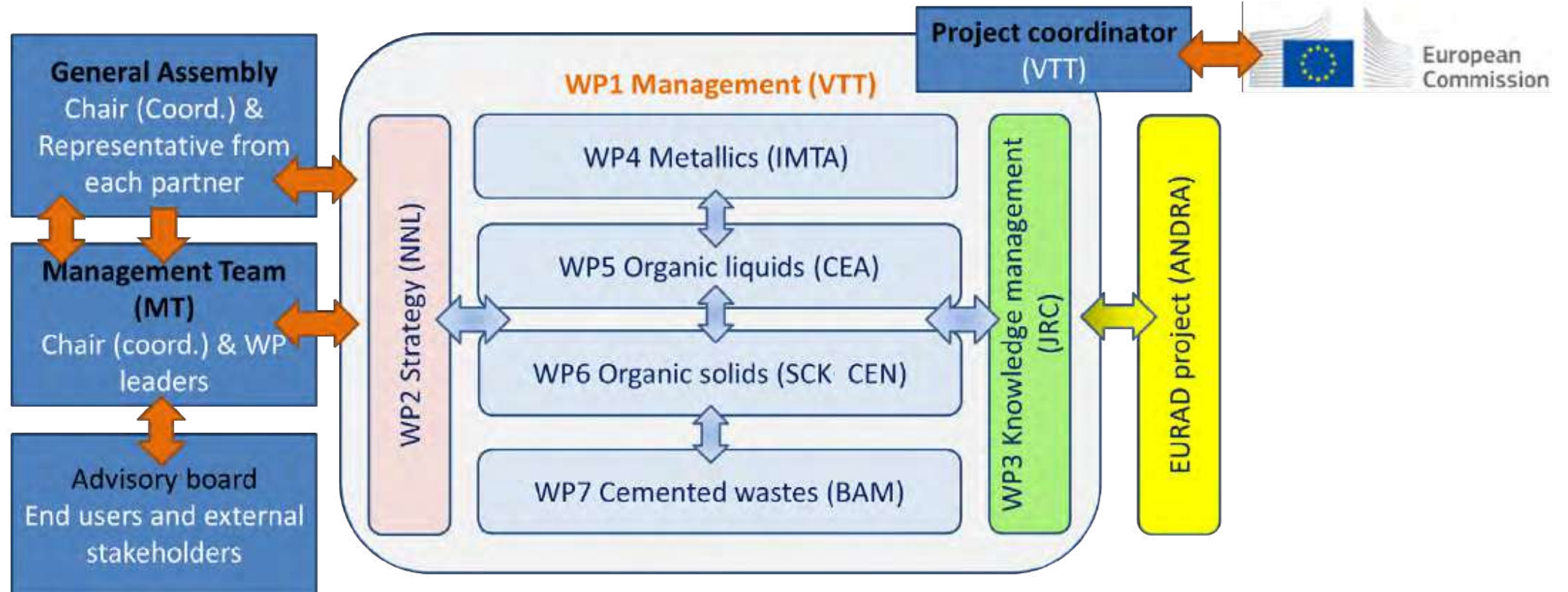
These high-level objectives will be met by PREDIS having specific objectives:

- 1) Applying **multi-disciplinary and multi-scale scientific approaches** to demonstrate technical, economic and environmental feasibility of the new solutions;
- 2) Addressing **project drivers** from the **end users' points-of-view**;
- 3) Fostering deeper **cooperation** between experts from many EU Member-states and across generations;
- 4) **Training** new experts in the field of pre-disposal waste management technologies;
- 5) **Updating and revising pre-disposal guiding documents** (vision, SRA, roadmap, governance and deployment mechanisms), together with the EURAD EJP executive bodies.

TECHNICAL SCOPE



PROJECT STRUCTURE



CONSORTIUM MEMBER

In bold: WP leaders = Project Management team

29 of 47 partners are also participating in EURAD

- **VTT Technical Research Centre of Finland, Finland**
- **National Nuclear Laboratory (NNL), UK**
- **Joint Research Centre (JRC), Belgium**
- **Institut Mines Télécom Nantes Atlantique (IMTA), France**
- **Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France**
- **Studiecentrum voor Kernenergie / Centre d'Etude de l'Energie Nucléaire (SCK CEN), Belgium**
- **Bundesanstalt fuer Materialforschung und Pruefung (BAM) Germany**
- Magics Instruments, Belgium
- Technical University Sofia, Bulgaria
- Ceske Vysoke Uceni Technicke V Praze (CTU), Czech Republic
- Centrum Vizkumu Rez (CVRez), Czech Republic
- Statni Ustav Radiacni Ochrany (SÚRO), Czech Republic
- ÚJV Rez, Czech Republic
- University of Helsinki, Finland
- Centre National de la Recherche Scientifique, France
- Ecole Centrale de Lille, France
- Institut de radioprotection et de Sûreté Nucléaire (IRSN), France
- ORANO CYCLE, France
- DMT GmbH & Co., Germany
- Forshungszentrum Julich GMBH, Germany
- Karlsruhe Institut fuer Technologie (KIT) Germany
- National Center for Scientific Research "Demokritos" (NCSR), Greece
- Isotoptech Nuklearis Technoloiai Esszolgaltato Reszvenytarsasag, Hungary
- Radioökologiai Tisztaságért Tarsadalmi Szervezet (SORC), Hungary
- TS Enercon Mernokiroda KFT, Hungary
- Ansaldo Nucleare SPA, Italy
- Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Italy
- Istituto Nazionale di Fisica Nucleare (INFN), Italy
- Nucleco Societa Per L'Ecoingegneria, Italy
- Politecnico di Milano, Italy
- Societa Gestione Impianti Nucleari (SOGIN), Italy
- University of Pisa, Italy
- Valstybinis Moksliniu Tyrimu Institutas (FTMC), Lithuania
- Nuclear Research and Consultancy Group, Netherlands
- Institutt for Energiteknikk (IFE), Norway
- Regiei Autonome Tehnologii pentru Energia Nucleara - Institutul de Cercetari Nucleare Pitesti (RATEN), Romania
- Amphos 21 Consulting SL, Spain
- Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas (CIEMAT), Spain
- Agencia Estatal Consejo Superior Deinvestigaciones Cientificas (CSIC), Spain
- Empresa Nacional de Residuos Radioactivos SA (ENRESA), Spain
- Universidad Autónoma de Madrid, Spain
- Paul Scherrer Institut, Switzerland
- Galson Sciences Limited, United Kingdom
- University of Manchester, United Kingdom
- University of Sheffield, United Kingdom
- National Science Centre Kharkov Institute of Physics and Technology (KIPT), Ukraine
- Institute of Environmental Geochemistry, National Academy of Science, Ukraine



End User Group

- 25 members within End User Group (defined as **waste generators, waste management organisations**)
- Additional 15 of our 47 partners are ALSO End User Group qualified
- Additional interest parties (i.e. researcher, regulators, civil society) are part of the **Stakeholder** group

Idaho National
Laboratory,
United States





WP 2

Strategic Implementation

Partners : NNL, VTT, CEA, SCK CEN, BAM, TUS, CVRez, SURO, Isotoptech, TS Enercon, SOGIN, FTMC, CIEMAT, ENRESA, GSL, UoM, SI IEG NASU



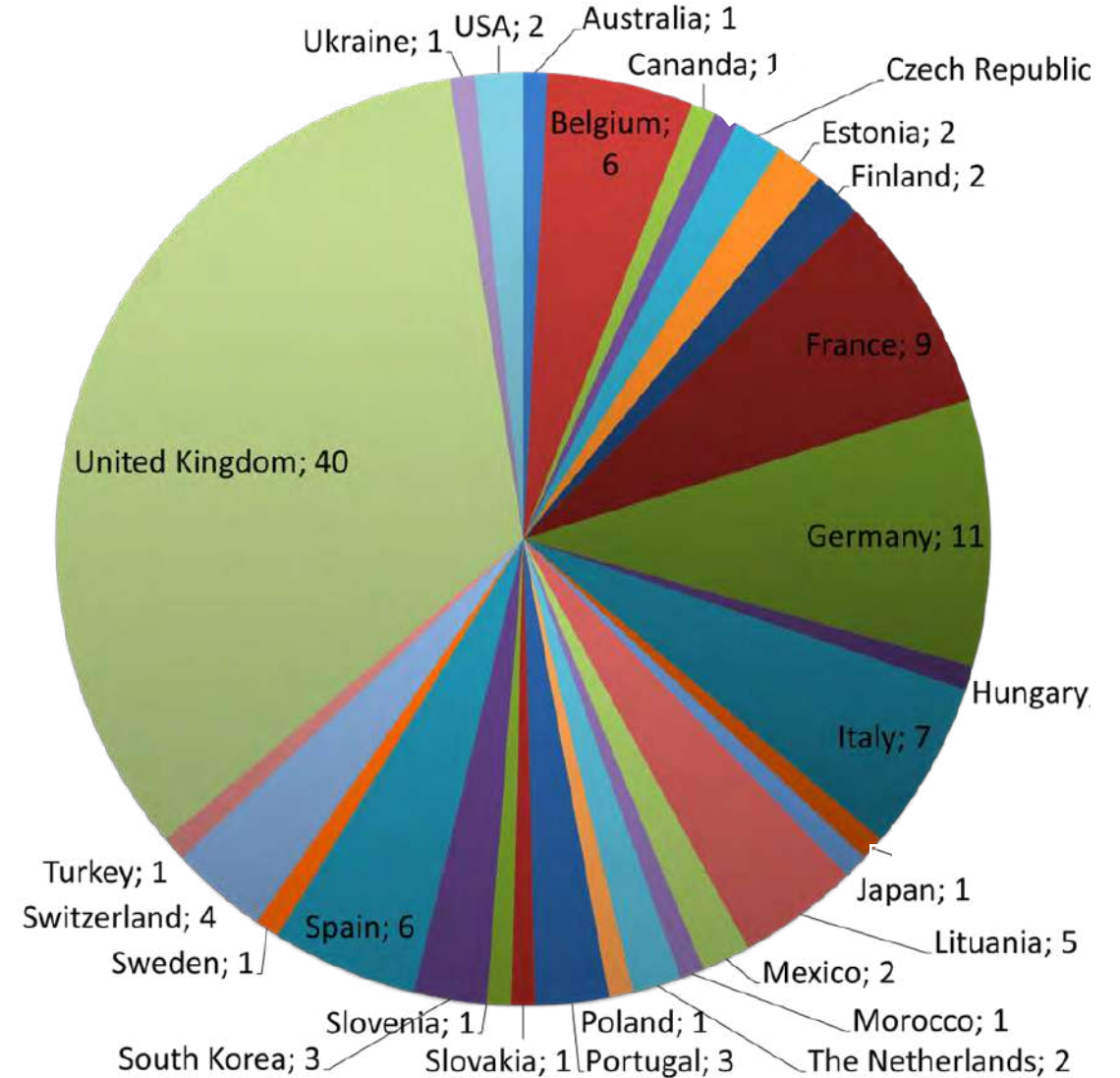
This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098.

Established a pre-disposal stakeholder community

Registered stakeholders

- o 119 individuals from **outside** project
- o both end users and stakeholders
- o 29 countries, 4 continents
- o Many different actors

..and 100s of additional participants in PREDIS stakeholder engagement / webinars etc.



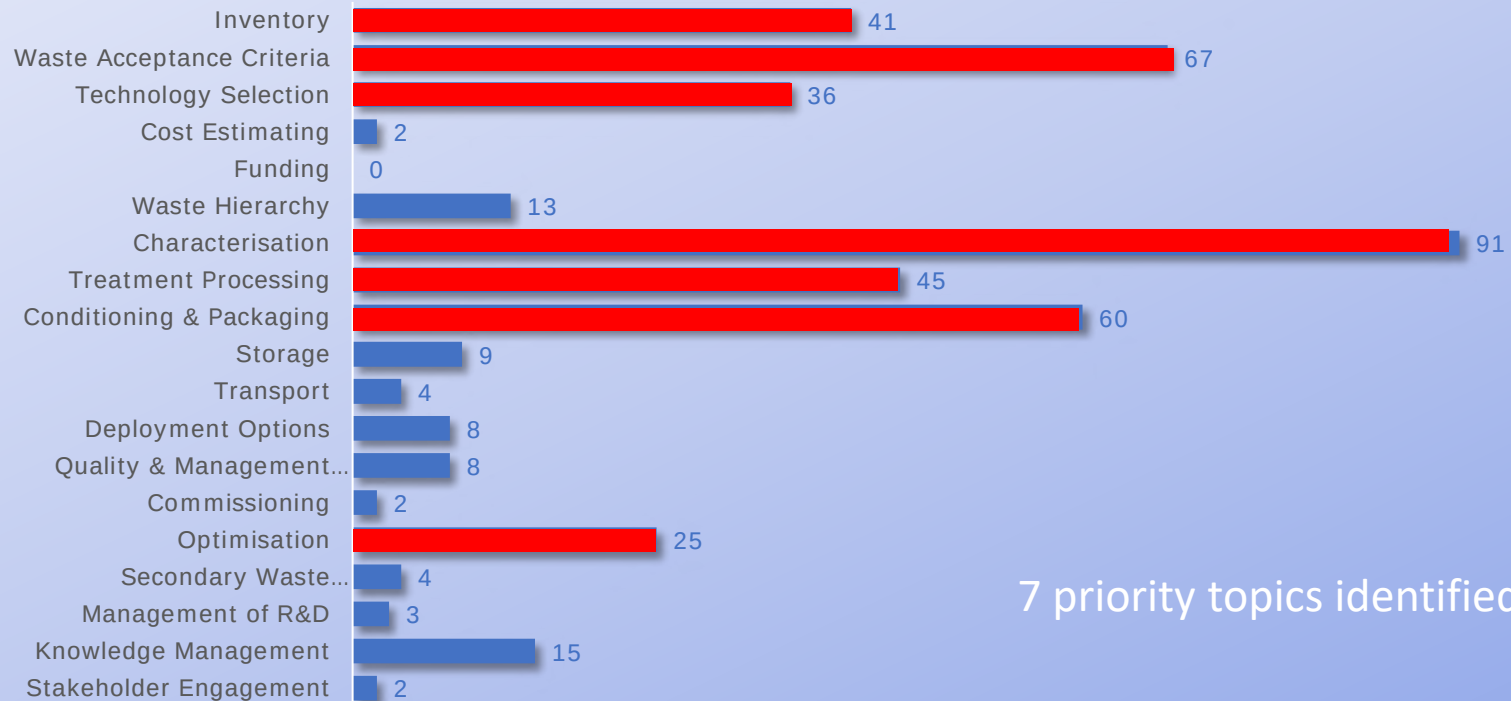
A Pre-disposal Strategic Research Agenda (SRA)

PREDIS SRA developed, in collaboration and engagement with the wider PREDIS team, partner organisations and stakeholders

Range of stakeholders



Please select the five most important topics for R&D from the list below.



7 priority topics identified



Providing Guidance on Waste Acceptance Systems/Criteria



Based on an overview of waste acceptance systems in 29 countries worldwide – PREDIS provided practical advice and guidance that will benefit stakeholders, especially the emerging programmes: including

Physical/chemical/radiological parameters and methods
for characterisation of radioactive waste



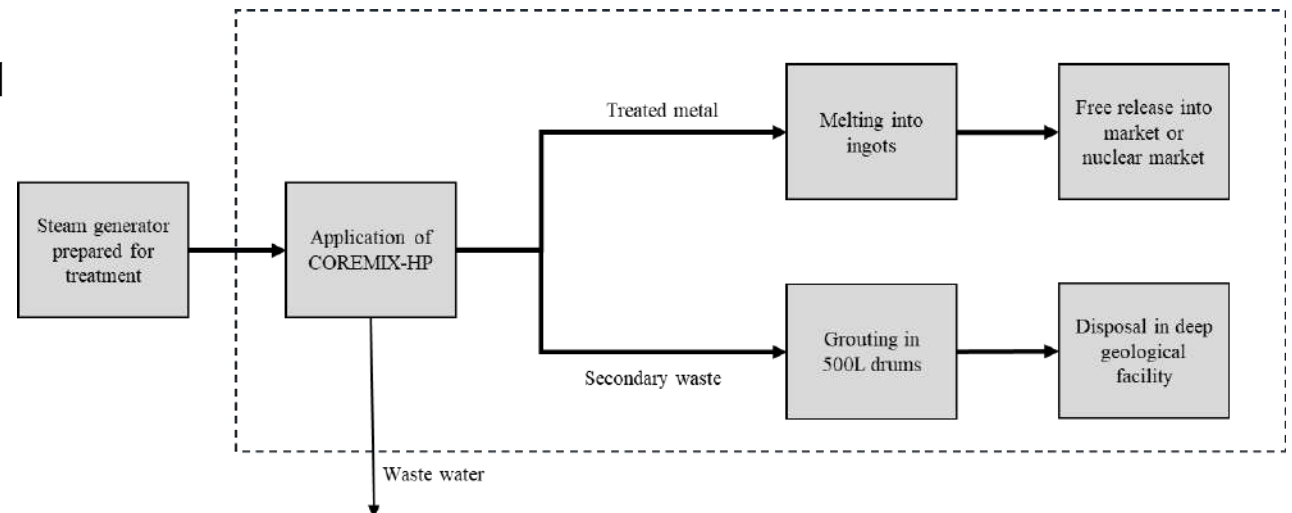
Guidance on Waste Form Qualification processes

Formulating generic waste acceptance criteria



Life cycle assessment (LCA) and costing (LCC)

- PREDIS delivered the first back-end focused LCA/LCC modelling in the sector via >15 case study models across PREDIS: demonstrated to industry that geopolymers encapsulation can environmentally outperform cementation by >60%
- Showed that using LCA/LCC during process development reduce impacts: e.g. 439 t CO₂eq saved per decontaminated steam generator; significant cost saved if diverting from GDF





WP3

Knowledge Management

Partners: JRC, AMPHOS 21, UJV, SCK CEN, GALSON-SCIENCES, VTT, IMT/SUBATECH, BAM, UNIPi, CEA, SOGIN



This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098.

WP3 Objectives

- To develop and **transfer knowledge** and **competence** across EU Member States national programmes.
- To **preserve knowledge** for coming generations.
 - Capturing knowledge (DI)
 - Building competences (courses, webinars...)
 - Acquiring tacit knowledge (mobilities)
 - Dissemination and networking (conferences, students, ...)

Achievements

- Webpage focused on Knowledge Management
- Learning by playing – 2 releases
- **Roadmap** – 1 Theme Overview + 12 Domain insight docs
- **Training**: 19 webinars + 8 courses
- 51 students (KPI = 15); students group founded
- 65 **Mobilities** (KPI = 20)

Join statement on KM with EURAD
High cooperation between projects



WP3: Knowledge Management

Training course on Radioactive Waste Management operations, from retrieval to conditioning – (La Hague)

A training on radioactive waste management was held at the La Hague spent fuel reprocessing plant in France on 20-23rd November 2023. The training was hosted by Orano as one of the PREDIS partners and end users of the project results. During the training, participants attended several lessons given by Orano professionals and also visited La Hague reprocessing plant, gained knowledge on LLW and ILW management operations, and discovered Orano's container manufacturing plants. The training was attended not only by students, but also by PREDIS experienced partners and End User Group members, making for great interactions by all.



Figure 4: Participants of the radioactive waste management course



An additional training was also provided by PREDIS and EURAD, within the Waste Acceptance Criteria Summer School, organized by partner CV Rez 4-8 September 2023 at Husinec, Czech Republic. The training provided a general overview of waste acceptance systems and criteria with a focus on different approaches in Europe. This training course was targeted to young specialists and consisted of lessons, discussion forums and visits to the Richard postscriptary as well as the UJV/CVR waste processing facilities. In total, almost 40 participated in the training, including students from PREDIS, and EURAD among others.

In the next period, an on-line training will be guidance signposting to key topics within the information and registration for this free course!

The EURAD final event, on 22nd of April 2024 in order to get the opportunity to learn about the actions, there will be a session open only for as well as pros and cons of their technical work, s within the PREDIS project. We are looking social environment.



PREDIS

WP 4 Innovations in metallic radioactive waste management

Partners : IMT, VTT, CNRS, UJV, POLIMI, GALSON-SCIENCES, UAM,>NNL, SCK CEN, CEA, ORANO, RATEN, CSIC, NUCLECO, DMT, CTU, ENRESA, NCSRD, KIPT, FZJ, FTMC, SORC



This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098.

Characterisation techniques

- Optimization of Non-Destructive Control using gamma spectrometry by reducing uncertainties:
 - e.g., geometry of segment
 - Cs-137 and Co-60 determination at the level of clearance in 1 – 2 minutes (amount of metallic waste about 100 kg)
 - Determination of activities in activated and/or contaminated metallic waste



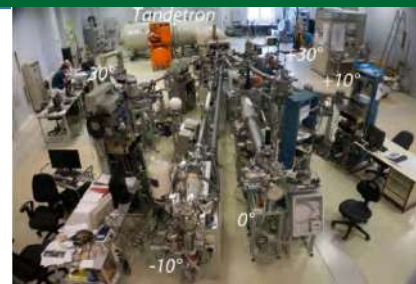
- Optimization of sorting of metallic waste.

- Development of procedures for DTM radionuclides.



$^{59,63}\text{Ni} \Rightarrow$ liquid scintillation

$^{41}\text{Ca} \Rightarrow$ Accelerator Mass Spectrometry



$^{93}\text{Zr} \Rightarrow$ liquid scintillation

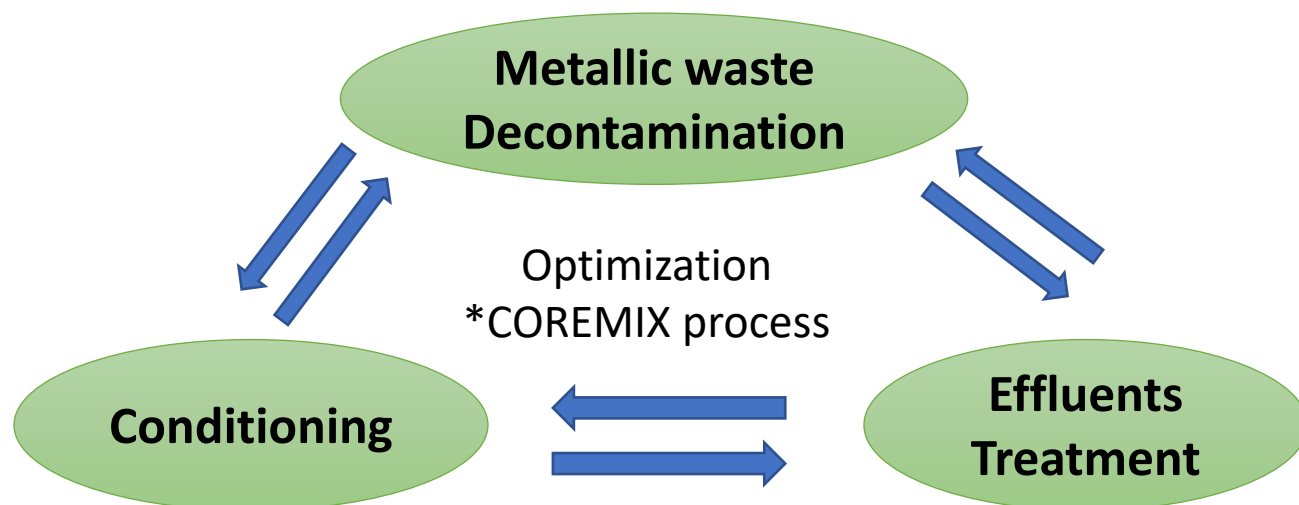
Acid digestion of surrogate metallic samples

$^{59,63}\text{Ni} \Rightarrow$ BEGe* gamma spectrometry

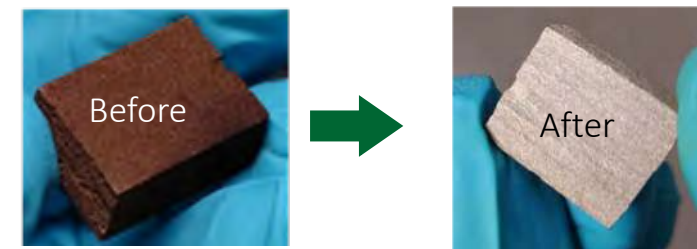


Direct evaporation on a membrane filter

Optimisation and innovation for Decontamination techniques mainly for recycling & clearance



- Simplification of the process for industrial application
- Replacement of toxic reactants
- Reduction of treatment time
- The chemicals involved are compatible with the effluent treatment step as well as the WAC for the conditioning/storage steps.



- Development of gel formulations for “dry” decontamination
- Optimization of chemical parameters of the gel for the decontamination of metals with small oxidized layer
- Hardly accessible surfaces

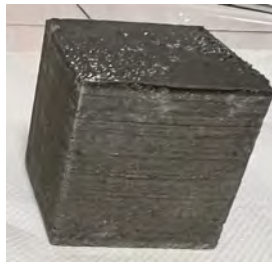


*Chemical Oxidation Reduction using nitric permanganate and oxalic acid MIXture

Conditioning of reactive metallic waste using innovative Magnesium Phosphate Cement (MPC)

- Development of MPC formulations
 - Testing new alternative fillers to replace fly ash (volcanic ash, wollastonite)
- Optimization of cost production
 - Replacement of dead burned MgO by reactive MgO + retarder. MPC price reduction by 15%.
 - Lowering the volume of cement and increase the volume of aggregates
- Qualification of the developed MPC formulations
 - Corrosion, irradiation of MPC-Al, MPC-carbon steel, **beryllium**

B0T5
5% thiosulfate



B2T3
2% boric acid +
3% thiosulfate



Ag/ClAg
external



WP 5 Innovations in liquid organic waste treatment and conditioning

Partners : CEA, SOGIN, RATEN, ECL, USFD, GALSON-SCIENCES, UNIPI, CIEMAT, CVREZ, ENEA, IMT, IRSN, KIPT,>NNL, NUCLECO, POLIMI, SCK CEN, SIIEG, UJV

Collection and review of data: reference waste

- **Description of RLOW inventories at European level** (owners, radiological and chemical compositions, volumes, storage conditions...) using questionnaires completed by WP5 partners and EUG members.
- Used RLOW inventories to identify **reference wastes**, a combination of:
 - Oils – Solvents – Scintillation cocktails**
(Cleaning and decontamination liquids – Organic effluents)
- A selection of raw materials and additives to formulate matrices:
 - Locally-sourced **Metakaolin** and **Blast furnace slag**
 - “Mixes (MK + Slag + Fly Ash)”**



Study of direct conditioning process

- Identification of 3 reference formulations families
- Robustness to test
 - RLOW variability
 - Raw materials variability
 - Process variability
- Tests with Real RLOW
- Process scale-up

1) NNL formulation – MK based

- **Row material:**
 - Metamax® - RC: Al_2O_3 = 43.99%, SiO_2 = 51.48%
- **Activator:**
 - K silicate (K120): K_2O = 21.3wt%, SiO_2 = 30.38 wt%, H_2O = 48.32 wt%
- **Optimized formulation:**
 - $\text{SiO}_2:\text{K}_2\text{O}$ = 1.2
 - $\text{K}_2\text{O}:\text{Al}_2\text{O}_3$ = 1.2
 - $\text{H}_2\text{O}:\text{K}_2\text{O}$ = 13
- **RLOW:**
 - Nevastane Oil (20% vol.)

2) SCK CEN formulation – BFS based

- **Row materials:**
 - BFS = 46.5 wt% (Al_2O_3 = 11.10%, SiO_2 = 32.40%)
 - Sand = 28 wt%
- **Activator:**
 - $\text{Na}_2\text{O} \cdot 2\text{SiO}_2 \cdot x\text{H}_2\text{O}$ - 1.5 wt. %
 - NaOH (10M) - 5.5 wt. %
 - Additional water -18.4 wt. %
- **RLOW:**
 - Ionic liquid (Aliquat 336) - 9.9 wt. % ⁽¹⁾
 - TBP - 19.1 wt. %

(1) Tween 80 surfactant used : 0.5 % and 0.95 % relative to the waste volume

3) KIPT formulation – MIX based

- **Row materials:**
 - FA = 34 wt. % (Al_2O_3 = 18 %, SiO_2 = 46.12 %)
 - BFS = 20 wt. % (Al_2O_3 = 6.02 %, SiO_2 = 40.6%)
 - MK = 14 wt. % (Al_2O_3 = 35.50 %, SiO_2 = 51 %)
- **Activator:**
 - K_2SiO_3 = 11 wt. %
 - KOH - 9 wt. %
 - Water -12 wt. %
- **RLOW:**
 - ShellSpirax: from 10% to 40% vol ⁽²⁾

(2) Castament FW 10 (solid Polyethylene glycol-based additive) used to improve several properties: 0.5 %



50 vol% loading of Nevastane EP 100 in MetaMax geopolymer (left) and Argicem geopolymer (right).



Geopolymer samples (curing 24h): comp. No.5 (left), and the same with pump oil content of 30 %wt (comp. No.8) of pump oil (right).

Availability of a treatment and conditioning process for RLOW

Tests results with Real RLOW

	Oil $^{137}\text{Cs} + ^{60}\text{Co}$	TODGA (solvent) $^{241}\text{Am} + ^{244}\text{Cm} + ^{152}\text{Eu}$	Ionic solution $^{63}\text{Ni} + ^{14}\text{C}$	Scintillation cocktail $^{63}\text{Ni} + ^{14}\text{C}$
MK-Based	~30 % vol.	~30 % vol.	~15 % vol.	~15 % vol. ~30 % vol.
BFS-based	~20 % vol.	/	~20 % vol.	~20 % vol.
MIX-based	~30 % vol. No incorporation of real RLOW	/	/	/

- No significant differences
- Good leaching resistance
- Decrease in compressive strength with RLOW

Process scale-up

	Nevastane oil 20 and 30 % vol.
MK-Based	50L – 100L Drum (20-30 % vol. pilot-scale)
BFS-based	50L Drum (20 % vol. pilot-scale) Need formulation optimization



Figure 1 Geopolymer composition during mixing (left), after curing (middle) and cut bottom of the drum after curing (right)

Disposability assessment related to Waste Acceptance criteria (WAC)

- **Leaching behavior** of three formulation families (MK-based, BFS-based and MIX-based):
 - Storage conditions must be in endogenous and not in aerated conditions (cracks)
 - Leaching and waste release (surrogate or real radionuclides) in basic and neutral solutions remains low
- **Stability to irradiation** (^{60}Co and ^{137}Cs sources, up to 200kGy): no significant impact on leaching
- **Evaluation** of the RLOW geopolymers waste form characteristics and properties in terms of **acceptability for disposal** at near-surface and geological disposal facilities
 - Comparison of geopolymers with different RLOW with the typical current waste management approach, called the baseline scenario
 - Criteria studied: physical form, mechanical stability, homogeneity, void space, free liquids, chelating/complexing agents, leaching

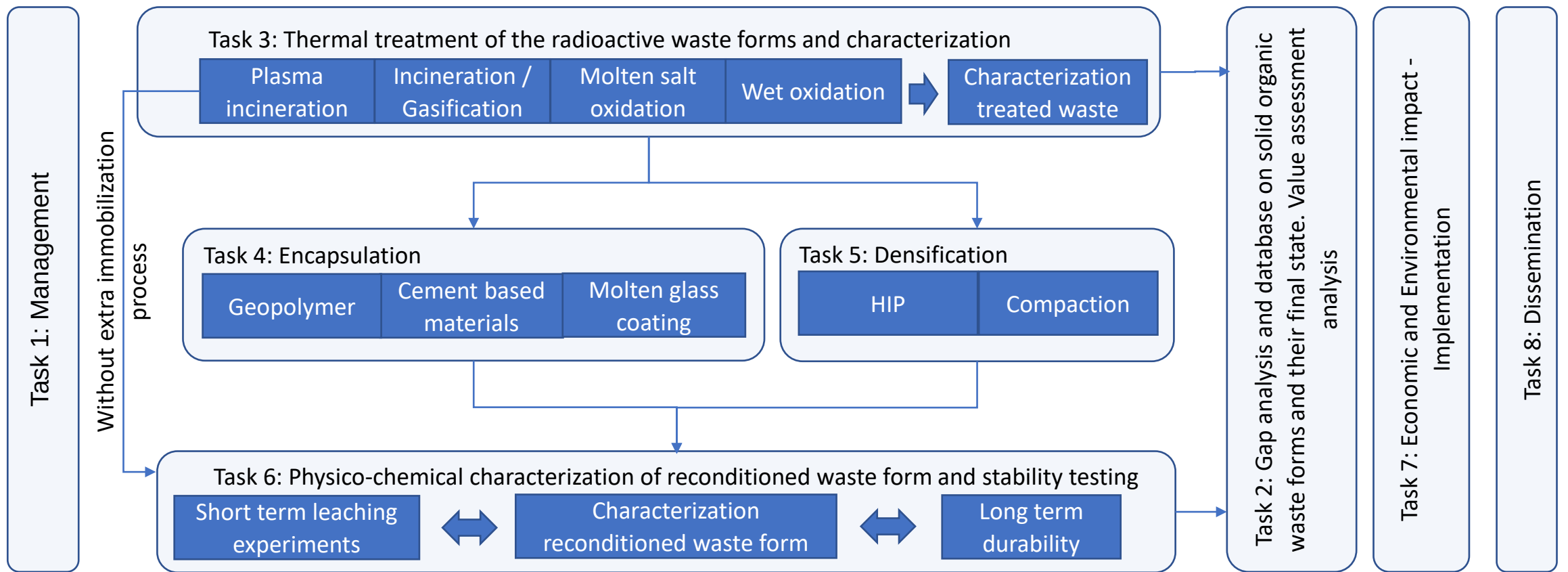
Rating	Risk to disposability
Green	No risk to disposability
Grey	No, limited or partially applicable experimental data
Amber	Limited risk to disposability
Red	Significant risk to disposability

Assessment area	Oil - MK	Oil - MK	Oil - Mix	Oil - BFS	Solven t - MK	Solven t - MK	Solven t - MK	CS - MK	CS - MK	CS - MK
	CIEMAT	NNL	KIPT	CVRez	NNL	POLIMI	UJV	POLIMI	UJV	CIEMAT
Physical form										
Mechanical stability										
Homogeneity										
Void space										
Free liquids										
Chelating agents										
Leaching										

WP 6 Innovations in solid organic waste treatment and conditioning

Partners : CEA, CIEMAT, CSIC, CVRez, GALSON-SCIENCES, KIPT, NNL, POLIMI, SCK CEN, SIIEG, UAM, Univ. Helsinki, USFD, VTT

Immobilization of RSOW after thermal treatment



RSOW after thermal treatment

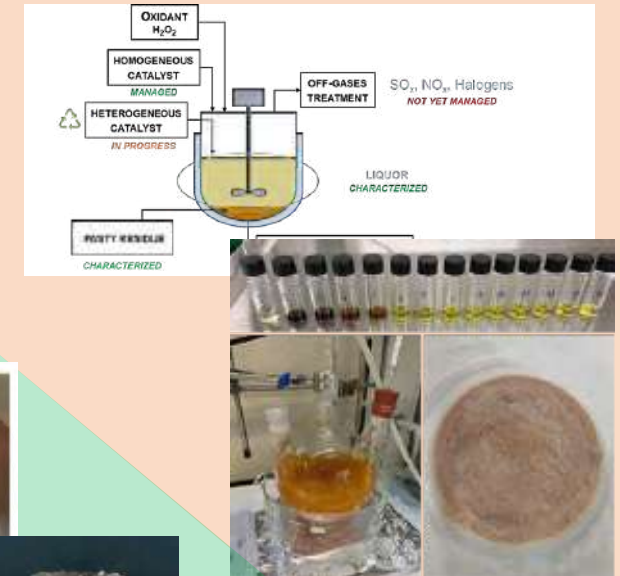
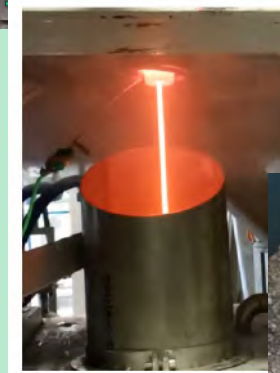
Task 3: Thermal treatment of the radioactive waste forms and characterization

Plasma
incineration

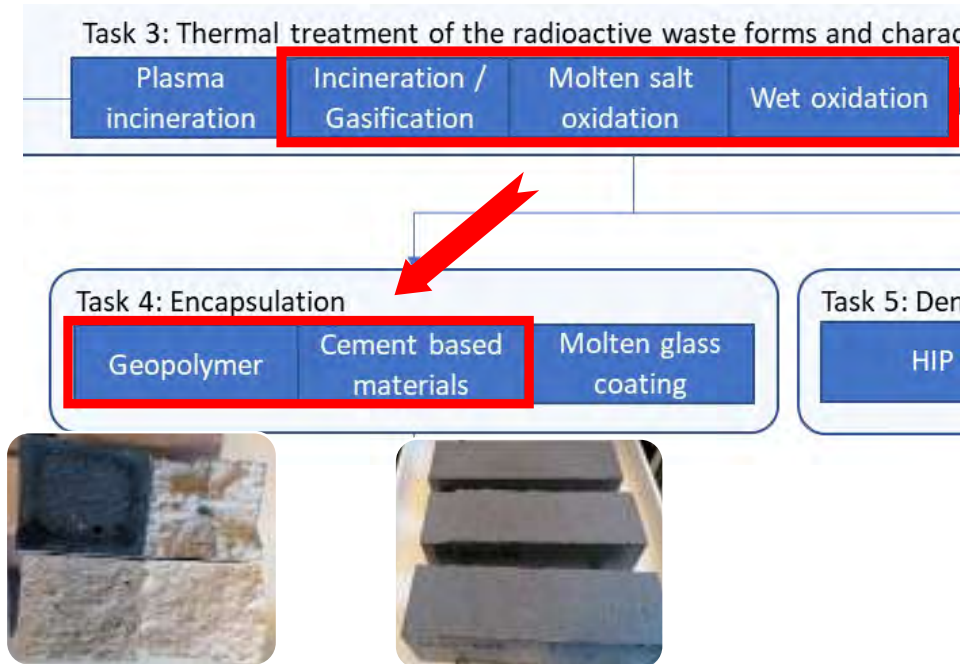
Incineration /
Gasification

Molten salt
oxidation

Wet oxidation

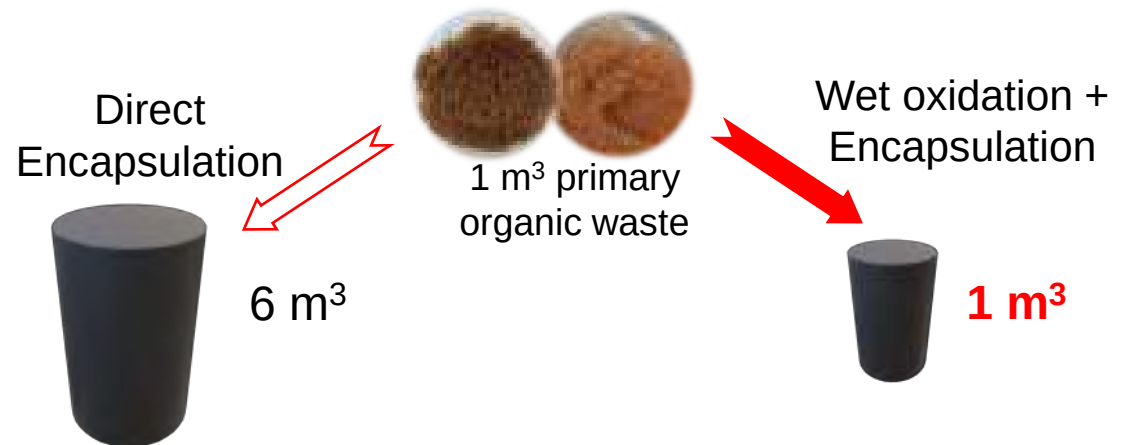


Geopolymer & Cement based materials immobilisation



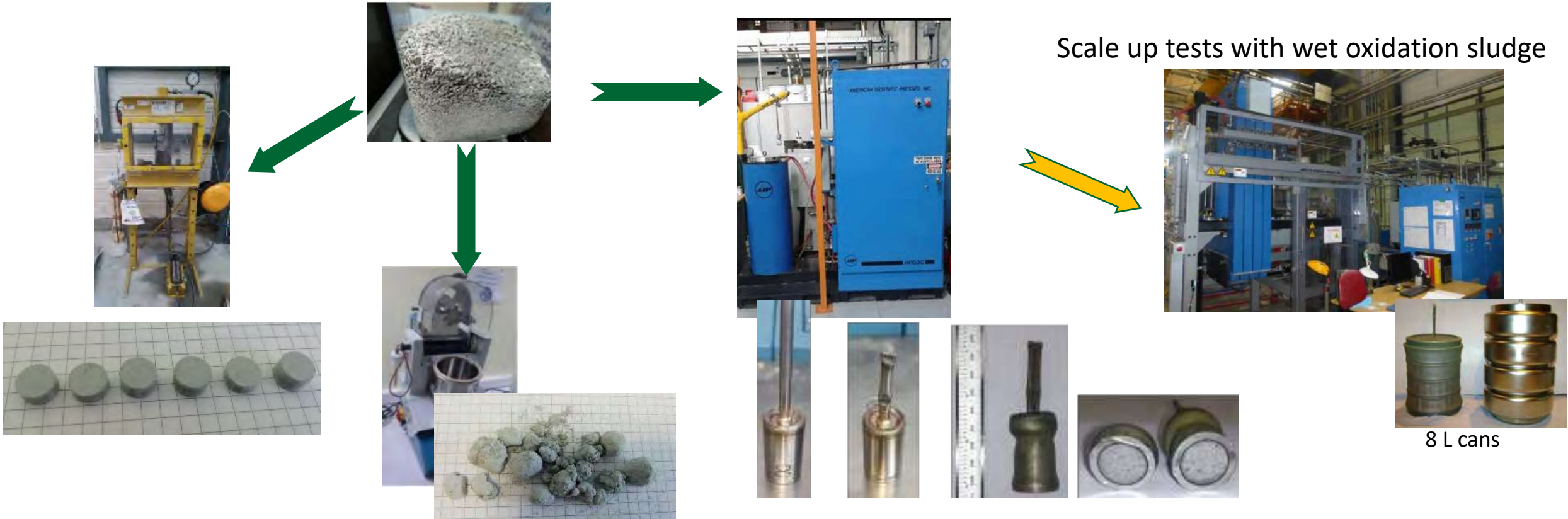
- Matrices design and optimization
 - 10% - 20% of thermally treated resins in the geopolymer
- Characterisation (calorimetry, μ -structure, mineralogy, porosity,...)
- Leaching experiments on reconditioned waste

Different treated wastes require different immobilisation matrices

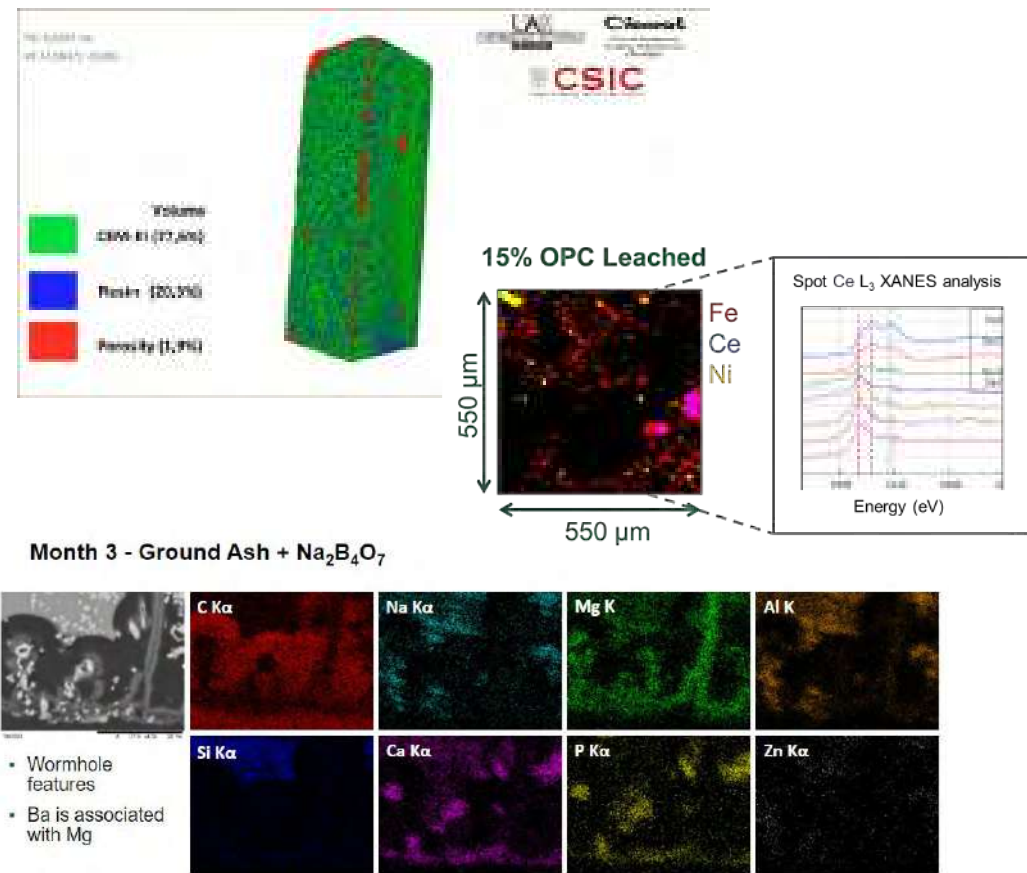


Densification / HIP

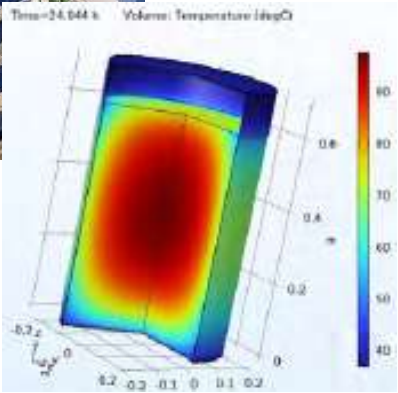
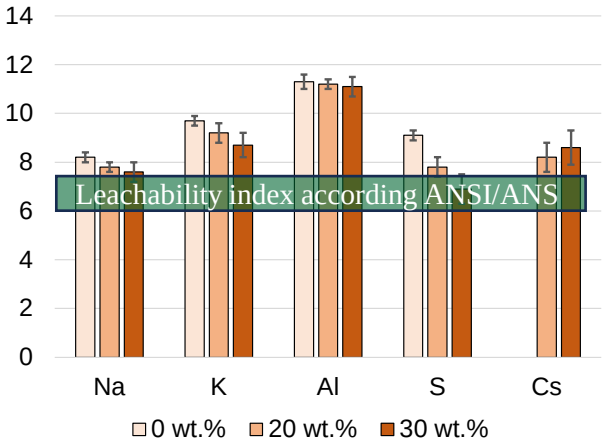
Scale up tests with wet oxidation sludge



Physico-chemical characterization of reconditioned waste forms and stability testing



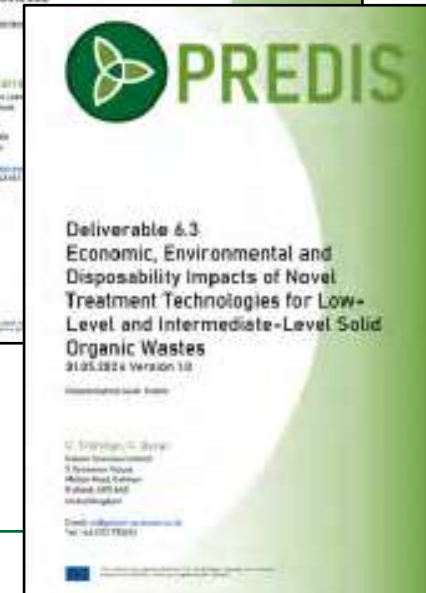
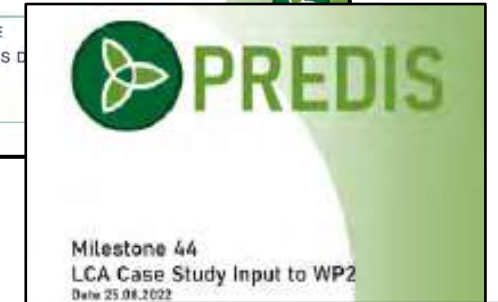
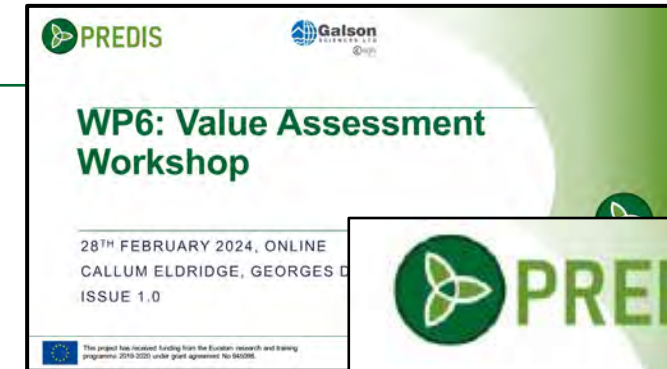
Leachability Indices



New treatment technologies generally offer benefits compared with current options

Scenario ID	Raw waste	Treatment baseline or novel technology	Treatment output
6.1	 Anionic IER Organic solids	   IRIS & HIP	200 L Drum
6.2		   IRIS & Compaction	
6.3		   IRIS & Geopolymer	
6.4		   MSO & Geopolymer	

- **Benefits in terms of** material environmental impact, package disposability and the disposal and storage costs for the product drums.
- **Further development** would remove or reduce the identified disbenefits of the considered technologies, which could in future become more **sustainable** and **less costly** alternatives for the long-term management of RSOW.

