ANCHORS WP: HYDRAULIC-MECHANICAL-CHEMICAL EVOLUTION OF BENTONITE FOR BARRIERS OPTIMISATION

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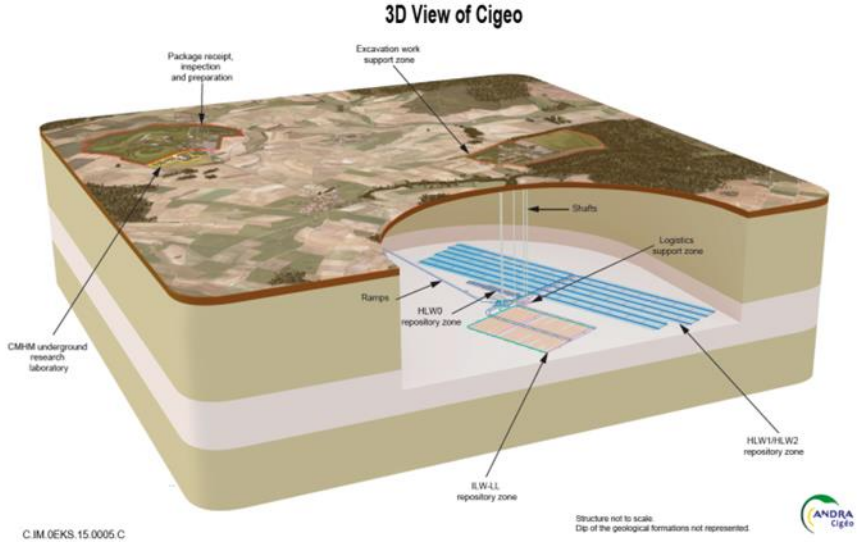
OUTLINE