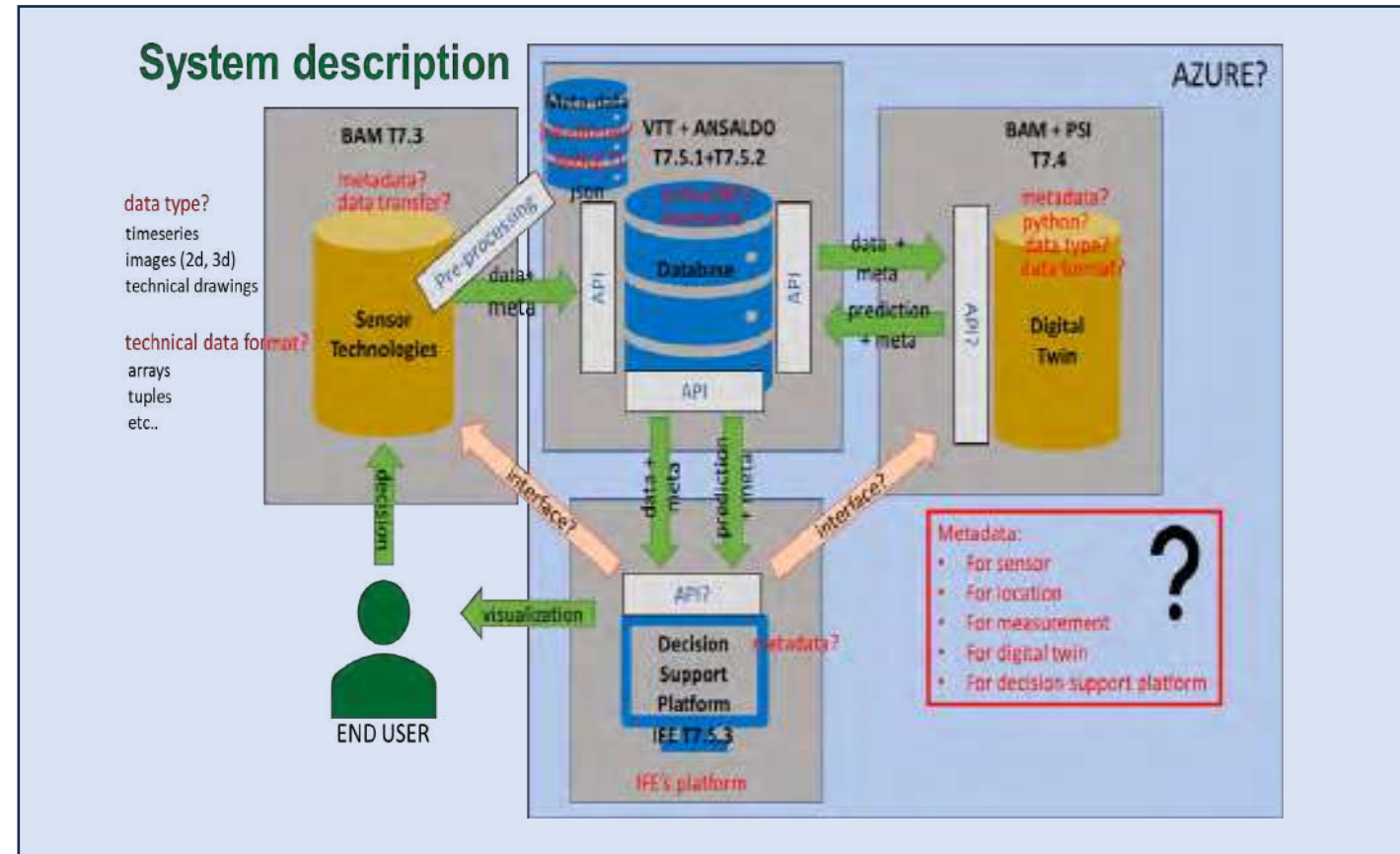


WP7 Innovations in cemented waste handling and pre-disposal storage

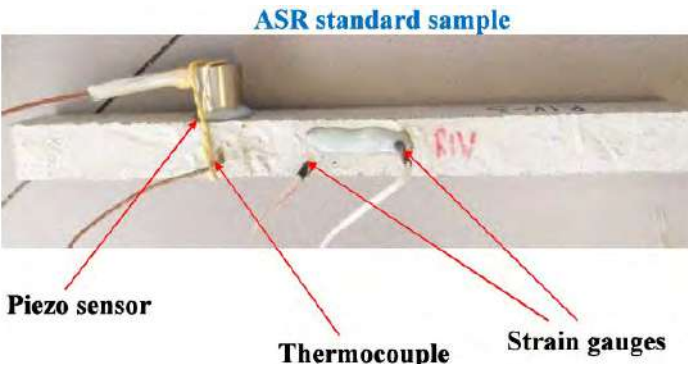
Partners : BAM, Amphos21, GALSON-SCIENCES, IFE, INFN, KIT, MAGICS, NNL, PSI, SCK CEN, VTT, UNIPI, NRG, ORANO, SOGIN, UJV

Objectives

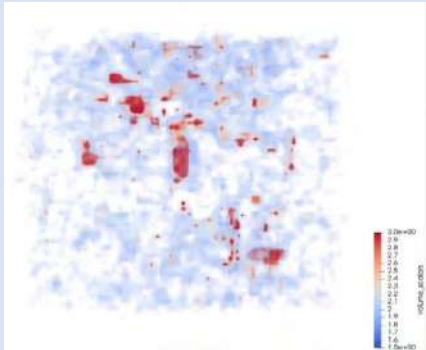
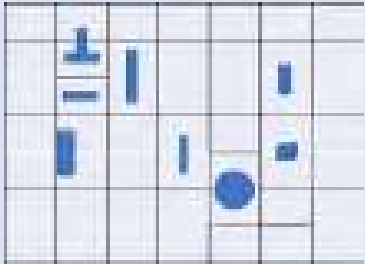
- Identify, **evaluate and demonstrate** store and package **quality assurance** (mainly NDE) and monitoring technologies
- Adapt and demonstrate **digital twin technology**
- Develop and demonstrate **methods for data handling**
- Develop and demonstrate a **digital decision framework**



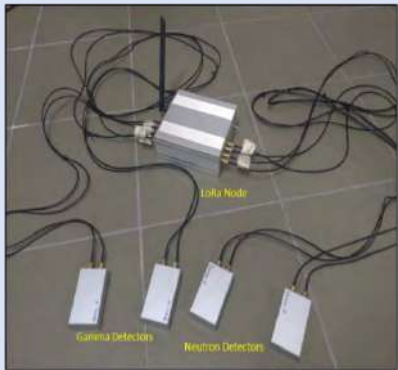
Testing and Monitoring: New sensing options



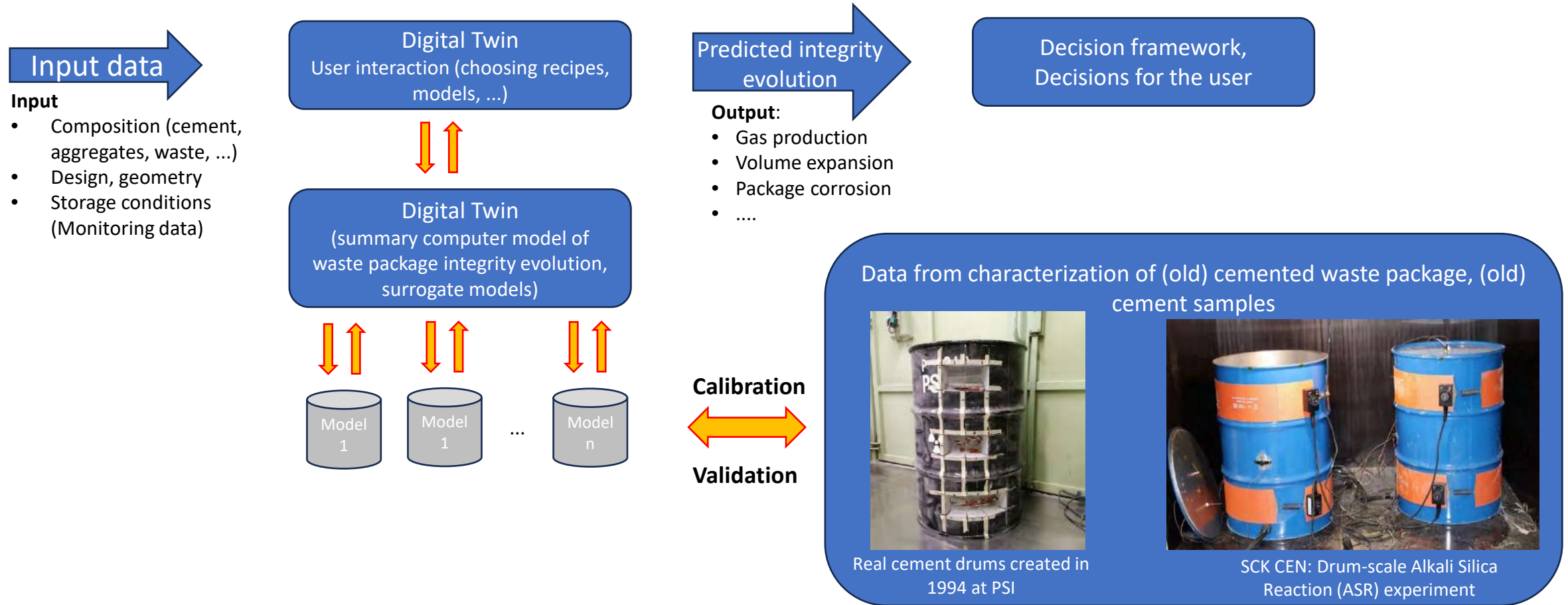
Muon Tomography



Waste Drum Embedded
Sensors (T, P, %RH)



Digital Twin Development



Demonstration tests

- **Demonstrate** that the technologies, methods, developed models, and the data handling/processing can be used in a **nuclear environment**.
- Demonstration test:
 - 3 technologies tested
 - 2 mock-ups to replicate nuclear cemented packages
 - 3 months test
 - many parameters tested and monitored on a specific Dashboard
- Demonstration test:
 - 1 technology tested on real historical waste packages during many months
 - Many parameters measured and monitored





PREDIS

Conclusions



This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098.

Few figures ...

Contributions



2500+ person months
450+ persons
(37 % **female**, 63 % male)
51 students

Outcomes



55 milestones
61 (+5) deliverables
3 large workshops (+3 online)
TRL increases, also LCA/LCC
Lab & field upscaling demos

Website



> 4500 users
> 10 000 sessions
> 30 000 pageviews

Publications



40+ Scientific articles
100+ Conference presentations
8 Newsletters
8 Blogs and Case Studies
1 Position paper + SRA

Webinars



20 organised
> 600 individual participants
> 40 countries
Webinars recorded, serving as e-training lectures

Collaboration



4 MoUs signed
1 Joint statement
Over 100 companies on stakeholder list



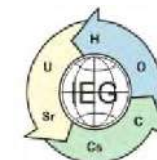
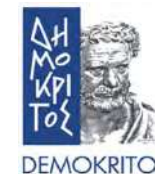
NATIONAL NUCLEAR
LABORATORY



sck cen



MAGICS®





Thank you for your attention!



This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098.

This study was carried out in the framework of a public-public cooperation between SCK CEN and ONDRAF/NIRAS.

This cooperation concerns scientific research and technical-scientific support for the safe management of radioactive waste on short-, middle- and long-term, including training and education on this subject.

With this partnership, ONDRAF/NIRAS and SCK CEN want to strengthen and consolidate their collaboration within strategic research domains of the Belgian national programme for radioactive waste management. In this way, a robust framework is created with a view on increased efficiency and long-term continuity of knowledge and expertise within the Belgian programme.



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SCK CEN

Belgian Nuclear Research Centre
Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire

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Stichting van Openbaar Nut
Fondation d'Utilité Publique

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Boeretang 200 - 2400 MOL - Belgium
Chemin du Cyclotron 6 - 1348 Ottignies-Louvain-la-Neuve - Belgium

KNOWLEDGE MANAGEMENT IN EURAD

Importance of knowledge and KM in daily life of implementing RWM activities

Niels Belmans (SCK CEN Academy, WP13 Lead)
on behalf of EURAD WP11, WP12 and WP13



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°847593



EURAD KNOWLEDGE MANAGEMENT & NETWORKING PROGRAMME

IAEA defines knowledge management (KM) as:

*“an integrated, systematic approach to identifying, acquiring, transforming, developing, disseminating, using, sharing and preserving knowledge, relevant to achieving specified objectives”**

*: Karseka and Yanev, IAEA, 2013



EURAD KNOWLEDGE MANAGEMENT & NETWORKING PROGRAMME

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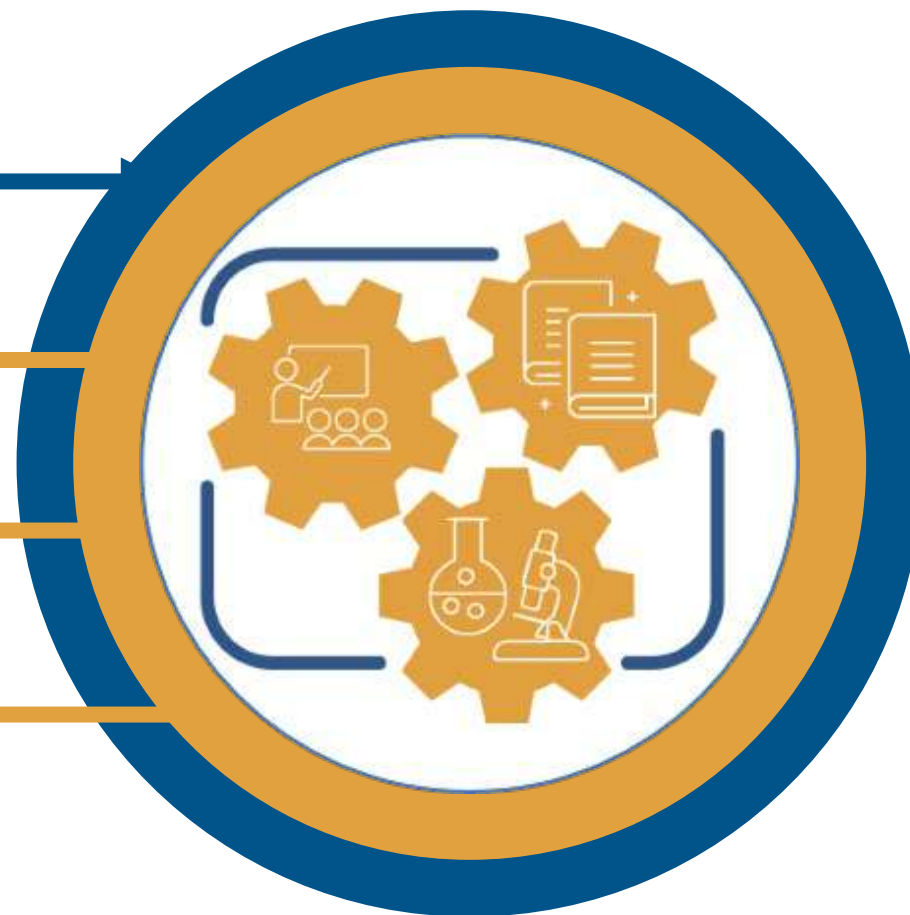
→ “Enhance knowledge management and transfer” is one of EURAD’s main objectives

→ EURAD Knowledge Management & Networking Programme

*: Karseka and Yanev, IAEA, 2013

EURAD KNOWLEDGE MANAGEMENT & NETWORKING PROGRAMME

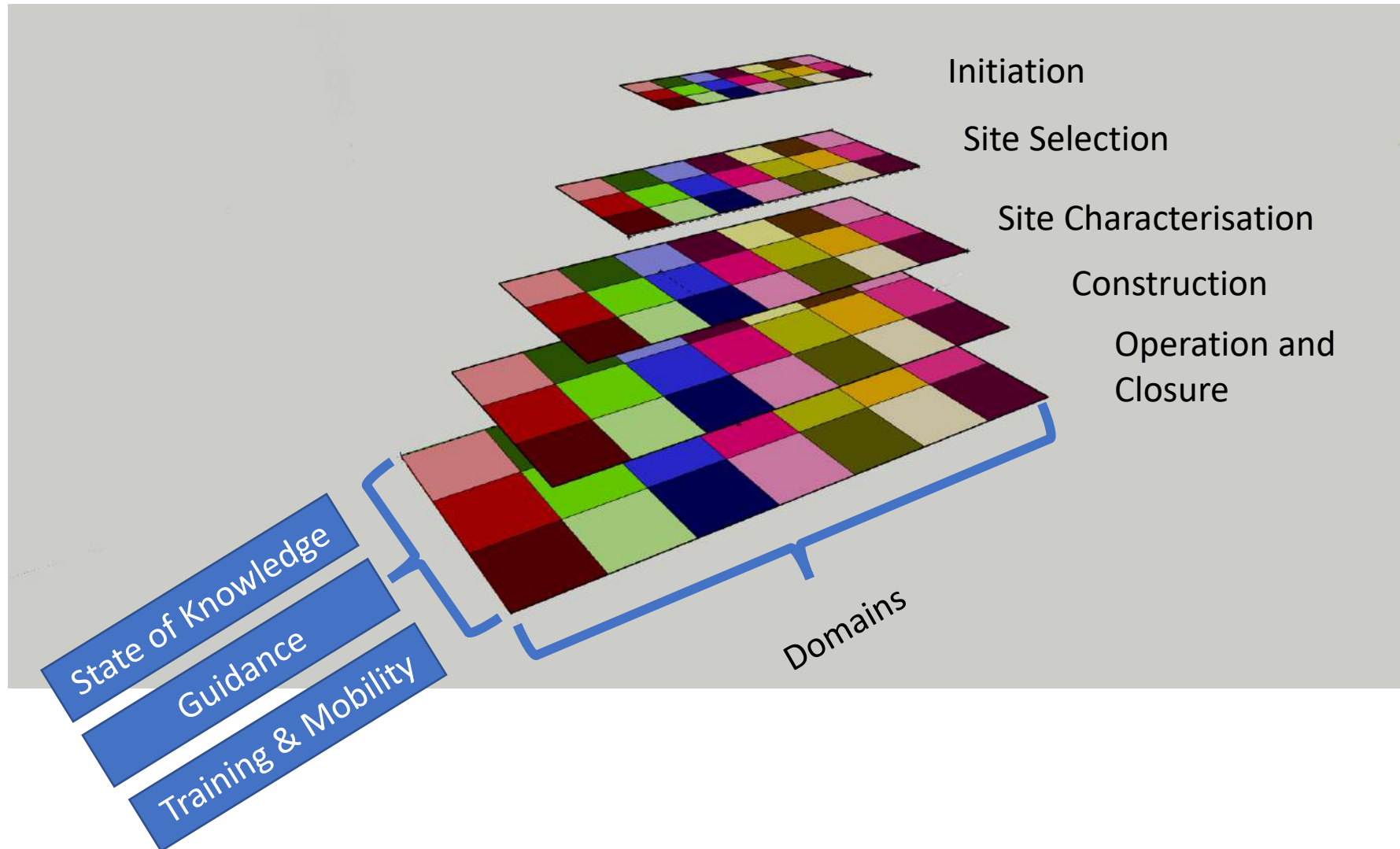
- 1 Roadmap
A common framework to structure knowledge
- 2 State of Knowledge
What we know and why its important
- 3 Guidance
Best practice and lessons learned
- 4 Training & Mobility
Nuclear experience and know-how
- 5 Networking & Tools
Connecting people to people, and people to content



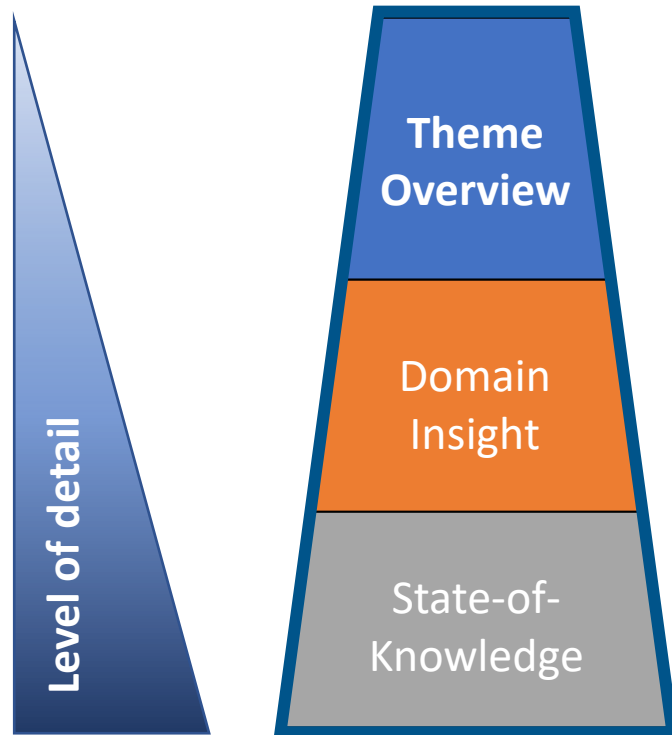
ROADMAP AND KM



ROADMAP AND KM



WP11 STATE OF KNOWLEDGE - THE DOCUMENT STRUCTURE



Theme Overview

Broad description of programme goals and typical activities for each theme and how they evolve over the phases of implementation

Domain Insight

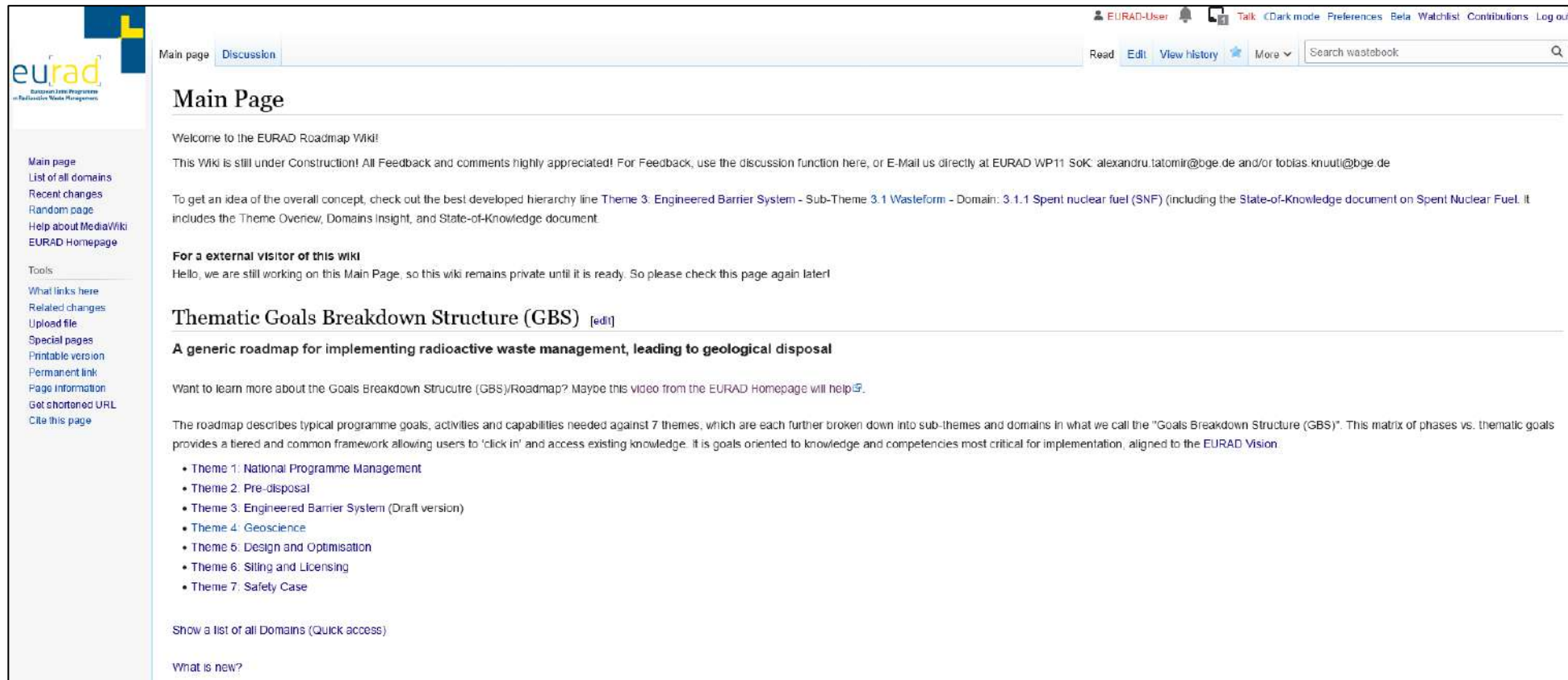
Context documents that provide direct links for each knowledge domain to safety and implementation goals related to DGR requirements

State-of-Knowledge

Experts' view of the most relevant knowledge and associated uncertainties in a specific domain applied in the context of a radioactive waste management programme

WP11 STATE OF KNOWLEDGE – MAKING KNOWLEDGE AVAILABLE

- It is not enough to just create documents, they need to be available and discussed
→ One way to share is through the EURAD Wiki



The screenshot displays the EURAD Wiki Main Page. The page features a top navigation bar with links for 'Main page', 'Discussion', 'Read', 'Edit', 'View history', and a search bar. A sidebar on the left contains links for 'Main page', 'List of all domains', 'Recent changes', 'Random page', 'Help about MediaWiki', 'EURAD Homepage', 'Tools', 'What links here', 'Related changes', 'Upload file', 'Special pages', 'Printable version', 'Permanent link', 'Page information', 'Get shortened URL', and 'Cite this page'. The main content area includes a welcome message, a notice about the wiki being under construction, and a list of thematic goals. The goals are listed as follows:

- Theme 1: National Programme Management
- Theme 2: Pre-disposal
- Theme 3: Engineered Barrier System (Draft version)
- Theme 4: Geoscience
- Theme 5: Design and Optimisation
- Theme 6: Siting and Licensing
- Theme 7: Safety Case

At the bottom of the page, there is a link to 'Show a list of all Domains (Quick access)' and a section for 'What is new?'.



WP12 GUIDANCE - OBJECTIVES

- **To facilitate orientation in**
 - the field itself;
 - existing knowledge resources;
 - existing international cooperation and networking
- **To facilitate understanding different solutions in different cases and countries.**



WP12 GUIDANCE – SET UP

- **Expected End user groups:**
 - expert in early-stage programs,
 - Young experts and beginners in all programs,
 - key decision makers and stakeholders
- **Relevant Guidance could be developed only on mature topics**
- **Need for transparent process of topics selection.**



OBJECTIVES AND SET UP

- The School of RWM:
 - Act as **coordinating structure** for all training activities
 - Pay attention to the **best-fitted training format**
 - Guarantee **scientific state-of-the-art** (by enlisting subject matter experts as lecturers)
- End-users are
 - Professionals
 - Students
 - Next generation of experts
- Training portfolio linked to EURAD **Roadmap** and referenced in SoK documents
- Mobility
- No registration fee



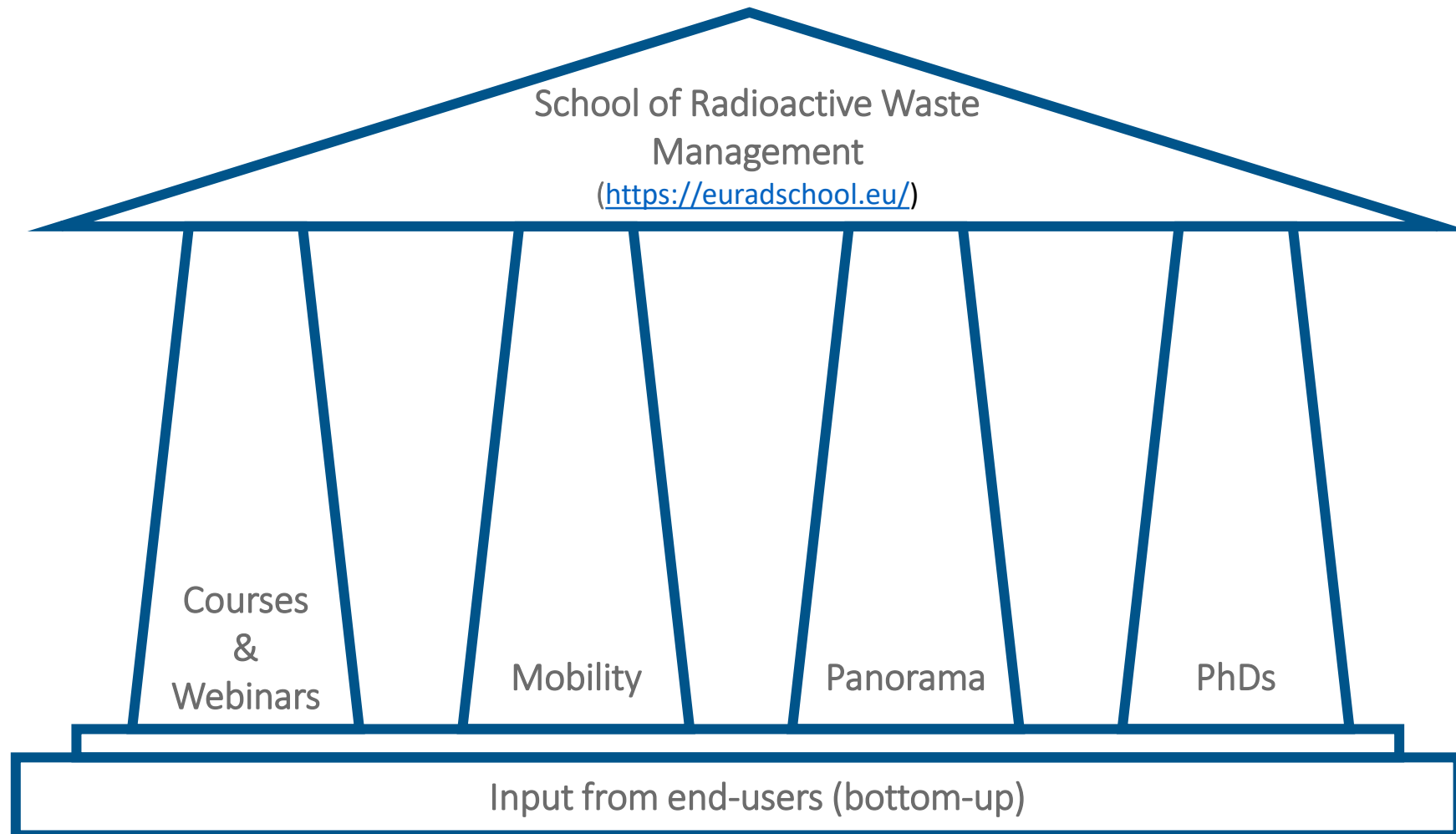
THE EURAD SCHOOL OF RADIOACTIVE WASTE MANAGEMENT

- The School of Radioactive Waste Management (RWM) aims to assist end-users in:
 - *“an integrated, systematic approach to identifying, **acquiring**, transforming, **developing**, **disseminating**, using, **sharing and preserving knowledge (and skills)**, relevant to achieving specified objectives”*

THE EURAD SCHOOL OF RADIOACTIVE WASTE MANAGEMENT

- The School of Radioactive Waste Management (RWM) aims to assist end-users in:
 - *“an integrated, systematic approach to identifying, **acquiring**, transforming, **developing**, **disseminating**, **using**, **sharing and preserving knowledge (and skills)**, relevant to achieving specified objectives”*
- To this end, the School supports competence (= knowledge, skills and attitudes) building through:
 - Creating a portfolio of needs-driven (existing and newly developed) training courses
 - Organisation of webinars on broad and specific topics by subject-matter experts
 - Hosting a dedicated Mobility Programme
 - Supporting the EURAD PhD community
 - ➔ Providing a panoramic view of all aspects involved in radioactive waste management
- ➔ Centralized on a dedicated website: <https://euradschool.eu/>

THE EURAD SCHOOL OF RADIOACTIVE WASTE MANAGEMENT



WP13 TRAINING – OBJECTIVES

- All new training courses are **needs-driven**
 - **End-user feedback** was gathered in 2020: 80 respondents
 - **Training needs** were identified
- Over 150 **existing courses** identified (September 2021)
- **A training gap analysis** was performed
 - E.g. uncertainty management in radioactive waste management
- All new training courses are **quality-driven**
 - Quality criteria based on **IAEA's Systematic Approach to Training** developed in EURAD
 - ➔ Ensure uniform quality in training courses

WP13 MOBILITY – OBJECTIVES

- The EURAD Mobility Programme financially supports:
 - Performing **internships**
 - Performing **technical visits**
 - Attending **training courses**
 - Attending **conferences**
- Focussed mostly on **implicit** and **tacit knowledge**
- Based on **learners needs**
 - Applicants can contact programme partners directly with specific questions
 - List of infrastructures is available on School of RWM website: <https://euradschool.eu/infrastructures/>
- Programme partners can offer internships

WP13 WEBINARS – OBJECTIVES

- The School of RWM organises webinars on **broad** and **specific** topics by subject-matter experts
- Aim is to **share knowledge** with the entire radioactive waste management community and beyond
- Recorded in order to **preserve knowledge** and **facilitate dissemination**



WP13 – SUPPORT THE PHD COMMUNITY

- **The School wants to support the EURAD PhD community by providing:**
 - Information on available/upcoming courses
 - The possibility to perform mobility actions
 - An overview of all PhD research performed in EURAD (<https://euradschool.eu/overview-of-phds/>)
 - A list of events of interest for PhD students
 - A discussion forum (<https://forum.euradschool.eu/>)
- **The aim is to foster a community between the PhD students, researchers and the Training and Mobility work package**

➔ **PhD students are the future key figures in radioactive waste management!**



EXPECTED IMPACTS

As per the original work package (WP) description, the objectives of the Training and Mobility WP are:

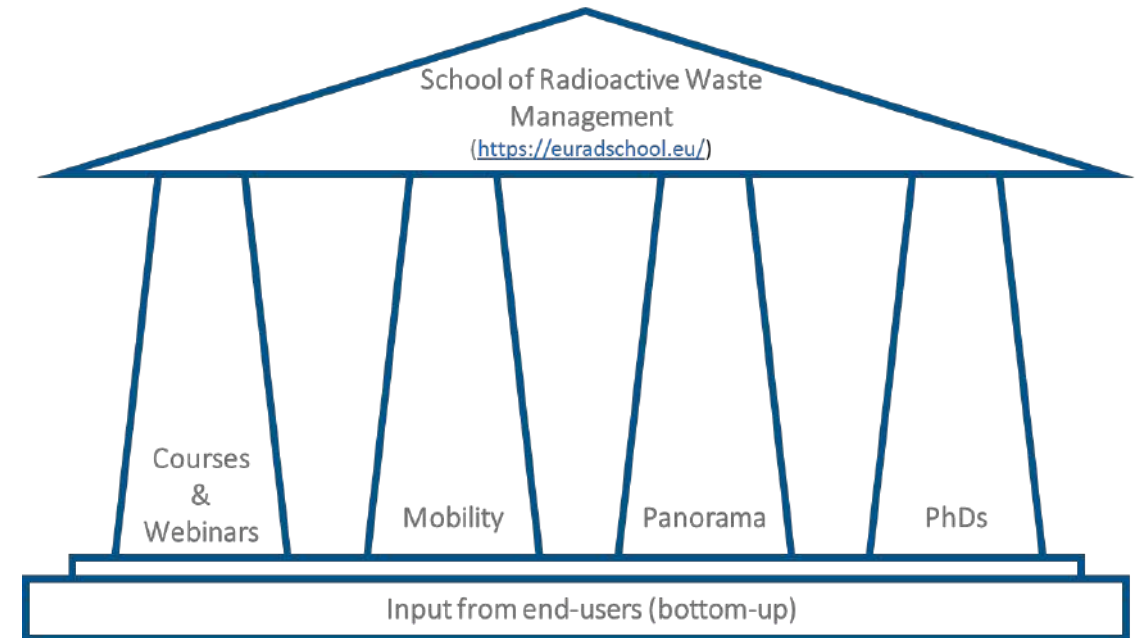
- To compose a diverse portfolio of tailored basic and specialised training courses for the end-users under the umbrella of a “School of RWM”
- To organise a Mobility Programme which provides access to dedicated infrastructures associated with the Mandated Actors/Linked Third Parties. Mobility actions can be seen either as a complementary action after one or more training course(s) or can be part of the Continuous Personal Development (CPD)

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As per the original work package (WP) description, the objectives of the Training and Mobility WP are:

- To compose a diverse portfolio of tailored basic and specialised training courses for the end-users under the umbrella of a “School of RWM”
- To organise a Mobility Programme which provides access to dedicated infrastructures associated with the Mandated Actors/Linked Third Parties. Mobility actions can be seen either as a complementary action after one or more training course(s) or can be part of the Continuous Personal Development (CPD)

RESULTS



The EURAD School of RWM served as an inspiration for the WP3 activities in PREDIS. Close collaboration between both EURAD WP13 and PREDIS WP3 was established. Furthermore, it serves as the foundation for WP2.4 in EURAD-2.

EXPECTED IMPACTS

As per the original work package (WP) description, the objectives of the Training and Mobility WP are:

- To compose a diverse portfolio of tailored basic and specialized training courses for the end-users under the umbrella of a “School of RWM”
- To organise a Mobility Programme which provides access to dedicated infrastructures associated with the Mandated Actors/Linked Third Parties. Mobility actions can be seen either as a complementary action after one or more training course(s) or can be part of the Continuous Personal Development (CPD)

RESULTS

Training courses:

- 15 training courses, including
 - Waste Acceptance Criteria Summer School
 - Safety Case Development and Review
 - Uncertainty Management
- 31 webinars
(mostly Lunch & Learn sessions)

Mobility:

- 98 mobility actions approved
- 93% success rate

PhDs:

- 4 PhD student-focused events
- Steps taken to launch a ‘Student Community’, managed by EURAD PhD students

RESULTS - TRAINING COURSES

Title	Date	Location
EURAD Training on Multiphysical couplings in geomechanics	January 20 – 24, 2020	University of Liège, Belgium
Introductory course on EURAD and Radioactive Waste Management	September 14, 2020	Online
WP FUTURE Education & Training Event on the scientific basis and safety relevant aspects of radionuclide transport and retention	November 17, 2021	Online
EURAD Training Course on Safety Case Development and Review	November 28 – December 2, 2022	SURO, Prague, Czech Republic
Information session and discussion on the Spent Fuel State-of-Knowledge document	January 18, 2023	Online
Geochemical and Reactive Transport Modelling for Geological Disposal	February 6 – 10, 2023	University of Bern, Switzerland
EURAD Training course on Uncertainty Management	February 14 – 16, 2023	BelV, Brussels, Belgium
Information and discussion session on the SoK document on Containers	June 5, 2023	Online
Training course Multiphysics and multiscale coupled processes in geomaterials – Focus on thermal effects and gas transfer impact on the behaviour of geomaterials	August 28 – September 1, 2023	University of Liège, Belgium
EURAD-PREDIS Summer School on Waste Acceptance Criteria	September 4 – 8, 2023	Rez Research Centre, Czech Republic
Workshop – Ukrainian experience from exercising radioactive waste management under exceptional conditions	October 16, 2023	Online
EURAD Training course on application of Requirement Management Systems	January 16 – 18; 2024	Mercure Budapest Castle Hill, Hungary
EURAD Training course on Monitoring in Geological Disposal facilities of radioactive waste	January 22 – 26, 2024	Online

RESULTS – WEBINARS (SELECTION OUT OF 32 WEBINARS ORGANISED*)

Title	Date	Number of live participants
Implementation of the world's first geologic disposal facility for spent nuclear fuel – Status update from Finland	22/06/2022	82
Knowledge Management in the German NWMO (BGE) – Origin, approach and practical implementation	29/06/2022	50
A pluralistic tool of dialogue on RWM: the Pathway Evaluation Process (PEP)	28/09/2022	40
The NEA Forum on Stakeholder Confidence: A Platform to Share Knowledge on Stakeholder Engagement in Radioactive Waste Management	2/11/2022	47
The role of Knowledge Management in Civil Society	30/11/2022	23
Guidance on Cost Assessment and Financing Schemes of Radioactive Waste Management Programmes	23/01/2023	70
Introduction to EC projects HARPERS and HARMONIZE	25/01/2023	23
Mission (almost) completed. The Swiss proposal for a combined repository in clay rocks.	22/02/2023	185
OFFERR - eurOpean platForm For accEssing nucleaR R&d facilities	31/05/2023	36
Advisory Board Committee (ESK)	28/02/2024	27
“Plus minus what?” - Uncertainty in destructive spent nuclear fuel inventory analysis	14/02/2024	53

* All webinars can be consulted via <https://euradschool.eu/events/category/eurad-webinar/list/?eventDisplay=past>

RESULTS - MOBILITY

At the end EURAD-1, there were:

- 105 complete applications
- 98 applications approved
- 7 applications rejected (due to illegibility)
- 79 mobility reports published online

MOBILITY MISSION REPORT

This work has been partially supported by the EURAD project that has received funding from H2020-EURATOM 1.2 under grant agreement ID 847593.

The information included in this mission report consists of personal data of applicants, and in the frame of GDPR we ask you place emphasis on its integrity: the personal data in this mission report cannot be used for purposes other than the evaluation and the management of EURAD Mobility Programme. For the avoidance of doubt, this information – out of its nature – is confidential information as mentioned in Article 10.1 of the EURAD Consortium Agreement Version (17/09/2019) with effective date of 1 June 2019 (although it might not be explicitly marked as such).

KLIKNETE NEBO KLEPNETE SEM A ZADEJTE TEXT.

MISSION TITLE

Reactive transport and geochemical modelling in engineered and geological barrier systems.

DESCRIPTION

Concerned organisations

Research entities (Lithuanian Energy Institute, SCK-CEN)

Concerned infrastructures or facilities

High-performance computing

Concerned phases

Phase 1: Site evaluation and site selection

Phase 5: Post-closure

Themes and topics

Theme 3: Engineered barrier system (EBS) properties, function and long-term performance

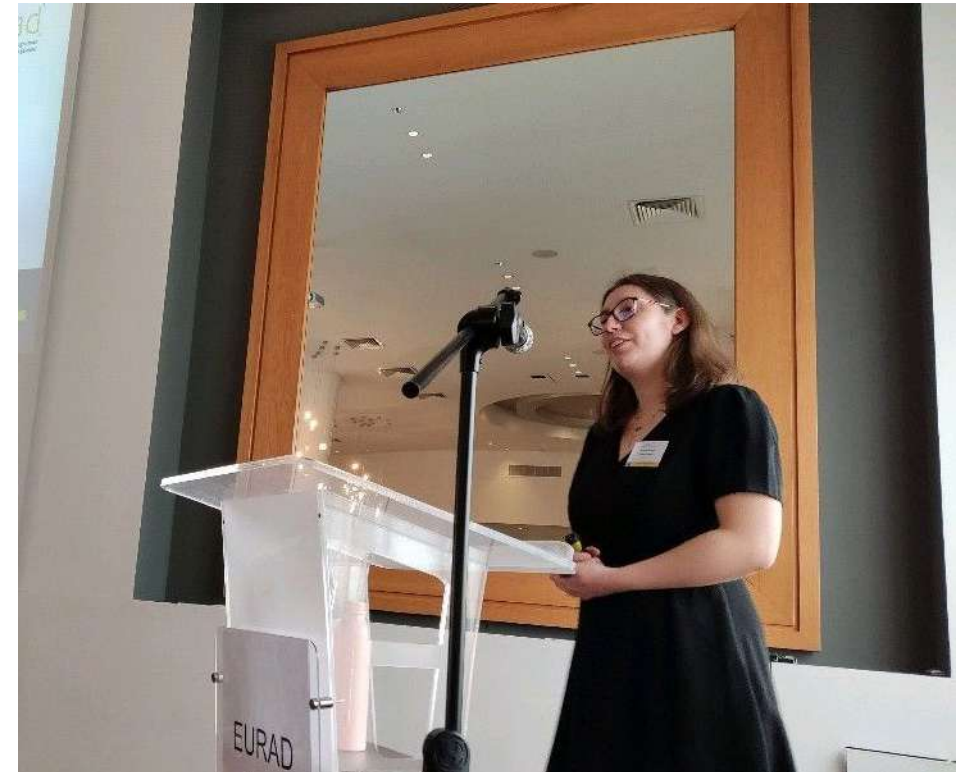
RESULTS – PHD COMMUNITY

At the end EURAD-1, there were:

- Over 120 PhD students involved
- 4 PhD student-focused events
- Steps taken to launch a 'Student Community', managed by EURAD PhD students



EURAD and PREDIS PhD students discussing among peers during the 3rd EURAD Annual Event.



Drs. Virginie Solans presenting her work in WP8 during the Student Session of the 3rd EURAD Annual Event.



CONCLUSION AND OUTLOOK

Having a competent workforce, now and in the future, is crucial for establishing safe and sustainable RWM programmes throughout Europe.

Therefore, there is a large need to continue the School of RWM's competence building activities beyond EURAD.

The School of RWM's activities will continue within EURAD-2's Knowledge Management Programme (WP2 Task 4) based on the feedback and lessons learned from EURAD-1 and PREDIS.

THANK YOU FOR YOUR ATTENTION

Niels Belmans (nbelmans@sckcen.be)



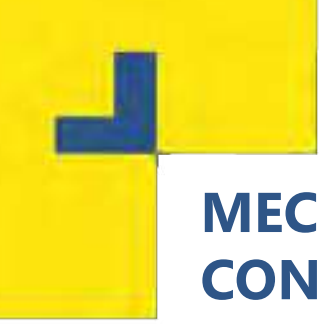
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°847593

EURAD-GAS: OVERVIEW OF KNOWLEDGE GAINED ON GAS TRANSPORT IN CLAYEY MATERIALS AND ADDED-VALUES FOR THE BELGIAN PROGRAM

October 25, 2024 • S. Levasseur (WP Leader, ONDRAF/NIRAS), E. Jacops (Task 2 leader, SCK CEN) and colleagues from ONDRAF/NIRAS, SCK CEN, UKRI-BGS, CIMNE, ULiège, TU Delft, BGR, PSI, LEI, EDF, Aalto University, COVRA, IRSN, Nuclear Waste Services, Andra and NAGRA who contributed to provide relevant input for the Belgian programme



This project has received funding from the European Union's Horizon 2020 research and innovation programme 2014-2018 under grant agreement N°847593



MECHANICAL UNDERSTANDING OF GAS TRANSPORT IN CLAYS (EURAD-GAS) – CONTEXT

1. Considerable amounts of gas can be produced in a Geological Disposal Facility (GDF)

- Mostly hydrogen, produced through anaerobic corrosion of metallic barriers & waste components
 - 2nd potentially important source is degradation of organic wastes (again, mostly hydrogen)
- Significant total gas volume even though its production will be spread over a long period of time

2. Clays as potential host rock and material for engineered barrier components

- Owing to their excellent properties for the confinement of contaminants
 - Also, a barrier for gas: low solubility of hydrogen, low diffusion coefficient for dissolved gas, high gas entry pressure, low permeability
- not easy for dissolved gas to diffuse away, not easy for free gas to displace pore water

Combining 1. and 2. above, even though gas production is slow, it is possible in some cases that it would be produced faster than it could be removed without significant gas pressures

- What consequences?

EURAD-GAS – “RAISON D’ETRE”

Address key end-users’ questions



- **How is gas transported?**

- Possible transport mechanisms throughout repository system, with focus on clay(ey) components
- How much can gas displace/carry away soluble and volatile radionuclides?



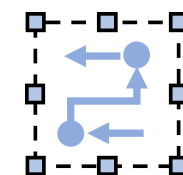
- **Effects of gas pressure on barrier integrity?**

- Gas-induced (mechanical) damage?
- Any lasting effect on performance?
- (Input for design options)

Support the safety case for gas aspects

- **Show how gas impact can be bound**

- Simple/robust conceptualizations built on properly integrated scientific bases: storyboards
- Comfort expert judgement from FORGE: gas is not a showstopper, but a question of managing uncertainties

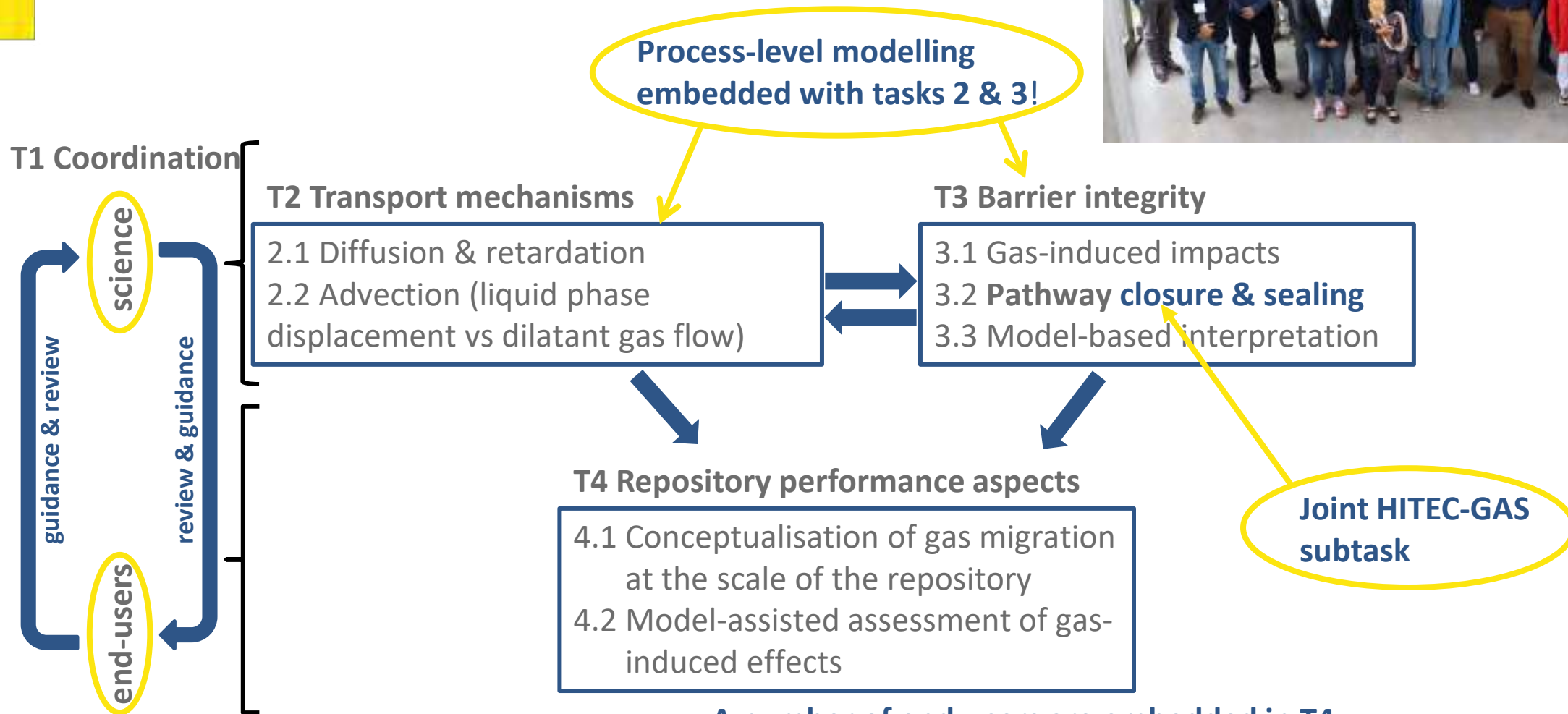


- **Develop a shared vision on gas management in *varietate concordia***

- Clear statements on scientific consensus
- Recognizing differences between national programmes as contexts can be different



GAS WP – ORGANISATION



+ Liaise with
KM SoC, guidance & training

A number of end-users are embedded in T4



EURAD-GAS – OVERVIEW OF KNOWLEDGE GAINED

Mechanistic understanding of gas transport in clay(ey) materials



- **What did we learn** from an experimental & modelling programme on gas transport?
- **What do we expect** about the impact of gas passage on clay materials and barrier integrity?

→ focus on the science

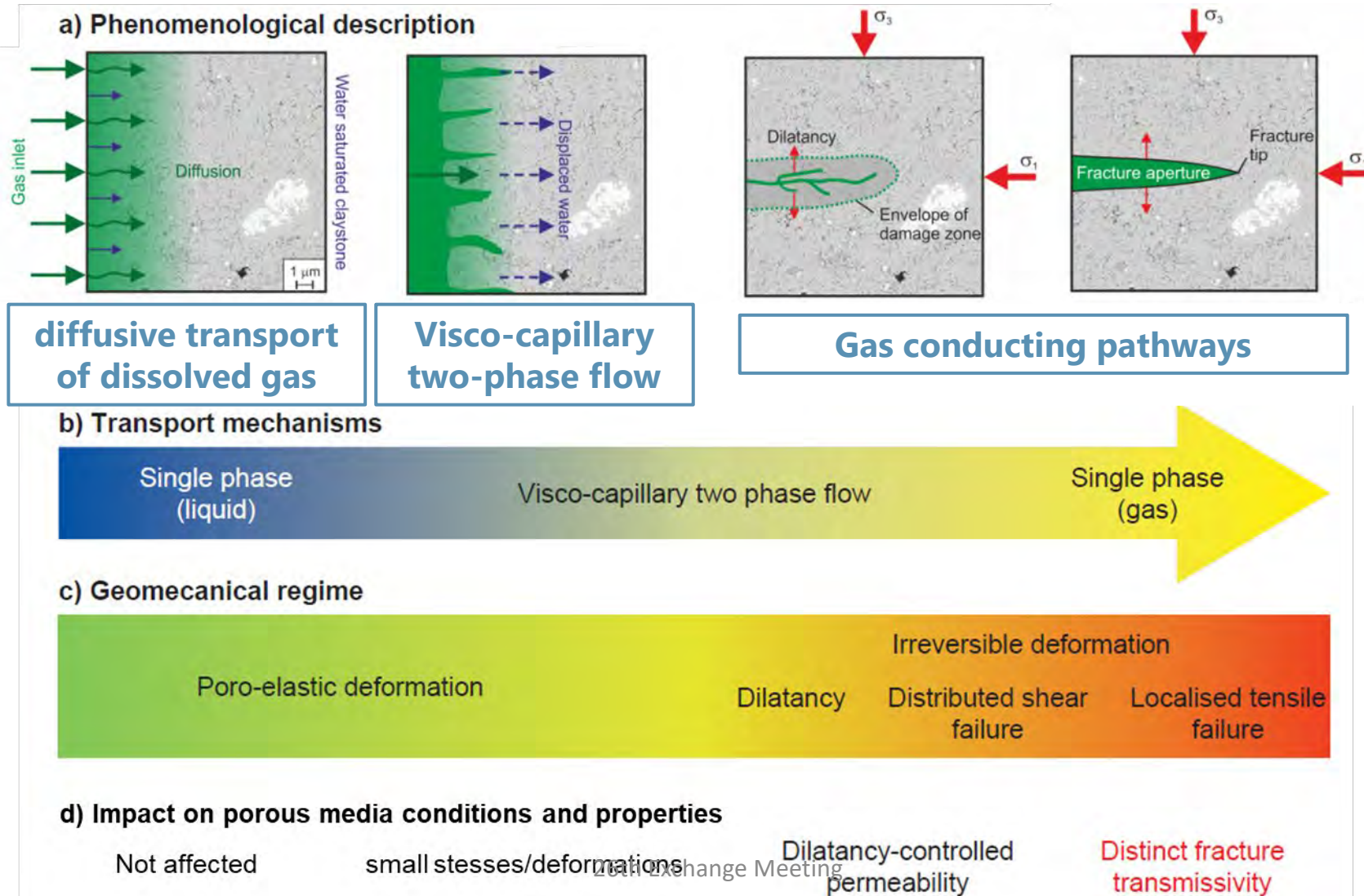
Integration in conceptualizations of the functioning of a repository system



- **Expert judgment and Storyboards** for typical repository configurations
- **Testing ≠ approaches** to represent gas effects at the component & system level

→ focus on the applications and impacts for end-users

GAS TRANSPORT MODES IN CLAYS



(adapted from
 Marschall et al. 2005
 and Cuss et al. 2014)

eurad

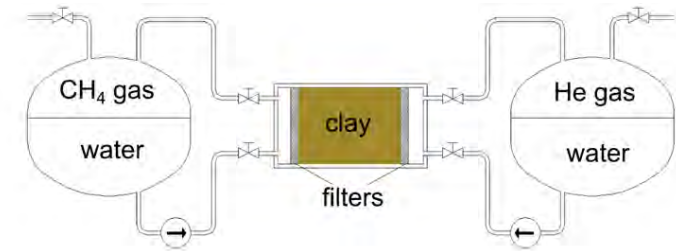
DIFFUSION OF DISSOLVED GAS IN SATURATED CONDITIONS

- Various types of laboratory setups exist for determining the diffusion coefficient over a wide range of water-saturated clayey materials and under various mechanical conditions

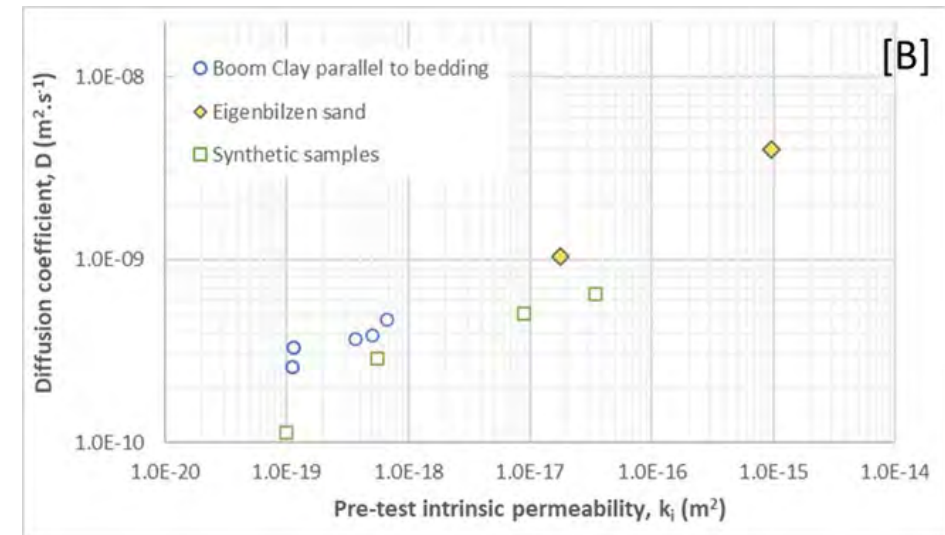
- Repeatability of such tests is good, large database
- Gas appears to **preferentially diffuse parallel to bedding** with nearly 60% of the diffusional capacity of the Boom Clay moving within the bedding planes

- A clear correlation between permeability and diffusion coefficient exists

- Variations of permeability over 3 orders of magnitude result on variations of dissolved gas diffusion coefficient of less than one order of magnitude
- **Material-dependent.** But quantitative relation to mineralogical composition & compaction remains elusive



Dissolved gas diffusivity exp. In constant volume cell (SCK CEN)



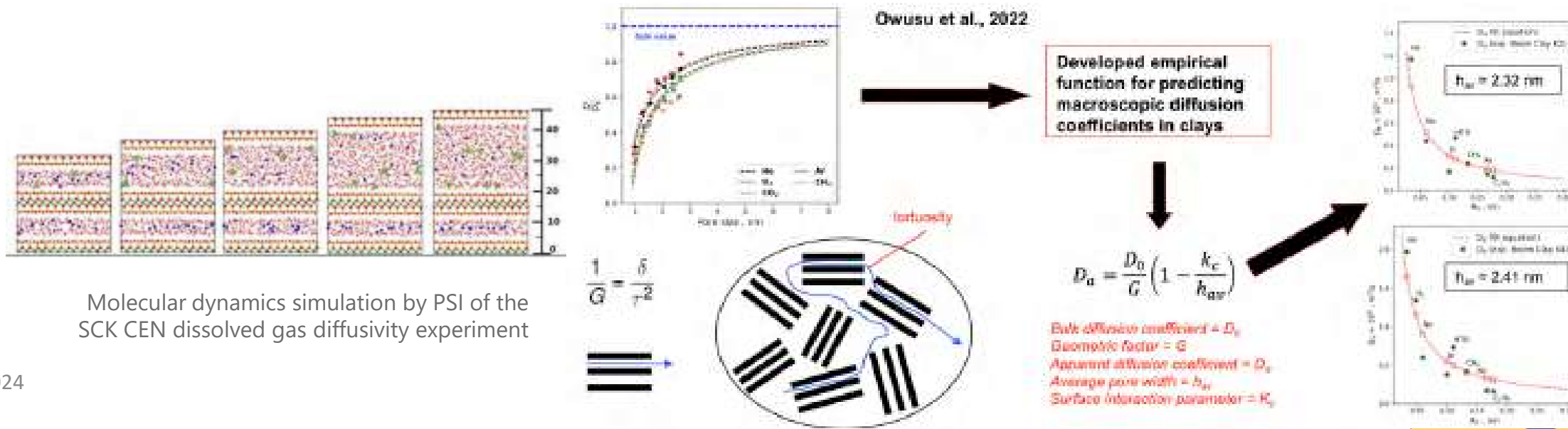
Compilation by BGS

DIFFUSION OF DISSOLVED GAS IN SATURATED CONDITIONS

• Modelling of diffusion processes at various scales

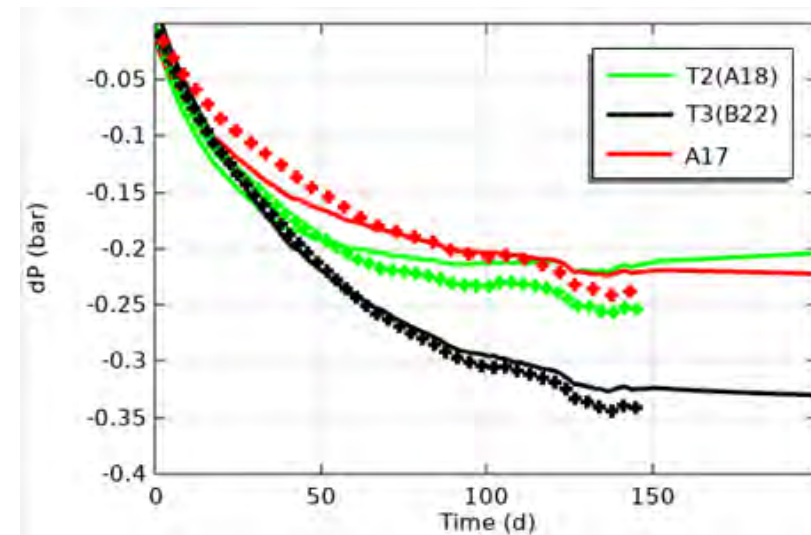
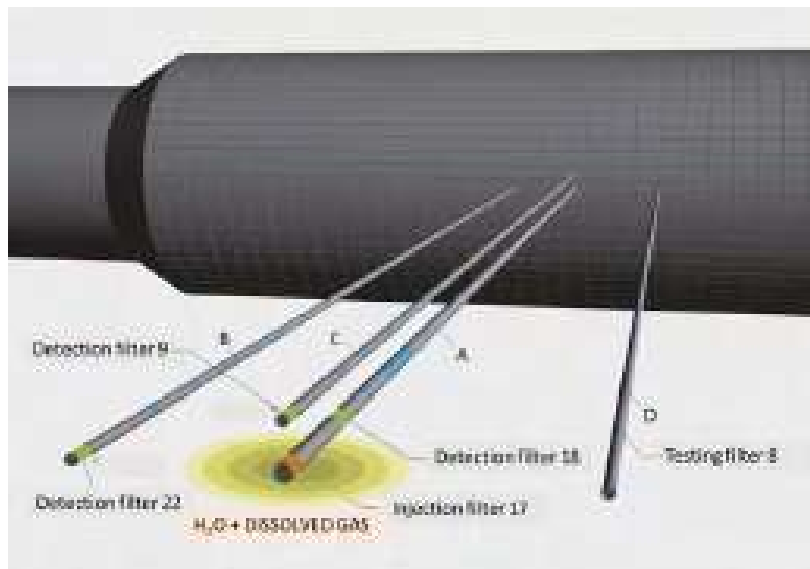
- **Macroscopic scale** modelling by BGR, Aalto University and LEI to consider the effect of various gases simultaneously
- **Molecular scale modelling** by PSI to understand in detail the mechanisms associated to diffusion processes through the analysis of the molecular diffusion trajectories of various gases

→ allow to capture the results of double through diffusion experiment performed by SCK CEN and well estimate macroscopic diffusion coefficient in Boom Clay



DIFFUSION OF DISSOLVED GAS IN SATURATED CONDITIONS – UPSCALING

- **NEMESIS Experiment: Neon diffusion in MEgaS In Situ experiment** (in situ through-diffusion exp. In HADES URL)
 - First results from Helium in-diffusion experiment → **very promising results, confirming at large scale our knowledge on diffusion coefficient**
 - Still has to be validated by a through-diffusion test that should be more accurate over time and able to capture anisotropy



DIFFUSION OF DISSOLVED GAS IN UNSATURATED CONDITIONS

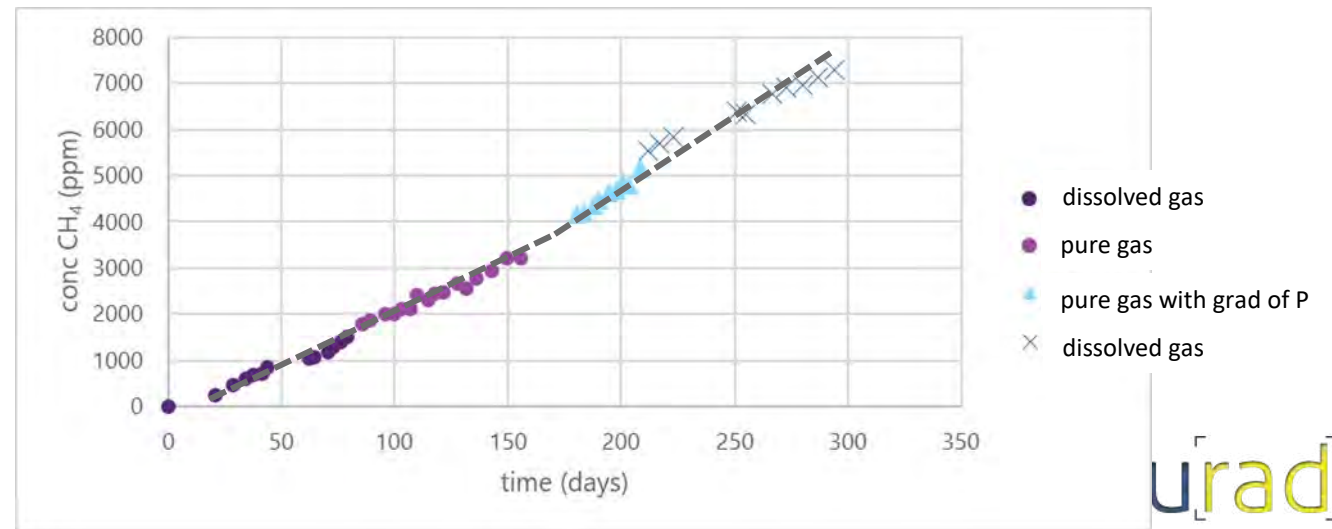
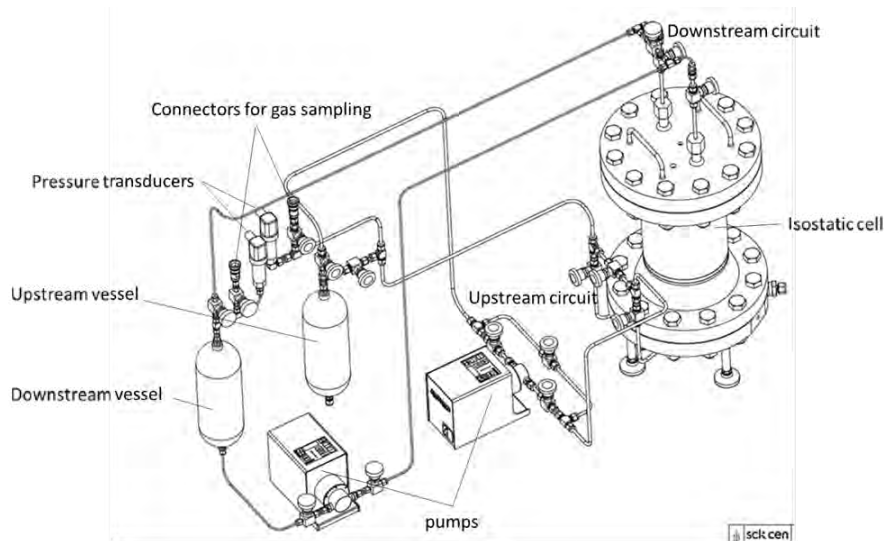
- **At relatively high levels of water saturation, between 75-100%, effect of the presence of gas-filled pores appears limited**
 - Connectivity of gas-filled pore probably limited; net gas transport remains controlled by diffusion in dissolved form
 - The experimental database is however not as comprehensive as for water saturated conditions and limited so far to synthetic clays



Double-through diffusion experiment setup
for unsaturated clay (SCK CEN)

LIMITS OF DIFFUSIVE TRANSPORT OF DISSOLVED GAS AND TRANSITION TO FREE GAS FLOW

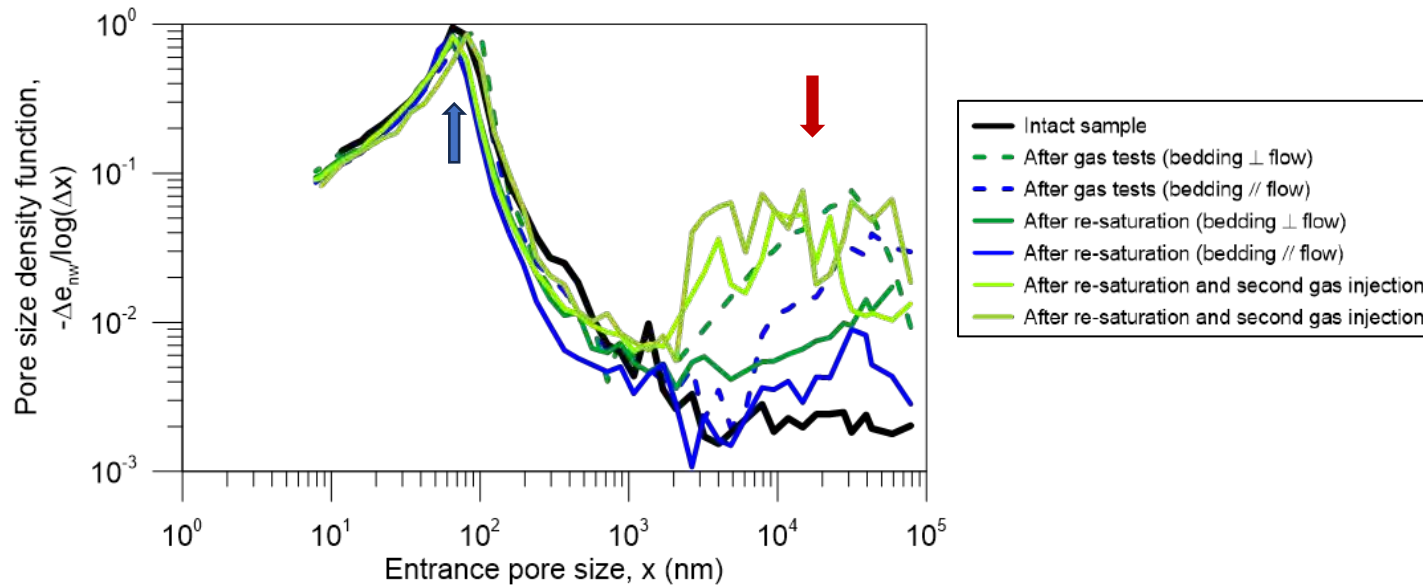
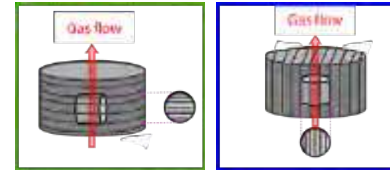
- The transition between diffusive transport of dissolved gas and free gas flow is known to be gas pressure dependent. However, the passage from one transport mode to another is not so simple in clays ...
- Gas injection test under controlled loading (in isostatic cell)
 - 1st results are comparable with diffusion coefficients estimated from constant volume cell experiments
 - Tests performed with pure gaseous gas (without any liquid) or dissolved gas in pore water provide same results



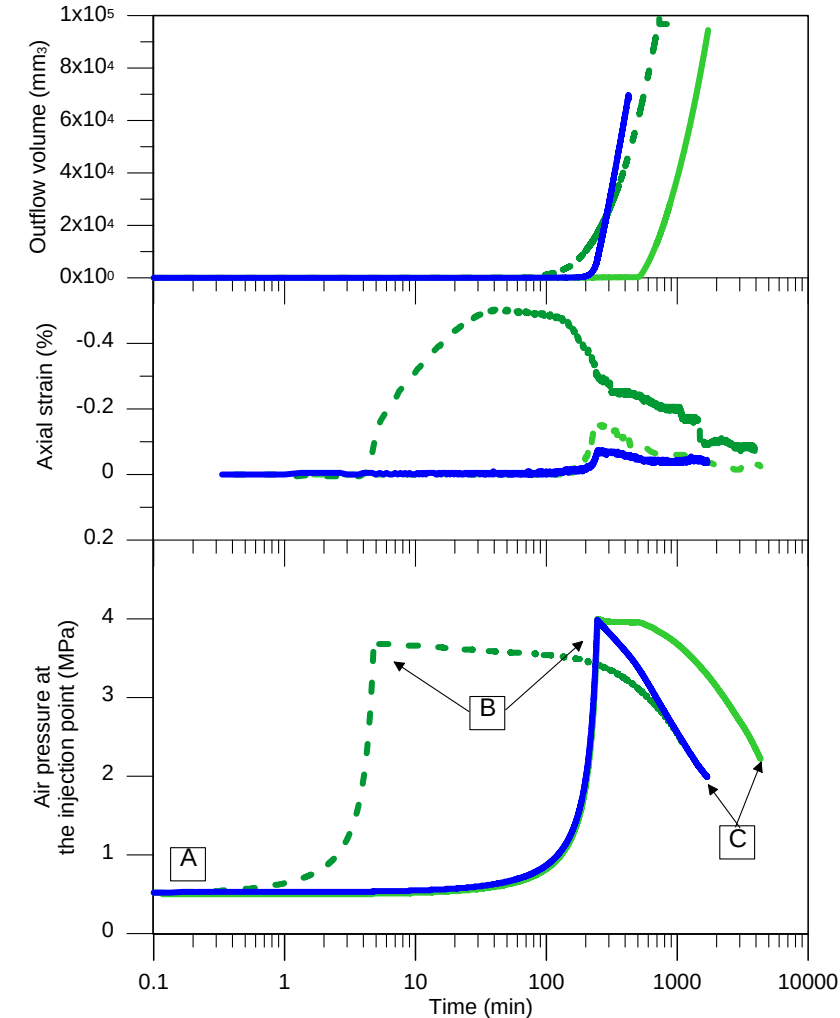
GAS PATHWAYS AND SELF-SEALING IN BOOM CLAY

Gas injection tests under oedometer conditions:

- Different bedding orientation (parallel and normal to the flow)
- Different volumetric gas injection rates (slow and fast)
- Several gas injections + re-saturation in between



Bi-modal pore size distribution after gas tests: **natural pores (matrix)** and **fissures (damage/degradation)**

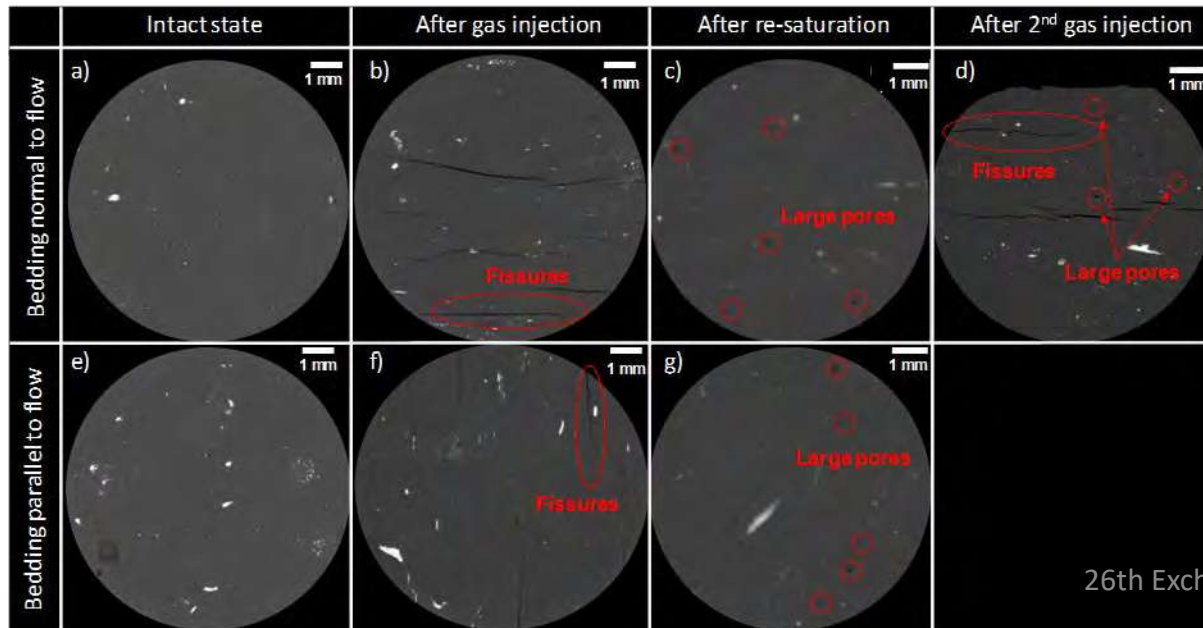


Small **deformations** during gas injection in both orientations, **larger for higher injection rates**

GAS PATHWAYS AND SELF-SEALING IN BOOM CLAY

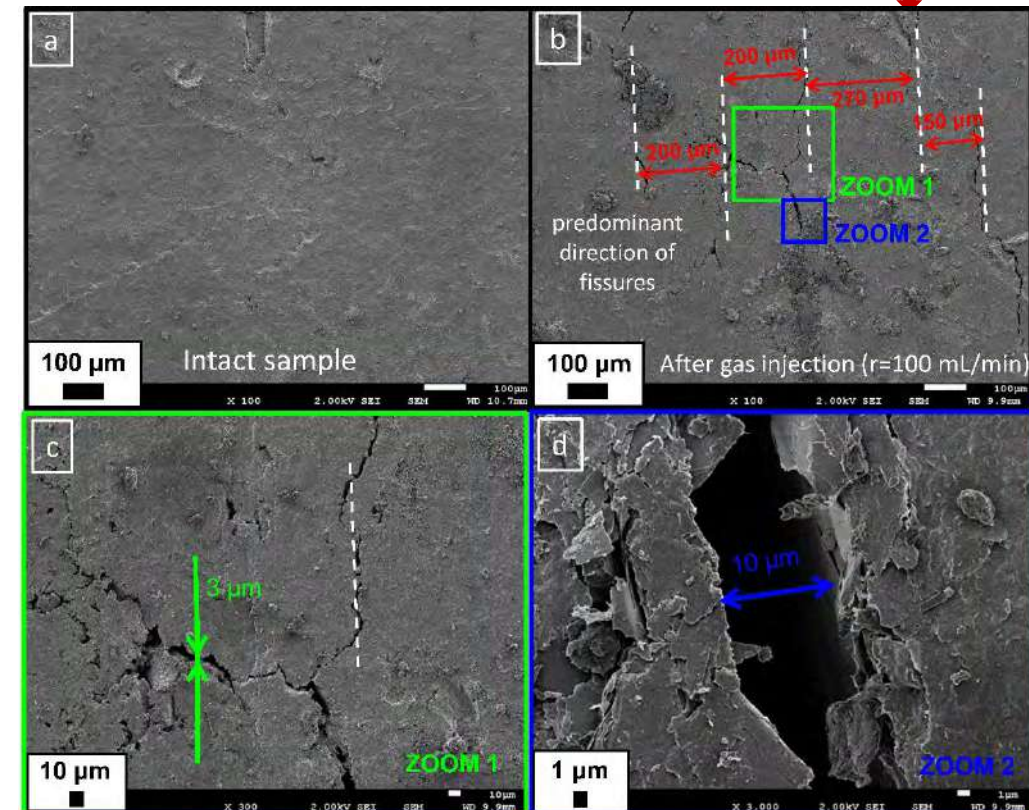
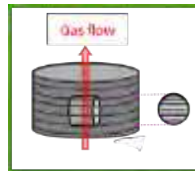
- Evidence a dilatant behaviour of the Boom Clay associated to gas passage
 - Gas mainly flowed through multiple dilatant preferential pathways (fissures) **taking advantage of local defects or planes of weakness**, confirmed by microstructural tests
 - After re-saturation, initial values of water permeability were restored despite the detection of some pores due to gas entrapment
→ **effective self-sealing**

MICRO-CT Resolution 20 μm



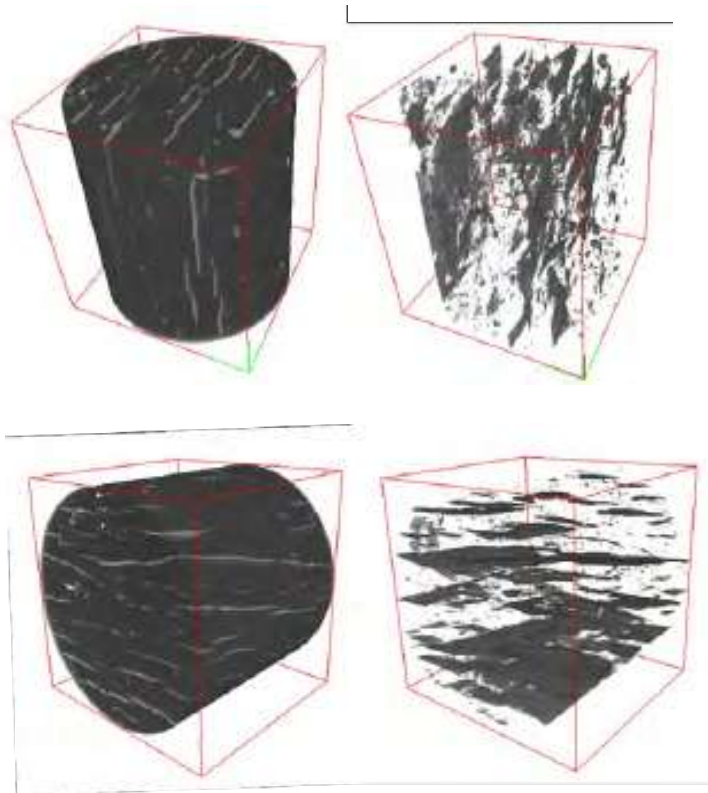
26th Exchange Meeting

FESEM

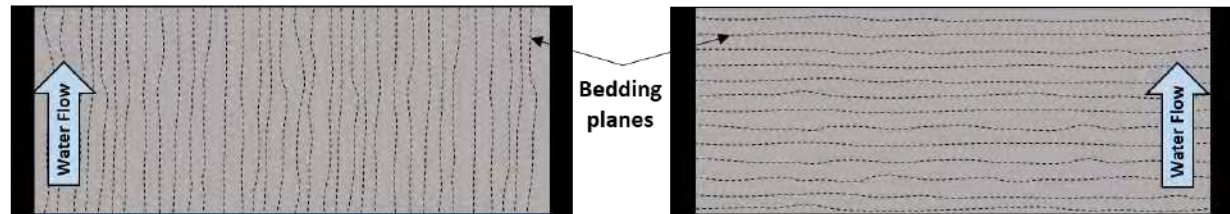


GAS PATHWAYS AND SELF-SEALING IN BOOM CLAY

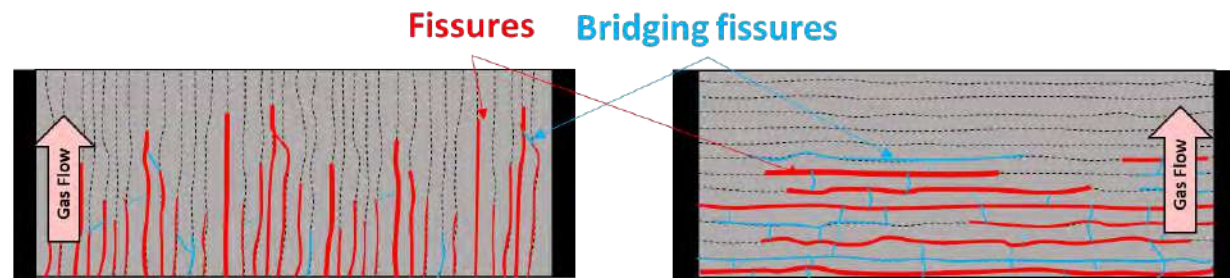
- Evidence a dilatant behaviour of the Boom Clay associated to gas passage → Conceptualization



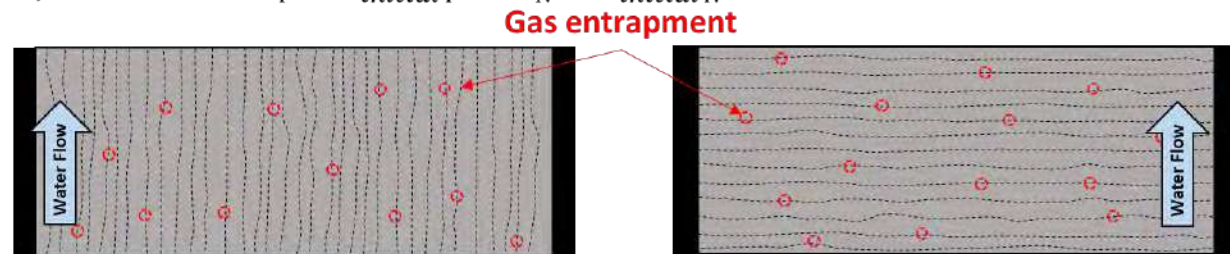
a) Water permeability: $k_{initial P} > k_{initial N}$



b) Gas injection: $k_P \approx k_N$



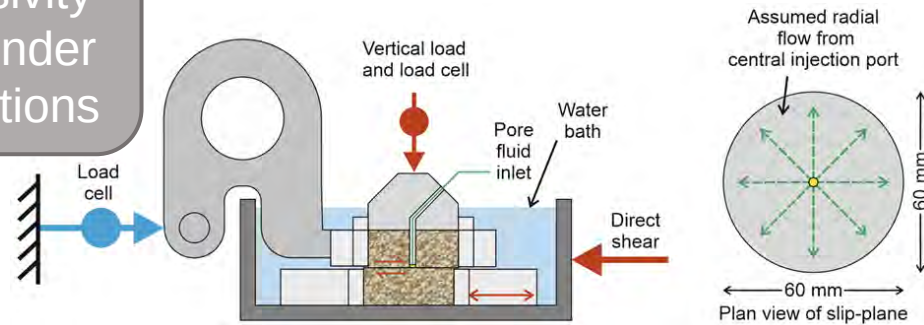
c) Re-saturation: $k_P \approx k_{initial P} > k_N \approx k_{initial N}$



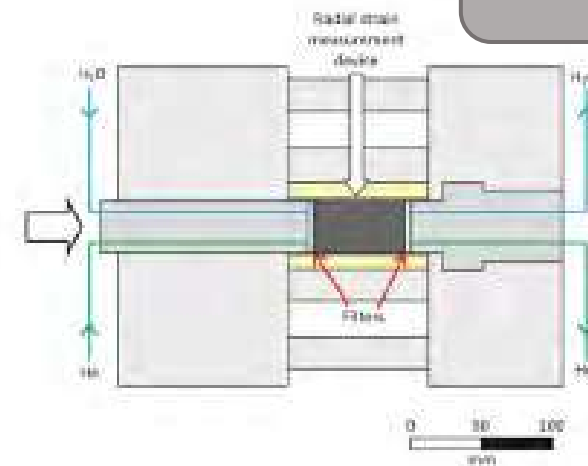
GAS PATHWAYS AND SELF-SEALING IN BOOM CLAY

- Evidence a dilatant behaviour of the Boom Clay associated to gas passage and efficient self-sealing confirmed in various mechanical load conditions

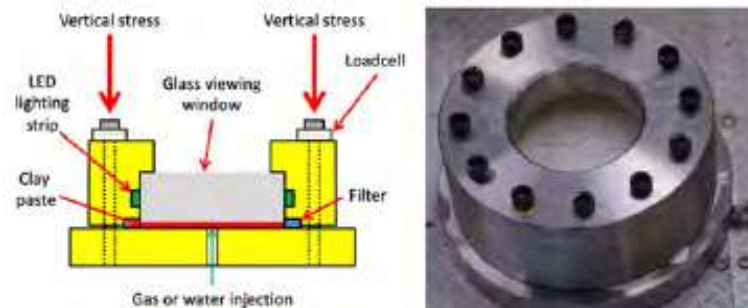
Gas transport on fracture transmissivity and self-sealing under direct shear conditions



Gas injection tests under triaxial conditions



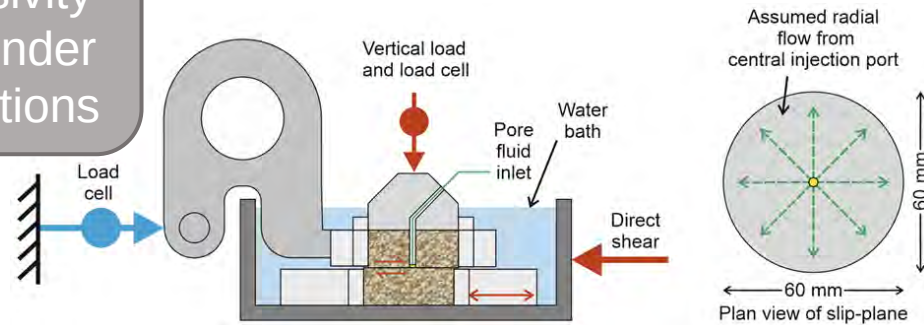
Fracture visualization and self-sealing



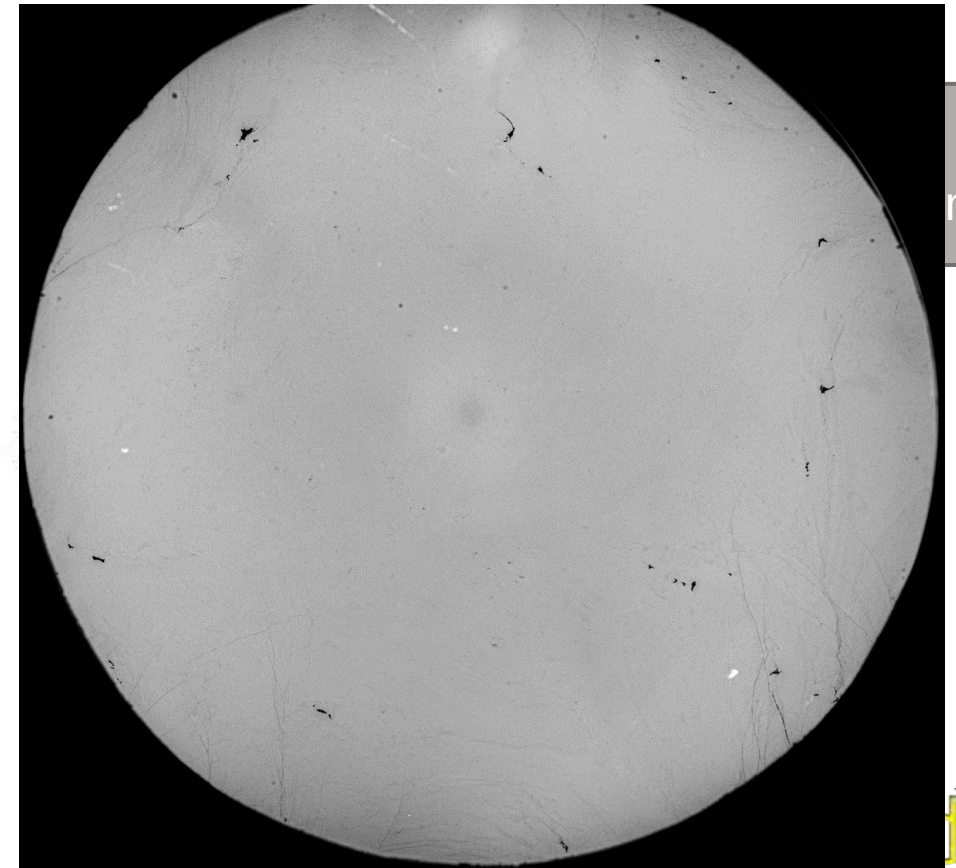
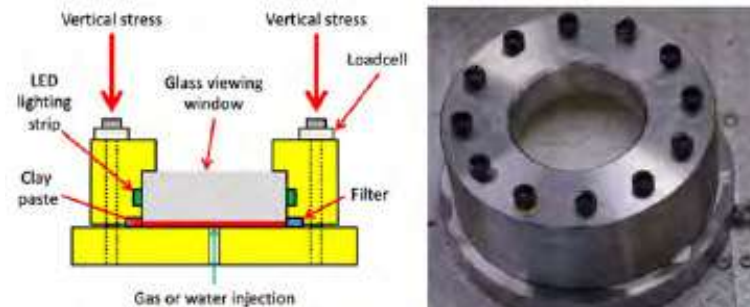
GAS PATHWAYS AND SELF-SEALING IN BOOM CLAY

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Gas transport on fracture transmissivity and self-sealing under direct shear conditions



Fracture visualization and self-sealing

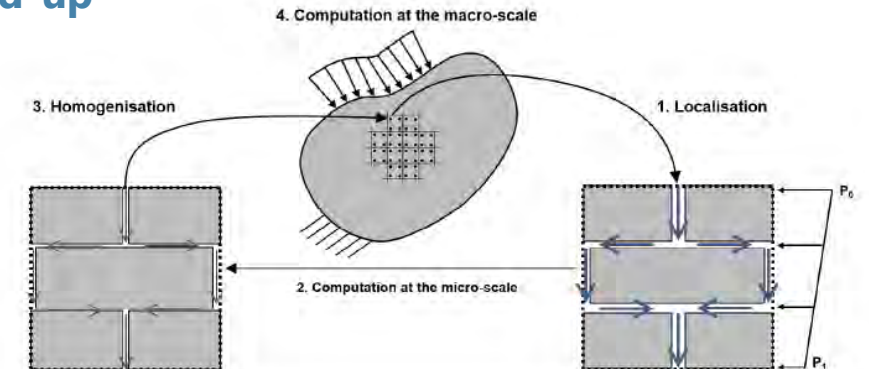
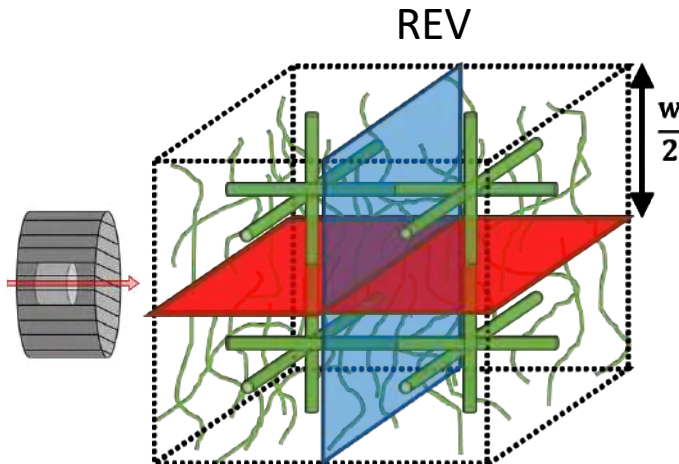
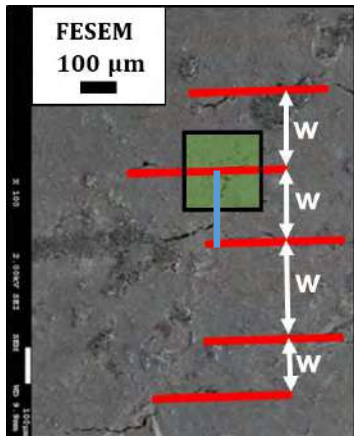


GAS PATHWAYS AND SELF-SEALING IN BOOM CLAY

Multi-scale hydro-mechanical modelling of gas transport

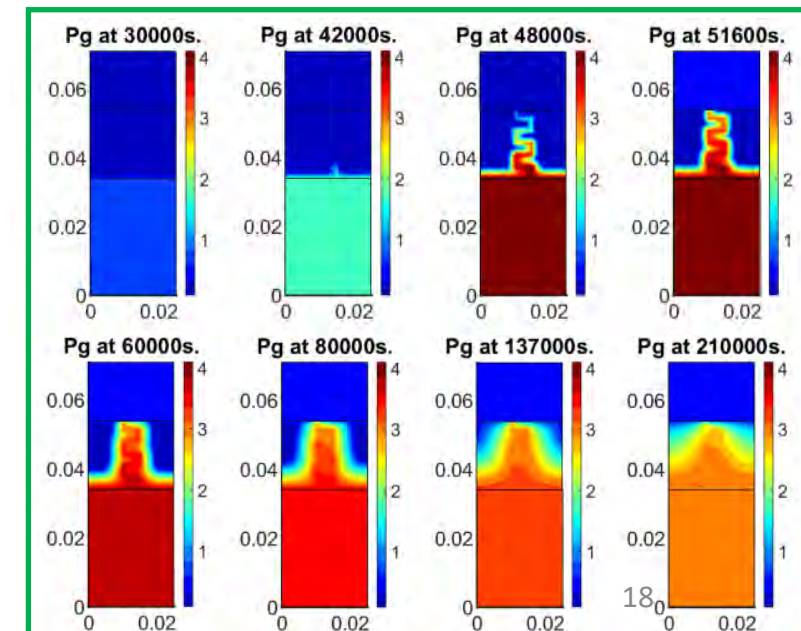
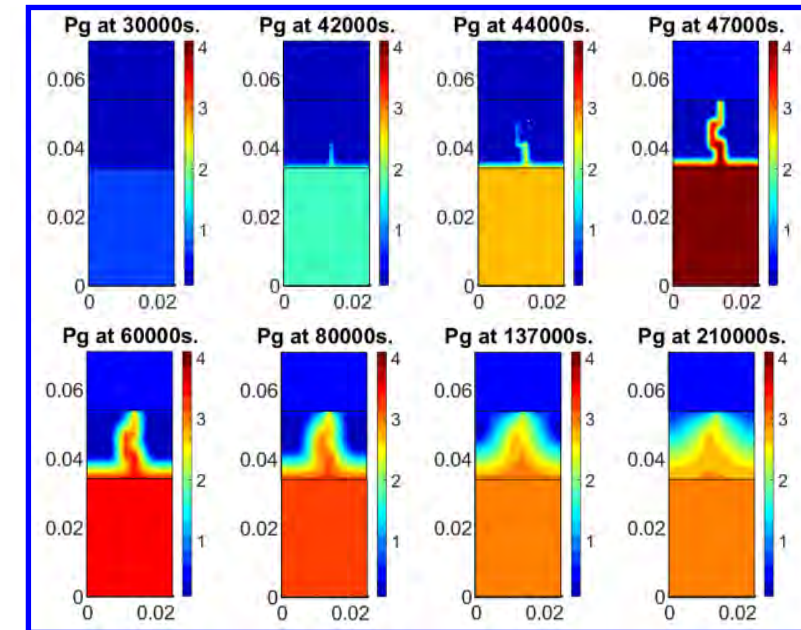
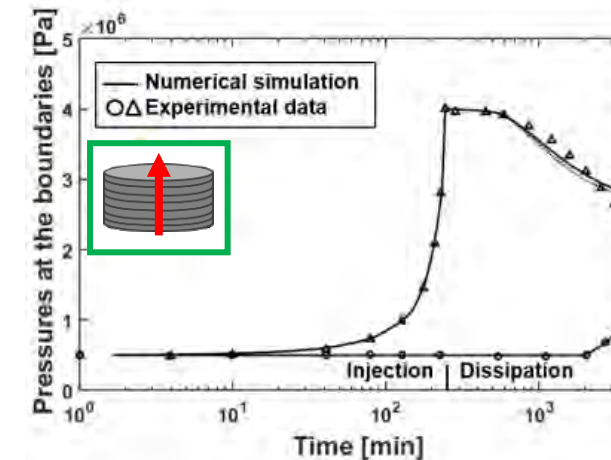
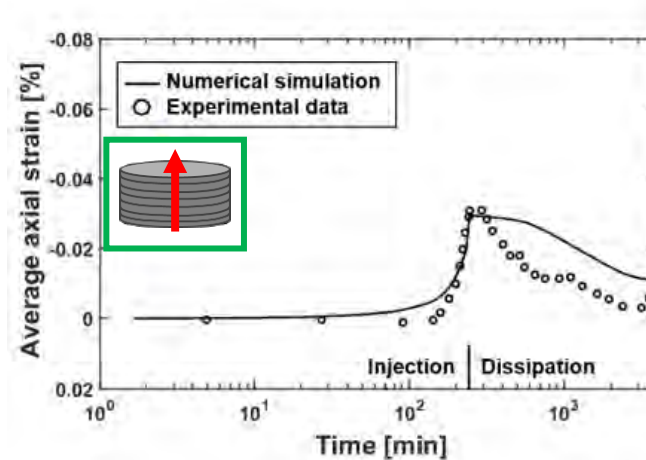
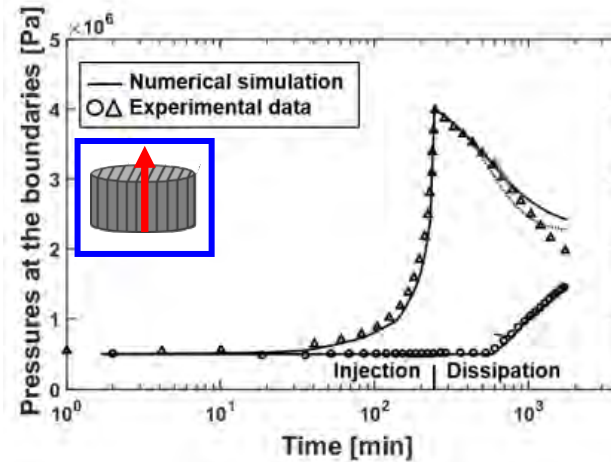
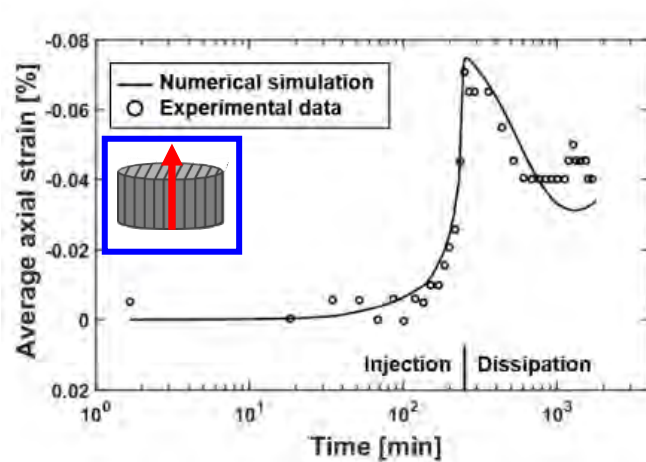
- Constitutive model at the micro-scale (REV) integrated into a multi-scale scheme using homogenisation and localisation techniques for the transitions to the macro-scale.
- Advection-diffusion model for multiphase flow along fractures and tubes embedded in a REV
- Implicit Hydro-mechanically coupling: dependency of the permeability on the fracture and tube apertures (flow channel model), which are stress-dependent

→ **diffusion mechanism of dissolved gas at low pressure + development of gas-filled pathways through the fractures within the microstructure of the material when pressure build-up**



- ▶ **1 fracture = bedding plane + a network of connected porosity**
- ▶ **The pore network is substituted with an assembly of tubes**
- ▶ **1 thinner fracture = bridging plane**

GAS PATHWAYS AND SELF-SEALING IN BOOM CLAY

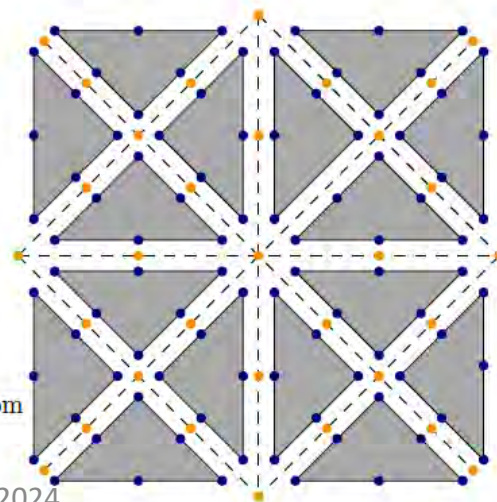
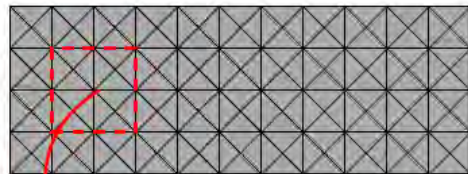


Model simulations well capture experimental results in terms of gas pressure evolution, volume change and outflow volume computation → **very useful support to interpretation and for testing of hypotheses on gas transport mechanisms**

GAS TRANSPORT IN FRACTURES

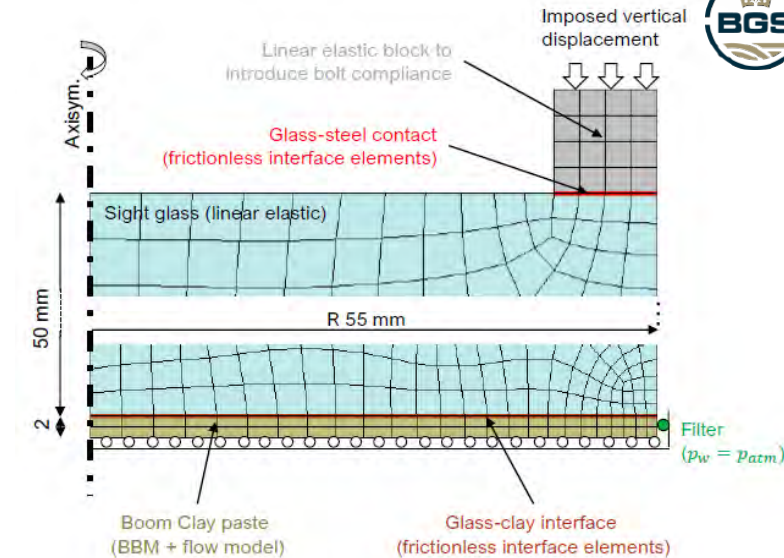
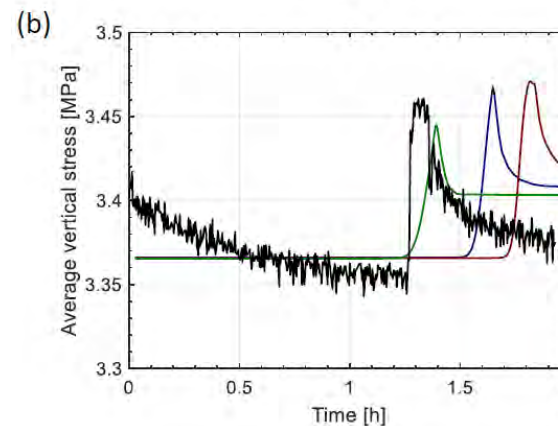
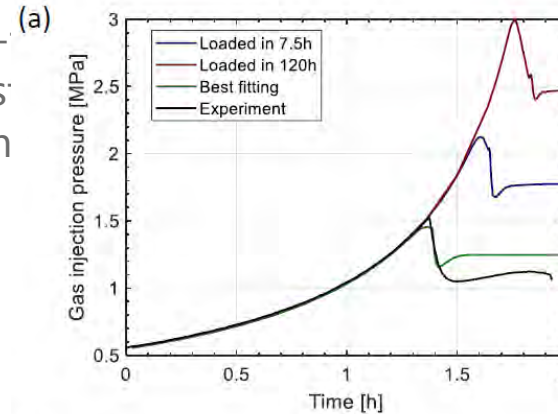
Pneumo-hydro-mechanical (PHM) model for gas cracking

- Explicit representation of gas cracking via zero-elements equipped with cohesive fracture cons introduced a priori in between continuum elem cracking paths

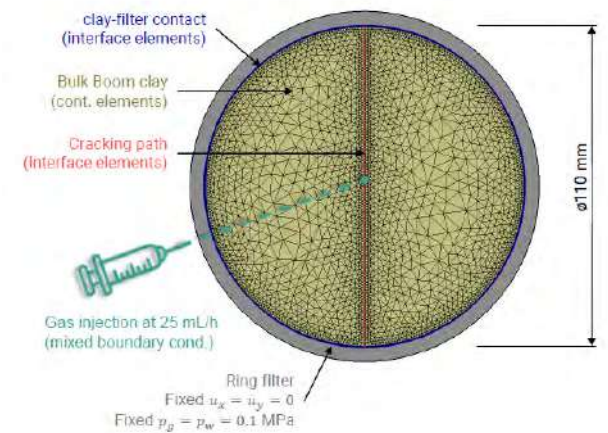


Degrees of freedom
 • x, y, p_w, p_g
 • p_w, p_g

Oct 25, 2024



Gas injection



With single straight cracking path, the model can qualitatively replicate the gas injection pressure and average vertical stress

26th Exchange Meeting

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19

EURAD-GAS – KNOWLEDGE GAINED

- The experimental programme has taken the setups developed in FORGE and before to a new level
- **Notable progress was done in visualization techniques** (post-mortem but also near-real time during experiments)
- **The numerical programme has made significant progress in support to interpretation and for testing of hypotheses on gas transport mechanisms**
- development of process-level modelling that combines pathways activation and development mechanisms at the microscopic scale and the evaluation of field parameters and conditions at larger scale → **predictive capabilities are still very limited**

Mechanistic understanding of gas transport in clay(ey) materials

- Diffusion of dissolved gas is pretty well understood and characterized
- Advective transport of gas is more likely to take place via specific pathways, without significant displacement of water from the matrix
- Role of coupling between gas transport and mechanical behaviour is confirmed
- Good understanding of the specific hydromechanical conditions imposed by each setup is essential for correct interpretation of the experiments and use of their results



EURAD-GAS – OVERVIEW OF KNOWLEDGE GAINED

Mechanistic understanding of gas transport in clay(ey) materials



- **What did we learn** from an experimental & modelling programme on gas transport?
- **What do we expect** about the impact of gas passage on clay materials and barrier integrity?

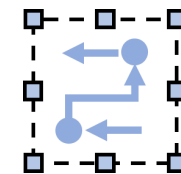
→ **focus on the science**

Integration in conceptualizations of the functioning of a repository system



- **Expert judgment and Storyboards** for typical repository configurations
- **Testing ≠ approaches** to represent gas effects at the component & system level

→ **focus on the applications and impacts for end-users**



CONCEPTUALISATION OF GAS TRANSPORT AT THE SCALE OF DISPOSAL SYSTEM

- **Integration of scientific knowledge in storyboards to evaluate**

- gas pressures and gas fluxes throughout the system,
- long-term integrity of barriers after the passage of gas
- gas-mediated radionuclide releases

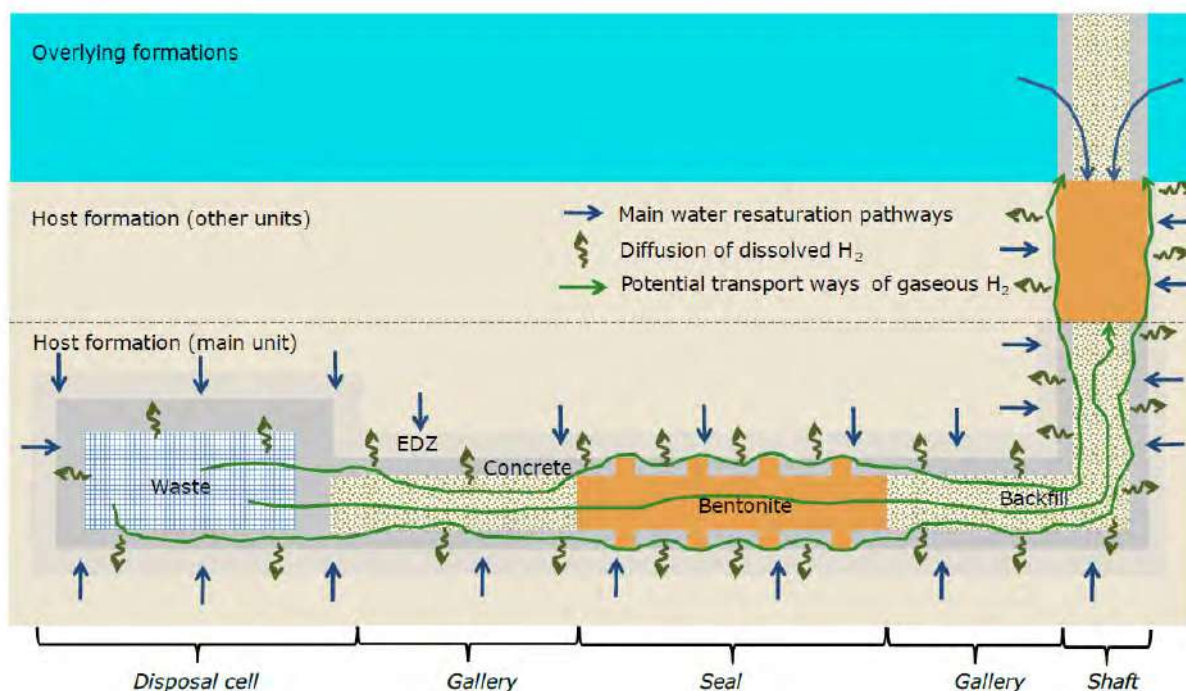


nagra



COVRA

Radioactive Waste Management



Evacuation from the disposal system is expected

- in **gas form**, through the EBS (gas-specific pathways through buffer, backfill and seal materials + lining & interfaces) & the EDZ
- only as **dissolved gas** throughout the undisturbed host rock, by diffusion

Should pathway formation be sufficient to relieve gas pressure, then closure of the pathways can occur

→ **self-sealing capacity of clays is preserved** for what concerns hydraulic conductivity but not necessarily with respect to gas entry (pathway may re-open at lower gas pressure)

eurad

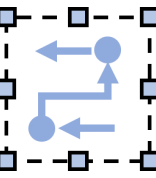


CONCEPTUALISATION OF GAS TRANSPORT AT THE SCALE OF DISPOSAL SYSTEM

- Mobilisation of water-soluble radionuclides by gas → expected to be very low because little or no water displacement is associated to the evacuation of gas
- Volatile radionuclides can be carried from the gas source to the shafts and/or ramps along with the inactive gas. However:
 - **Part will continue to dissolve** (as inactive gas also does) into the porewater present in the surrounding materials
 - **Transport may take several hundreds to several thousand years** (order of magnitude, concept dependent)
 - Only radionuclides with $\frac{1}{2}$ lives around this duration or higher will present a significant concentration in the gas phase when arriving in the upper formations

In-depth, quantitative evaluation is system-specific, but should be based on such a prior conceptualisation of the functioning of a disposal system

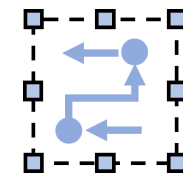




GAS IMPACT ASSESSMENT BY REPOSITORY SCALE MODELLING

- Repository-scale modelling of gas transport accounting for all couplings
- Out of reach and will remain so in the foreseeable future
- However, modelling at the scale of the repository is possible today using simplified, modular approaches guided by the gas transport storyboards and based on dissolution, diffusion and two-phase flow phenomena
 - Gas is expected to flow over the network of excavation of the repository toward the shafts and/or ramps. Quantification of such process can be done by:
 - Simplified models at repository scale to get an estimate of maximum gas pressures in the repository
 - Component scale coupled models for finer, hydromechanical understanding of the system





RECOMMENDATIONS TO AVOID HIGH GAS PRESSURES

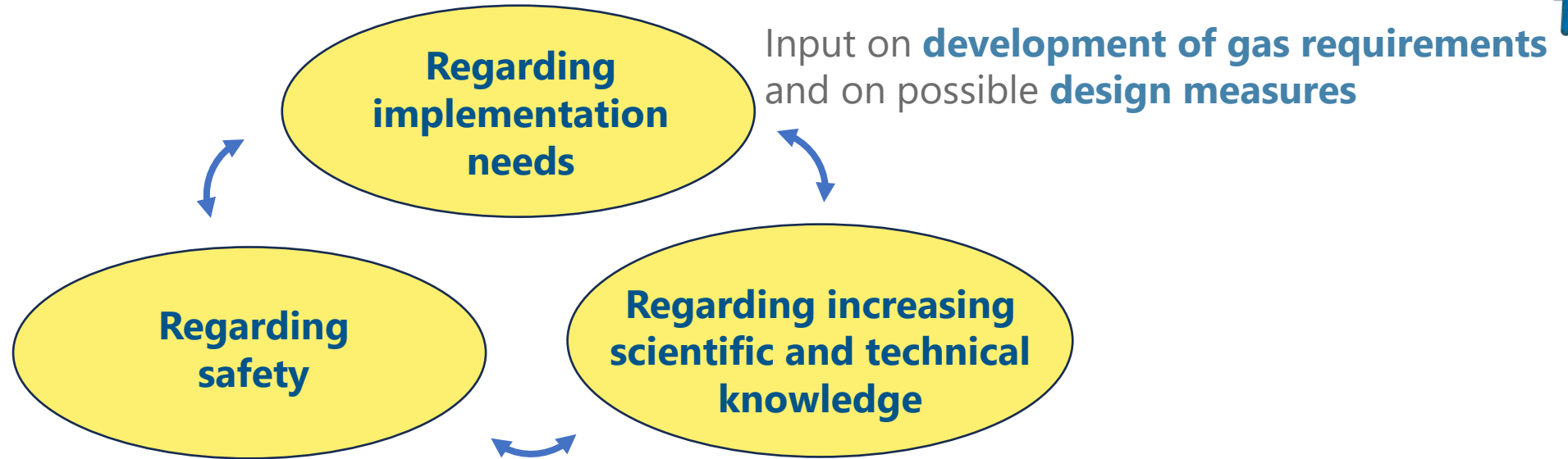
- **Hand-in-hand approaches for the development of the design**
 - Dialogue between Science, Engineering and Safety
 - Example of mitigation measures against too high gas pressures (i.e. preserve the host rock integrity, avoid fracturing pressure):
 - limit as far as possible the surface of metal present in the repository at closure (e.g., limit quantities, use non-metallic rebars for concrete reinforcement,...)
 - design repository layout, backfill and/or seals to favor diffusion of dissolved gas

→ Good practices to avoid painful adaptations at a later phase require a management of gas requirements together with all other requirements early in the design stage!





IMPACTS OF EURAD-GAS FOR END-USERS



Experimental evidences that can be referred to by national programmes in the **arguments supporting claims about long-term safety**

Build confidence in and extending the scientific bases
Data of relevance for a large variety of disposal concepts
Good understanding of processes which has broad end-user appeal

Identification of **strengths and limitations of various approaches** to assess their **suitability in different contexts**

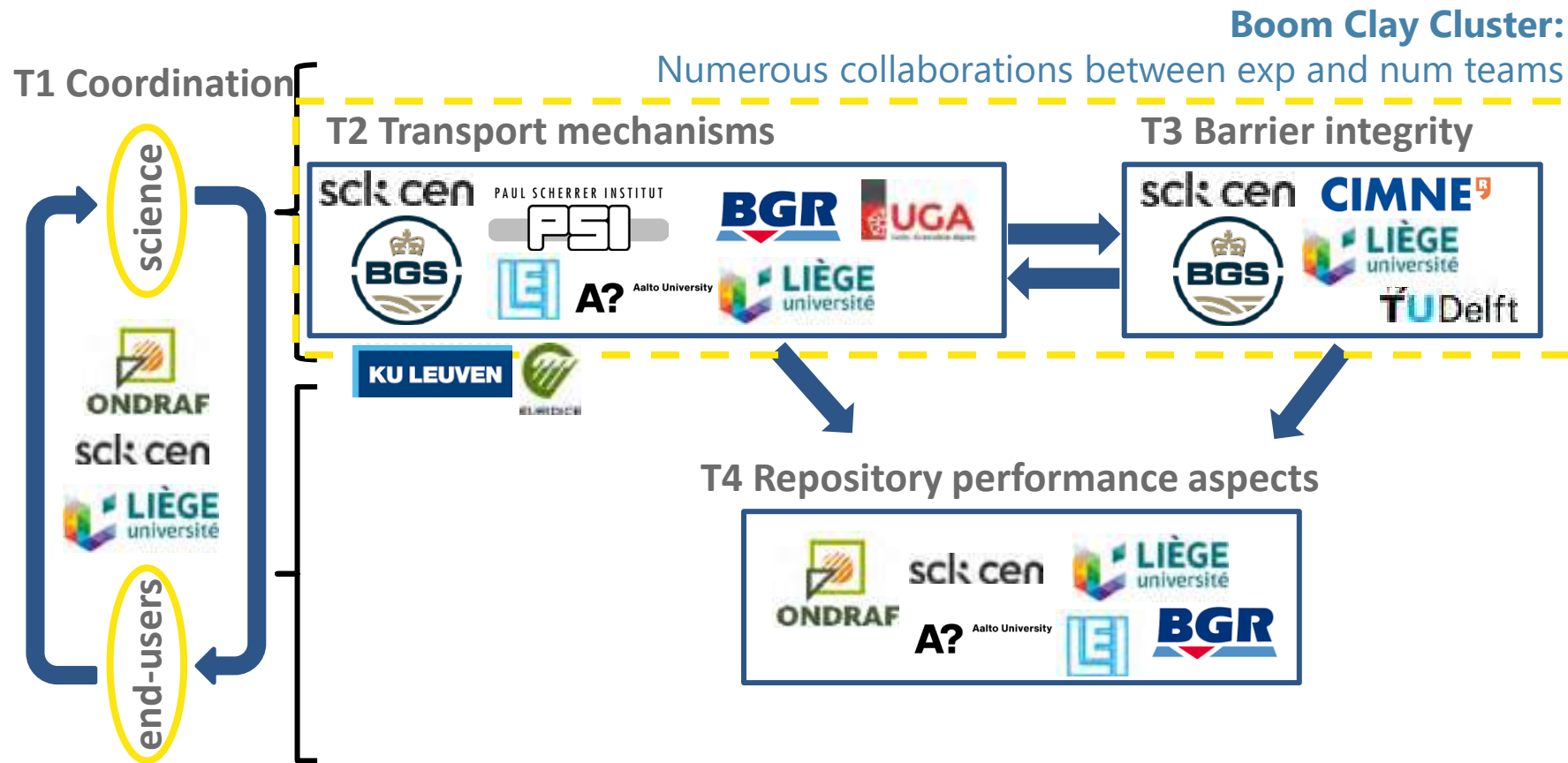


EURAD-GAS AS A MAJOR STEP FORWARD ...

- **Consolidation of knowledge:** extension of the scientific bases, both for EBS and clayey rocks
- **Shared understanding and confirmation of the FORGE insights about gas-related processes**
- **Stepwise integration of the scientific knowledge under the form of a generic description of gas transport at repository scale and of its impact in terms of barrier integrity and fate of radionuclides**
- **EURAD-GAS results and conclusions are**
 - Summarized in **EURAD deliverables**: state-of-the-art report (D6.1), main conclusion report (D6.6) and Technical reports detailing the results of each scientific tasks (D6.7 – Characterization of gas transport modes, D6.8 – Effects of gas on barrier integrity, D6.9 – Repository scale modelling) - <https://www.ejp-eurad.eu/publications>
 - Put in perspective as a **state-of-knowledge** on gas transport in clay barriers in the 2nd state-of-the-art (D6.2)
 - + the **publication of a special issue of *Environmental Geotechnics*** (to be published beg. 2025)



... WHICH IS BENEFICIAL TO THE BELGIAN PROGRAM



WP has benefited from the mobility and training program **sck:cen**, as well as significant support from **nagra**.



13 mobility grants obtained for EURAD-GAS

2 training courses organized by and at **LIÈGE université**, one jointly with ALERT Geomaterials network





EURAD-GAS IS A SUCCESS FOR THE BELGIAN PROGRAM

- **SCK CEN** → European leader for experiments on diffusion of dissolved gas
- **CIMNE and ULiège** → key contributions to characterizing gas transport, an example of collaboration
- **ONDRAF/NIRAS** → Conceptualisation of gas transport on the scale of a repository acclaimed by peers

EURAD-GAS is a success for the Belgian Programme, an example of fruitful and beneficial collaboration between ONDRAF/NIRAS and SCK CEN, which began right from the development of the initial project proposal

- EURADWASTE'22 Paper – Host rocks and THMC processes in DGR EURAD GAS and HITEC: mechanistic understanding of gas and heat transport in clay-based materials for radioactive waste geological disposal (Levasseur et al., 2022) – **ONDRAF/NIRAS – NAGRA – Andra**
- Gas transport in Boom Clay: the role of the HADES URL in process understanding (Jacops et al., 2023) – **SCK CEN – ONDRAF/NIRAS – EURIDICE**
- Finite element modelling of multi-gas flow in expansive clay (Gupta, Jacops et al., 2023) – **SCK CEN – UAalto**
- On multi-component gas migration in single-phase systems (Pitz et al., 2024) – **SCK CEN – BGR**
- An experimental methodology to assess the impact of desaturation on gas diffusion in clay-based materials (Gowrishankar et al., 2023) – **SCK CEN – KULeuven**
- Mobility of dissolved gases in smectites under saturated conditions: effects of pore size, gas types, temperature, and surface interaction (Owusu et al., 2022) – **PSI**
- Diffusion and gas flow dynamics in partially saturated smectites (Owusu et al., 2023) – **PSI**
- A multi-scale insight into gas transport in a deep Cenozoic clay (Gonzalez-Blanco and Romero, 2022) – **CIMNE**
- Hydro-mechanical response to gas transfer of deep argillaceous host rocks for radioactive waste disposal (Gonzalez-Blanco et al., 2022) – **CIMNE – NAGRA – ONDRAF/NIRAS**
- Self-sealing of Boom Clay after gas transport (Gonzalez-Blanco et al., 2023) – **CIMNE – ONDRAF/NIRAS**
- Hydro-mechanical modelling of gas transport processes in clay materials using a multi-scale approach (Corman et al., 2024) – **ULiège – CIMNE – ONDRAF/NIRAS**
- Numerical investigation of the couplings between strain localisation processes and gas migrations in clay materials (Corman et al., 2022) – **ULiège – Andra**
- Modelling gas fracturing in saturated clay samples using triple-node zero-thickness interface elements (Liaudat et al., 2023) – **TU Delft**



Thank you for your attention



Thanks to the European Union's Horizon 2020 research and innovation programme for its financial support to EURAD-GAS

CONCORD

CONtainer CORrosion under Disposal conditions

25/10/2024 • Roberto GAGGIANO



This project has received funding from the European Union's Horizon 2020 research and innovation programme 2014-2018 under grant agreement N°847593

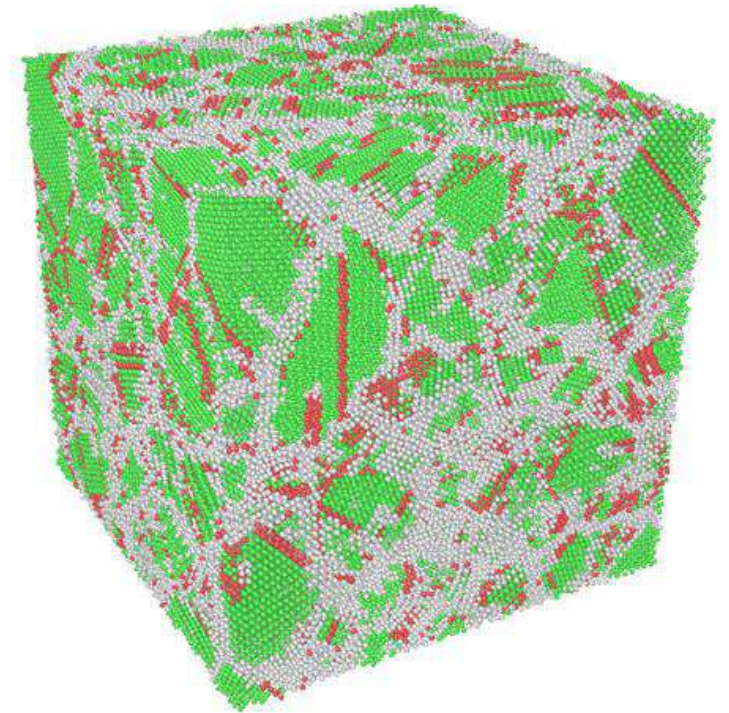
MOTIVATION

- Long-lived disposal containers for SF/HLW have been shown to be **feasible and safe** in several national programmes.
 - Can they be optimised?
 - Can the prediction of their lifetime become more accurate and robust?



OBJECTIVES

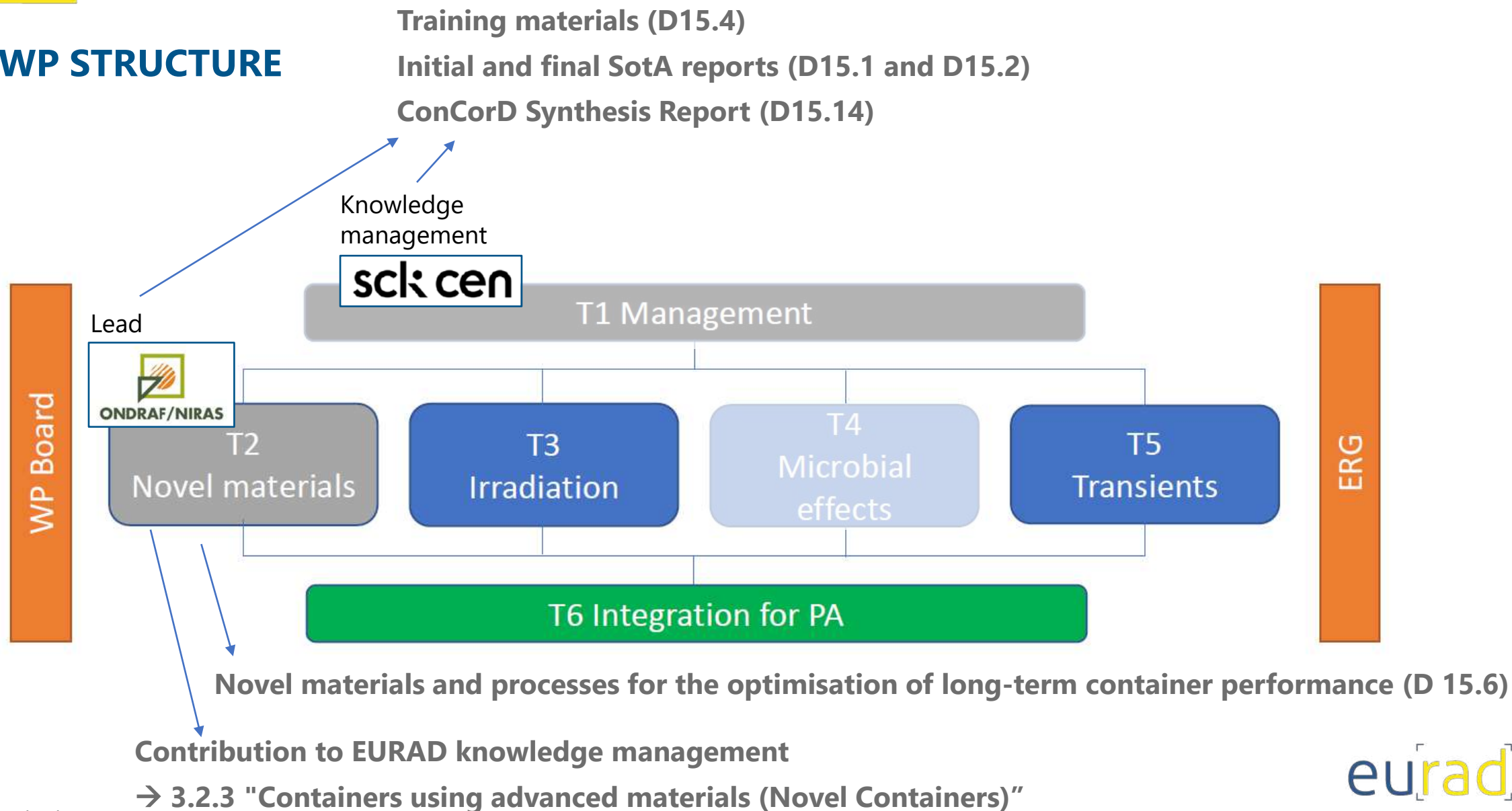
1. Explore the potential of **novel container materials** for the optimisation of container design and performance within the engineered barrier system.
2. Deepen the understanding of **coupled interfacial processes** influencing container performance under repository-relevant conditions, with a focus on:
 1. irradiation-accelerated corrosion,
 2. microbial activity,
 3. degradation during near-field transients.
3. Support **performance assessment** by demonstrating mechanistic understanding and by developing predictive models.



22 ORGANISATIONS FROM 12 COUNTRIES

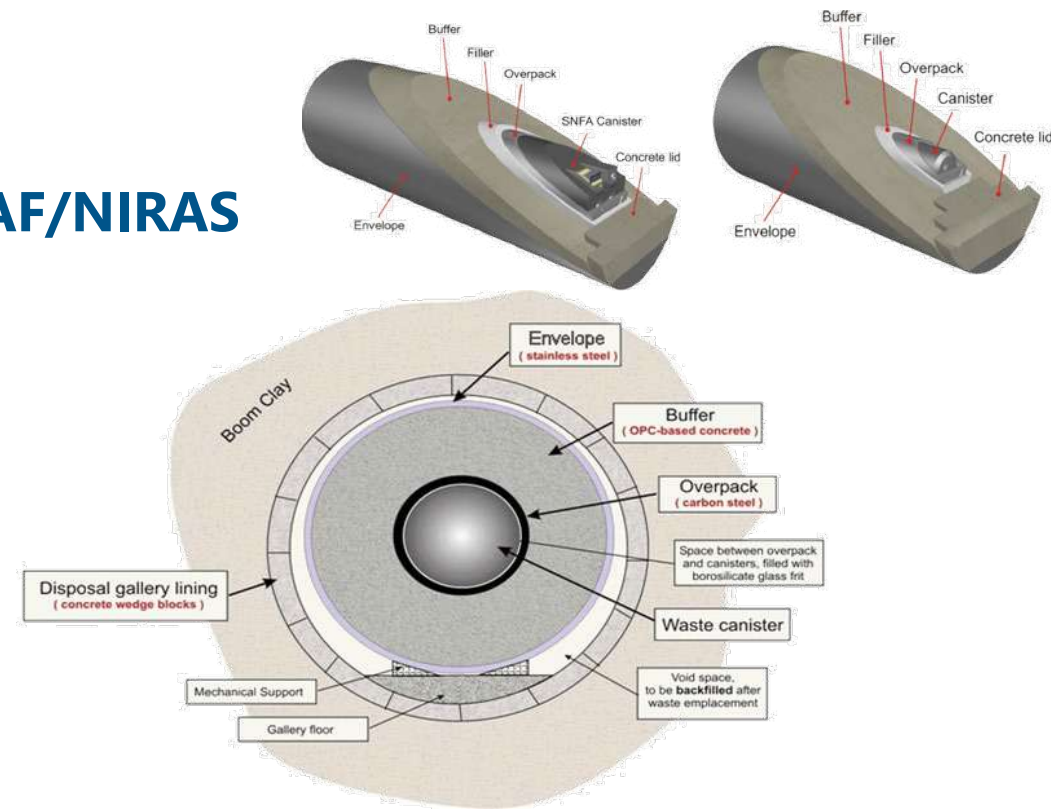


WP STRUCTURE



IMPORTANCE OF THE CONCORD WP FOR ONDRAF/NIRAS

- Up to now, *no specific rock has been selected as host for geological disposal in Belgium and the repository design itself is still generic to a large extent.*
- In addition, *cement formulation could change in the future, towards lower pH cements*
 - impact on the evolution of the environmental conditions



Long-term safety function of the overpack: total containment of the radionuclides during at least the thermal phase by preventing contact between the wasteform and the porewater coming from the host formation.

- Important to:
 - Understand the general trends related to the corrosion behaviour of carbon steel in different environments
 - Keep an eye on alternative material solutions for the overpack



SCIENTIFIC & TECHNICAL IMPACTS

- Pre-screening and preliminary optimisation of promising **novel materials**
- In depth understanding of the **relationship between irradiation and corrosion**
- Refined understanding of the **role of microbes** in canister degradation and identification of critical factors affecting viability
- Systematic exploration of **corrosion in an evolving environment**
- Developed **models** for interpretation of experiments and for canister lifetime predictions
- Synthesis of all the above for use in canister development and performance assessment programmes
- Addressed fundamental questions will lead to:
 - Better designed and **more focused future experiments**
 - Pave the way for **further canister optimisation**

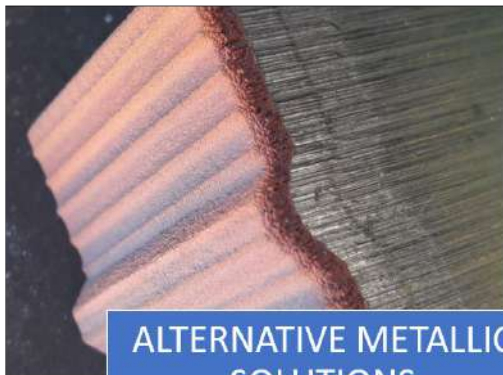
TASK 2: NOVEL MATERIALS



NON METALLIC
SOLUTIONS

- Subtask 2.1 Ceramic Materials and Coatings
 - Bulk materials:
 - $\text{SiO}_2/\text{Al}_2\text{O}_3 \rightarrow$ sealing of ceramic container
 - Cr-doped SiC $\rightarrow$ sintering
 - Coatings:
 - TiO_2
 - CrN

Process optimisation
(porosities and flaws)



ALTERNATIVE METALLIC
SOLUTIONS

- Subtask 2.2 Metallic materials and coatings
 - Bulk materials:
 - Cu alloy optimisation (+influence of impurities)
 - Coatings:
 - Cu, Ti, Cr,
 - $\text{Cu}/\text{Al}_2\text{O}_3$

Process optimisation
(porosities and flaws)



Activities:

- Process optimization
 - Coatings
 - sealing of ceramics
- Determination of properties :
 - physical/mechanical properties
 - leaching tests
 - simplified corrosion tests



ALUMINA SOLUTIONS

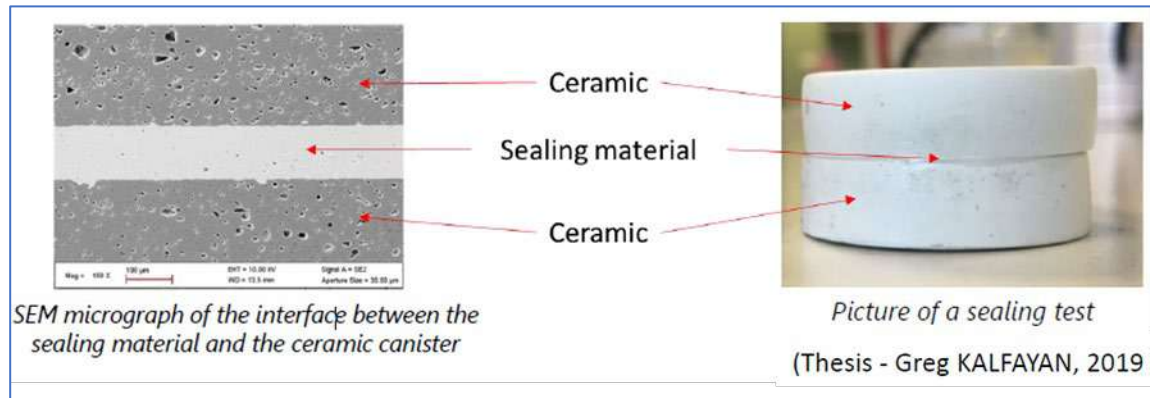


Andra's half-scale model of $\text{Al}_2\text{O}_3/\text{SiO}_2$ VHLW container



- **Sealing by microwaves process**

- Sealing materials previously achieved using specific *silica-based glass* ($T < 700^\circ\text{C}$)

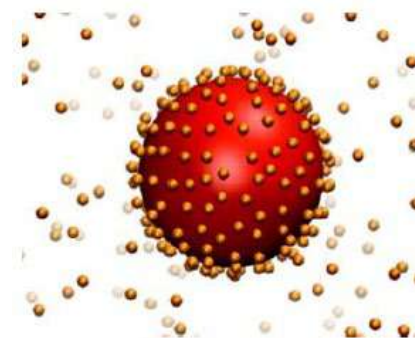


SEM micrograph of the interface between the sealing material and the ceramic canister

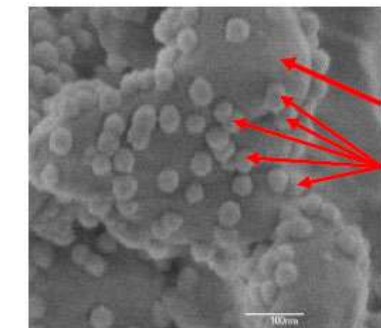
Picture of a sealing test

(Thesis - Greg KALFAYAN, 2019)

- **Functionalization of particles by hetero-aggregation**



3D illustration of alumina/silica heteroaggregation
Orange : Silica particles
Red : Alumina particle



SEM micrograph of alumina/silica heteroaggregation

- New materials targeted : **Glass-bonded ceramics**

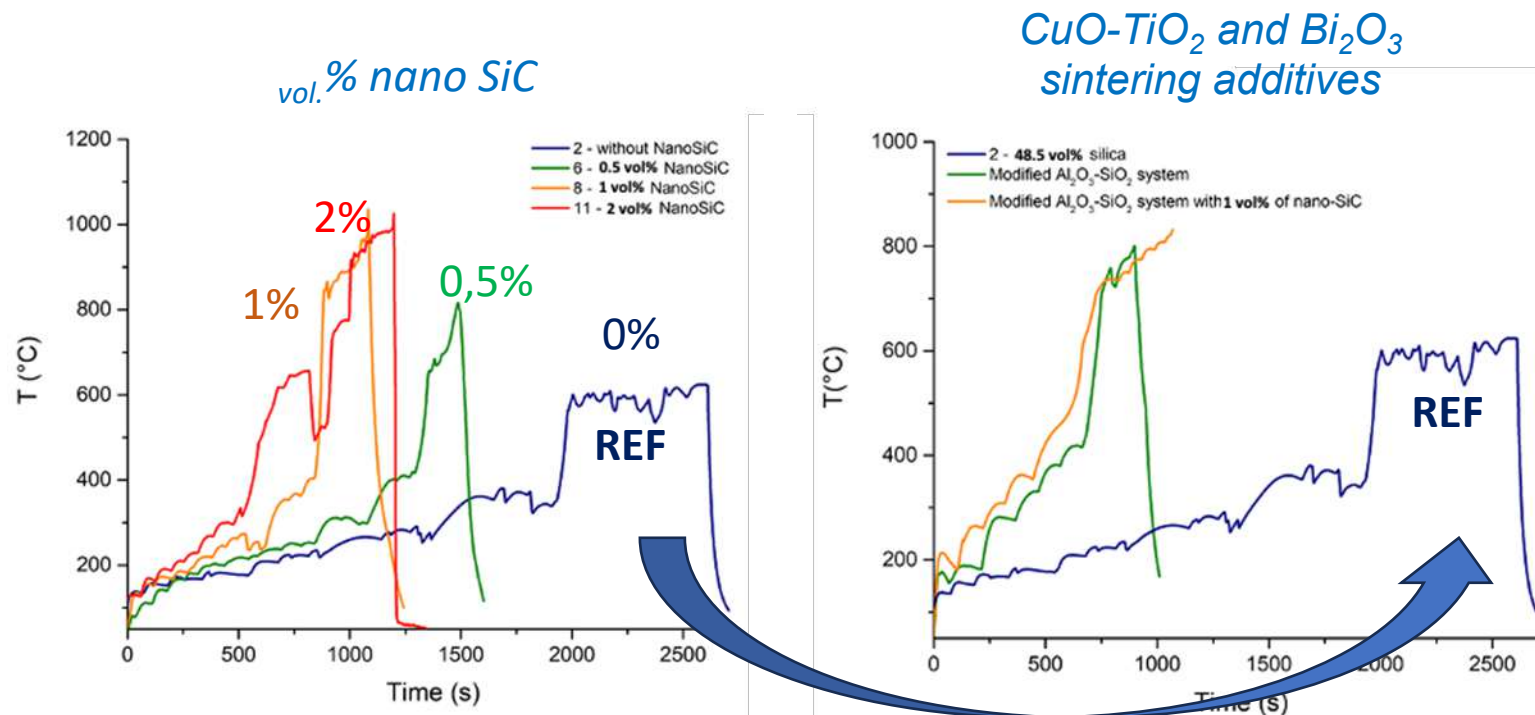
Sealing formulations based on silico aluminates with microwaves coupling

Objective: Improve the chemical affinities between the sealing material and the ceramic canister

eurad

ALUMINA SOLUTIONS

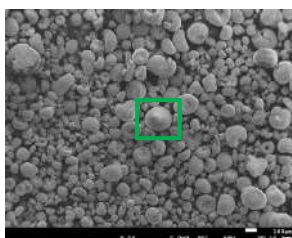
$\text{Al}_2\text{O}_3 + 48,5\% \text{SiO}_2$ = reference composition $\rightarrow$ Different $\text{Al}_2\text{O}_3/\text{SiO}_2$ systems as sealing materials



Real breakthrough in the optimisation of microwave coupling for such type of formulations.

SILICON CARBIDE

- Focus on the optimization of the sintering process for the manufacture of composite materials based on SiC doped with Cr.

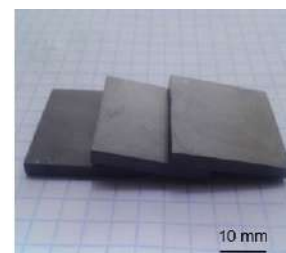


SiC powder (40÷100 μm)



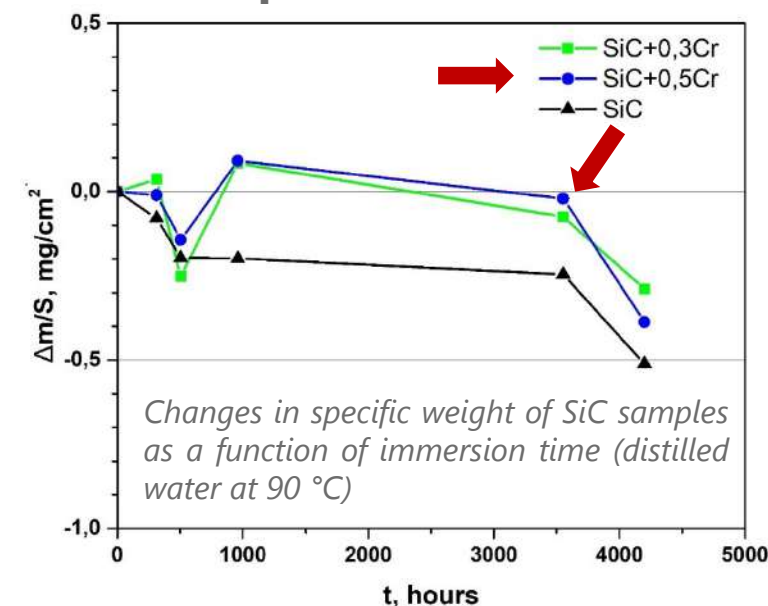
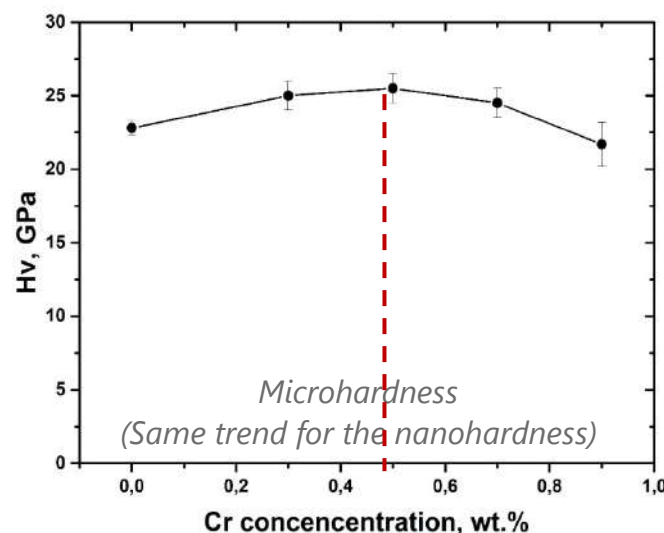
Addition of Cr to the SiC powder (ball milling)

Hot isostatic pressing



SiC(Cr) samples

Samples	Measured density, g/cm ³	From theoretic density of pure SiC, %
SiC (0 % Cr)	3.161	98.5
SiC (0.3 % Cr)	3.108	96.8
SiC (0.5 % Cr)	3.181	99.1
SiC (0.7 % Cr)	3.167	98.7
SiC (0.9 % Cr)	3.129	97.5



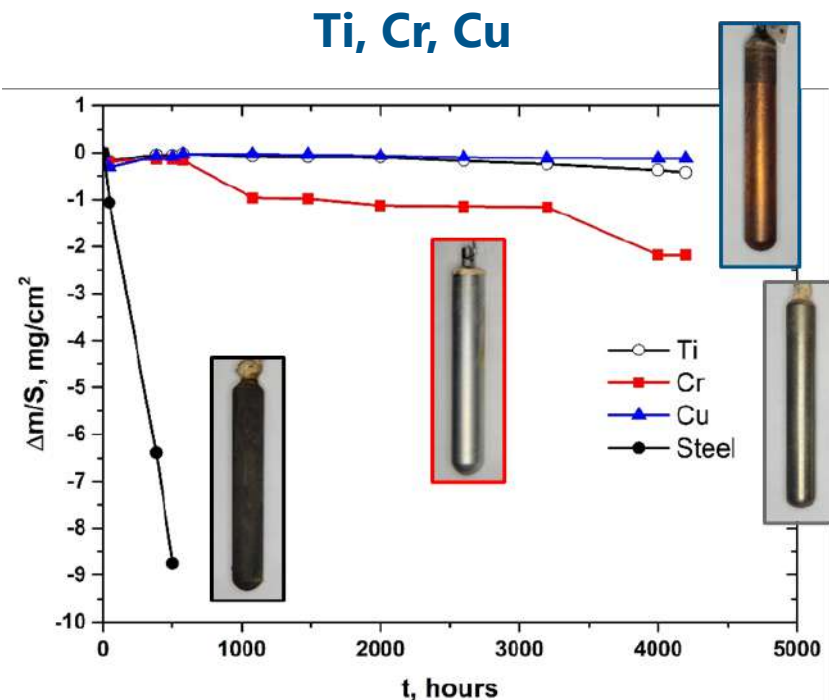
Oxidation and dissolution of SiC in water:

- $\text{SiC} + 2\text{H}_2\text{O} = \text{SiO}_2 + \text{CH}_4$
- $\text{SiO}_2 + 2\text{H}_2\text{O} = \text{Si(OH)}_4$

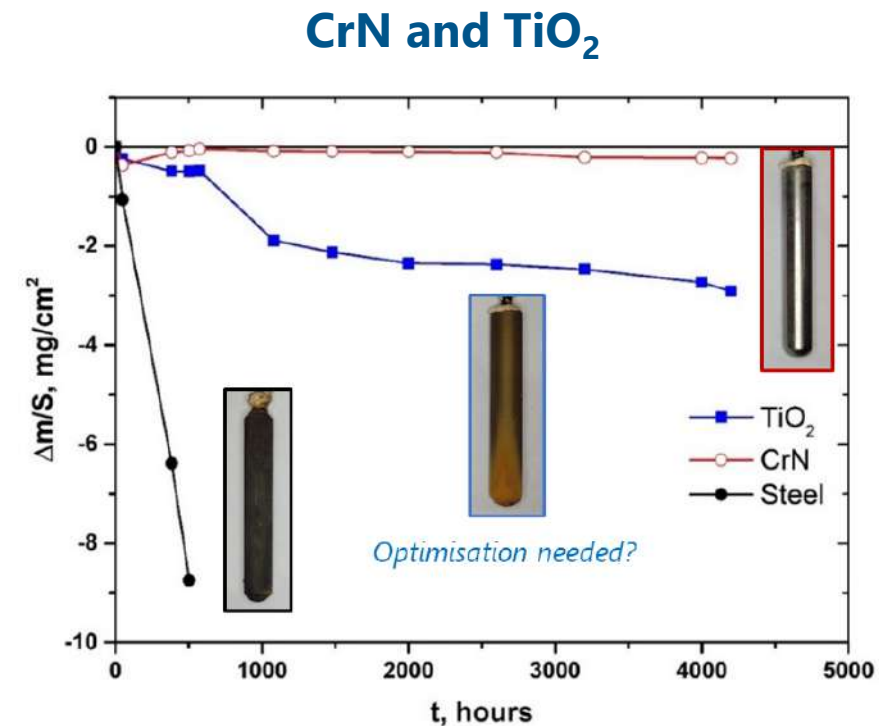
Cr forms a protective Cr oxide layer

CERAMIC AND METALLIC COATINGS

- Focus on optimization of the **PVD** method for coating production (thickness : **30 μm**)
- Good mechanical properties and a high degree of adhesion to the steel substrate at the **optimum bias potential**.



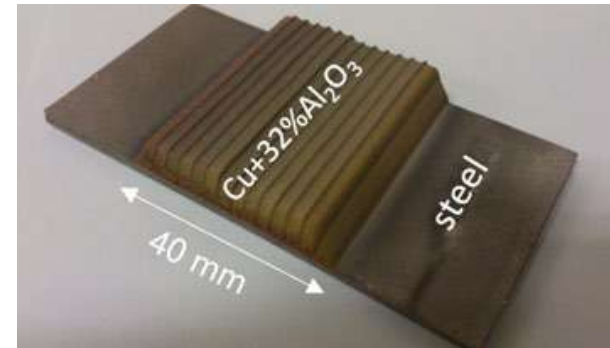
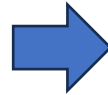
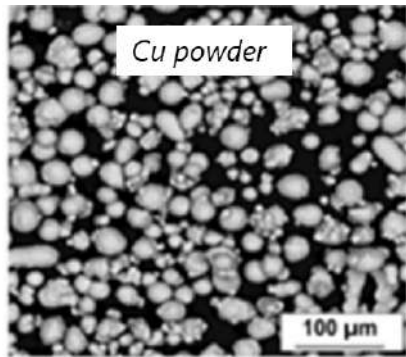
Changes in the specific weight as a function of immersion time in distilled water at 90 °C.



Changes in the specific weight as a function of immersion time in distilled water at 90 °C.

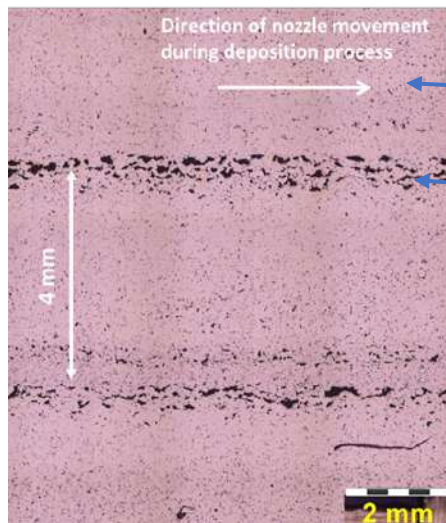
COPPER-ALUMINA COMPOSITE COATINGS

- Cold spray coatings studied are produced from a mixture of powders Cu+32vol.%Al₂O₃.



Composite cold spray coating coupon

- N₂ carrier
- 35 bars and 500°C
- 2 deposition speeds:
 - 20 mm/s
 - 40 mm/s



Low porosity in deposition lines (around 0.37%)

Higher porosity (2.47% to 3.31%) **in overlap zones**

Materials	2 months (53-60 days)	3-4 months (87-120 days)	6 months (180 days)
Wrought Cu	14 μm/y	16 μm/y	23 μm/y
Pure Cu CSC	17 μm/y	13 μm/y	26 μm/y
Composite Cu+32vol.%Al ₂ O ₃ CSC (low strategy)	21 μm/y	17 μm/y	-
Composite Cu+32vol.%Al ₂ O ₃ CSC (fast strategy)	-	47 μm/y	-

Corrosion rates vs. immersion time in synthetic groundwater at 90°C (50-100 ppb O₂)

Light optical microscope image (cross-section parallel to the surface of the coating)

TASK 3: CORROSION UNDER IRRADIATION

Jacobs



SÚRAO



- **Goal: assess whether irradiation will contribute/accelerate the corrosion of candidate canister materials (steel and copper) under realistic conditions**
 - T3.1 Total dose vs. Dose rate
 - Experimental window of several orders of magnitude of dose rates, total doses and exposure durations using simplified model systems
 - T3.2 Repository conditions
 - Explore the influence of type of bentonite, nature of irradiation source, effect of bentonite saturation, limit dose rate where no irradiation effect is seen.
- **Activities:**
 - Corrosion tests in irradiation facilities
 - Post-mortem characterisation

TASK 3: CORROSION UNDER IRRADIATION

Jacobs



SÚRAO



- **Goal: assess whether irradiation will contribute/accelerate the corrosion of candidate canister materials (steel and copper) under realistic conditions**

- Focus on *bentonite buffer materials* with different saturation levels (FEBEX, MX-80, Ca-Mg Czech bentonite)
- C-steel, copper, Ni-Alloy ; corrosion products
- Groundwater compositions (SGW3, FEBEX, NaHCO_3)
- Temperature (RT to 150°C)
- Redox (aerobic, anaerobic)
- Water saturation (full, partial, non saturated)
- Nature of irradiation sources (Co-60, Cs-137)
- Dose rates / Total dose (0-1000 Gy/hr ; 0-400 kGy)

Bentonite buffers are not representative for the current Belgian programme:

- pH from near-neutral to slightly alkaline
 - *active corrosion*
 - *film formation slowing down the corrosion rate with time*

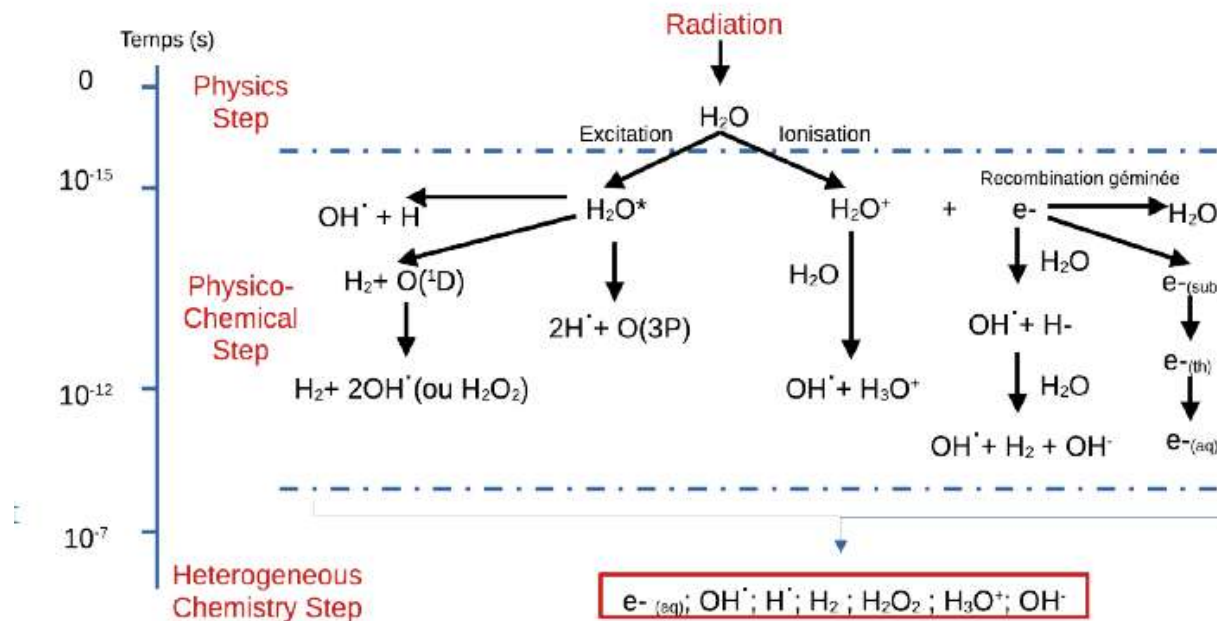
However **irradiation affects water chemistry, generating oxydants**

Understanding the general mechanisms and trends remains relevant.

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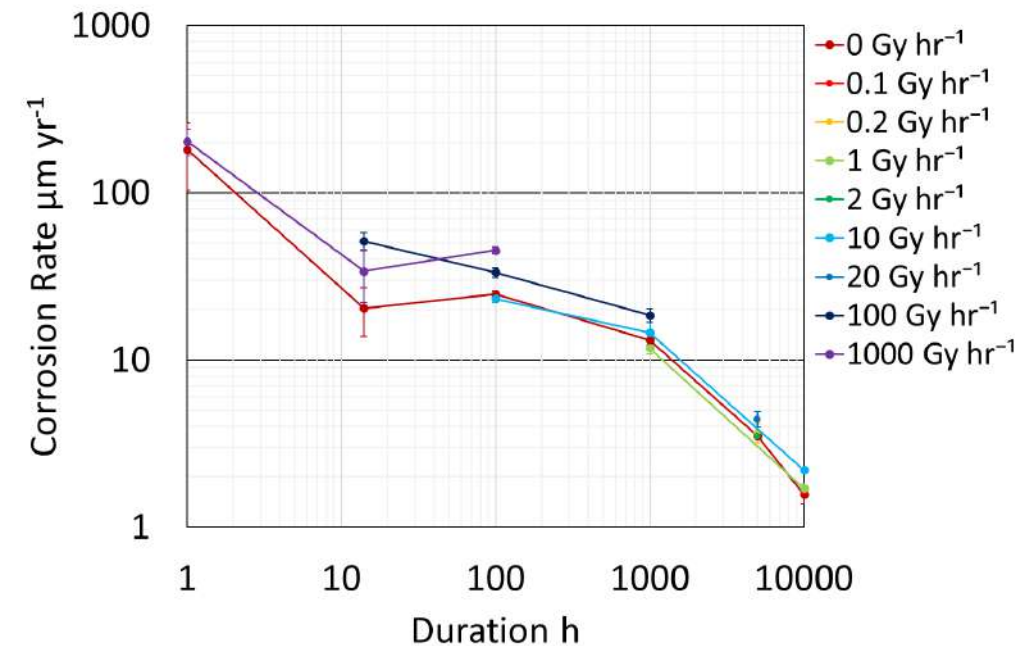
TASK 3: CORROSION UNDER IRRADIATION

- In terms results outcome:
 - A kind of **consensus** has been found **on corrosion products of C-steel with basically a mixture of *Fe-oxy-hydroxides and carbonate*** → the same “overall” mechanism?
 - **Corrosion kinetics were found to depend on the experimental parameters and conditions (water saturation, temperature)** → Link with expected **repository conditions**



TASK 3: CORROSION UNDER IRRADIATION

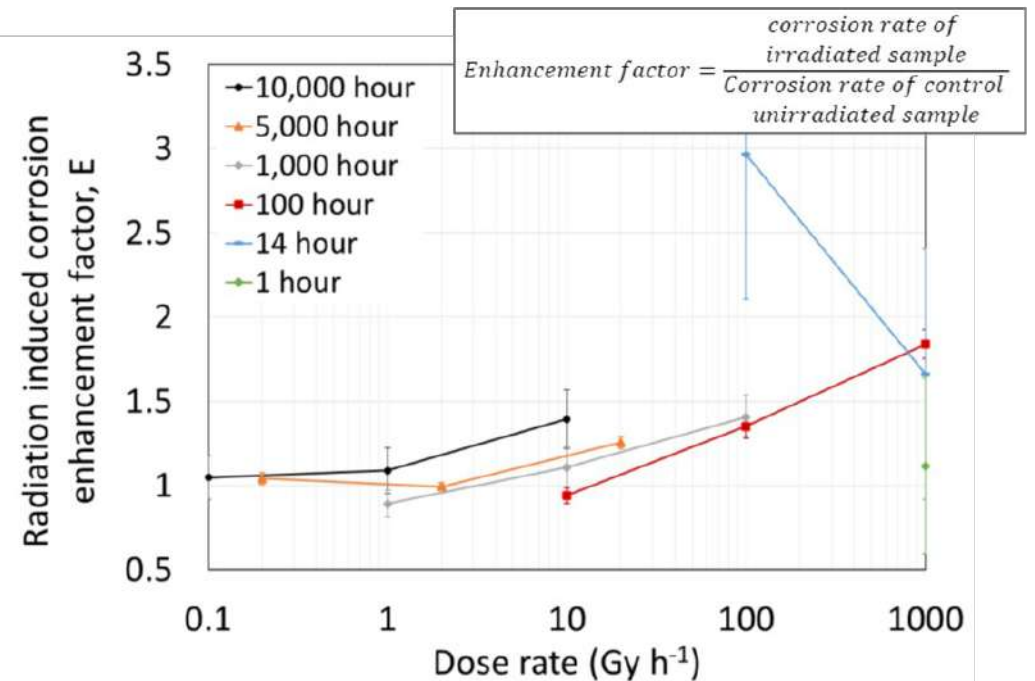
- The corrosion rate of **carbon steel** most strongly depended on exposure duration and could be loosely approximated by a power law relationship.



Average corrosion rate of carbon steel for set dose rates

TASK 3: CORROSION UNDER IRRADIATION

- The corrosion rate of **carbon steel** most strongly depended on exposure duration and could be loosely approximated by a power law relationship.
- A **significant increase in the corrosion rate** due to radiation exposure was only observed **at dose rates of 10 Gy/h or greater**.
- **At dose rates lower than 10 Gy/h no increase in corrosion rate associated with radiation was observed.**

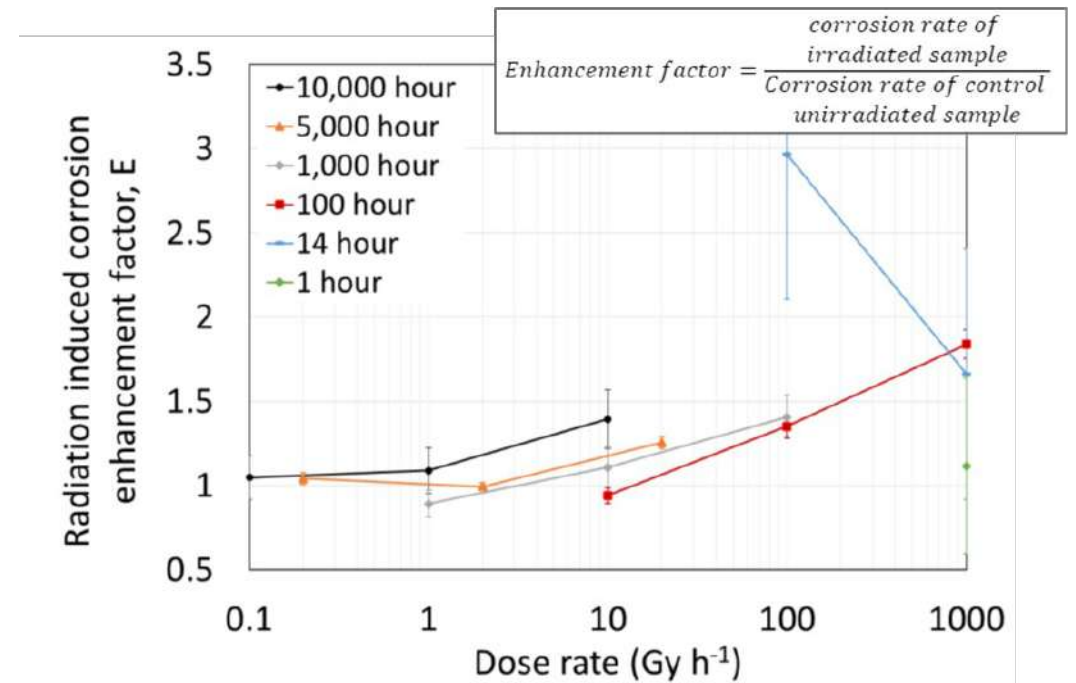


Influence of dose rate on the radiation induced corrosion enhancement factor, E .

TASK 3: CORROSION UNDER IRRADIATION

- The corrosion rate of **carbon steel** most strongly depended on exposure duration and could be loosely approximated by a power law relationship.
- A **significant increase in the corrosion rate** due to radiation exposure was only observed **at dose rates of 10 Gy/h or greater**.
- **At dose rates lower than 10 Gy/h no increase in corrosion rate associated with radiation was observed.**
- At durations longer than those explored here, it is expected that a significant increase in enhancement factor may be observed at dose rates lower than 10 Gy/h

Reference:
25 Gy/h at the surface of the overpack of the supercontainer



Influence of dose rate on the radiation induced corrosion enhancement factor, E .

TASK 5: TRANSIENTS



SÚRAO



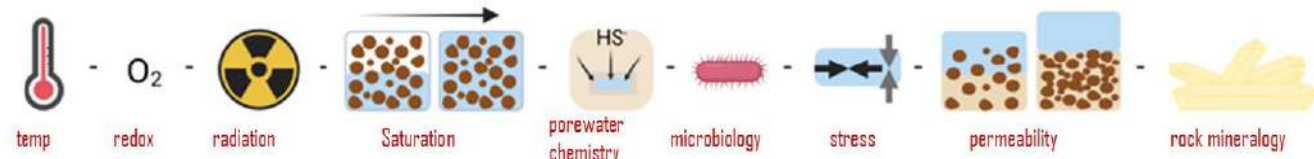
- Understand container **corrosion during transients** that would lead to chemo-mechanical interactions between the container material or coating (if present), corrosion products and buffer.

→ **Link to Task 3 and Task 4 activities**

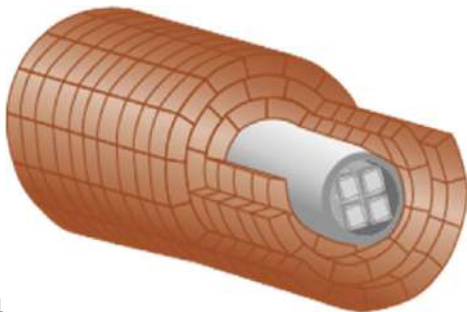
- To address existing **uncertainties** and to provide relevant experimental data to adequately account for these processes in performance assessment

→ **Link to Task 6 activities**

- Both laboratory and in-situ experiments



Focus: canister/bentonite interface



TRANSIENTS ANALYSED

- Thermal
- Redox
- Radiation
- Hydraulic (saturation)
- Chemical evolution
- Gas evolution

TASK 5: TRANSIENTS

- **Studied materials:**
 - **Carbon steel**
 - **Spheroidal graphite cast iron**
 - **Copper-nickel alloy** (Cu with about 30wt.% Ni)
 - **Cu-OFP**
 - **Contact to different types of bentonites, hydration with waters of different salinity and nature:**
 - low salinity granitic waters,
 - bentonite porewater
 - sedimentary clay groundwater of high salinity.
- **Carbon steel corrosion rate:**
 - increase at higher temperatures
 - enhanced by combining temperature and irradiation
 - strong influence of bentonite type and porewater salinity
 - **Spheroidal graphite cast iron corrosion rate**
 - Dependence on bentonite environment and salinity
 - Higher values found combining a γ -radiation dose of 130 Gy/h and temperature
 - **Very diverse corrosion products, highly dependent on the specific material and environmental conditions established at equilibrium.**

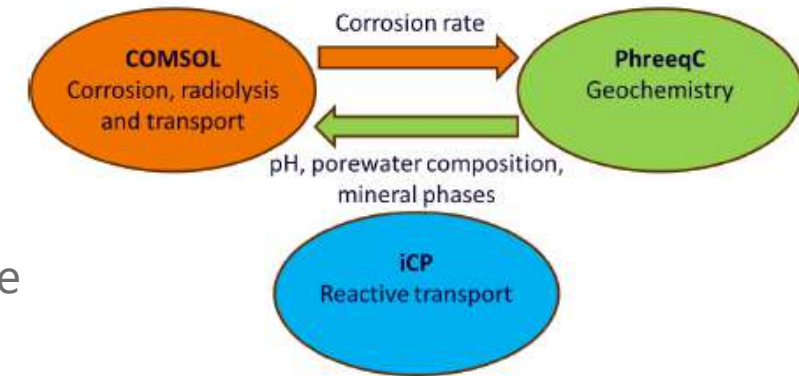
TASK 6: MODELLING

- **Modelling work:**
 - Reactive transport modelling – Links with Task 3 (irradiation) and Task 5 (transients)
 - Geochemical modelling with microbial activity – Links with Task 4 (microbial corrosion)
 - Repository scale modelling – contained within Task 6
- **Other work:**
 - ConCorD Synthesis Report (D 15.14) – Linked with all other Tasks

TASK 6: MODELLING

- **Development of modelling tools:**

- Development of a water and chloride radiolysis model
- Development of an electrochemical corrosion model for carbon steel
- Integration of radiolysis and steel corrosion models into a reactive transport computational platform



- **Model application (Task 3 and Task 5)**

- Simulation of irradiated experimental cells (carbon steel coupons embedded in compacted bentonite)
 - *Corrosion rate*
 - *Corrosion potential*
 - *Porewater chemistry*
 - *Precipitation of corrosion products*

The background features a light gray diamond shape in the center, surrounded by overlapping yellow and blue geometric shapes, including squares and rectangles, creating a modern, abstract design.

EURAD-2
**Innovative and new
Container/canister materials
under disposal field conditions:
Manufacturing feasibility and
improved Durability
InCoManD (WP9)**

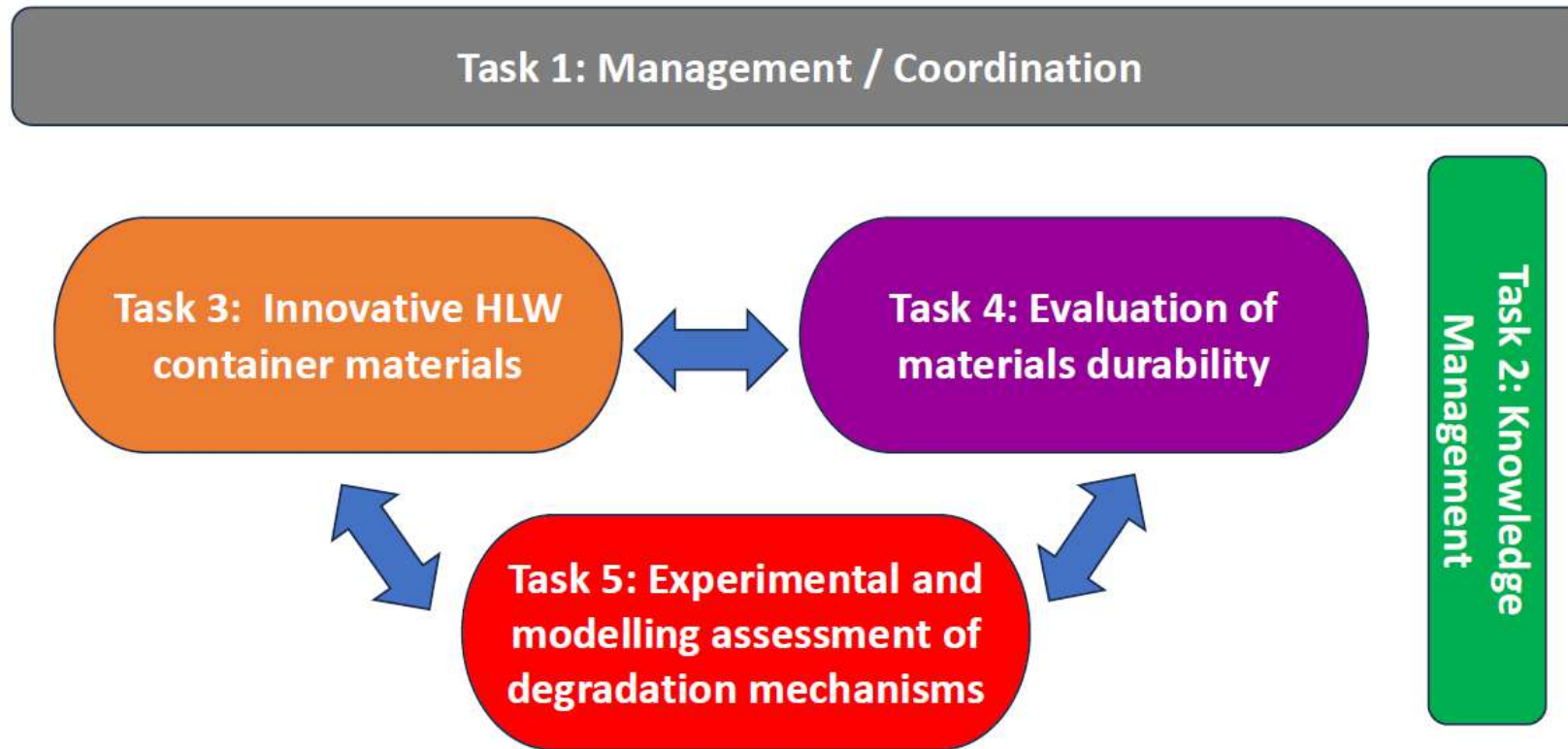
InCoManD: Objectives

Innovative and new Container/canister materials under disposal field conditions:
Manufacturing feasibility and improved Durability

- **Innovative: solutions** (materials and/or processes) **never implemented or tested.**
- **New: more traditional solutions** (materials and/or processes) **that need to be optimized, improved, tested in more realistic conditions...**
- **Container and canister:** same meaning, can be referred to as “component”
- The WP aims* at **identifying and qualifying innovative solutions for the HLW containers/canisters**, as well as **providing a deep knowledge of the long-term durability of any selected material in**, as realistic as possible, **field conditions.**

*starting from the ConCorD project outcomes and going beyond...

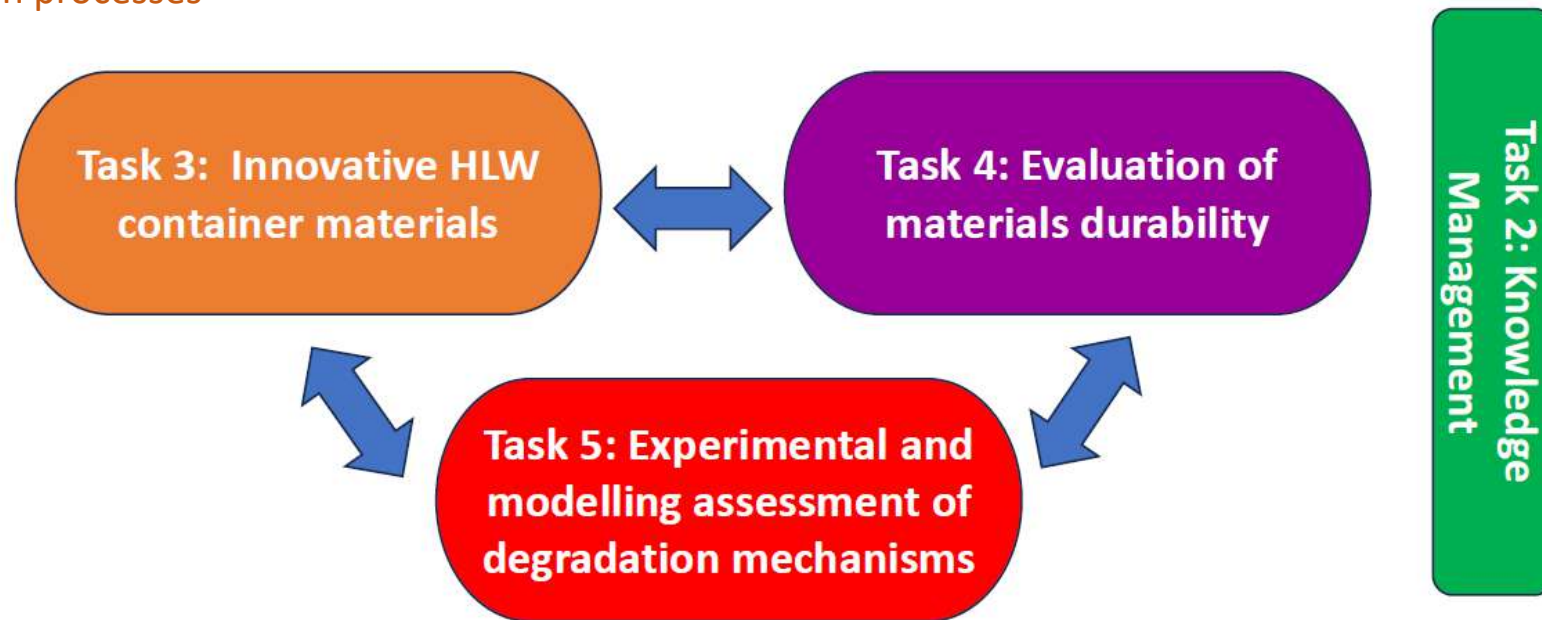
InCoManD: Organization in 5 Tasks



InCoManD: Organization in 5 Tasks

- Improve recently selected (within ConCorD) innovative bulk and coating materials
- Seek new options
 - Elaboration and optimization of fabrication processes

Evaluate the durability (i.e. corrosion resistance under **transients**) of the materials identified in Task 3 or previously recognized as reference materials
→ Identification of main degradation mechanisms



- Study of joint mechanical-corrosion degradation modes
- Determine threshold stresses for SCC
- Modelling of geochemistry and time-dependent transients

- Knowledge capture
- Knowledge transfer
- Additional KM activities: Summer School in Slovenia in 2027

THANK YOU FOR YOUR ATTENTION!



ANY QUESTION?



sck cen

Belgian Nuclear Research Centre

EURAD FUTURE & CORI

*Radionuclide migration in
clays and cement*

Norbert Maes, Liesbeth Van Laer

Delphine Durce, Nele Bleyen

2 WP's on RN mobility in EURAD

FUTURE - Host Rocks

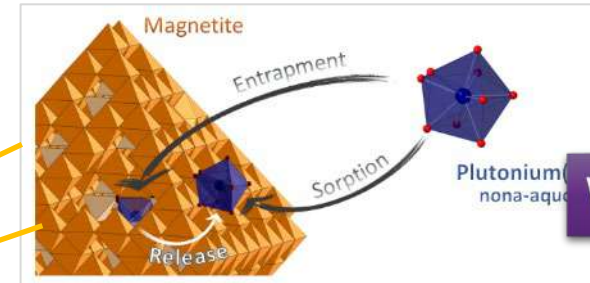
CORI - Cementitious barriers

- Belgian partner(s) in FUTURE:
 - SCK CEN with a limited experimental program (own funding), SCK CEN input to PPS domain Migration
 - Impact/role:
 - Responsible for the SOTA report (<https://www.ejp-eurad.eu/publications> look for D5.2)
 - Task responsible for T2.1 mobility in clays & experimental work within task 2.1
- Belgian partners in CORI:
 - SCK CEN involved in all 3 experimental tasks (task 2 co-funded by ONDRAF/NIRAS), SCK CEN input to PPS domains 'Organic Waste' and 'Migration'
 - Impact/role:
 - Experimental work within tasks 2, 3 and 4
 - Review of the SOTA report task 2 (<https://www.ejp-eurad.eu/publications> look for D3.2)
 - N/O involved as end-user

FUTURE
*Fundamental
understanding of
radionuclide retention*

Pillars of RN Transport & Retention

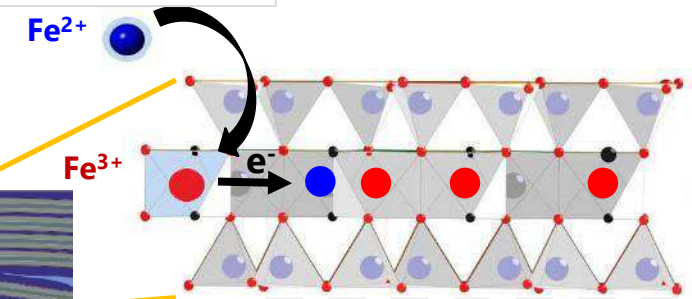
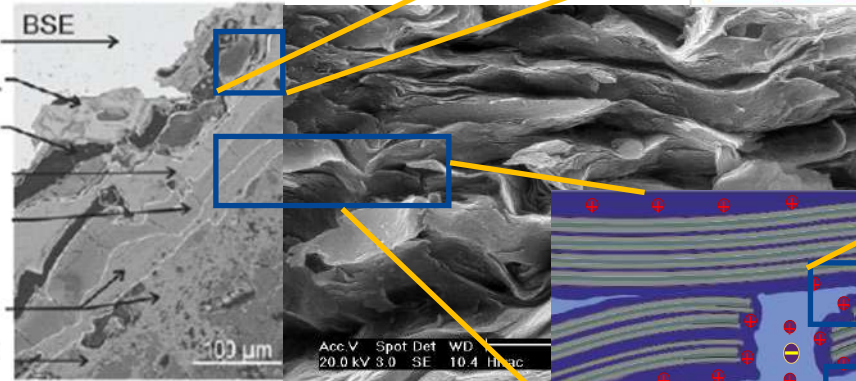
Argillaceous
Rocks



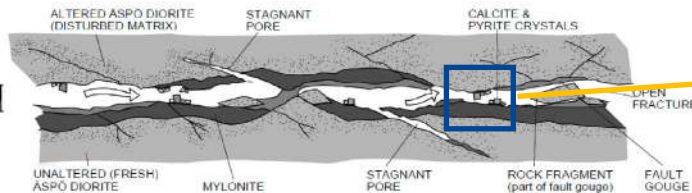
WP 3.0 REDOX

Crystalline
Rocks

Fe metal
Magnetite
Chukanovite
Fe^{II} phyllosilicate
Ca-doped siderite
Clay



WP 2.3 SORPTION
REVERSIBILITY



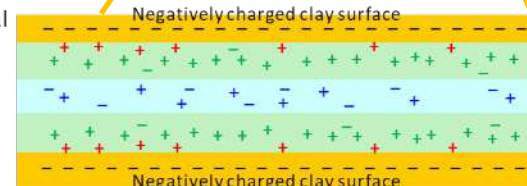
WP MOBILITY:
2.1 Clay & 2.2 Crystalline

Profile of electrical

potential

Clay
Pore

Ψ_D 0



EDL

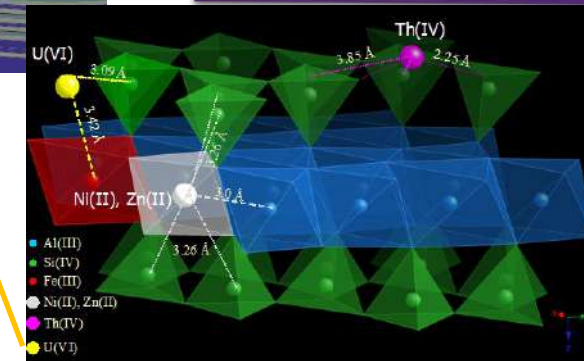
Free water

EDL

$J_{i,DL}$

$J_{i,free}$

$J_{i,DL}$



Objectives of the task “mobility in clays”

To enhance the quantitative and mechanistic understanding of the impact on radionuclide mobility (sorption & migration) wrt.

- Charge effects (surface charge, anion exclusion, enhanced flux in Electric Double Layer)
- Solution characteristics (pH, IS, competing elements)
- Microstructural effects (grain boundaries, water saturation, pore characteristics)

To obtain an improved understanding of adsorption mechanisms, specifically those controlling Long Term retention and sorption competition

- Reversibility of sorption, incorporation, surface precipitation,...
- Sorption competition

Approach: “Bottom-up schemes”

Bottom-up schemes:

- I From dispersed to compacted solids
- II From single mineral to clay rock
- III From single Radionuclide to multiple (competition)

- Pure mineral phases
- Single electrolytes
- Synthetic pore waters
- Isotropic diffusion
- Equilibrium situation
- Representative radionuclide

Step-Up



- Mineral assemblage, clay rock
- Equilibrium pore water
- Anisotropic diffusion
- Kinetic phenomena/LT processes
- Multiple elements/species

Bottom-up schemes translated into practice

- Systems:
 - 3 groups of elements: Weakly, moderately or strongly sorbing radionuclides
 - Pure clay minerals (e.g. illite), mixtures and clay host rocks (OPA, COX, BODA), both in *dispersed* and *compacted* state
 - Saturated and partial saturated state
- Methods:
 - Ad(de)sorption in dispersed and compacted systems
 - Diffusion experiments (through-, in-, out-)
 - Advanced spectroscopic methods: EXAFS, μ XAS, AMS, ATR-FTIR, LA-ICP-MS,...
- Expected Outcome:
 - Filling data gaps wrt. sorption parameters (e.g. SC constants) to feed into sorption models
 - Characteristic parameter dependence of D_e and K_d values (wrt. to above system properties)
 - Transferability of sorption and diffusion properties (wrt. to above system properties)

Matrix for dispersed systems

		<u>Kaol</u>	<u>Illite</u>	<u>Momo</u>	<u>I/M</u>	<u>COx</u>	<u>OPA</u>	<u>Boda</u>	<u>Others</u>
<u>weakly</u>	Se(IV)/(VI)		SCK-CEN			CIEMAT (T3)		EK	CIEMAT (Nau-1)(T3)
<u>moderately</u>	Ra/Ba		CIEMAT FZJ	CIEMAT FZJ		CIEMAT			CIEMAT (Nau-1)
(Trans. metals)	Co/Ni/Zn/ Mn/Fe/Pb	CIEMAT (Zn/Kaol)	CIEMAT (Zn) SCK-CEN (Zn/Ni)	CIEMAT (Cd, Zn, Co) BRGM (Co/Mg) JGU (Fe)	CIEMAT (Zn)			EK (Ni/Co)	
			PSI (Zn)	PSI (Zn)					
<u>strongly</u>	<u>tri-val</u>								
(Ln, An)	<u>tetra-val</u>		JGU (Pu)	JGU (Pu)					
	<u>hexa-val</u>		IPHC (U/phos) ATR FTIR			Subatech (U)			
<u>part.sat.</u>		CEA	CEA						
<u>Methods</u>			IPHC	BRGM JGU					
<u>Materials</u>		IC2MP	IC2MP						
<u>Reversibility</u>									

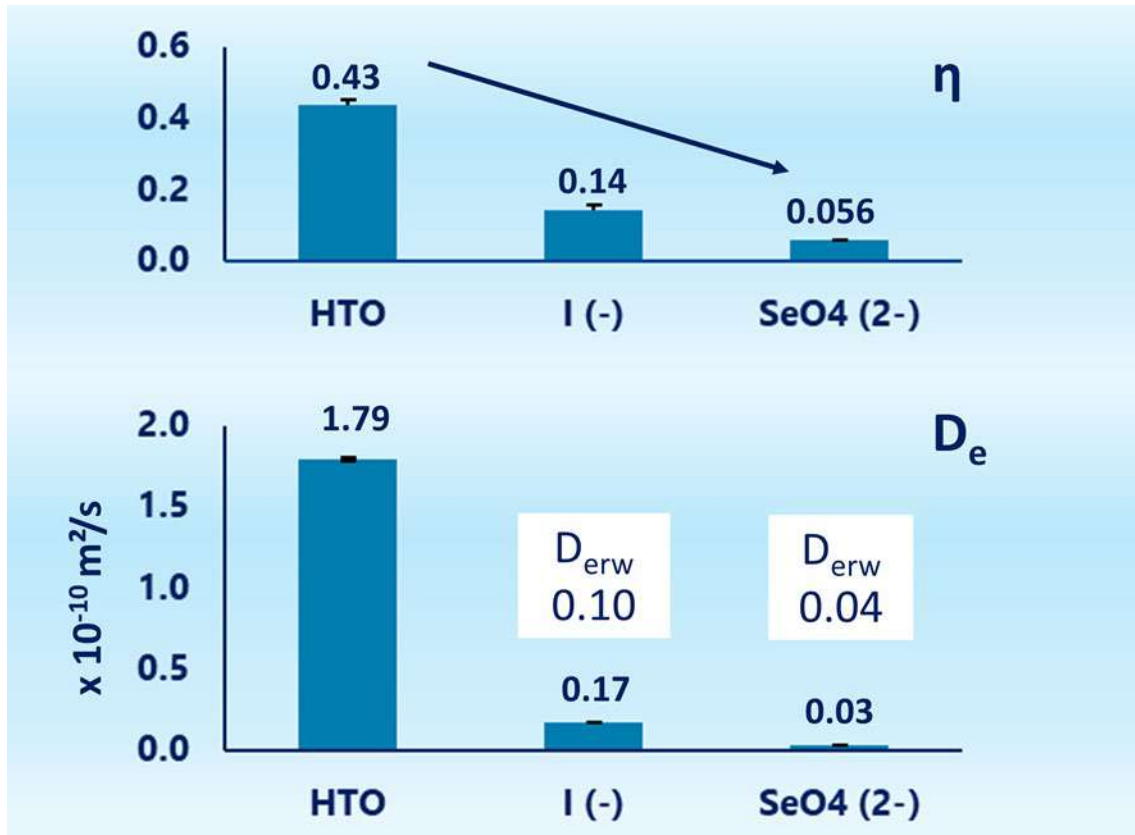
Matrix for compacted systems

		<u>Kaol</u>	<u>Illite</u>	Momo	I/M	<u>COx</u>	OPA	<u>Boda</u>	<u>Others</u>
<u>weakly</u>	Se(IV)/(VI)		SCK-CEN	CIEMAT (<u>Kd</u>)		CIEMAT (<u>dif</u>)		EK	CIEMAT (Lutite) <u>unsat</u>
<u>moderately</u>	Ra/Ba			CIEMAT (<u>Kd</u>)		CIEMAT (<u>Kd+Diff</u>)	FZJ (<u>diff</u>)		
(Trans. Metals)	Co/ <u>Ni</u> /Zn/ Mn/ <u>Fe</u> /Pb		PSI-LES (<u>Zn</u> , Co) SCK-CEN (<u>Zn</u> / <u>Ni</u>)	CIEMAT (<u>kd</u>) (<u>Zn</u> , Co, <u>Cd</u> , <u>Ni</u>)				EK (<u>Ni</u>)	
<u>strongly</u>	<u>tri-val</u>					<u>Subatech</u> (<u>Eu</u>)	(KIT <u>Am</u>)		
(Ln, An)	<u>tetra-val</u>					<u>Subatech</u> (<u>U</u>)	JGU (<u>Pu</u>)		
	<u>hexa-val</u>						(KIT <u>U</u>)	EK (<u>U</u>)	
<u>part.sat.</u>	HTO/ <u>I</u> ⁻	CEA	CEA						CEA (<u>vermic.</u>)
<u>Methods</u>		CEA	CEA	PSI-LES		<u>Subatech</u>	JGU	EK	CEA
<u>Materials</u>		IC2MP	IC2MP						IC2MP(<u>vermic</u>)

Some highlighted examples

Effect of anionic charge on diffusion accessible porosity

HTO, I^- , SeO_4^{2-} diffusion in Na-illite du Puy at 0.01 M NaCl - pH 8.2 (n=2)



Anion exclusion effect is larger for divalent compared to monovalent anions

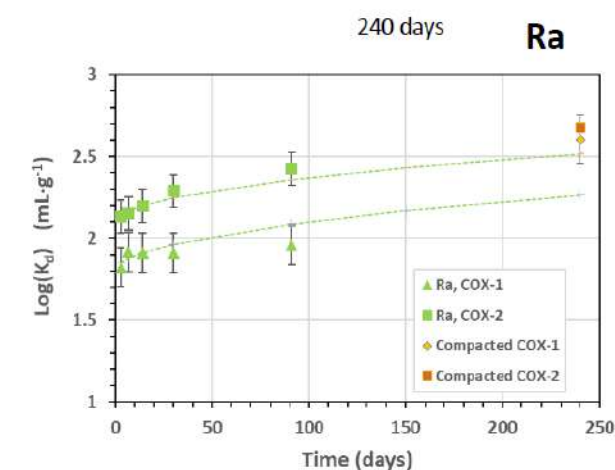
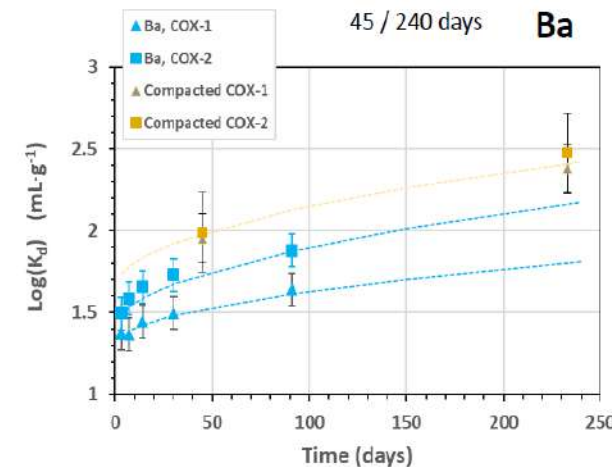
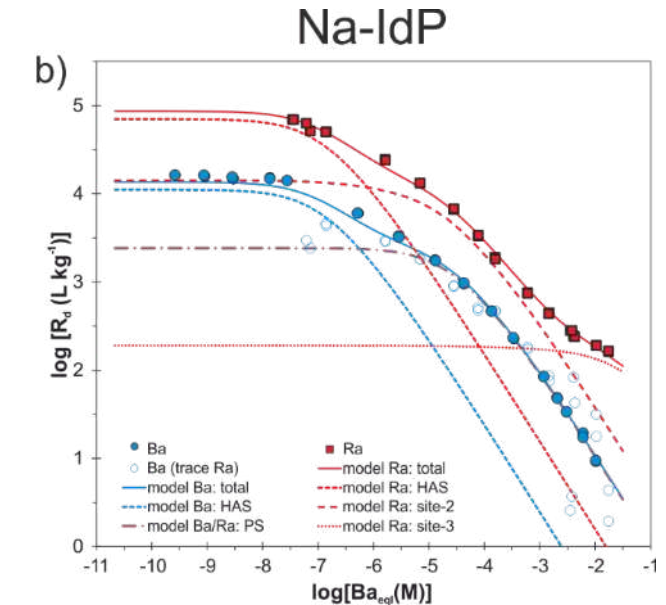
=> stronger repelled from the negatively charged clay surface

Normalized diffusion coefficient D_{erw} (anion vs. HTO)

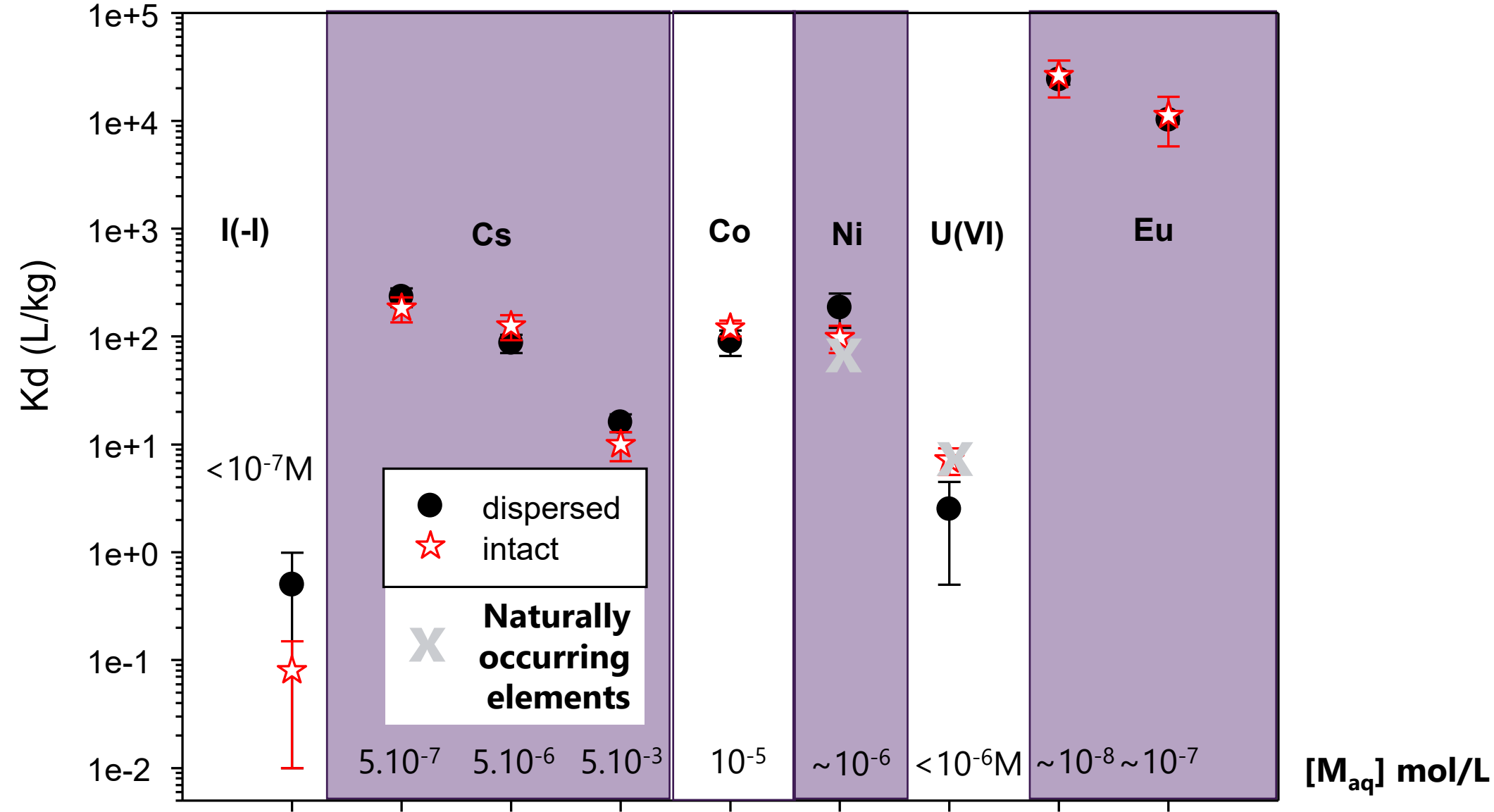
$$D_{erw} = \frac{D_e(\text{anion})D_0(\text{HTO})}{D_e(\text{HTO})D_0(\text{anion})}$$

Retention of ^{226}Ra and Ba

- Ra and Ba surface complexation could be described with a unified model on Montmorillonite, but behavior of Ra and Ba on Illite is distinct.
- Transferability of Ba/Ra data from dispersed to compacted systems could be demonstrated, including intact natural rocks (i.e. Cox)
- In crystalline rocks, Ra retention can be clearly assigned to phyllosilicates and the connection to clay systems is established
- Molecular sorption mechanism of Ba/Ra on mica has been identified by ab initio simulations
- A coupled pore scale reactive transport model for Ba/Ra retention in $(\text{Sr}, \text{Ba}, \text{Ra})\text{SO}_4$ solid solution was developed based on state-of-the art microfluidic experiments & pore scale modelling
- Mechanistic Ra sorption and transport model is available now



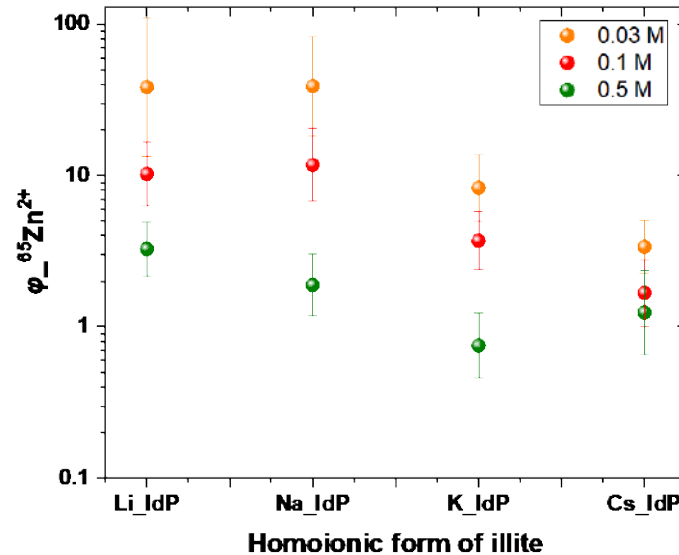
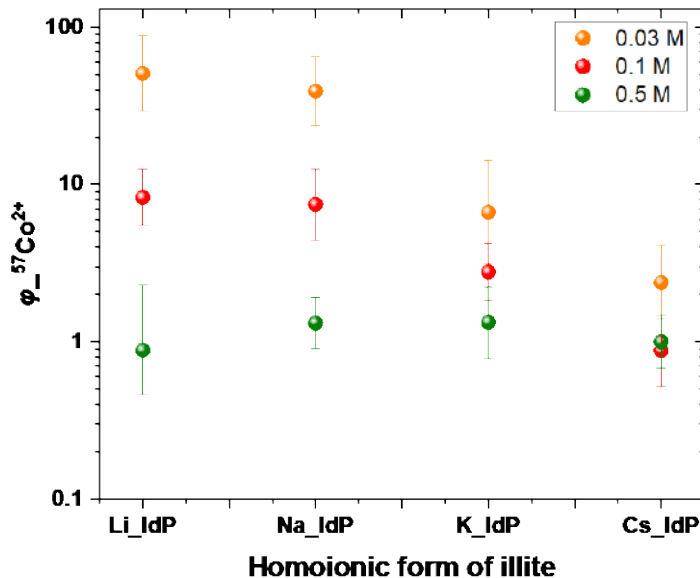
Consistent Sorption data on dispersed and intact rocks (COX)



Concentration of naturally occurring elements and pore water chemistry must be accounted for properly

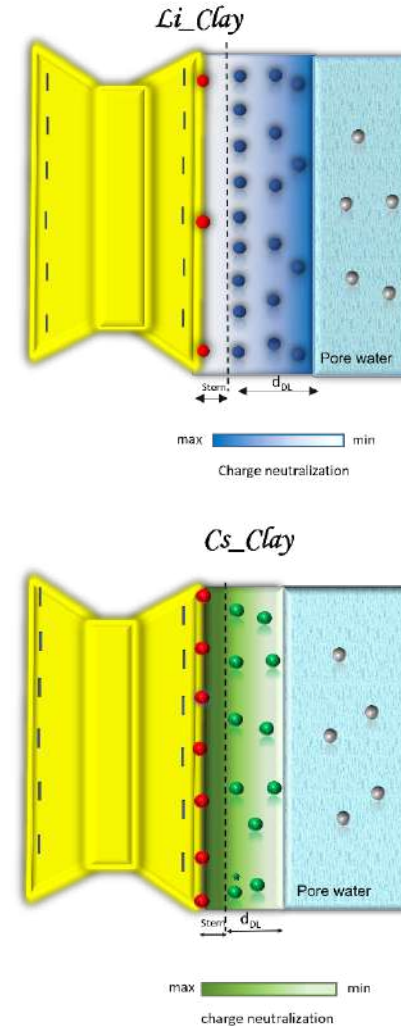
Surface diffusion contribution to Co and Zn transport

Normalised diffusivity (φ):
$$\varphi = \frac{D_e(\text{cation})}{D_e(\text{HTO})} \cdot \frac{D_w(\text{HTO})}{D_w(\text{cation})}$$



$\varphi > 1$: surface diffusion contribution

$\varphi = 1$: no surface diffusion



Conclusions and outcome of the project - 1/2

- **Validity of *bottom up* approach for sorption is broadly confirmed but not always straightforward... as all underlying mechanisms and parameters must be known:**
 - From dispersed systems to compacted systems → **straightforward if system chemistry is well known**
 - From single mineral to complex systems → **straightforward**
 - From single RN to RN mix (competition) → **remains challenging and needs further studies**
- **New/missing data became available and included into sorption models (e.g. Ra & Ba)**
- **Mechanistic sorption models obtained from sorption studies are applicable in the interpretation of transport experiments (but PW chemistry should be accounted for)**

Conclusions and outcome of the project - 2/2

- **Important insights are obtained on how partial saturation affects the mobility of different charged RN in clays with different surface charge**
- **Development of spectroscopic techniques helped to:**
 - Push detection limits for concentration measurements by several orders of magnitude
 - Provide detailed zoom into surface properties
 - Revealed quantitative information about the RN speciation in aqueous phase, in solids and at interfaces

Relevance Belgian Program

Provided input to the assessment basis for sorption and diffusion on minerals relevant for clay based host rocks.

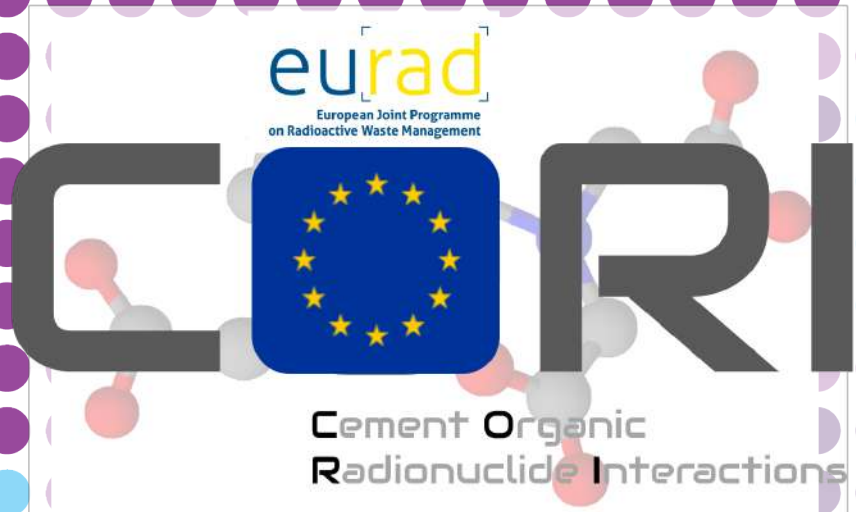
Mechanistic sorption models obtained from sorption studies are applicable in the interpretation of transport experiments (but PW chemistry should be accounted for).

Clear evidence for enhanced cation diffusion in clay systems (surface diffusion)

- Affects *all* cationic species and becomes very important at low ionic strength
→ For predictive modelling, classical transport models do not suffice, EDL effects should be accounted for

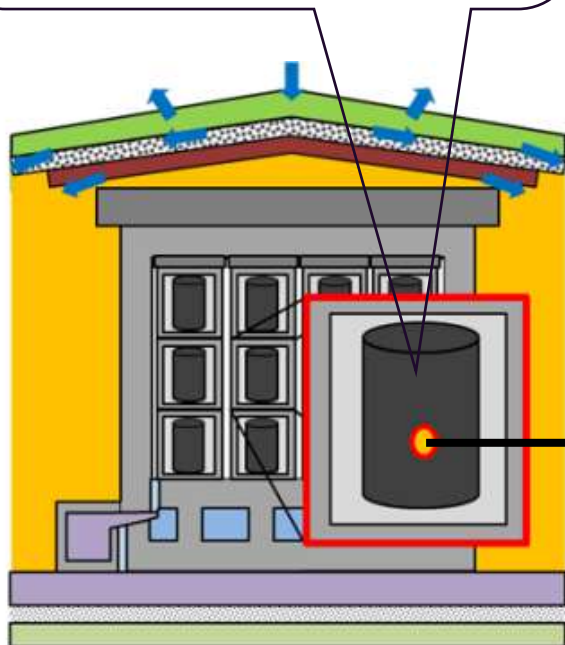
CORI

***C**ement **O**rganic
Interactions*





Organic waste matrices
Organic waste
Organic cement additives



ONDRAF/NIRAS (2019)

Radiolysis

Hydrolysis

TASK 2

Gas production
+
Organic
degradation
products

Organic – cement
interactions

TASK 3

Cement

TASK 4

(1) Increased
solubility?
(2) Reduced
sorption on
cement phases

(3) Sorption
competition

Radionuclide

CORI Task 2

Organic waste



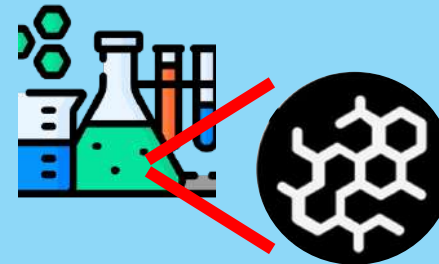
- ❑ Cellulose
- ❑ Polyvinylchloride
- ❑ Polyethylene
- ❑ Ion Exchange Resins
- ❑ Superplasticizers

Radiolytic degradation



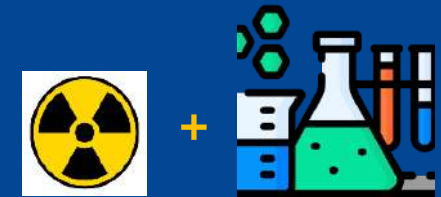
- ❑ Determination of gas production yields
- ❑ Production of soluble organics
- ❑ Investigation degradation mechanism

Hydrolytic degradation



- ❑ Degradation of organics at high pH
- ❑ Production of soluble organics

Radiolytic + hydrolytic degradation



- ❑ Radiolysis followed by hydrolysis
- ❑ Combined radiolysis and hydrolysis
- ❑ Production of soluble organics
→ used in tasks 3-4

CORI Task 2

Organic waste



- ☐ Cellulose
- ☐ Polyvinylchloride
- ☐ Polyethylene
- ☐ Ion Exchange Resins
- ☐ Superplasticizers

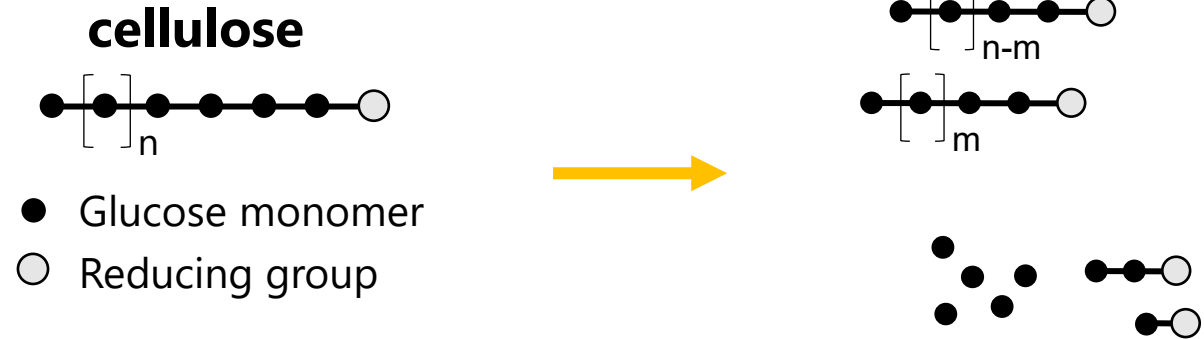
Cellulose degradation studies

Radiolytic degradation

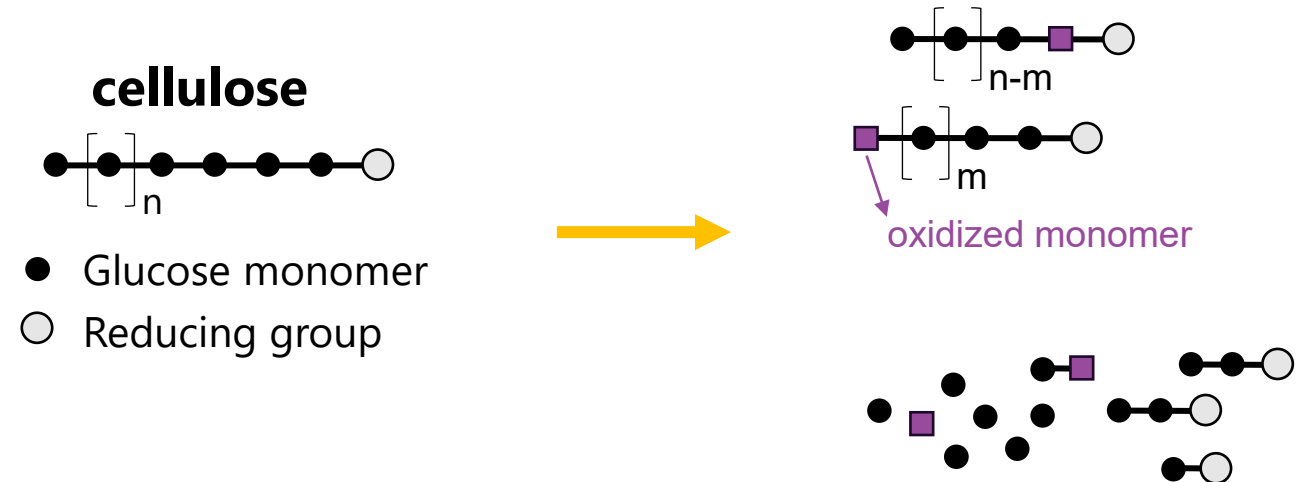


- ❑ Determination of gas production yields
- ❑ Production of soluble organics
- ❑ Investigation degradation mechanism

- Under anoxic conditions: chain scission → reducing end groups↑ + water-soluble sugars and oligosaccharides

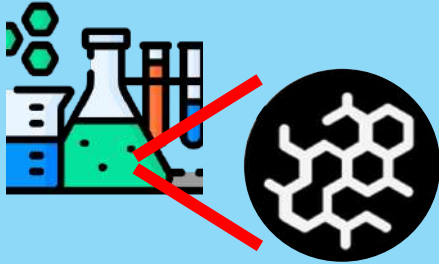


- Under oxic conditions: chain scission + radio-oxidation of cellulose backbone



Cellulose

Hydrolytic degradation



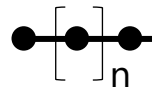
□ Degradation of organics at high pH

□ Production of soluble organics

- Long-term degradation of cellulose (pure, paper, tissues, cotton) in fresh cement water (pH 13.3): continuation tests started in 1996*
- Results in line with previously published results (Glaus et al 2008)
- Proposed degradation mechanism and kinetics is still applicable

Tissues (Tela) C1

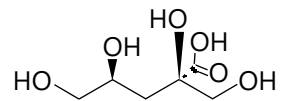
cellu



● Gluco
○ Reduc

tion products:
nts of

β -ISA



tion products:
weight organic acids

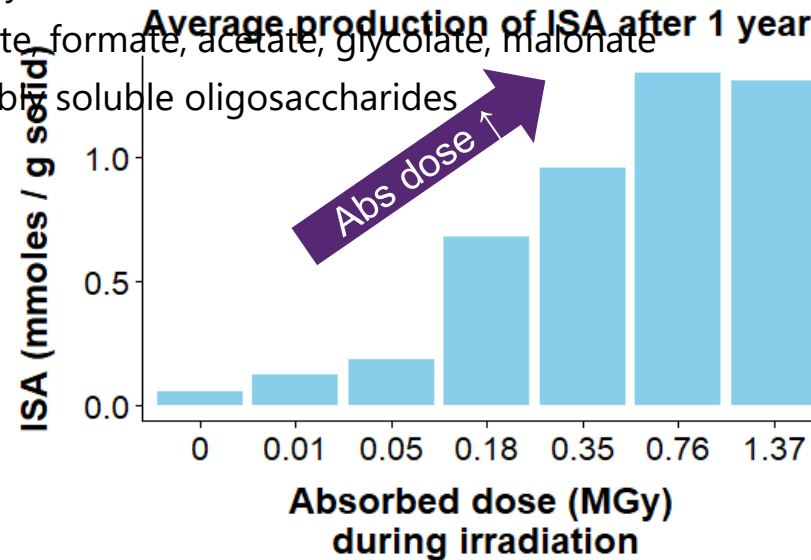
Radiolytic + hydrolytic degradation



❑ Radiolysis followed by hydrolysis

❑ Production of soluble organics
→ used in tasks 3-4

- Effect of pre-irradiation on subsequent alkaline degradation of cellulosic tissues
 - Pre-irradiation accelerates alkaline degradation of cellulose rather than causing additional reactions
 - Radio-oxidation even further accelerates alkaline degradation
 - Cellulose degradation products (C_DP) → tasks 3 and 4:
 - Mainly ISA
 - Lactate, formate, acetate, glycolate, malonate
 - Possible soluble oligosaccharides



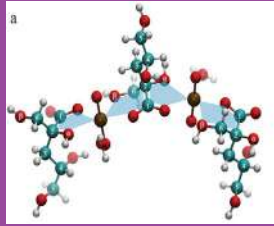
CORI Task 3-4

Cementitious phases



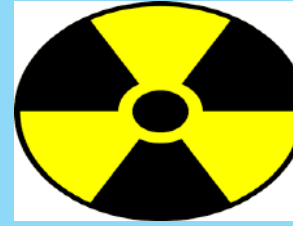
- ❑ **Cements:**
 - ❖ CEMI
 - ❖ CEMIII
 - ❖ CEMIV
 - ❖ CEMV
 - ❖ RICHARD Cement
- ❑ **Degradation States**
 - ❖ State I (fresh)
 - ❖ State II
 - ❖ State III
- ❑ **Cement minerals**
 - ❖ CSH/CASH
 - ❖ Afm/Aft
 - ❖ Portlandite

Organics



- ❑ **Degradation products:**
 - ❖ ISA
 - ❖ Phthalate
- ❑ **Small Organic**
 - ❖ EDTA, NTA
 - ❖ Citrate, Adipate, Oxalate, Formate
- ❑ **Ion Exchange Resins**
 - ❖ GTA, HIBA, HBA
- ❑ **Concrete admixture**
 - ❖ Gluconate
 - ❖ Superplasticizers
- ❑ **Degradation mixtures Task2**

Radionuclides



- ❑ **Trivalent Actinides/Lanthanides**
 - ❖ Am, Eu, Cm
 - ❖ Pu(III/IV)
- ❑ **Tetravalent Actinides**
 - ❖ Pu(III/IV)
 - ❖ Th(IV)
- ❑ **Divalents**
 - ❖ Ni
 - ❖ Pb
- ❑ **U(VI)**
- ❑ **HTO, CI**

Type of studies



- ❑ **Solubility**
- ❑ **Retention**
- ❑ **Transport**

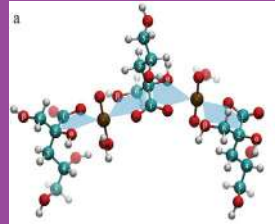
CORI Task 3

Cementitious phases



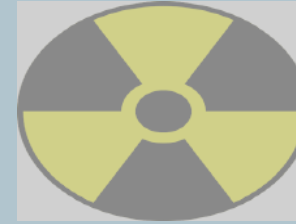
- ☐ **Cements:**
 - ❖ CEMI
 - ❖ CEMIII
 - ❖ CEMIV
 - ❖ CEMV
 - ❖ RICHARD Cement
- ☐ **Degradation States**
 - ❖ State I (fresh)
 - ❖ State II
 - ❖ State III
- ☐ **Cement minerals**
 - ❖ CSH/CASH
 - ❖ Afm/Aft
 - ❖ Portlandite

Organics



- ☐ **Degradation products:**
 - ❖ ISA
 - ❖ Phthalate
- ☐ **Small Organic**
 - ❖ EDTA, NTA
 - ❖ Citrate, Adipate, Oxalate, Formate
- ☐ **Ion Exchange Resins**
 - ❖ GTA, HIBA, HBA
- ☐ **Concrete admixture**
 - ❖ Gluconate
 - ❖ Superplasticizers
- ☐ **Degradation mixtures Task2**

Radionuclides



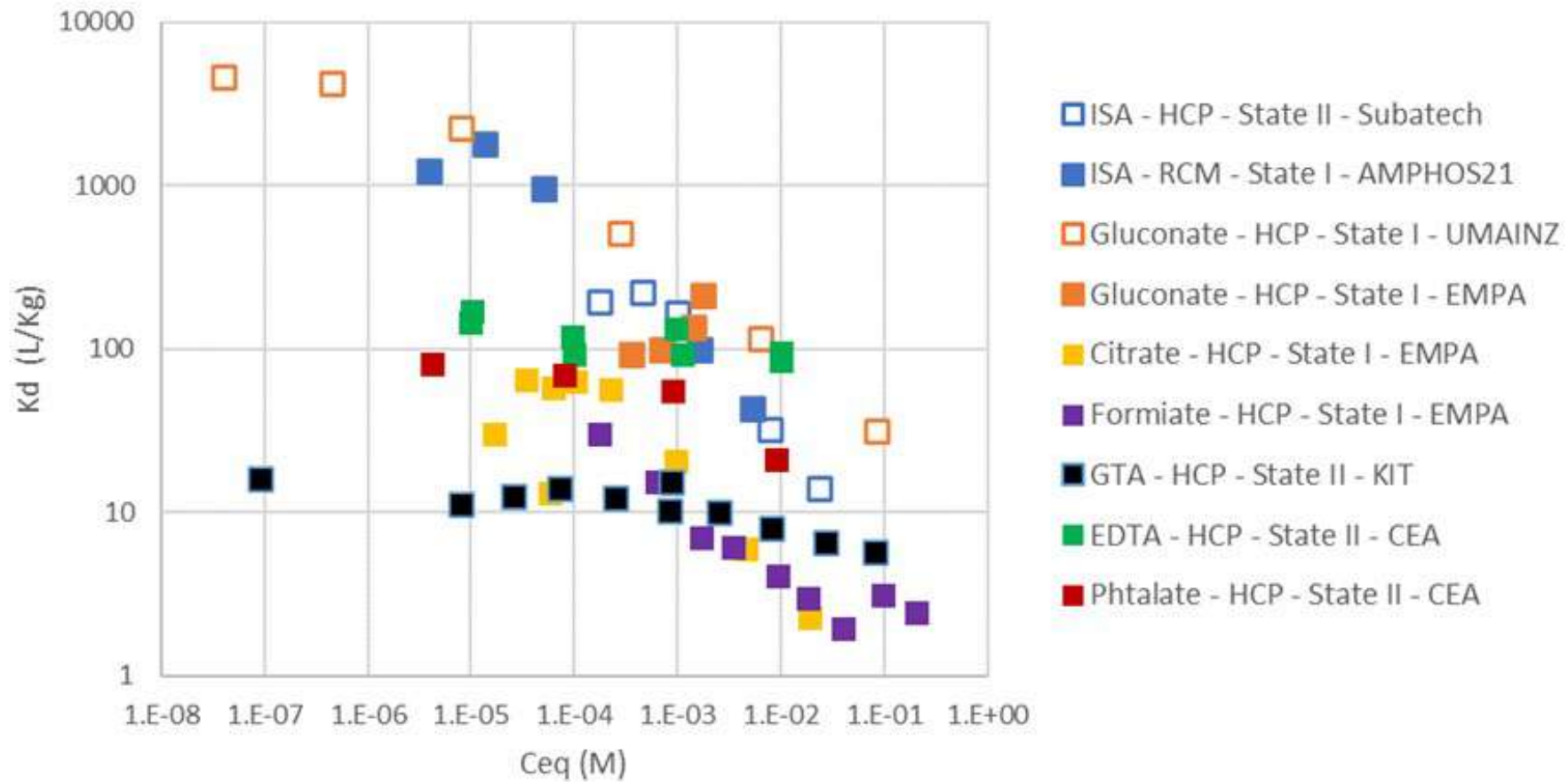
- ☐ **Trivalent Actinides/Lanthanides**
 - ❖ Am, Eu, Cm
 - ❖ Pu(III/IV)
- ☐ **Tetravalent Actinides**
 - ❖ Pu(III/IV)
 - ❖ Th(IV)
- ☐ **Divalents**
 - ❖ Ni
 - ❖ Pb
- ☐ **U(VI)**
- ☐ **HTO, CI**

Type of studies

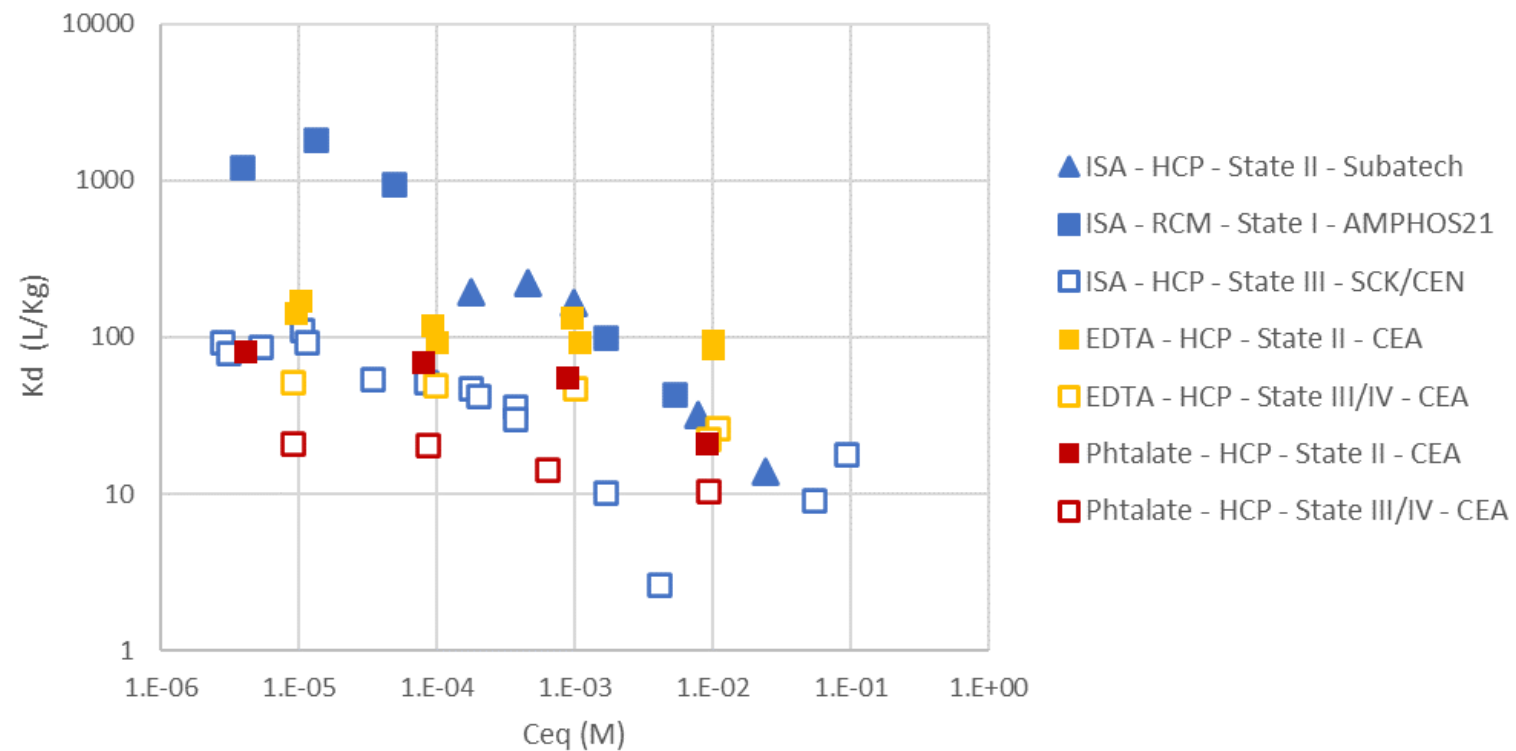


- ☐ **Solubility**
- ☐ **Retention**
- ☐ **Transport**

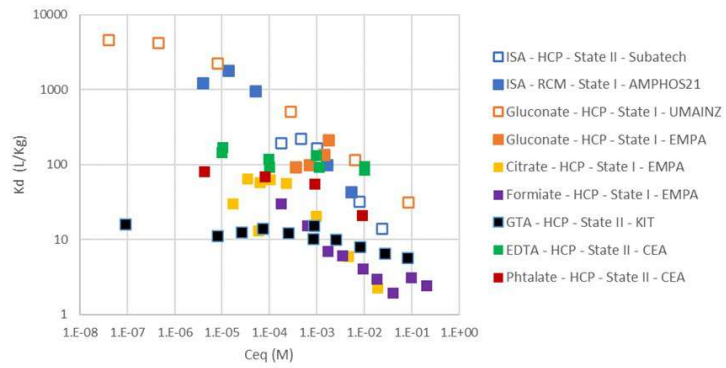
Sorption of organics



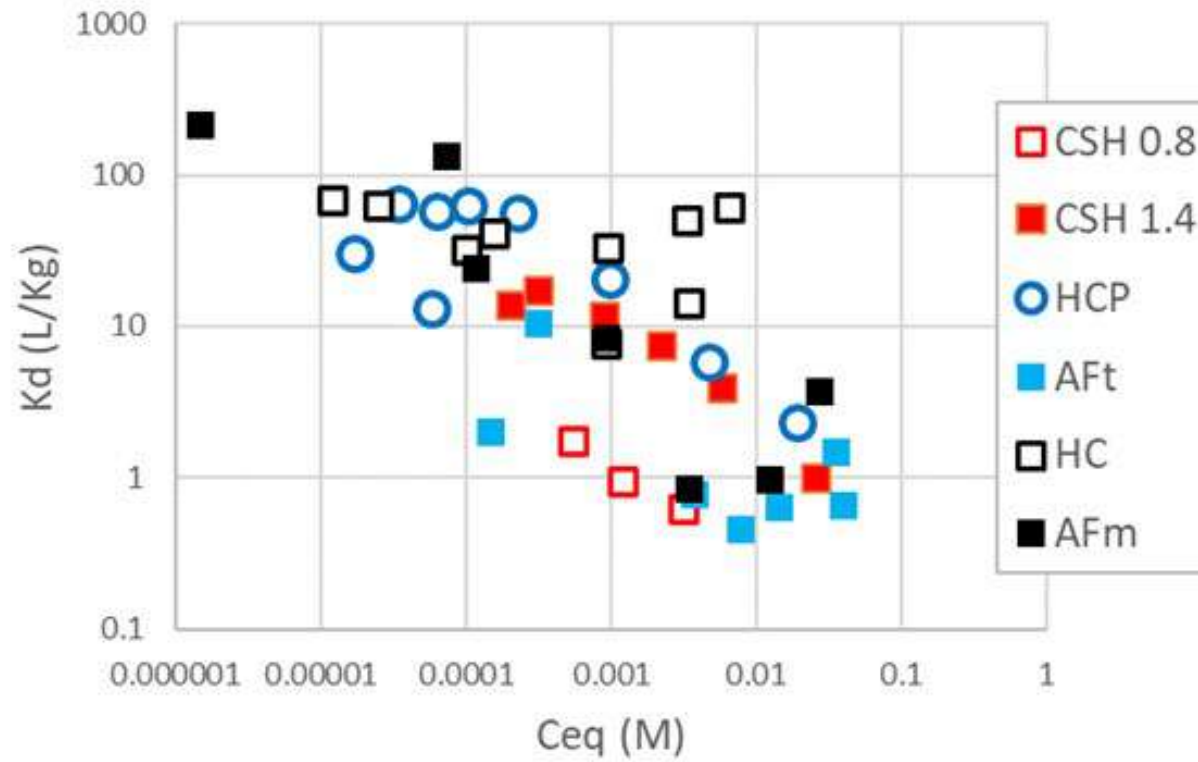
Sorption variable for the different organics and concentration dependent



Sorption can depend on the degradation state of the cement-based materials



Sorption variable for the different organics and concentration dependent



Sorption occurs on various hydrates

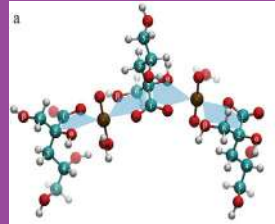
CORI Task 4

Cementitious phases



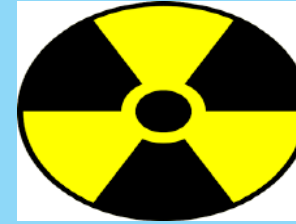
- ☐ **Cements:**
 - ❖ CEMI
 - ❖ CEMIII
 - ❖ CEMIV
 - ❖ CEMV
 - ❖ RICHARD Cement
- ☐ **Degradation States**
 - ❖ State I (fresh)
 - ❖ State II
 - ❖ State III
- ☐ **Cement minerals**
 - ❖ CSH/CASH
 - ❖ Afm/Aft
 - ❖ Portlandite

Organics



- ☐ **Degradation products:**
 - ❖ ISA
 - ❖ Phthalate
- ☐ **Small Organic**
 - ❖ EDTA, NTA
 - ❖ Citrate, Adipate, Oxalate, Formate
- ☐ **Ion Exchange Resins**
 - ❖ GTA, HIBA, HBA
- ☐ **Concrete admixture**
 - ❖ Gluconate
 - ❖ Superplasticizers
- ☐ **Degradation mixtures Task2**

Radionuclides



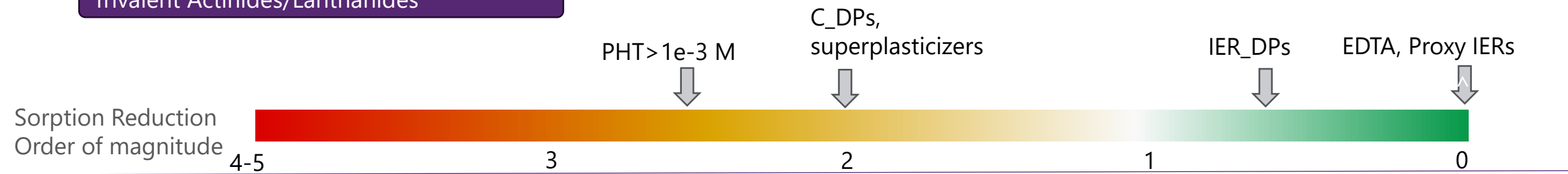
- ☐ **Trivalent Actinides/Lanthanides**
 - ❖ Am, Eu, Cm
 - ❖ Pu(III/IV)
- ☐ **Tetravalent Actinides**
 - ❖ Pu(III/IV)
 - ❖ Th(IV)
- ☐ **Divalents**
 - ❖ Ni
 - ❖ Pb
- ☐ **U(VI)**
- ☐ **HTO, CI**

Type of studies

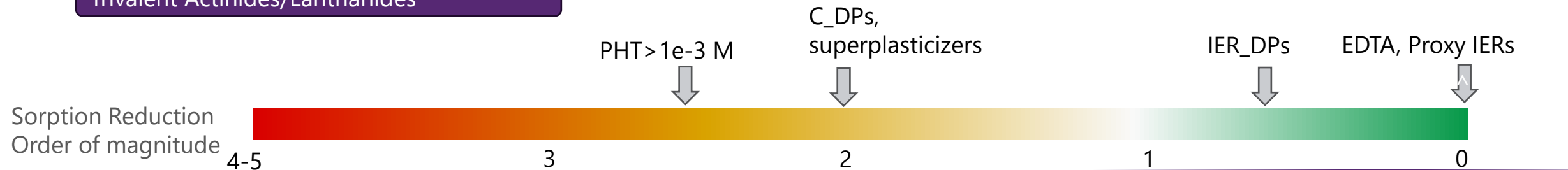


- ☐ **Solubility**
- ☐ **Retention**
- ☐ **Transport**

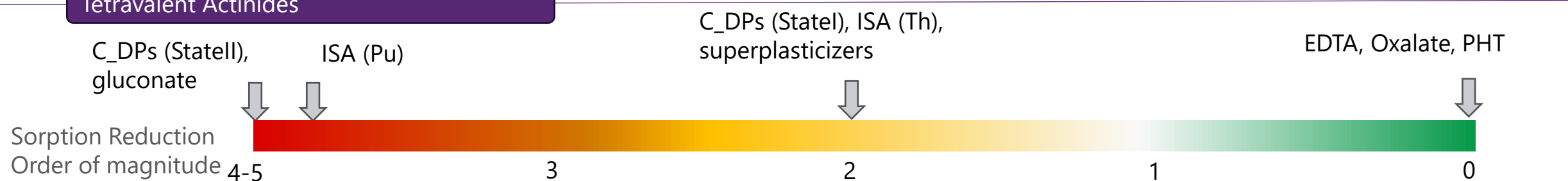
Trivalent Actinides/Lanthanides



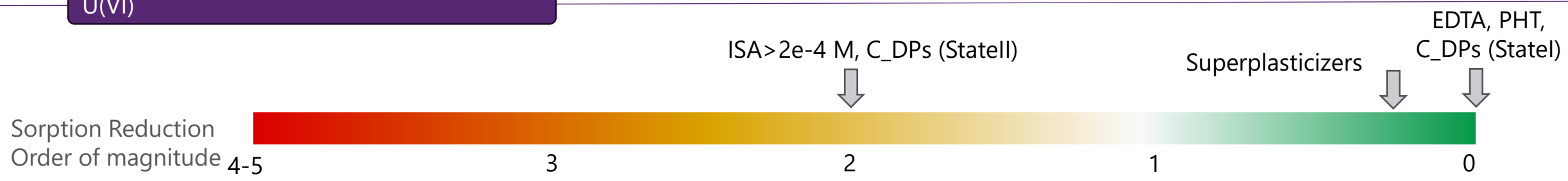
Trivalent Actinides/Lanthanides



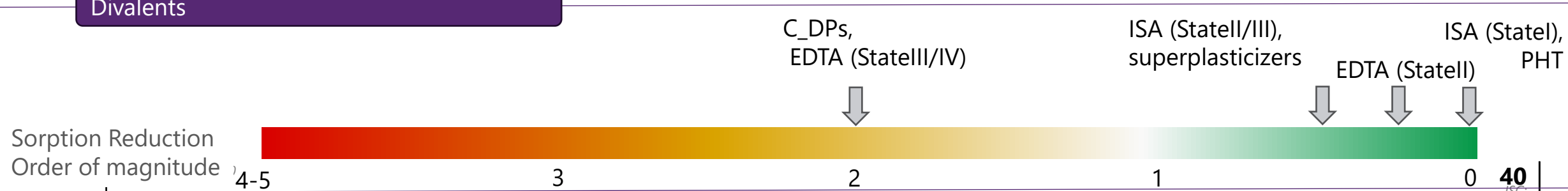
Tetravalent Actinides



U(VI)



Divalents



Trivalent Actinides/Lanthanides

Sorption Reduction
Order of magnitude

4-5

3

2

1

0

PHT > $1e-3$ M

C_DPs,

superplasticizers

IER_DPs

EDTA, Proxy IERs

Tetravalent Actinides

Sorption Reduction
Order of magnitude

4-5

3

2

1

0

C_DPs (Statell),
gluconate

ISA (Pu)

C_DPs (Statell), ISA (Th),
superplasticizers

EDTA, Oxalate, PHT

U(VI)

Sorption Reduction
Order of magnitude

4-5

3

2

1

0

ISA > $2e-4$ M, C_DPs (Statell)

Superplasticizers

EDTA, PHT,
C_DPs (Statell)

Divalents

Sorption Reduction
Order of magnitude

4-5

3

2

1

0

C_DPs,

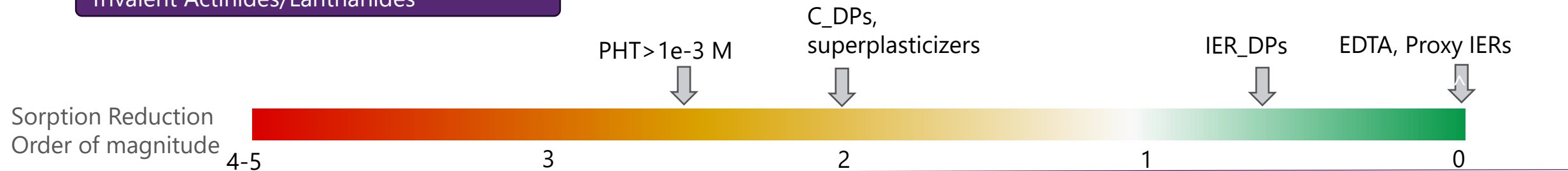
EDTA (Statell/IV)

ISA (Statell/III),
superplasticizers

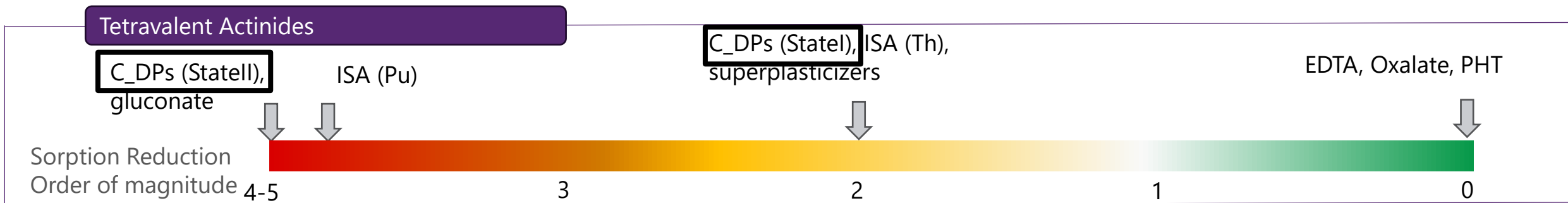
EDTA (Statell)

ISA (Statell),
PHT

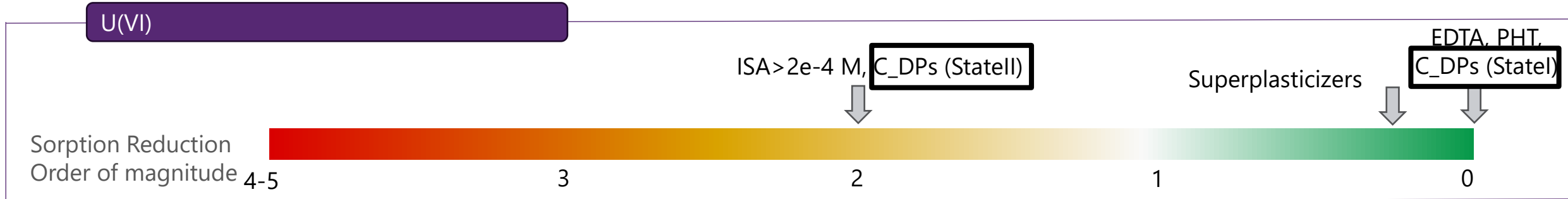
Trivalent Actinides/Lanthanides



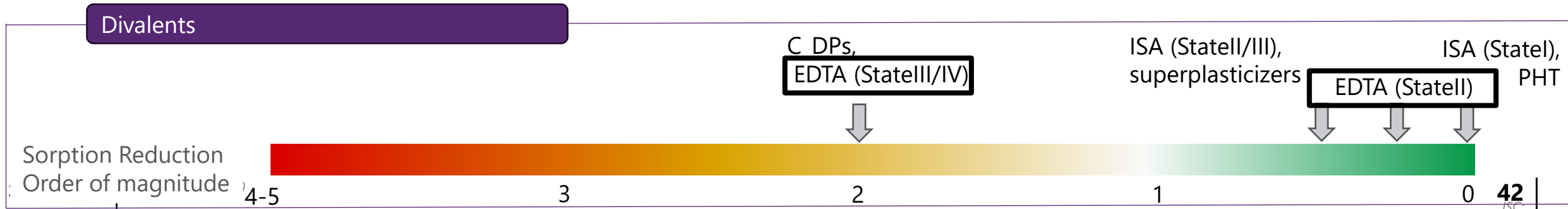
Tetravalent Actinides



U(VI)



Divalents



Trivalent Actinides/Lanthanides

PHT > 1e-3 M

C_DPs,
superplasticizers

IER_DPs

EDTA, Proxy IERs

Sorption Reduction
Order of magnitude

4-5

Tetravalent Actinides

C_DPs (Statell),
gluconate

Sorption Reduction
Order of magnitude

4-5

U(VI)

Sorption Reduction
Order of magnitude

4-5

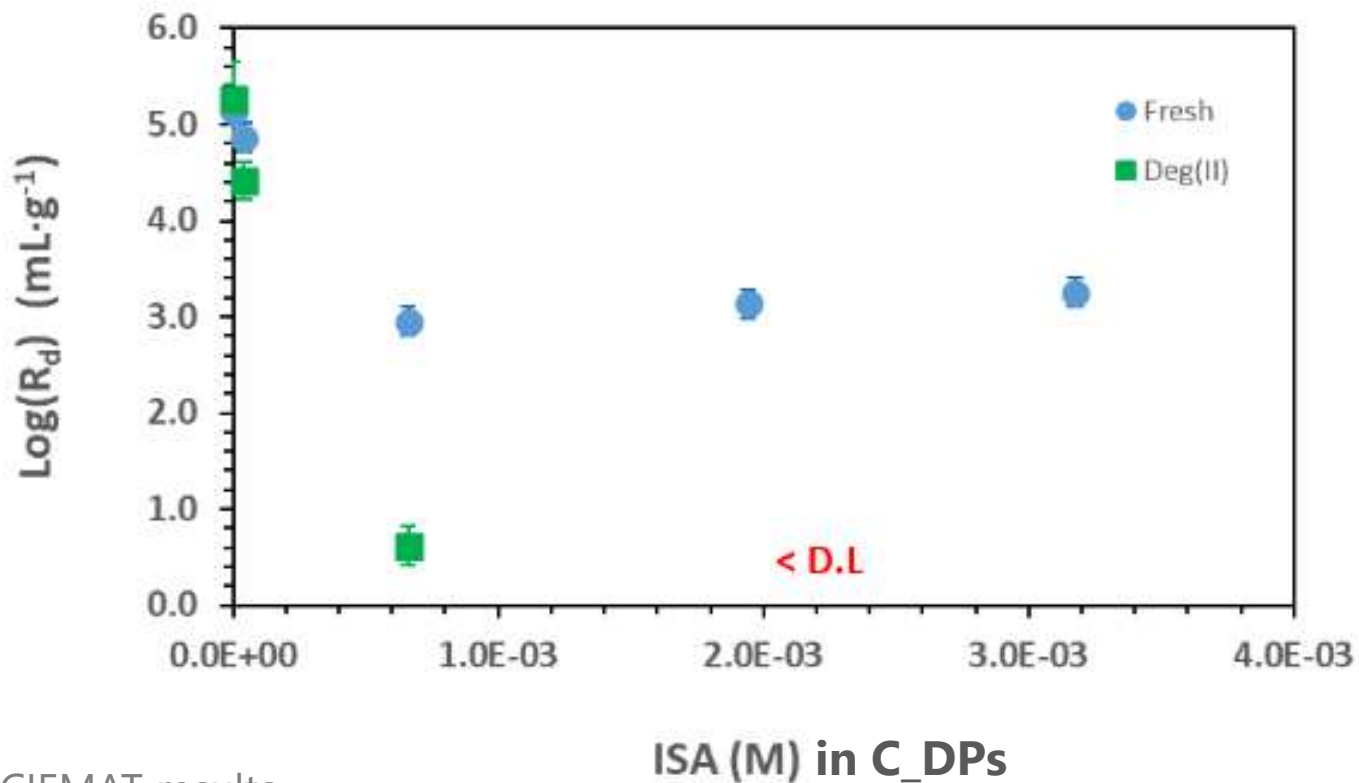
Divalents

CIEMAT results

Sorption Reduction
Order of magnitude

4-5

Pu sorption on Reference Cement with C_DPs



Effect of organics can depend on the degradation state of the cement-based materials

EDTA, Oxalate, PHT

EDTA, PHT,
Ps (Statell)

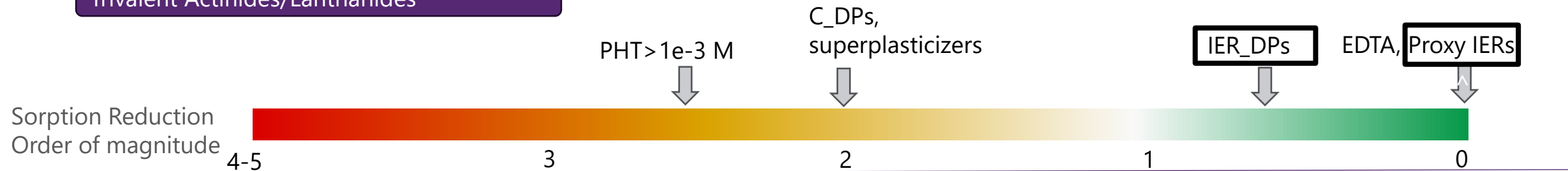
EDTA (Statell)

ISA (Statell),

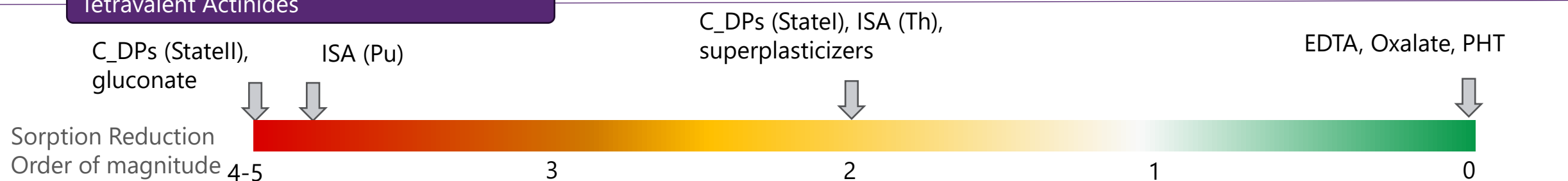
0

43

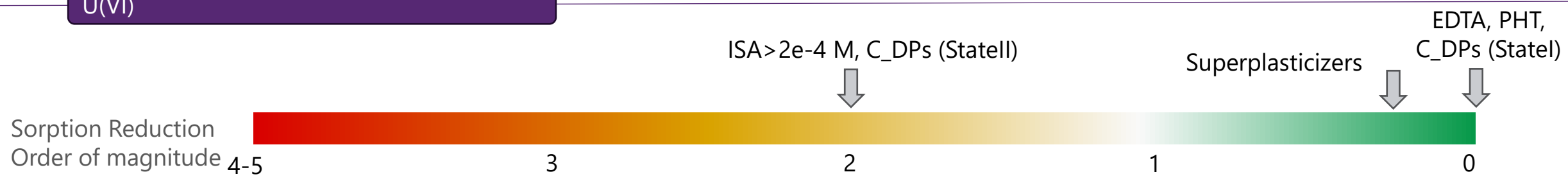
Trivalent Actinides/Lanthanides



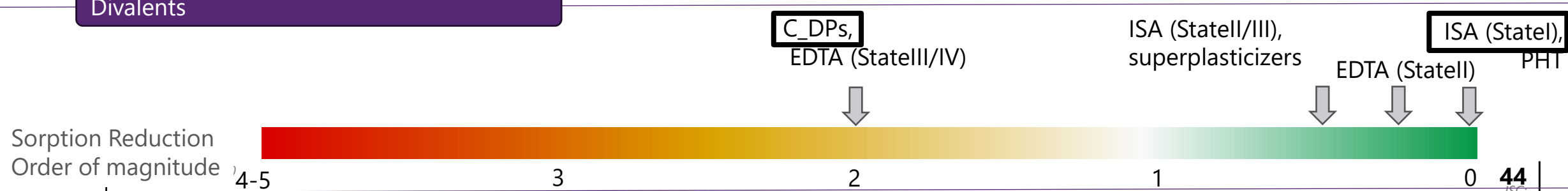
Tetravalent Actinides



U(VI)



Divalents



Trivalent Actinides/Lanthanides

PHT > 1e-3 M

C_DPs,
superplasticizers

IER_DPs

EDTA, Proxy IERs

Sorption Reduction
Order of magnitude

4-5

Tetravalent Actin

**C_DPs (Statell),
gluconate**

Sorption Reduction
Order of magnitude

4-5

U(VI)

Sorption Reduction
Order of magnitude

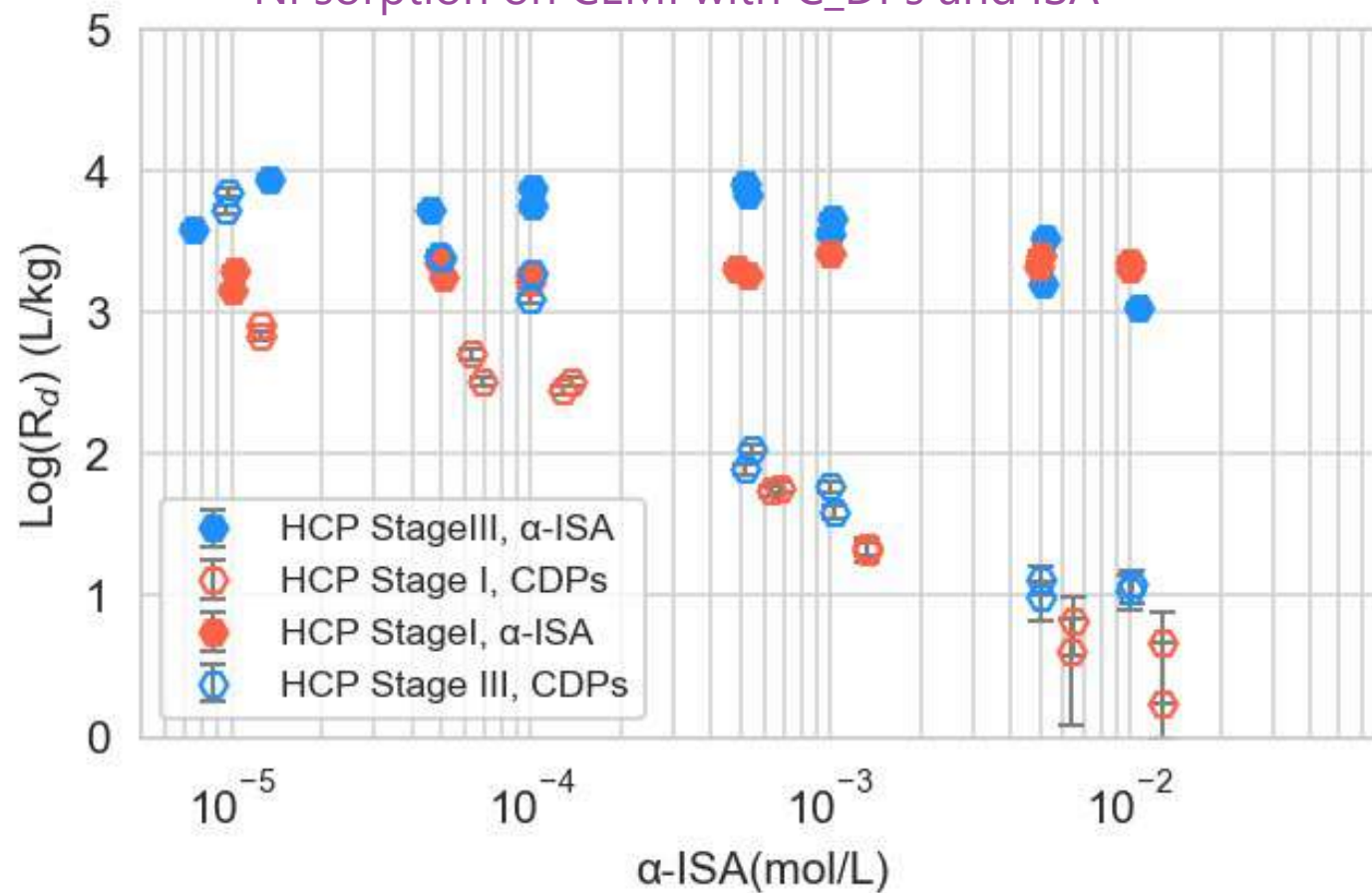
4-5

Divalents

Sorption Reduction
Order of magnitude

4-5

Ni sorption on CEMI with C_DPs and ISA



SCK CEN results

Effect of mixture of degradation products can differ from the proxies

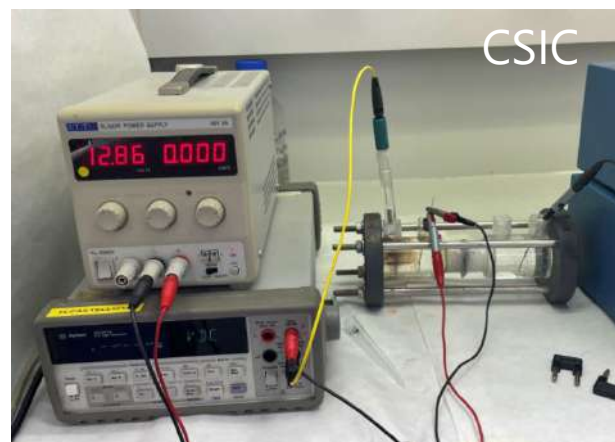
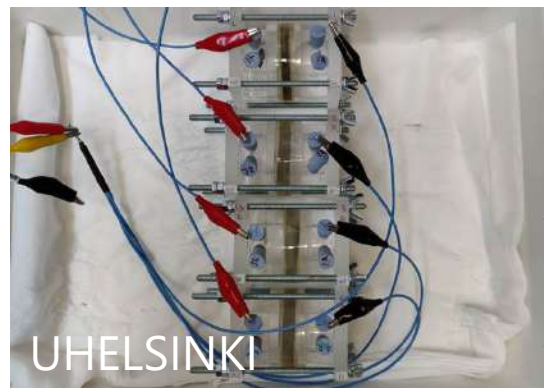
EDTA, Oxalate, PHT

EDTA, PHT,
Ps (Statell)

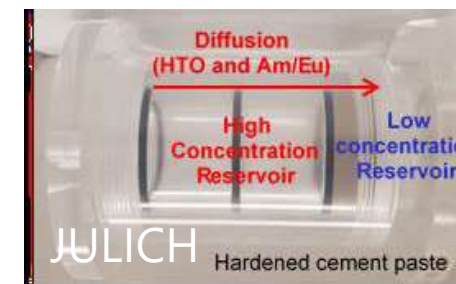
EDTA (Statell)

Transport Experiments

Electromigration Experiments



Diffusion Experiments



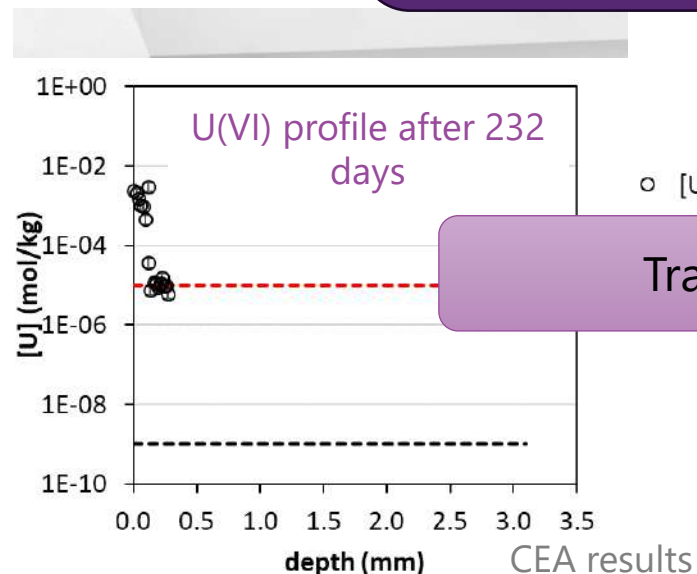
Transport Experiments

Diffusion Experiments

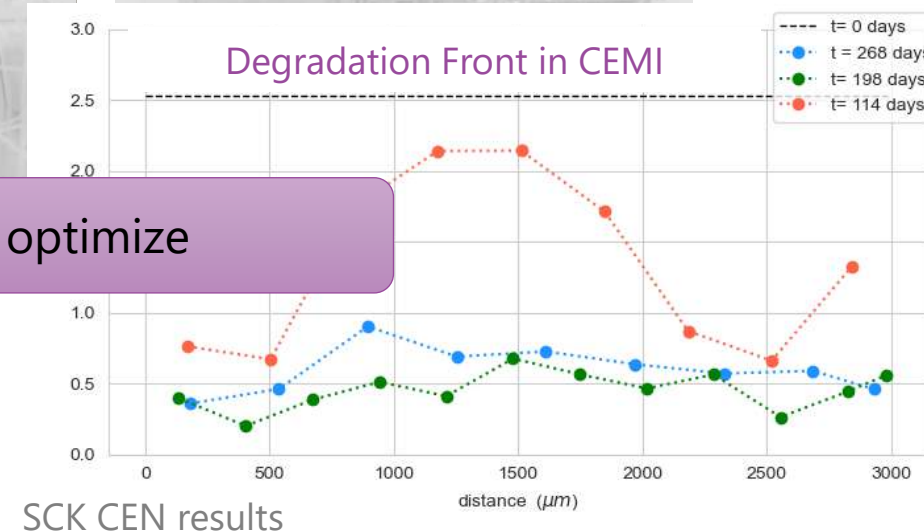
Electromigration Experiments

Very few quantitative results (diffusion coefficients, K_d)

1. Diffusion of retarded species in cement takes long
2. Degradation of cement in 'natural conditions' takes long



Transport experiments still to optimize



Relevance Belgian Program

Cellulose degradation

- Quantification of ISA production
- Refinement of ISA production kinetics
- New insights on the identity of other cellulose degradation products

Sorption of organics

- Extended database on sorption of organics
- New insights on sorption of organics: effect of the degradation state of the cementitious materials

Effect of organics on sorption/transport of radionuclides

- Extended database on sorption of radionuclides in presence of organics
- Though limited some diffusion coefficients of radionuclides in presence of organics
- New insights :
 - Role of the degradation state of the cementitious materials on the sorption reduction factors
 - Proxies compounds not always representative of the full degradation products

How can it help?

- ❖ Refinement of ISA inventory
- ❖ Refinement of the ACRIA

- ❖ Refinement of an organic plume calculation

- ❖ Refinement/estimation of sorption reduction factors for various scenarios/time

Relevance Belgian Program

Bleyen, N., Van Gompel, V., Smets, S., Eyley, S., Verwimp, W., Valcke, E., Thielemans, W. (2023). **Radiolytic degradation of cellulosic materials in nuclear waste - Effect of oxygen and absorbed dose.** *Radiation Physics and Chemistry*, 212.

Durce, D., Wang, L., Bleyen, N., Van Gompel, M. (2024). **Effect of cellulose degradation products on ^{63}Ni sorption on Portland Cement.** *Accepted for publication in Applied Geochemistry*

Bleyen, N., Van Gompel, V., Durce, D., Nushi, Valke, E. **Gamma irradiation accelerates alkaline degradation of cellulosic materials.** *Submitted to Radiation Physics and Chemistry*

Bleyen, N., Van Gompel, V., Eyley, S., Durce, D., Verpoucke, G., Thielemans, W., Valke, E. **New insights in long-term alkaline degradation mechanism of cellulosic materials in radioactive waste .** *In preparation*

How can it help?

- ❖ Refinement of ISA inventory
- ❖ Refinement of the ACRIA

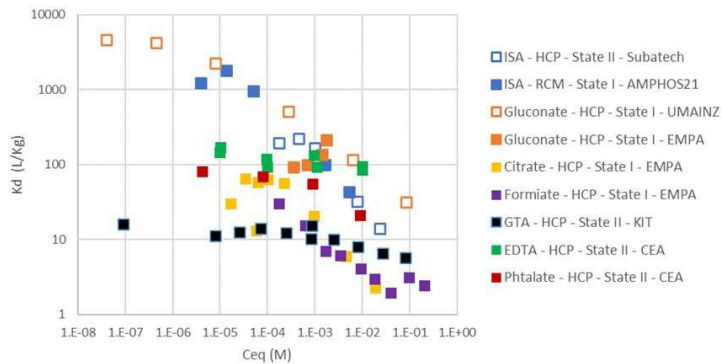
- ❖ Refinement of an organic plume calculation

- ❖ Refinement/estimation of sorption reduction factors for various scenarios/time

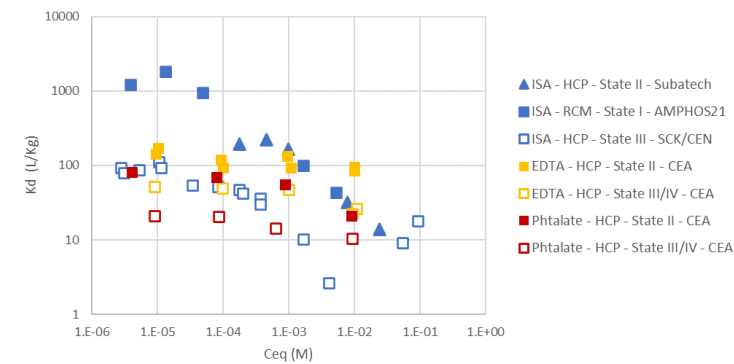
- Through limited some diffusion coefficients of radionuclides in presence of organics
- New insights :
 - Role of the degradation state of the cementitious materials on the sorption reduction factors
 - Proxies compounds not always representative of the full degradation products



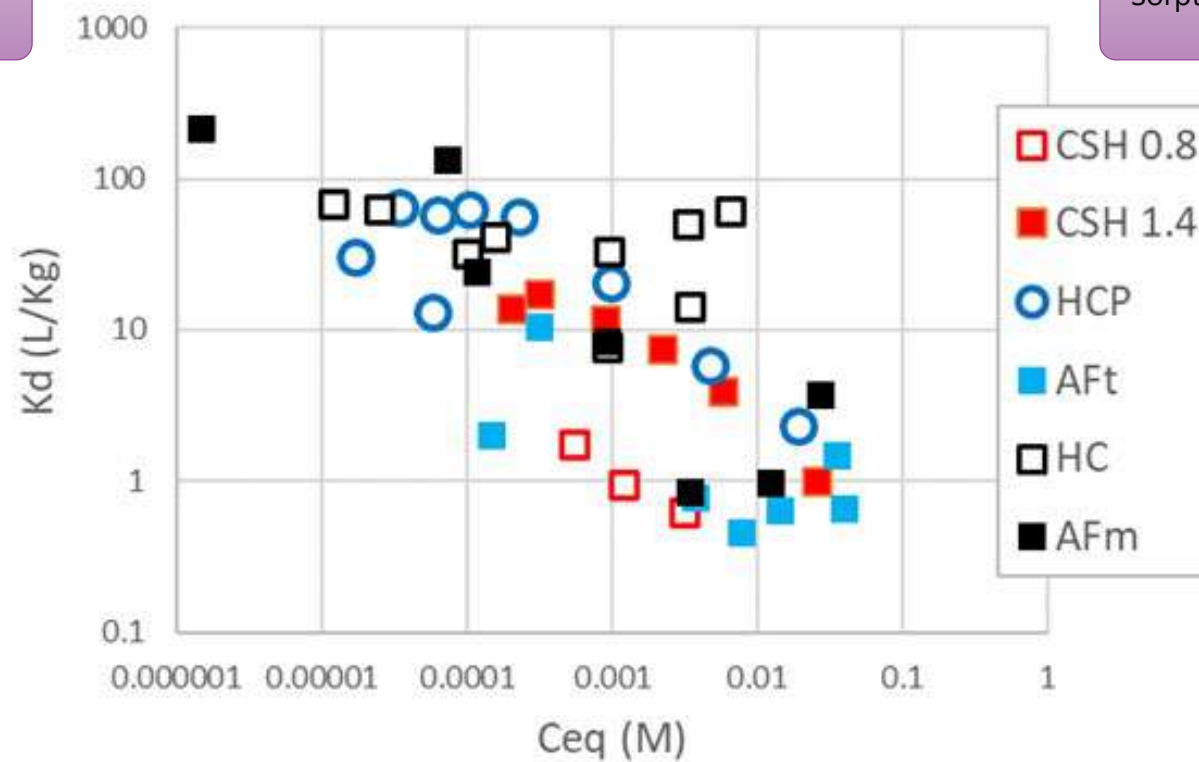
Thank you for your attention



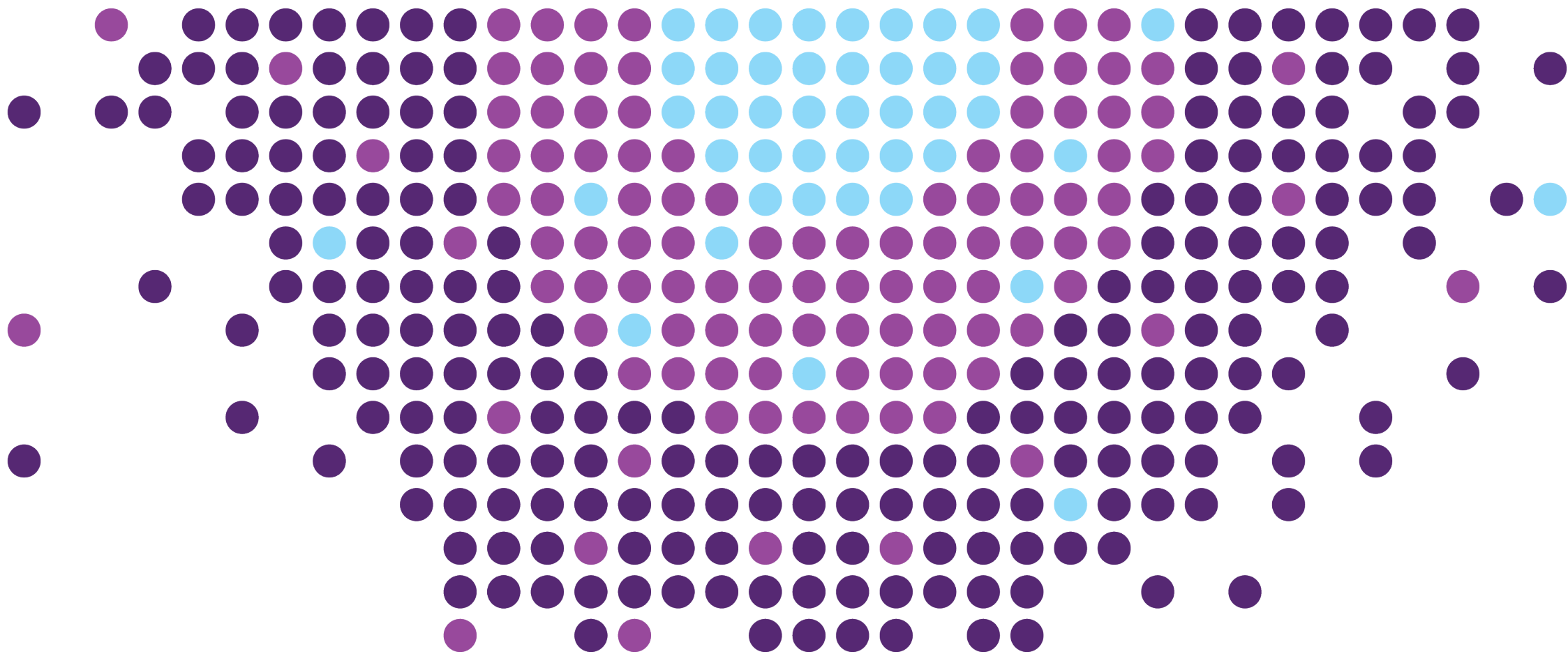
Sorption variable for the different organics and concentration dependent



Sorption can depend on the degradation state of the cement-based materials



Sorption occurs on various hydrates



sck cen
Belgian Nuclear Research Centre

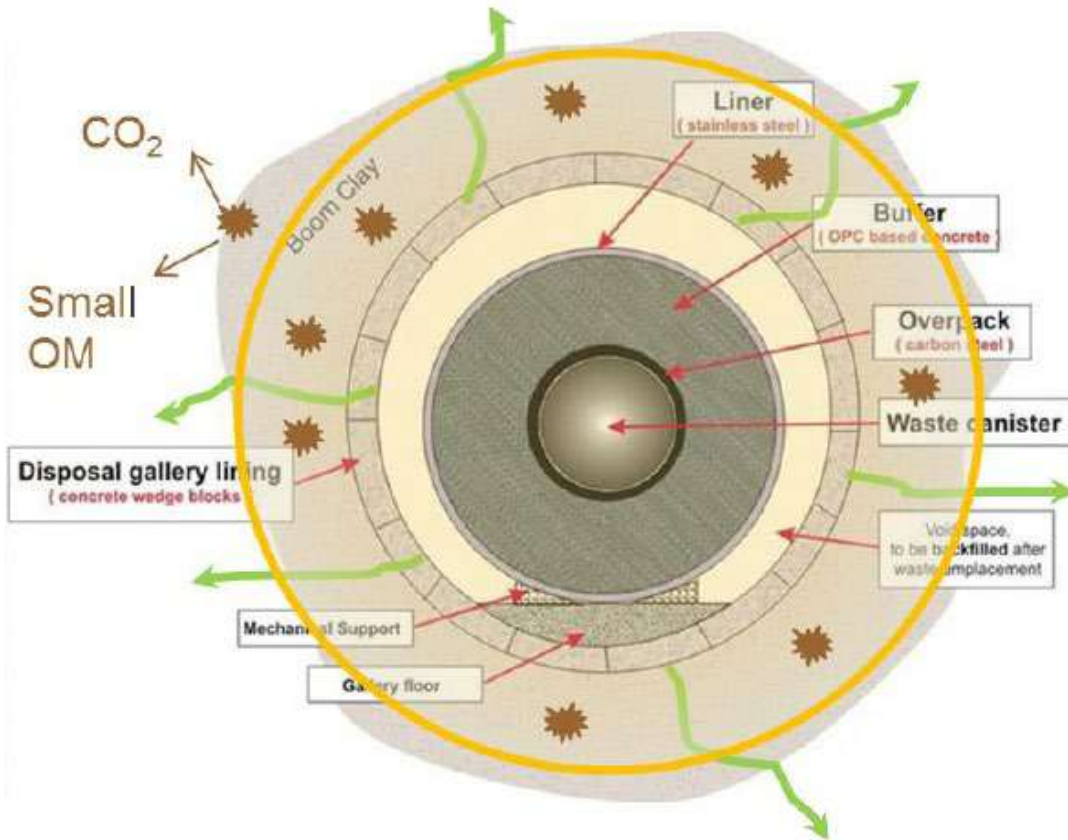
eurad
European Joint Programme
on Radioactive Waste Management

Diederik Jacques - 25/10/2024
EURAD WP ACED

ACED

Assessment of the Chemical Evolution at the Disposal Cell Scale

WP in a glance



- **DISPOSAL CELL.**
 - Intermediate level waste package
 - High level waste package
 - Engineered barrier system
 - Immediate surrounding host rock (clay, crystalline)
- **CHEMICAL EVOLUTION**
 - Different materials (glass, steel, different types of cement-based materials, host rocks)
 - Chemical gradients – Transport
 - Disequilibrium – Geochemical reactions
- **ASSESSMENT**
 - Large structures
 - Long times

WP in a glance

Long term chemical evolution forms an important input for the assessment of the evolution of a disposal system and the assessment of safety- and performance-related aspects

AIM – A better conceptual and mathematical representation of the chemical evolution to:

- Improve the assessment and quantification of generic safety functions such as isolation and containment of waste constituents
 - Input to (or coupling with) other processes M - B
- Obtain a better substantiation of conservatism and reduction of uncertainty
- Increase the scientific basis for definition of requirements of materials

Consortium

ANDRA (FR)

Bel-V (BE)

BRGM (FR)

CEA (FR)

CIEMAT (ES)

CNRS/GeoRess (FR)

COVRA (NL)

Ecole des Mines (FR)

EDF (FR)

FZJ (DE)

IRSN (FR)

LEI (LT)

ENRESA (SP) via LTP

MTA-EK (HU)

PSI (CH)

SCK•CEN (BE)

SUBATECH (FR)

SURAO (CZ)

UAM (ES)

UDC (ES)

UFZ (DE)

UJV (CZ)

UBern (CH)

VTT (FI)

ZAG (SI)

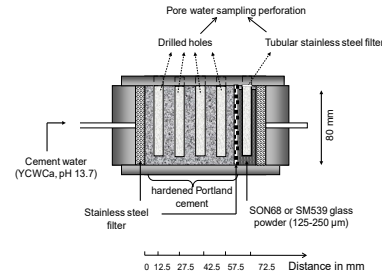


Workplan – Chemical evolution at different scales

INTERFACE SCALE

Experimental study

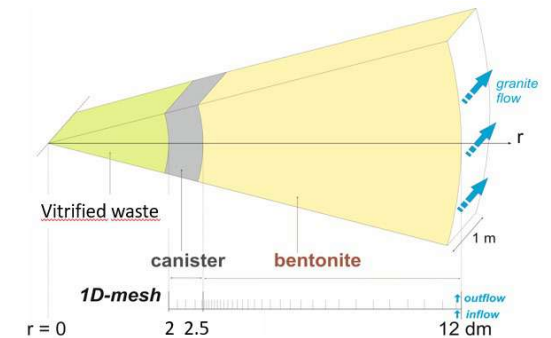
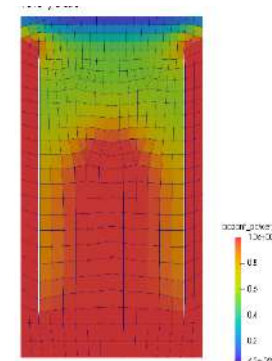
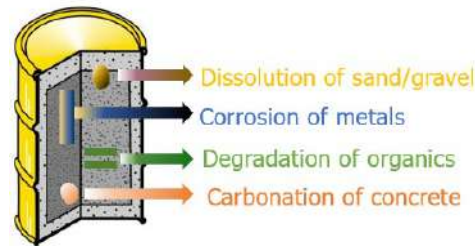
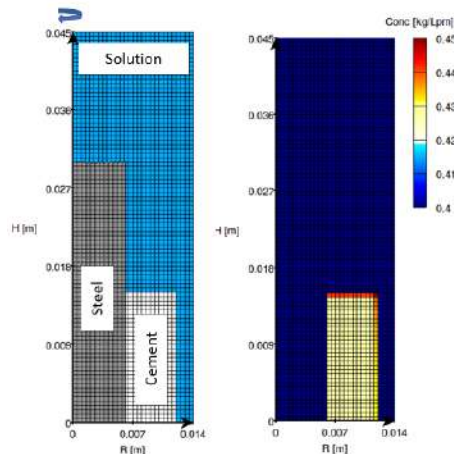
STEEL-CONCRETE and STEEL-CLAY



WASTE PACKAGE SCALE

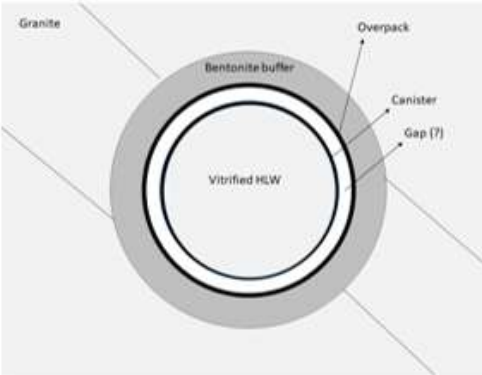
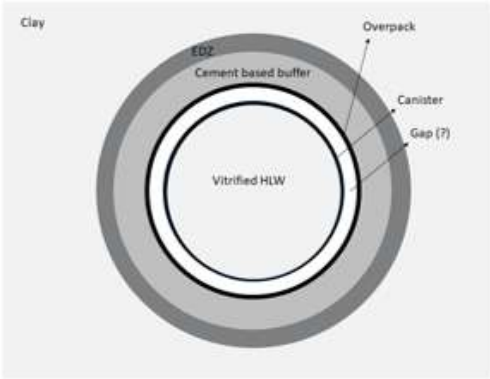
DISPOSAL CELL SCALE

Numerical study – coupled reactive transport models

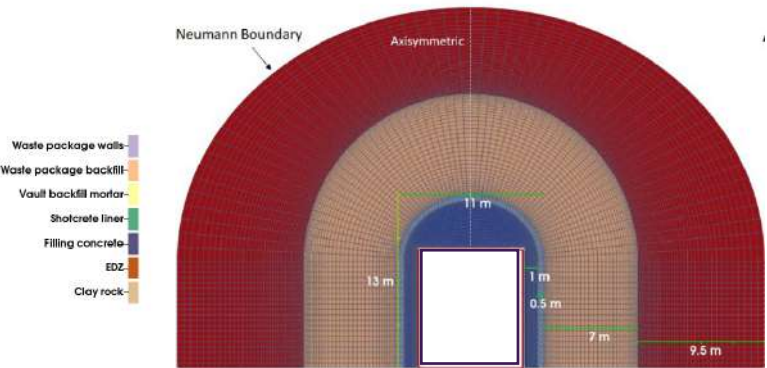
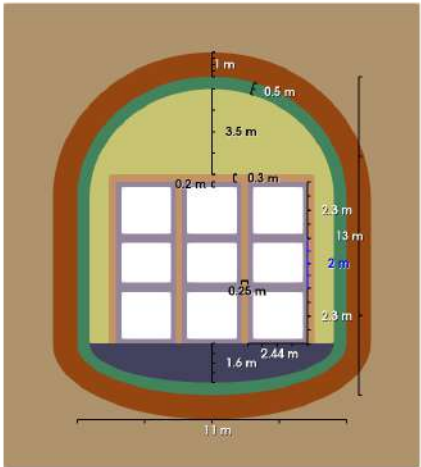
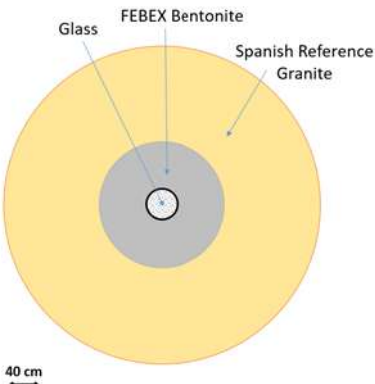
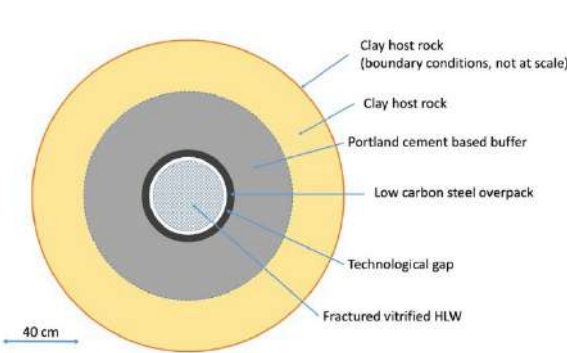
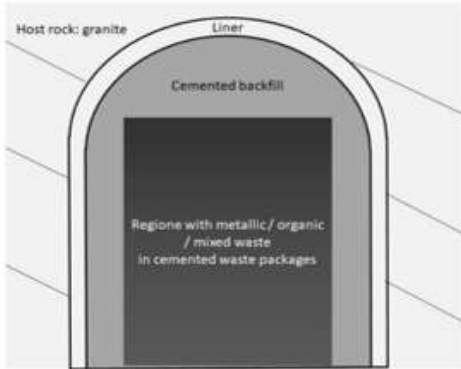
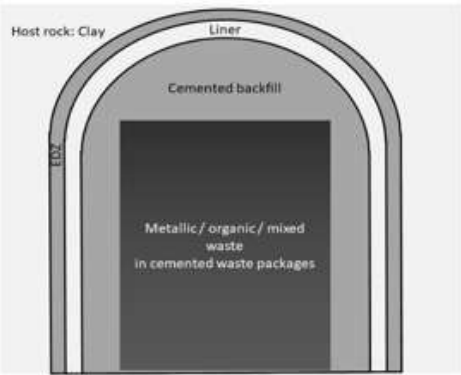


Generic disposal cell

HIGH LEVEL ACTIVITY DISPOSAL CELLS



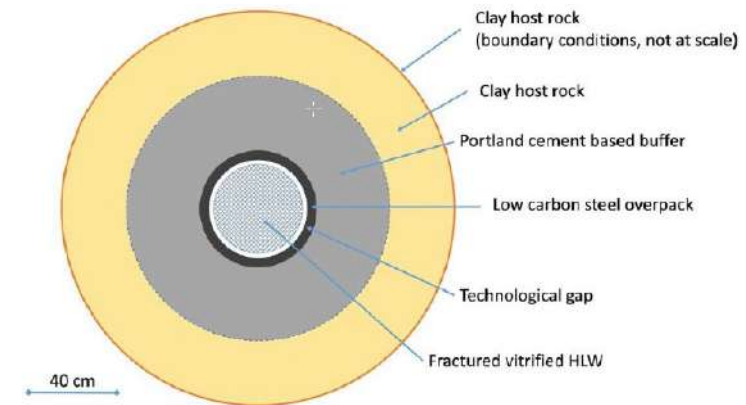
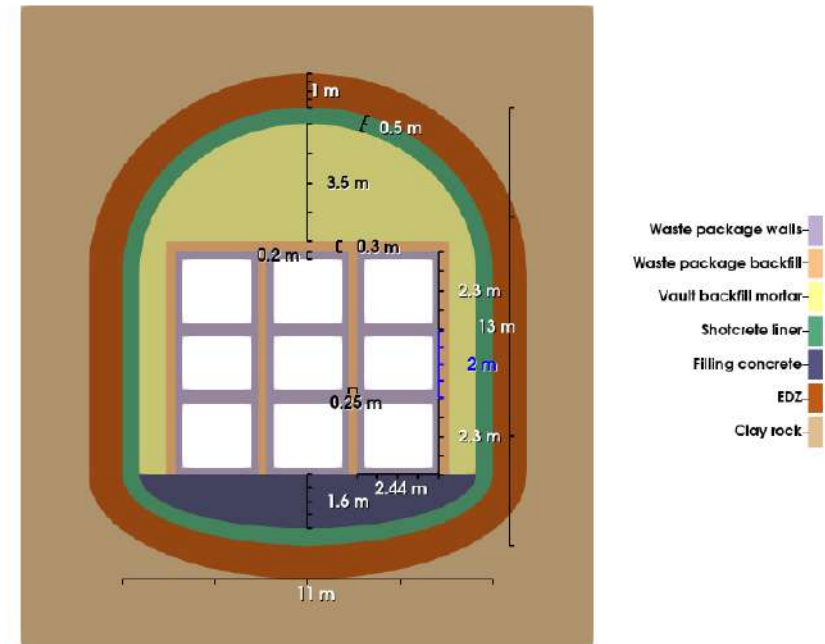
INTERMEDIATE LEVEL ACTIVITY DISPOSAL CELLS



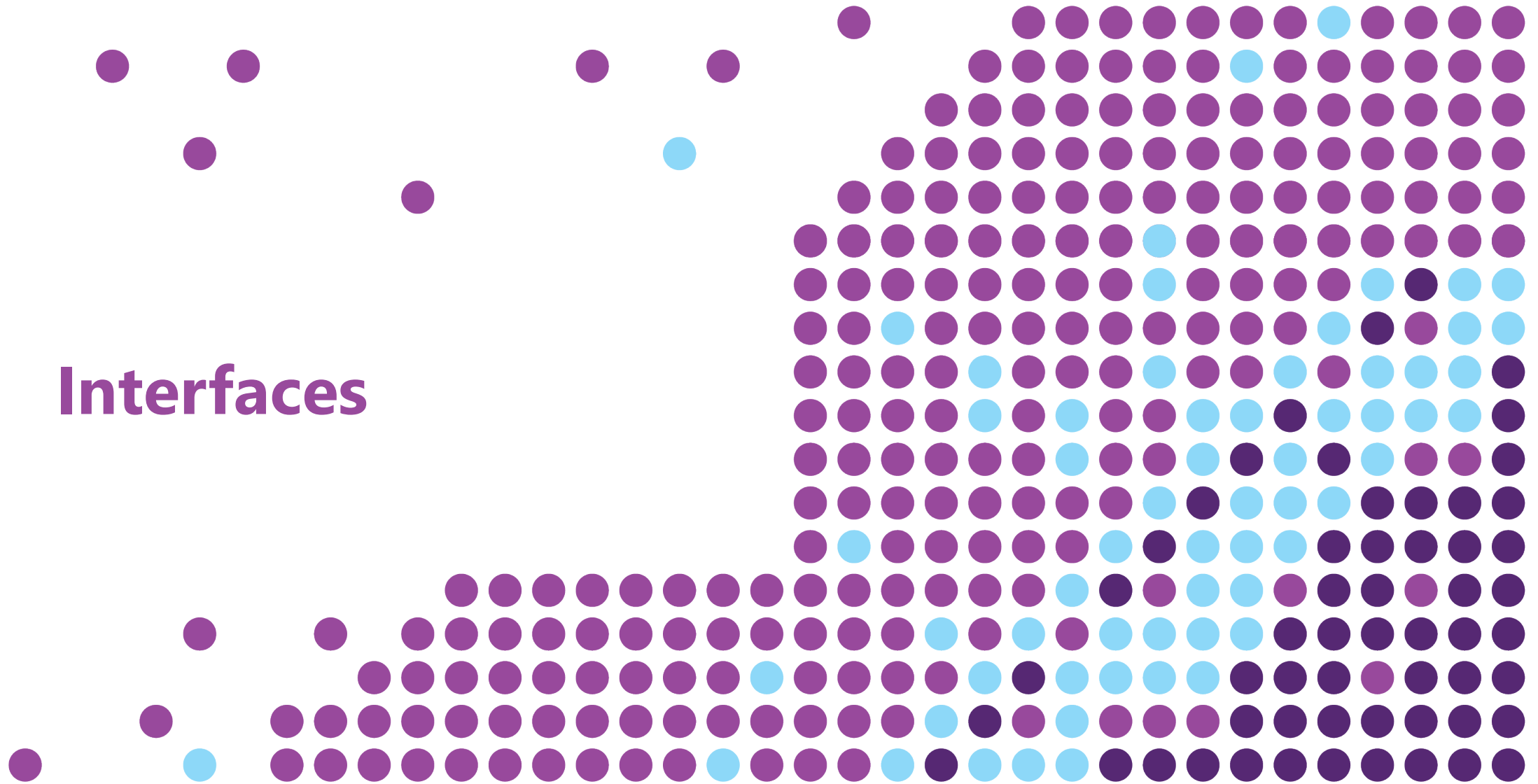
Disposal cell scale models

NARRATIVE, CONCEPTUAL and MATHEMATICAL MODELS

- **Integrated** model describing chemical reactions between engineered barriers at the disposal cell scale
- Models were developed by interaction between partners from different college's and countries
- Contains a lot of models and parameters



Interfaces



Phenomena at interfaces: experimental Steel/Cement

Corrosion measured

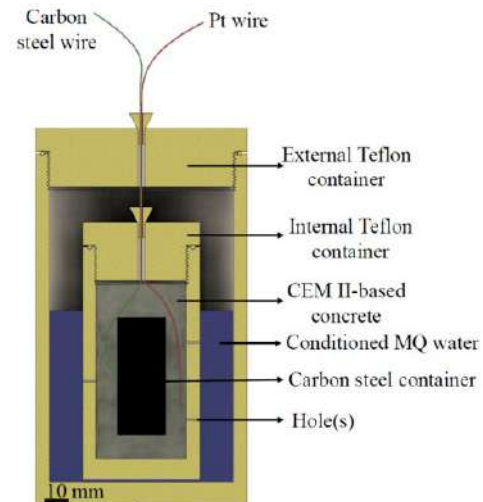
- High Temperature (80°C)
- Different pH (CEM-I/CEM-II – low pH cement-grout)
- In-situ / mock-ups

CEM-I/CEM-II

- Confirmation of low corrosion rate
- Identification of Fe-phases in cement

Low pH cement grout

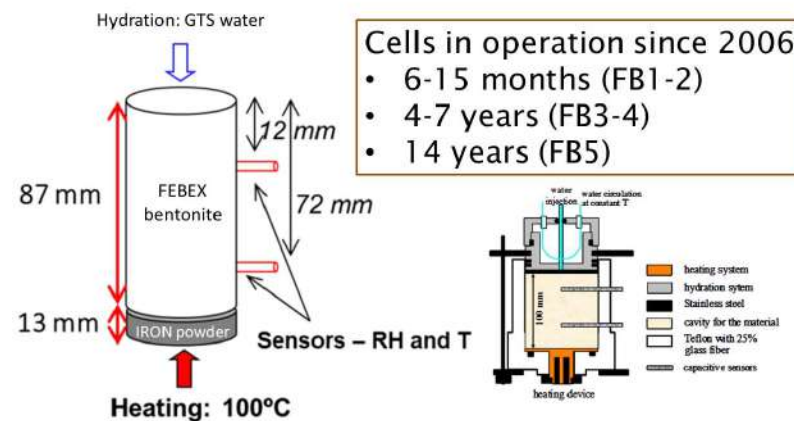
- Localized corrosion mechanism (S(-2))
- Coalescence of pits seems to lead to a more generalized corrosion mechanism over a period of about 2 y
- Identification of phases led to conceptual model for development of corrosion products



Phenomena at interfaces: experimental Steel/Clay

long-term lab tests

iron/FEBEX compacted bentonite interface
Impact of simultaneous hydration/heating
corrosion processes/products/rates
determination



batch and diffusion experiments

Fe^{2+} /montmorillonite interactions

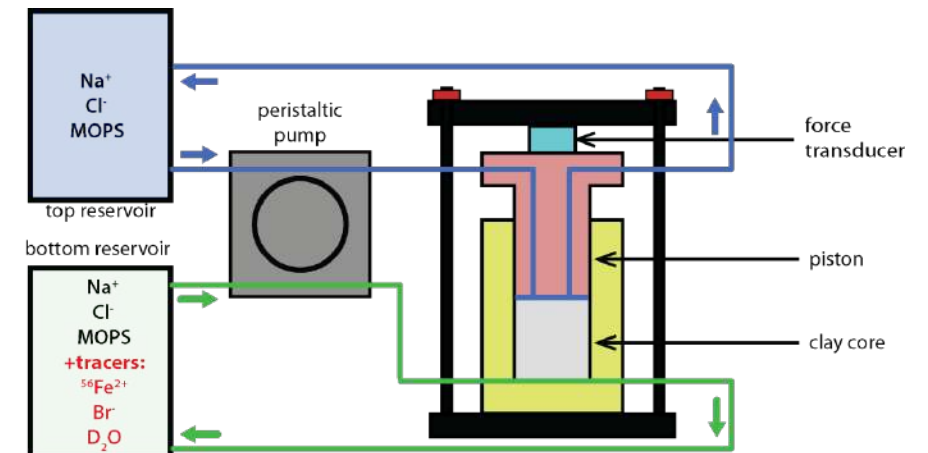
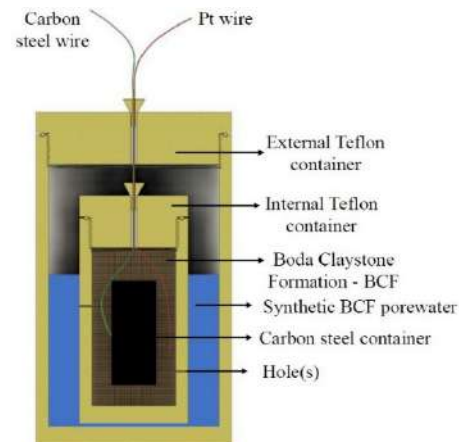
Fe^{2+} transfer in montmorillonite

Redox processes (electron transfers $\text{Fe}^{2+}_{\text{dis}} / \text{Fe}^{3+}_{\text{str}}$)

Cell experiments

carbon steel/Boda clay interactions

corrosion processes/products/rates determination



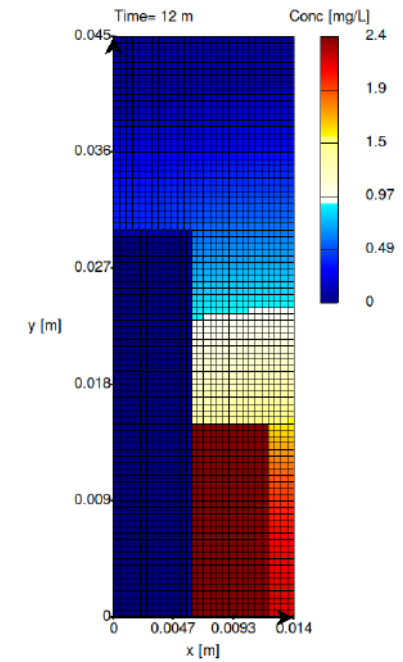
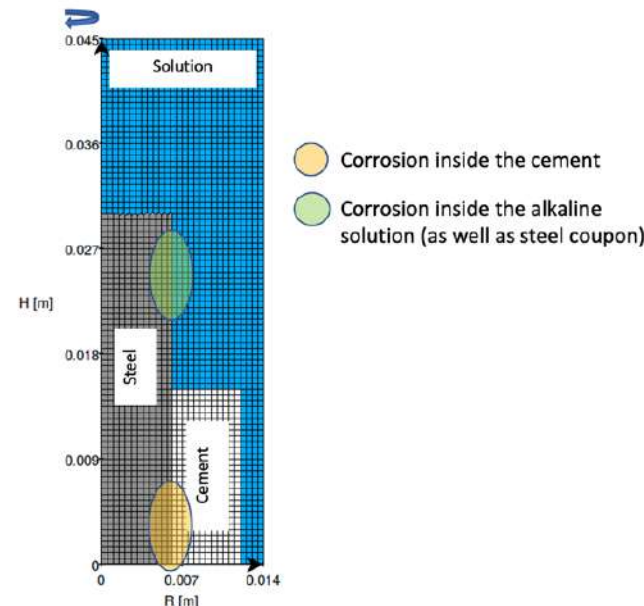
Phenomena at interfaces: Modelling Steel/Cement

Thermodynamics of Fe-bearing cement hydrates

- Thermodynamics – Fe-garnet
- Extended C-A-S-H⁺ model for Fe(III) & Fe(II)
 - Uptake Fe(III) >> Fe(II)
- Extend the flexibility of using multisite C-A-S-H⁺ model
 - Script to translate solid solution model to discrete model usable in many more coupled reactive transport models

Modelling Mock-up experiments

- Geometry implemented for steel in contact with water or steel
- Models for material evolution were implemented including effects of temperature and pH



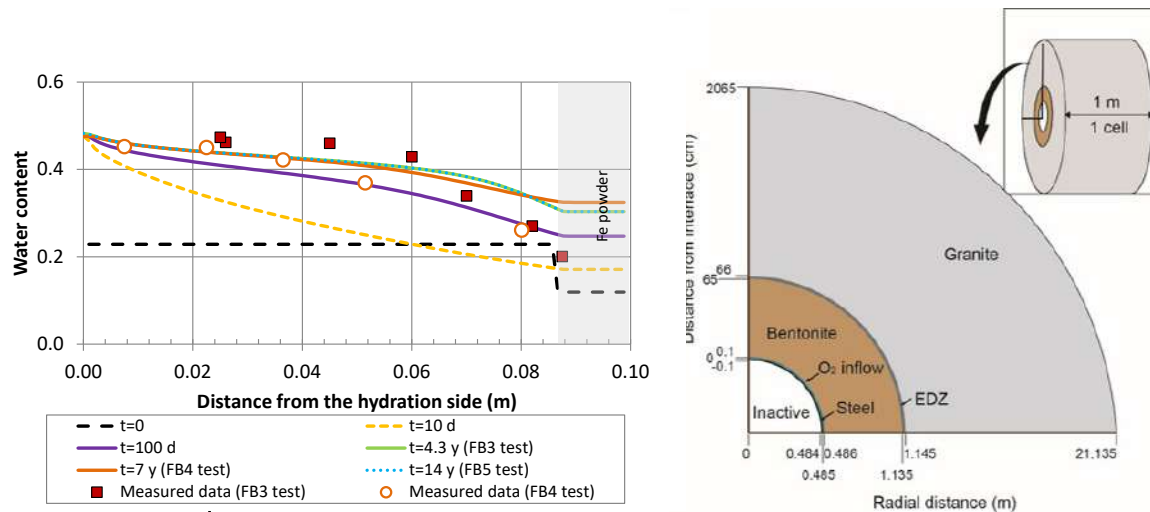
Phenomena at interfaces: Modelling Steel/Clay

long-term lab tests modelling

THCM reactive transport model

water content/temperature/porosity gradient

geochemical (pH, dissolved ions, CEC) distribution



FEBEX in situ experiment modelling

(i) reactive transport code (simplified corrosion approach)

(ii) steel-bentonite interaction model

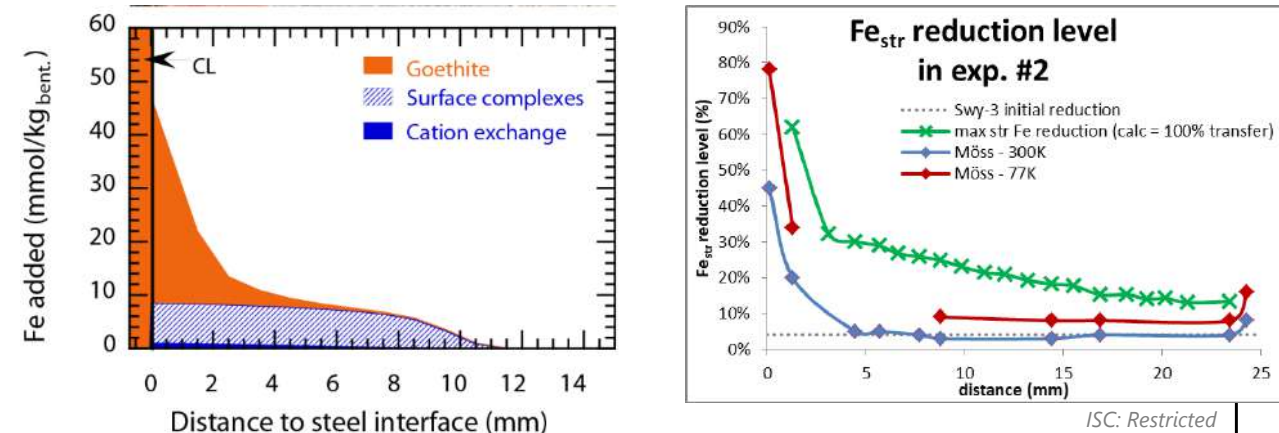
Corrosion rate and corrosion products estimation

Fe²⁺/montmorillonite interactions modelling

Sorption (batch) and reactive transport (diff + sorption) models

Solute diffusion and Fe sorption (complexes, cation exch, redox sorpt)

water content, pH, dissolved ions spatial distribution



Waste packages

Phenomena at multiple interfaces – Experiments HLW

Experiments



Glass/steel/clay

Glass/steel/cement buffer/clay

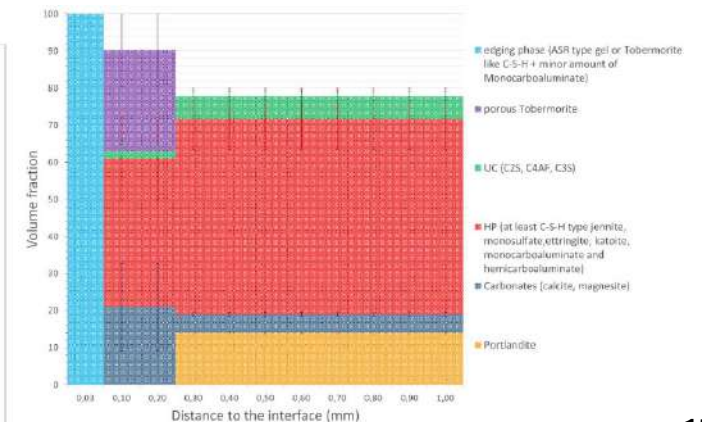
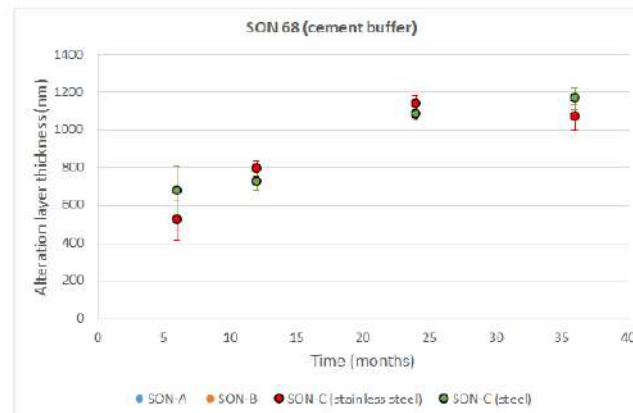
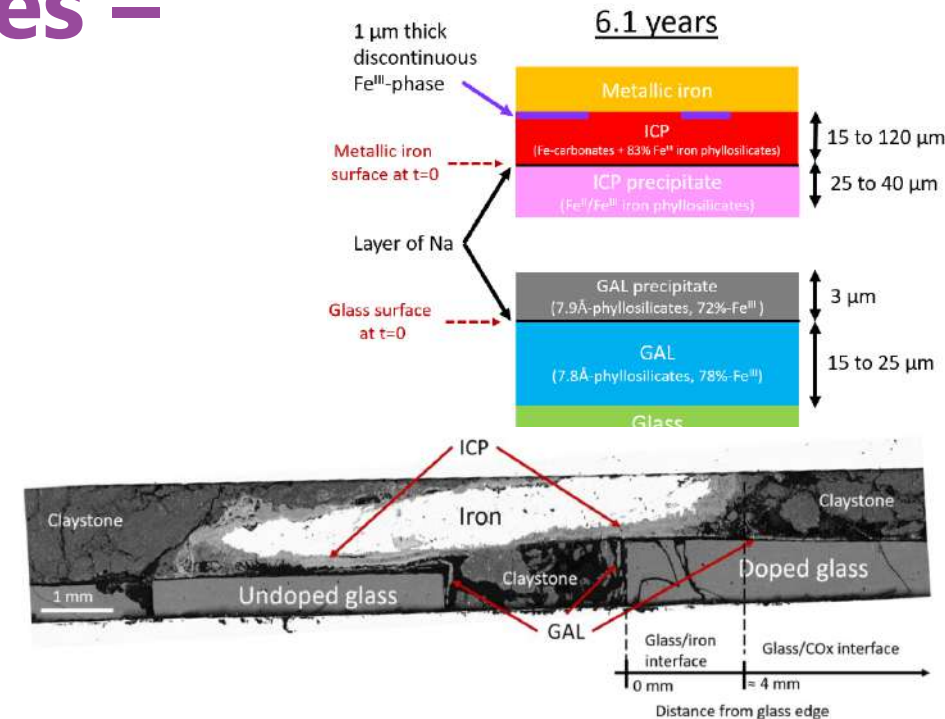
Glass/steel/cement

Identification of neoformed phases (although difficult because small amounts & poorly crystallized) has been done with multiscale analytical approaches

Pore water sampling for representative disposal conditions (high solid/liquid ratio) was successful in 1 set-up

Insight in development of alteration zones

Estimates of alteration/corrosion rates



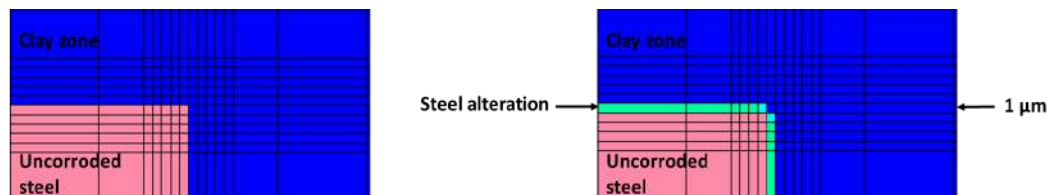
Phenomena at multiple interfaces – Modelling HLW

Modelling

Glass dissolution models for

- “Low” pH – GRAAL model implemented in PHREEQC-based reactive transport model
- “High” pH model for interaction with cement

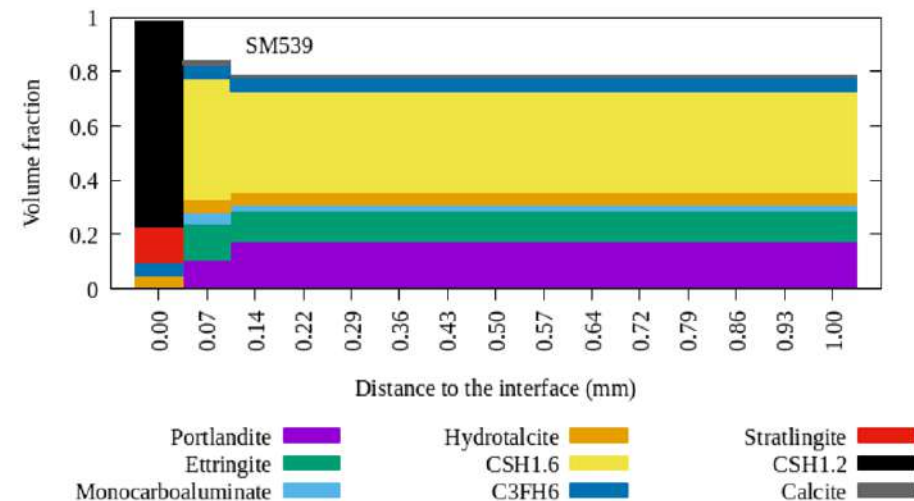
Implementation of layer by layer corrosion model of steel



Insight of evolution of alteration zones through modelling

Qualitative(/quantitative) agreement with experiments

However, careful selection of “minerals” for alteration products is required

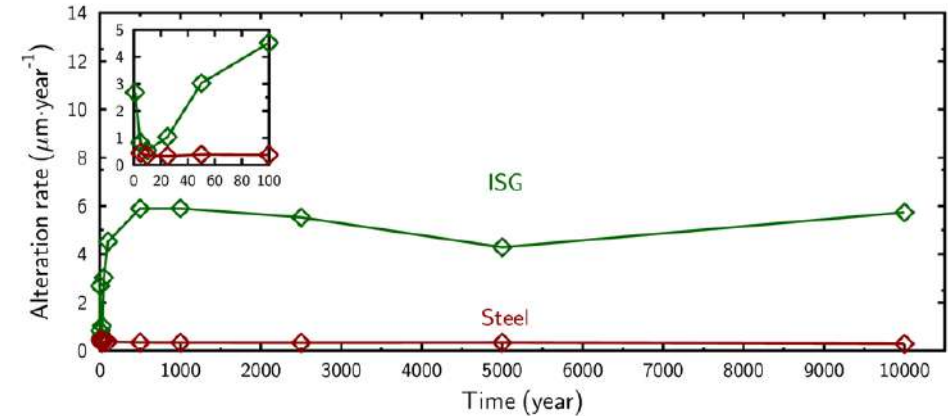


Upscaling to waste package and disposal cell – HLW

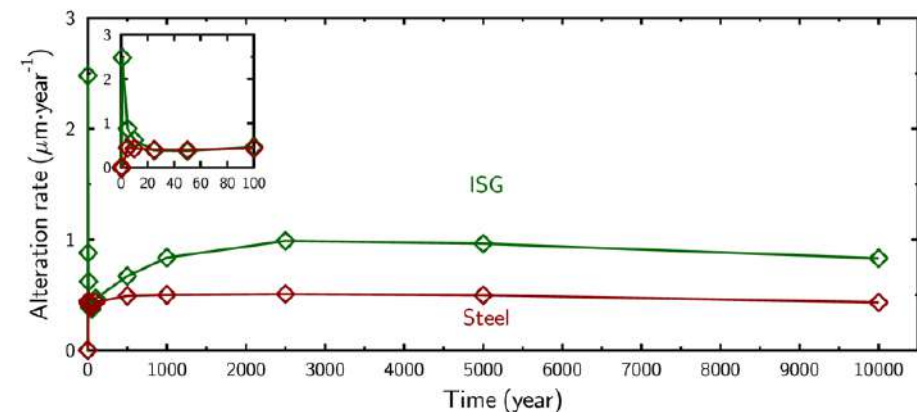
Waste Package

Upscaling to larger time and spatial scales (by considering coarser discretization)

Upscaled models allowed assessment of time-variable alteration zones as a function of geochemical conditions

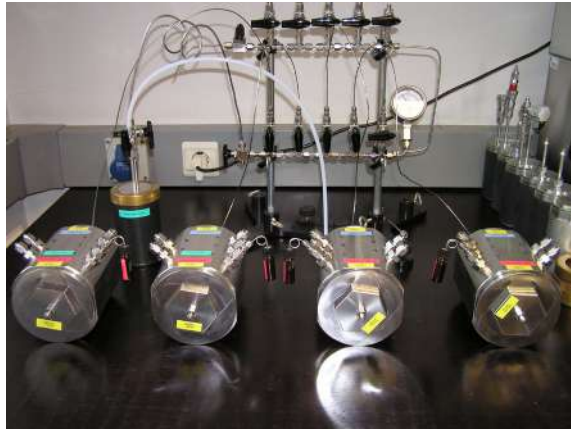


Alteration rates calculated at the waste package scale with the BRGM model at the glass – steel interface with a young concrete for a cement buffer of 100 cm thickness at 25°C.

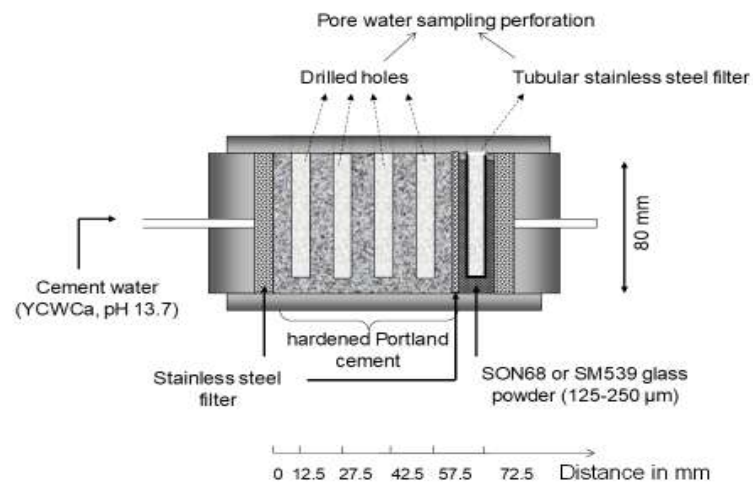
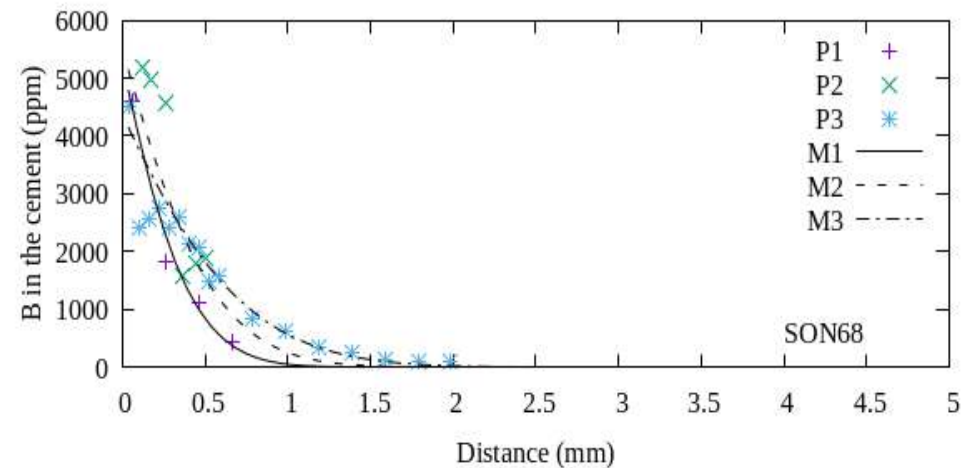
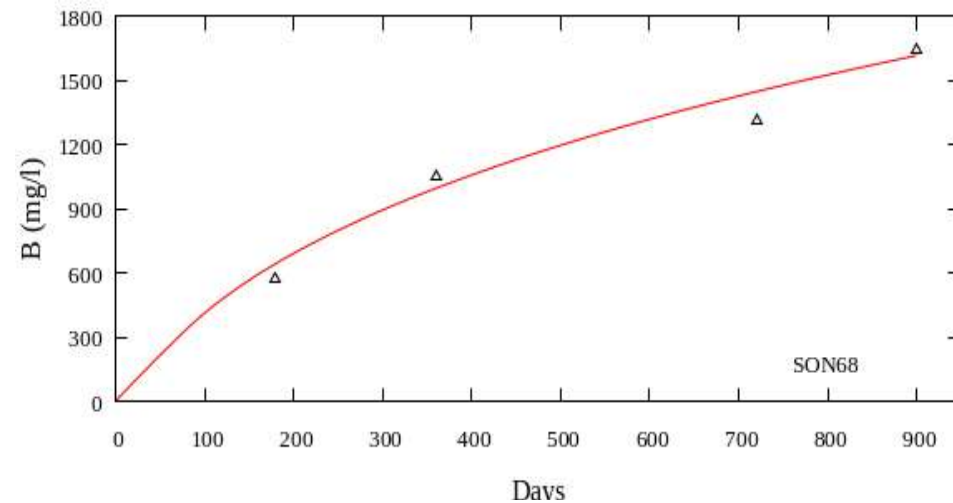


Alteration rates at the glass – steel interface, calculated with the BRGM model for an aged concrete at the waste package scale at 25°C.

Glass – Steel - Cement

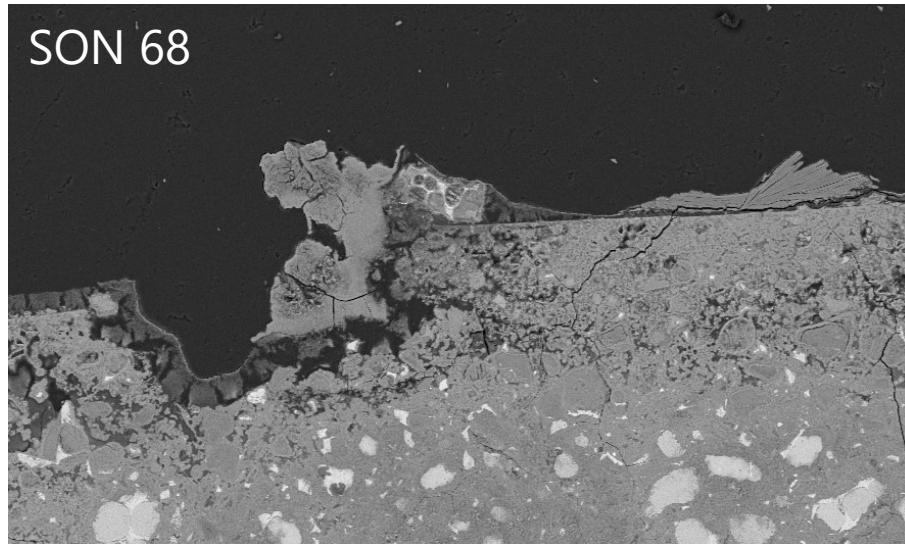


Aqueous chemistry: Model for glass dissolution & diffusion in cement

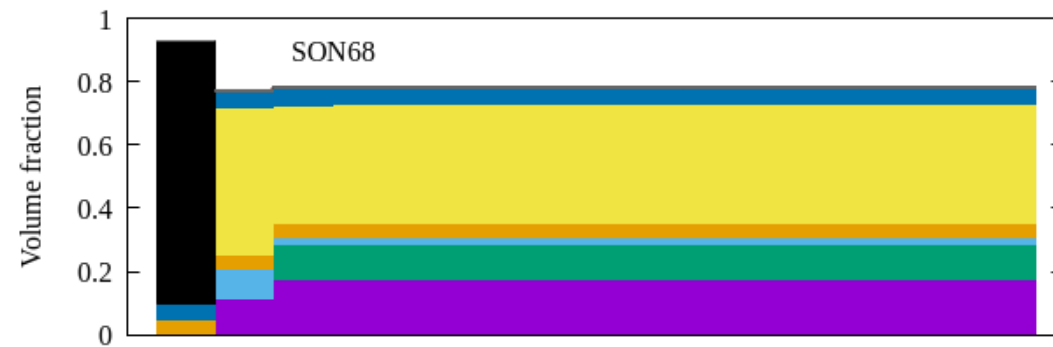


Glass – Steel - Cement

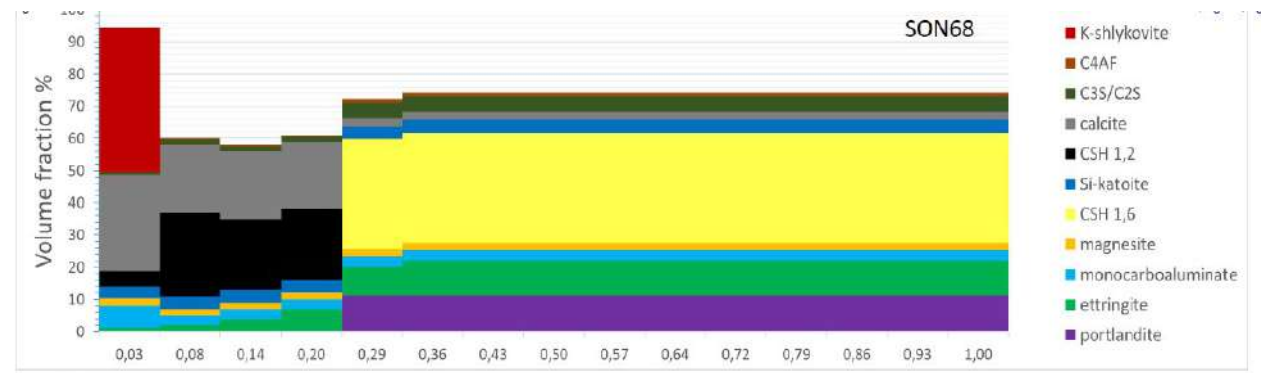
Solid phase characterization and modelling



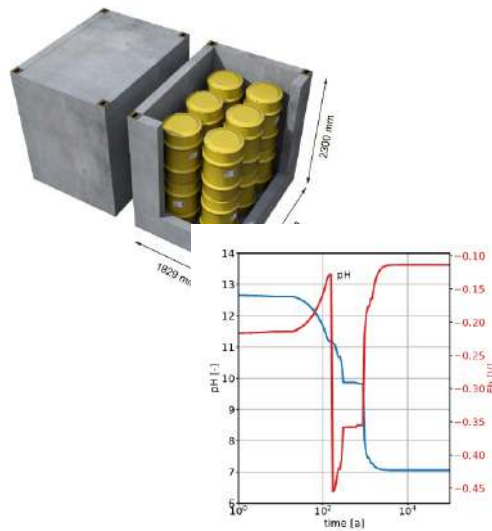
Model



Solid phase characterisation

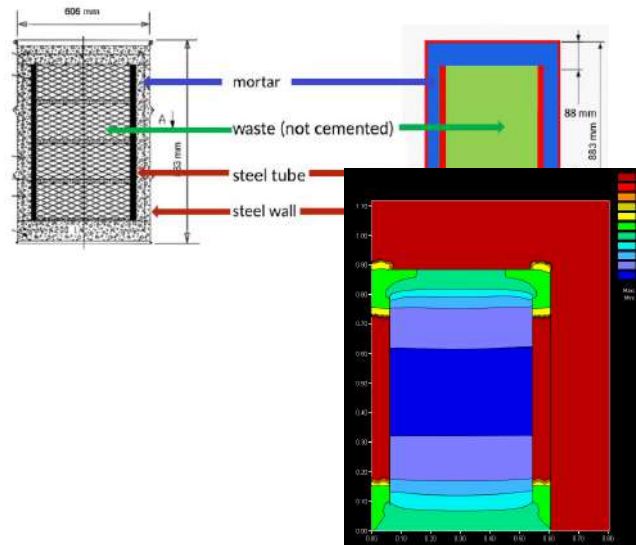


Waste package scale – ILW



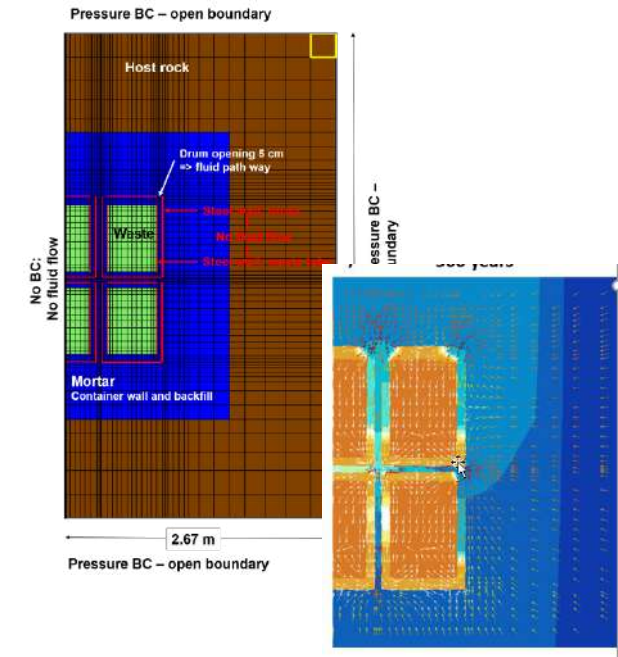
Mixing tank approach

Modelling time-dependent evolution without spatial dimension



Coupled reactive transport

Modelling temporal-spatial evolution – neglecting multiphase phenomena



Multiphase flow & transport

Modelling time-spatial evolution including multiphase phenomena but with abstracted chemistry

Disposal Cell



Upscaling disposal cell – HLW

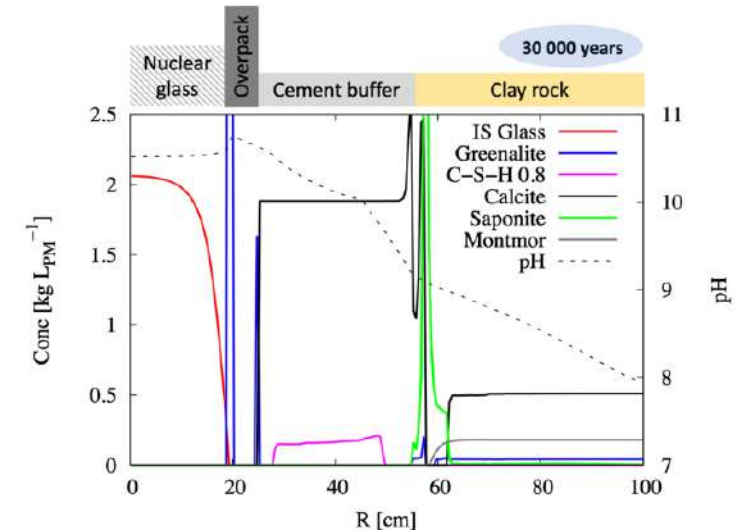
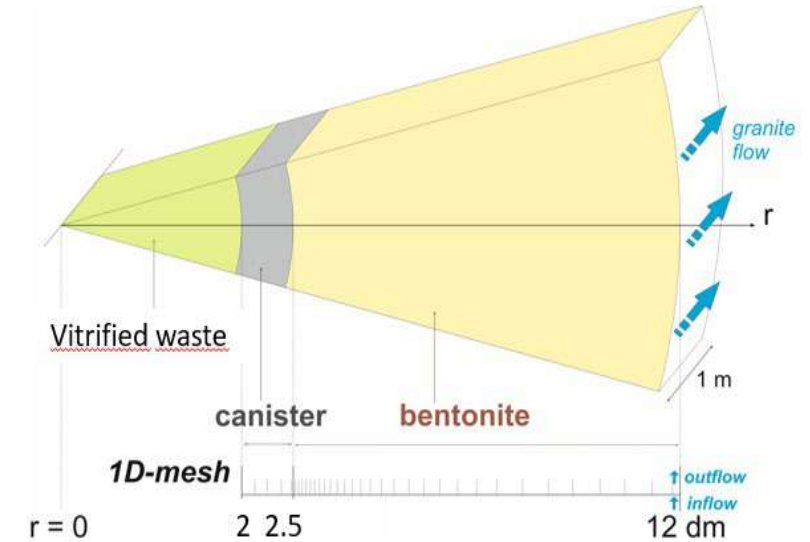
Disposal cell

Successful implementation of models starting from detailed mathematical model (D2.16)

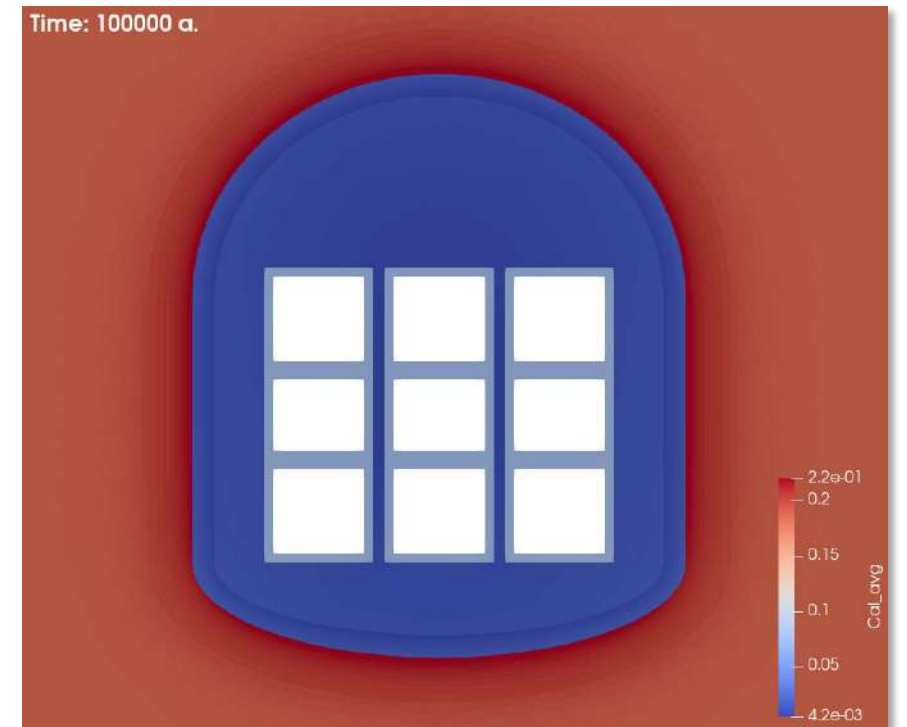
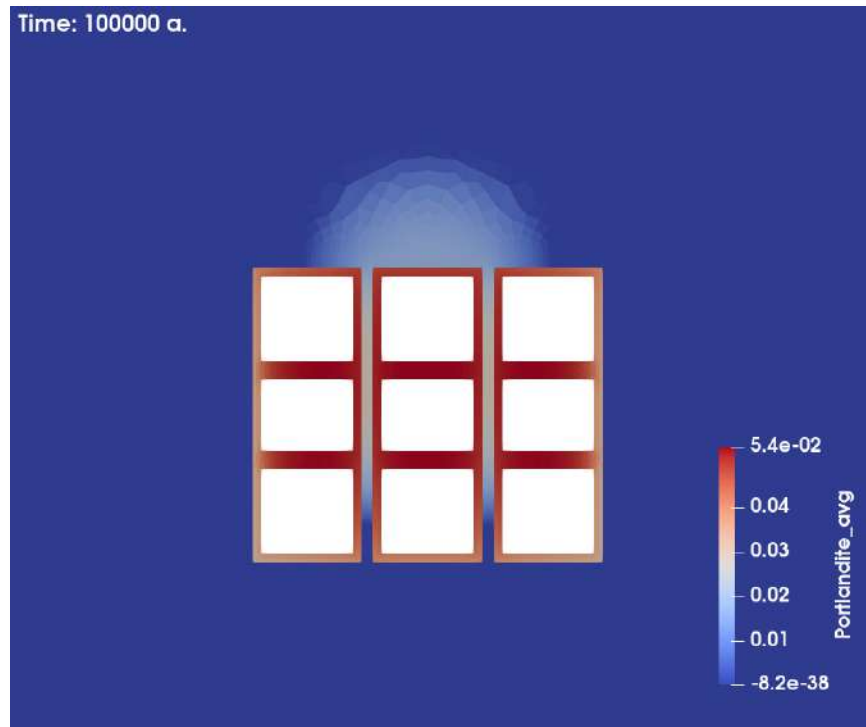
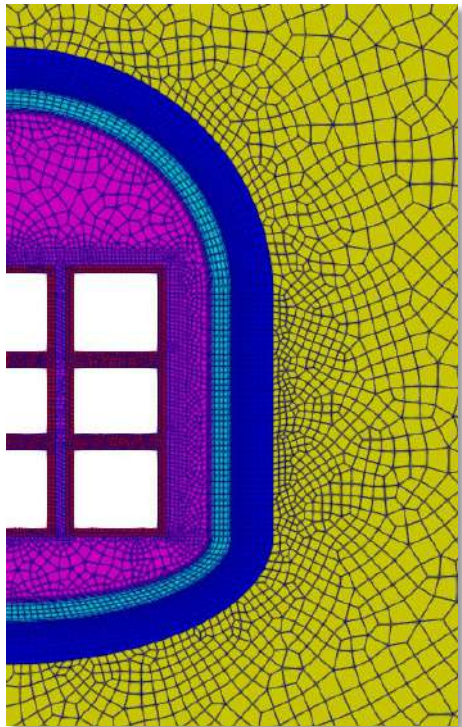
Two time frames are implemented (before and after breaching of canister)

Insight in geochemical evolution caused by interactions of different barriers (**complete system**) over long time frames

Transients (hydric, temperature) during first 1000 y in system with cement buffer could be neglected for rather thick buffers (>30cm) but accounted for in thin buffers (5 cm)

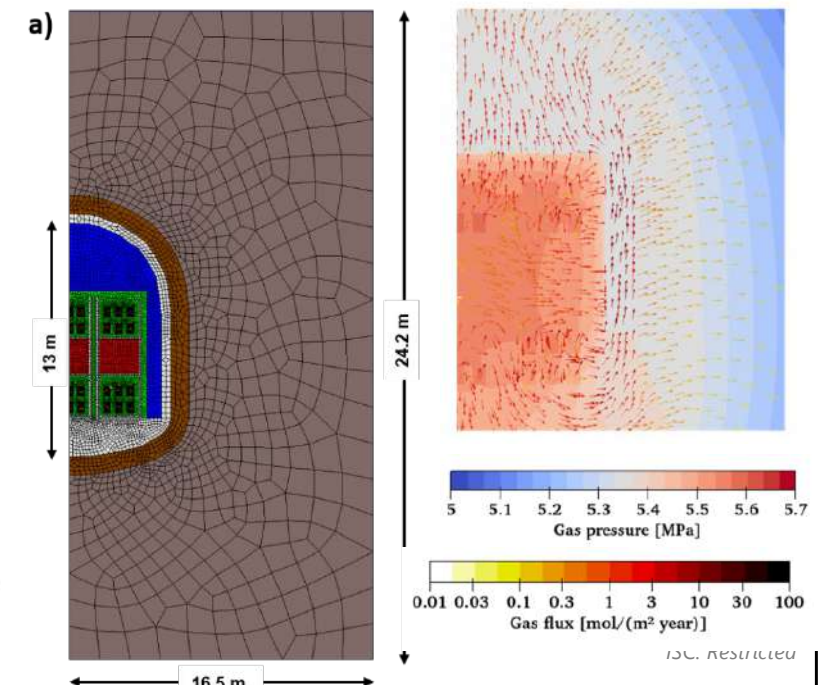
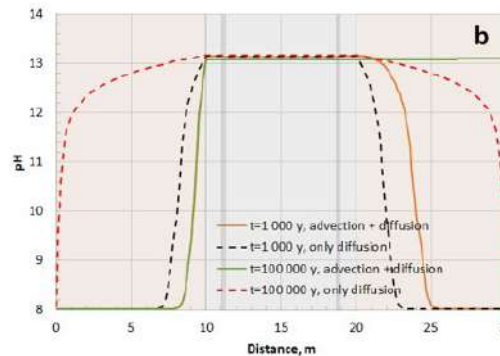
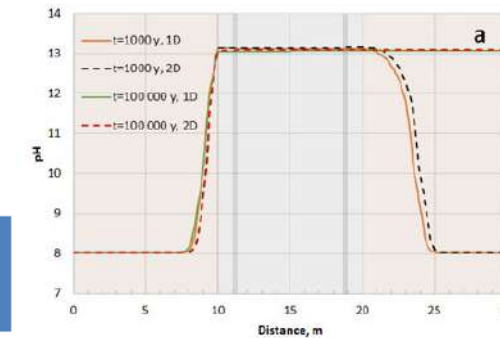
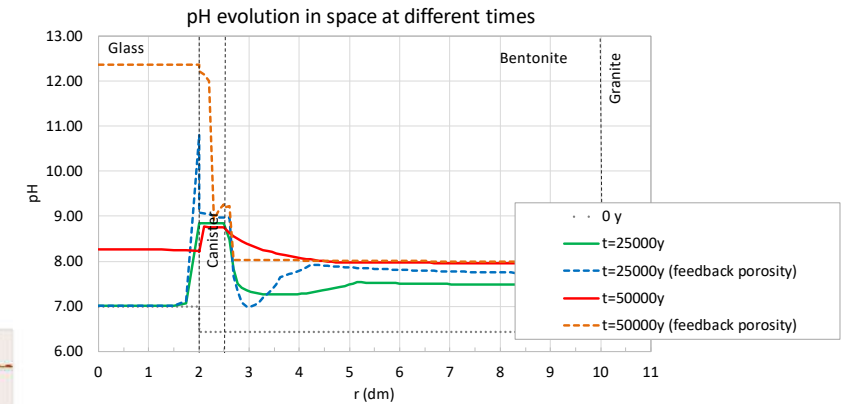
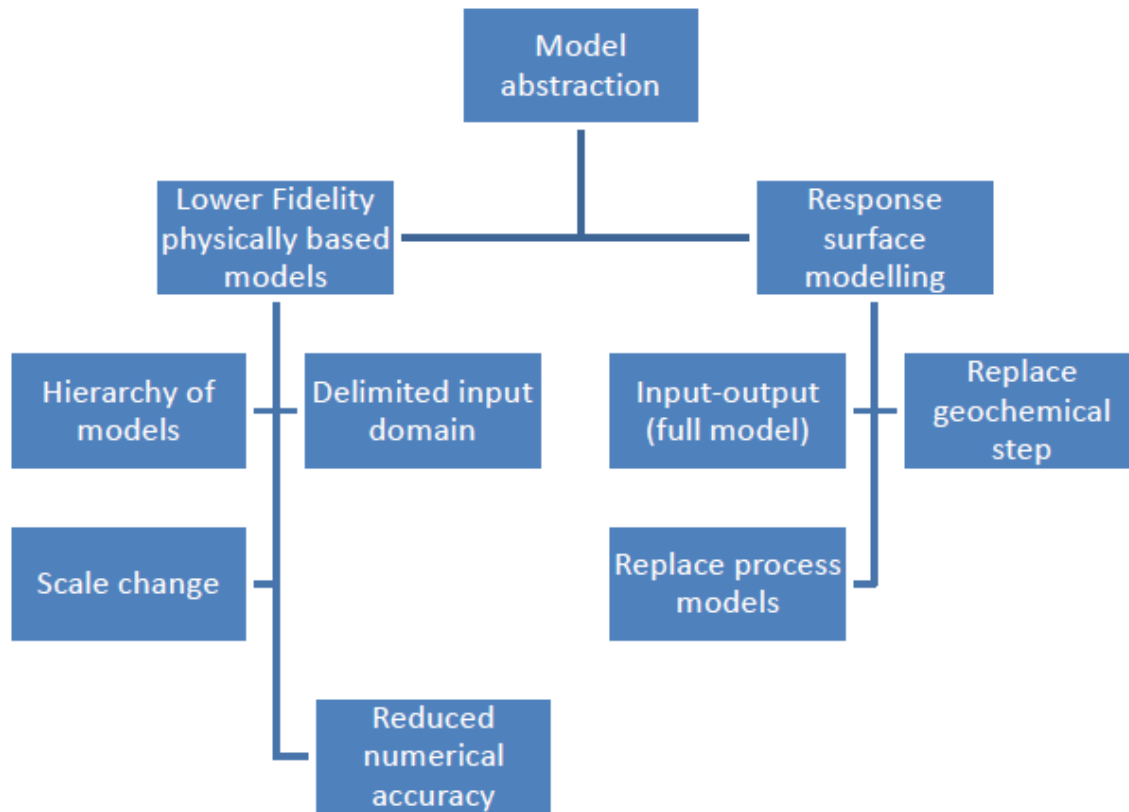


Upscaling to disposal cell – ILW



Abstraction - Sensitivity

Classification of abstraction methodologies and recent examples



Conclusions

Key Achievements

Experimental work

Advanced experimental set-ups

Advanced multi-scale characterizations

Training of less-advanced partners

Modelling work

Advancement in reactive transport models

Applications at different scales

Training of less-advanced partners

Insight in chemical processes at studied interfaces

New materials, different conditions

Input toward modelling (e.g. secondary phases)

Numerous examples of “full” and “abstracted” coupled reactive (transport) models

Integrated conceptual models

Approaches to modelling the processes

Lot of parameters

Final statement on « The modelling results in ACED »

Demonstrate the power of coupled reactive transport calculates

For realistic engineering configurations specific for the ILW/HLW in DGR with all its complexities based on the good (mature) but still evolving scientific understanding

Many first-time implementations of conceptual model where evolution is driven by processes

Geochemical conditions – and transient effects – determine degradation of waste, waste packages and barriers
degradation with multiple interacting degradation pathways

However – not the aim to predict the exact geochemical evolution, but rather insight in role of processes from interface to full disposal cell scale

Dissolution/degradation rates at time scales far beyond experimental duration

Therefore, a significant step forward has been made to include geochemical evolution calculations in national programs as an input to several aspects of scientific understanding, safety and optimization.

Belgian program

- Characterization of experiments that were running at SCK CEN
 - Additional interpretation and model development
- Disposal cell HLW in clay
 - Many relevant materials and processes for supercontainer
 - Variant available with thicker cement buffer
- General knowledge, models, parameters,... for e.g. Fe speciation and migration in concrete
- Demonstration of models coupling migration and geochemistry at different scales and for integrated systems (different barriers together)

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SCK CEN

Belgian Nuclear Research Centre

Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSELS

Operational Office: Boeretang 200 – BE-2400 MOL



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



sck cen

Belgian Nuclear Research Centre

eurad 2
European Partnership
on Radioactive Waste Management

Norbert Maes

Overview and objectives

EURAD-2 builds upon EURAD-1 and PREDIS to further implement a joint strategic programme of research, development and knowledge management activities at the European level for the management of radioactive waste.

- Bringing together and complementing EU Member States programmes
- Ensuring cutting-edge science creation and preservation
- Delivering safe, responsible and publicly acceptable solutions
- Taking into account the various stages of advancement of national programmes
- Throughout all programme phases

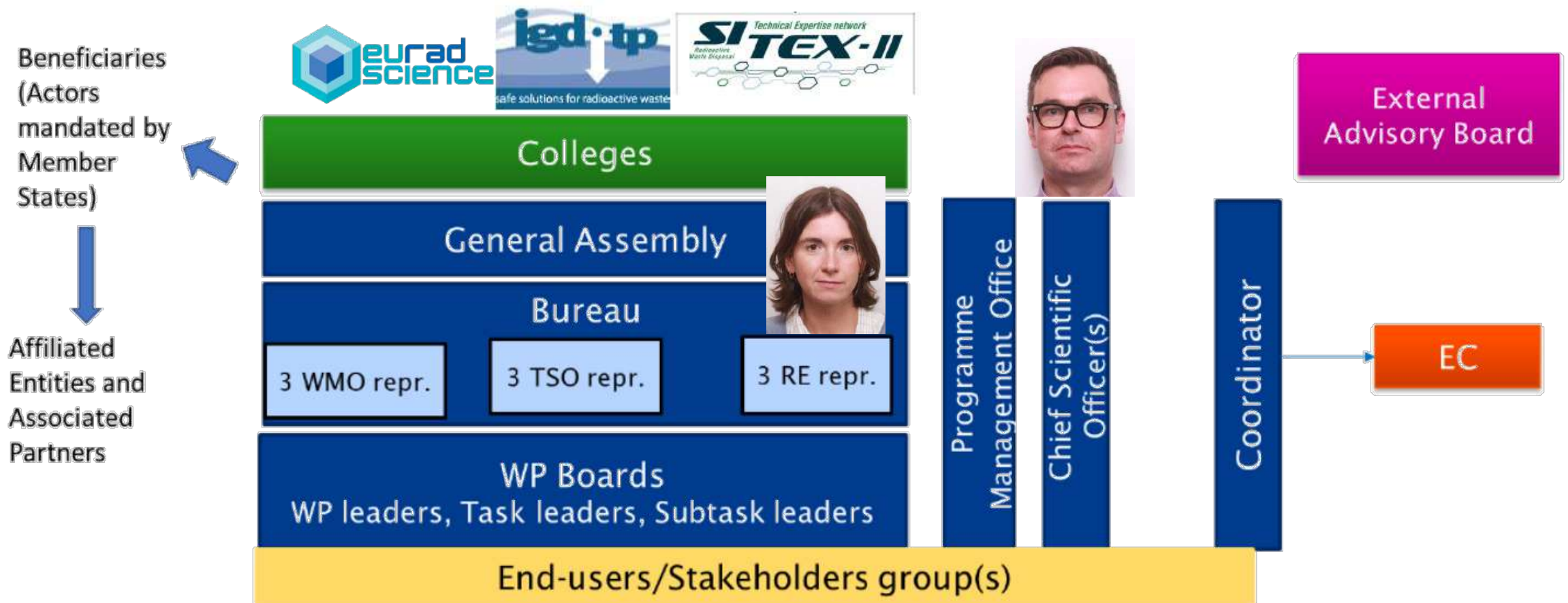
Consortium

143 participating organisations

- 51 Beneficiaries from 21 European countries representing the following Colleges :
 - Waste Management Organisation (WMO)
 - Technical Safety Organisation (TSO)
 - Research Entity (RE)
- 69 Affiliated Entities (mostly universities and research centres)
- 22 Associated Partners (Japan, Norway, South Korea, Switzerland, UK, USA)

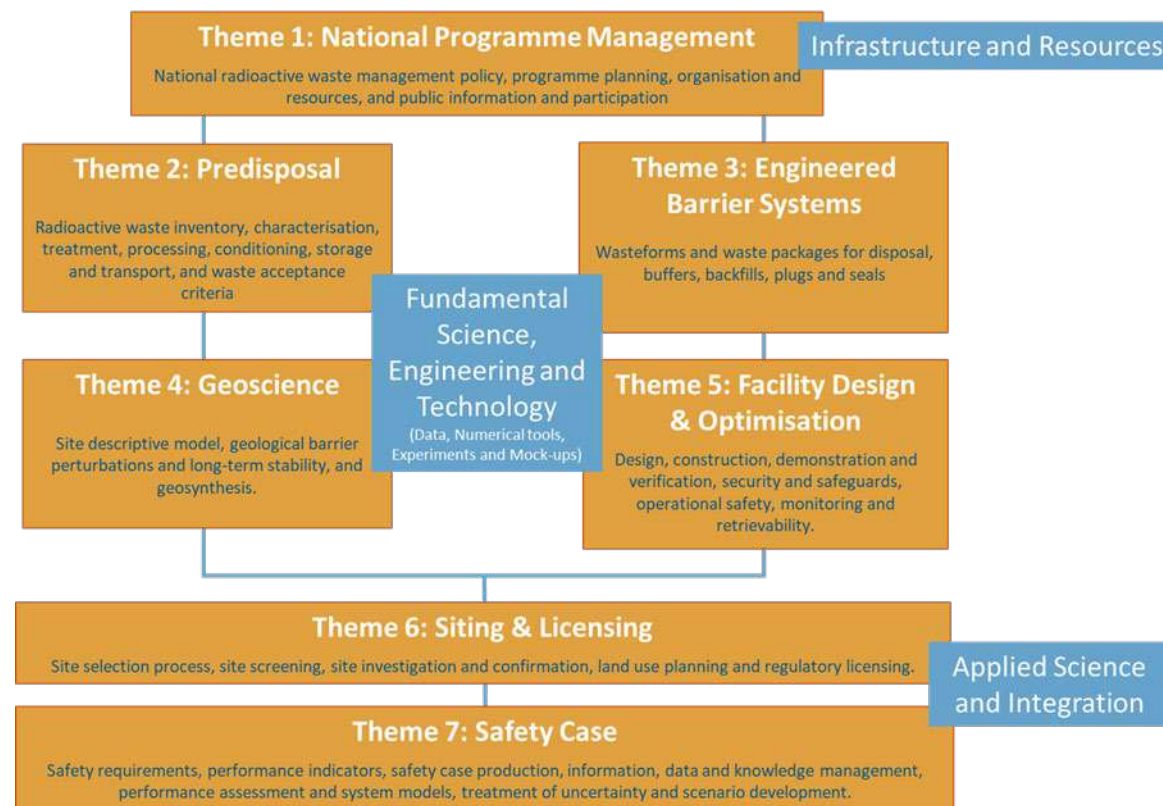


EURAD – 2 Governance



Strategic Research Agenda (SRA)

- **Complements national programmes' strategic priorities**
 - identifying activities of joint interest between WMOs, TSOs and REs
 - identifying activities where there is added value at the European level
- **Built on existing networks, coordination activities, initiatives, and on the work established in EURAD-1 and PREDIS**
- **Developed with a 10 year forward horizon**



<https://www.ejp-eurad.eu/publications/eurad-sra>

Deployment – EURAD 2 workpackages

10 RD&D WP (50% EC funding, 5 yrs)

- developing and consolidating scientific and technical knowledge

6 Strategic Studies WP (100% EC funding, 2 yrs)

- enabling experts and specialists to network on methodological / strategical issues and advance significant challenges in direct link with scientific and technical issues

1 Knowledge Management WP (100% EC funding)

- establish, capitalize and transfer the state of scientific and technical knowledge, competences and capabilities in the field of RWM

1 Coordination/Dissemination WP (100% EC funding)

Civil society engagement

Funding in 2 parts:

Budget as in the proposal:

€ 67 000 000, € 40 000 000 EC contribution

Budget approved only for first 2 years:

€ 33 400 000, € 20 000 000 EC contribution

Belgian Partners involvement (17 WP's)

- SCK CEN
 - Involved in 14 WP's: PMO&KM, 7 R&D studies, 5 Strategic studies
- ONDRAF/NIRAS
 - Involved in 5 WP's: 3 R&D studies, 2 Strategic studies
- EURIDICE
 - Involved in 1 WP: 1 Strategic study
- Uliege:
 - Involved in 2 WP's: 1 R&D, 1 Strategic study
- Tractebel:
 - Involved in 3 WP's: 2 R&D, 1 Strategic study
- BelV:
 - Involved in 2 WP's: 2 Strategic studies



WP1 PMO

Project Management Office



- WP leader: ANDRA
- SCK CEN persons involved
 - Elke Jacobs (Bureau – RE representative)
 - Thierry Mennecart (WP leader)
- Other Belgian Partners: ONDRAF/NIRAS, BelV

WP2 KM

Knowledge Management



Objective

The overall objectives of the KM program are to overcome the competence generation gap by making sure resources are effectively aligned to maintain a sufficient, competent and qualified radioactive waste management workforce.

- Theme KM
- WP leader: Amphos21
- SCK CEN persons involved
 - **Niels Belmans (ACA)**
 - Diederik Jacques, Eric Laloy (EGA)

WP3 ASTRA



Alternative RWM strategies



Objectives

Analysis of readiness, feasibility and challenges of alternative RWM solutions needed by many countries, in particular SIMS, but also larger programs due to new requests accruing in national programs to safely manage and dispose of their waste.

- Theme National program management
- Strategic study
- WP leader: COVRA
- *No Belgian partners involved*

WP4 FORSAFF



Waste Management for SMR's and future fuels



Objectives

Develop understanding and provide recommendations on SMR deployment and supplier options, with respect to nuclear waste management.

- Theme national program management
- Strategic study
- WP leader: VTT
- SCK CEN persons involved
 - Eef Weetjens (EGA)
 - Robbe Gysmans (NST)
- Other Belgian partner: BelV

WP 5 ICARUS



Innovative characterisation techniques for large volumes

Objectives

Further development, optimization and harmonization of innovative techniques for characterizing radiological, physical and chemical properties of LLW/ILW-mixed waste which could be critical for the safe implementation of radioactive waste management programs, 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.

- Theme Pre-disposal
- R&D study
- WP leader: Politecnico Milano
- SCK CEN persons involved
 - **An Bielen (D&D)**
 - Mirella Vasile (LRM)
 - Patrick Maris (MWL)
 - Phung Quoc Tri (W&D)
- Other Belgian Partner: Tractebel
- Co-funding:
 - ENGIE for PhD on DTM
 - N/O for Be studies



WP 6 STREAM

Treatment/immobilization of challenging waste



Objectives

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

- Theme Pre-disposal
- R&D study
- WP leader: CEA
- SCK CEN persons involved
 - **Phung Quoc Tri**, Lander Frederickx (RDD)
 - Sébastien Caes (RDW)
 - Suresh Seetharam (EGA)
- Co-funding by N/O

WP 7 L'OPERA

sck cen

Long term performance of waste matrices

Objectives

Demonstrate long term behaviour and durability of matrices and final wasteforms.

- Theme Pre-Disposal
- R&D study
- WP leader: SCK CEN (**Thierry Mennecart**)
- SCK CEN persons involved
 - Eduardo Ferreira (RDW)
 - Phung Quoc Tri, Lander Frederickx (RDD)
- Co-funding by N/O





WP 8 SAREC

Release of safety relevant radionuclides from Spent Fuel under deep disposal conditions

Objectives

Improved quantification and mechanistic understanding of the release of safety relevant radionuclides covering most representative types of spent nuclear fuel (SNF) and of the fuel evolution both prior and posterior to contact with ground water to better predict the radionuclide source term for post-closure safety assessment.

- Theme EBS
- R&D study
- WP leader: SKB
- SCK CEN persons involved
 - Karel Lemmens, Thierry Mennecart, Christelle Cachoir (RDW)
- Other Belgian partner: ONDRAF/NIRAS (**Roberto Gaggiano**)
- Co-funding by N/O



WP9 InCoMand

Innovative and new container/canister materials under disposal fields condition: manufacturing feasibility and improved durability

Objectives

The WP aims at identifying and qualifying novel materials for the HLW containers/canisters, as well as providing a deeper knowledge of both traditional and novel materials long-term durability in, as realistic as possible, field conditions.

- Theme EBS
- R&D study
- WP leader: ANDRA
- SCK CEN not involved as partner but Vanessa Montoya involved as expert in external review group
- Other Belgian partner: ONDRAF/NIRAS



WP10 ANCHORS

Hydraulic mechanical chemical evolution of bentonite for barriers optimisation



Objectives

*The objective of this WP is to increase the optimisation potential of bentonite barrier systems: buffer, backfill and seals, and the Safety Case resilience 1) by qualifying the Hydro Mechanical (HM) behaviour of various kind of bentonite types and mixtures through laboratory experimental program focused on **heterogeneity, chemical effects** and **friction** at different scales and 2) by improving the numerical tools that are necessary to carry out **performance assessment** of bentonite barriers in a Thermo Hydro Mechanical Chemical (Gas) (THMC(G)) repository environment.*

- Theme EBS
- R&D study
- WP leader: IRSN
- SCK CEN not involved
- Other Belgian Partner: Uliège (**F. Collin**)

WP 11 CLIMATE



Impact of climate change in waste management

Objectives

Identify knowledge gaps and provide recommendations for future research needs on the impact of climate change on radioactive waste management facilities and sites (predisposal; shallow and near surface low level waste, LLW; deep geological repositories, DGR, for low and intermediate level waste LILW, and high-level waste HLW) during construction, operation and post-closure phases.

- Theme Geosciences
- Strategic study
- WP leader: Amphos21
- SCK CEN persons involved
 - **Koen Beerten**, Vanessa Montoya (EGA)

WP 12 RAMPEC

Radionuclide mobility under perturbed conditions



Objectives

Improve the predictive capacity of models of disposal system chemistry and radionuclide mobility under perturbed conditions based on a combination of new experimental and modelling studies up to the cell scale.

- Theme Geosciences
- R&D study
- WP leader: KIT
- SCK CEN persons involved
 - **Norbert Maes**, Liesbeth Van Laer, Elke Jacobs, Miro Honty, Lian Wang (RDD)
- Co-funding by N/O

WP 13 OPTI

HLW repository optimization including closure



Objectives

Develop a mutual understanding and provide recommendations about methodologies and further activities for design and optimization of specific HLW deep geological repository systems, structures and components (SSCs) and procedures.

- Theme facility design and optimization
- Strategic study
- WP leader: BGE
- SCK CEN persons involved
 - Suresh Seetharam, Vanessa Montoya (EGA)
- Other Belgian partners: BelV (**Valery Detilleux**), EURIDICE, ONDRAF/NIRAS, ULiège

WP 14 SUDOKU

LLW/ILW Disposal Optimisation



Objectives

Understanding the behaviour and performances of (i) covers and (ii) cementitious barriers of near-surface disposal facilities for short lived waste (ground level facilities) and ILW (shallow deep facilities) in view of these barriers optimization to ensure the long-term safety of disposal facilities.

- Theme Facility design & optimization
- R&D study
- WP leader: RATEN
- SCK CEN persons involved
 - **Diederik Jacques**, Vanessa Montoya, Chen Guangjing (EGA)
 - Delphine Dure (RDD)
- Other Belgian partner: ONDRAF/NIRAS (**Frank Lemy**)
- Co-funding by N/O

WP 15 DITOCO2030

Next generation Digital Twins to support optimization construction of surface and subsurface radioactive waste management facilities

Objectives

Lay-out the path on how to close the R&D gap between the currently fragmented digital twins (DT) of individual disciplines, common data environments and decision-making platforms to better understand the opportunities and limitations of DT in their deployment in whole life cycle of waste management.

- Theme Facility design & optimisation
- Strategic study
- WP leader: IFE
- SCK CEN persons involved
 - **Vanessa Montoya**, Diederik Jacques (EGA)
- Other Belgian partner: Tractebel



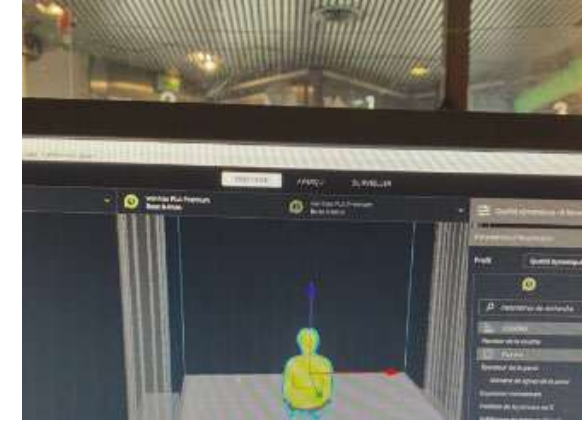
WP 16 HERMES

High-Fidelity numerical simulations of strongly coupled processes for repository systems and design optimization with physical models and machine learning

Objectives

This WP aims at the development of high-fidelity numerical models for simulations of strongly coupled THMC processes in repository nearfield, repository design optimisation and interpretation of mock up experiments using a combination of physics based models and accelerated computing assisted with machine learning and artificial intelligence.

- Theme Facility design & optimisation
- R&D study
- WP leader: PSI
- SCK CEN persons involved
 - **Eric Laloy**, Diederik Jacques, Cheng Guangjing, Suresh Seetharam (EGA)



WP17 CSFD

Criticality safety for final disposal

Objectives

Explore the optimisation potential of the technical and administrative measures available for ensuring criticality safety in final disposal, attain an improved understanding of their methodological validation and experimental verification, and further consolidate the technical basis of the criticality safety argumentation for final disposal of fissile wastes.

- Theme Safety Case
- R&D study
- WP leader: NAGRA
- SCK CEN not involved
- Other Belgian partner: Tractebel



WP 18 DITUSC

Thermodynamic Databases



Objectives

Thermodynamic understanding and quality assured data in support of the Nuclear Waste Disposal Safety Case, with special focus given to a transversal understanding.

- Theme Safety Case
- Strategic study
- WP leader: ONDRAF/NIRAS (**Stéphane Brassinnes**)
- SCK CEN persons involved
 - Sonia Salah, Lian Wang (RDD)
- Other Belgian Partner: ONDRAF/NIRAS

EUROPEAN PARTNERSHIP ON RADIOACTIVE WASTE MANAGEMENT (EURAD-2)



5 years
2024-2029



10 R&D
WPs



6 Strategic
Studies



Knowledge
Management
WP

Objectives :

- Develop, maintain and consolidate the scientific and technical basis of RWM
- Address important and complex issues and enable expert networking
- Enhance KM and transfer between organisations, Member States and generations

Ministries from 21 European countries rec role of directing RD&D at the national l mandates to **51 organisations** acting a within EURAD:

- Waste Management Organisations
- Technical Support Organisations
- Research Entities
- ... with 69 affiliated entities & 22 associated partners (international) also participating



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

Coordination : Andra

Website : <https://www.ejp-eurad.eu/>



EURAD



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eurad2

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SCK CEN

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Foundation of Public Utility

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ONDRAF/NIRAS

Conclusions and outlook on EURAD programmes

Maarten Van Geet
Christophe Bruggeman
Valéry Detilleux

Meeting KORAD

September 16th 2024

EURAD 1

- First **Joint** Programme where all concerned parties (WMO's, RE's, TSO's) defined the priorities together
- Radical change in research collaboration concerning radioactive waste cofinanced by the European Commission
 - ◆ Despite different priorities and points of view between the different countries and parties, we managed to come with convincing results in the different work packages, which are useful to many partners
- **Strong Belgian presence** with 3 WP leads (Gas, Aced, T&M) and 2 Bureau positions (RE, TSO), and of course many scientific contributions (task leaders, collaborators, etc.)
 - ◆ Belgium, with more than 40 years of experience in DGR RD&D, remains a powerful voice at the European level
- We would like to thank all the staff of the Belgian partners who made this first Joint programme a success!

EURAD 1

- **Maintaining knowledge** (competence and capability) is important, independent of the stage of the national programme, and notably requires to bring in new people
 - ◆ The training and knowledge management activities are very useful for early career participants
- The joint programming allows to promote the national programmes abroad (advances and expert knowledge domains)
- Prioritizing topics jointly between WMO's-TSO's-RE's allows to **learn each others' views** and should help on defining what is closed/solved for a specific programme step and what remains as open question
- Joint programming should, even more in the future, allow for **efficient use of available resources** through facility sharing, including large-scale in-situ experiments at European level

EURAD 1

- Collaborating at an international level allows to scrutinize knowledge and scientific progress much more than at national level
 - ◆ This allows confidence building in the obtained results, supporting the principle that geological disposal can be safe
- Participation by Belgian partners remains important to
 - ◆ Benchmark our science and results with international experts
 - ◆ Create networking to continue the advancements in specific domains
 - ◆ Knowledge management & training of young careers + pool of resources
 - ◆ Efficient use, or even rationalization, of available facilities and know-how at a European level
 - ◆ Remain informed on emerging topics for more advanced programmes and assess their impact for the Belgian programme
- But opportunities at European level should not divert us too much from our national priorities

PREDIS

- Complementary “sister” programme to EURAD 1
- Expanding the scope beyond deep geological repositories RD&D, to include predisposal activities and focus on low and intermediate level waste
 - ◆ Characterisation, treatment and conditioning of historical and legacy waste
 - ◆ Connecting with the waste producers as additional player in the radioactive waste management domain
 - ◆ Complementary knowledge management activities, efficiently using the structures and processes of EURAD-1

EURAD-2



EURAD 2

- Where EURAD-1 was mostly focused on geological disposal, Belgian and French partners have succeeded to convince everyone to include also aspects on further optimization of surface disposal facilities
 - ◆ Belgium is again well represented and has impact on the programme
- Next to several R&D projects, EURAD 2 has much more strategic studies
 - ◆ Allow to screen the status of specific topics and the needs from the different countries and colleges
 - ◆ Aim to, when possible, close an item or the be able to prepare the next phase of more in-depth research
- EURAD 2 kick-off meeting was held yesterday in Ghent. We thank all collaborators that were involved in the preparation work (which already took some time) and wish all collaborators a lot of success with the upcoming projects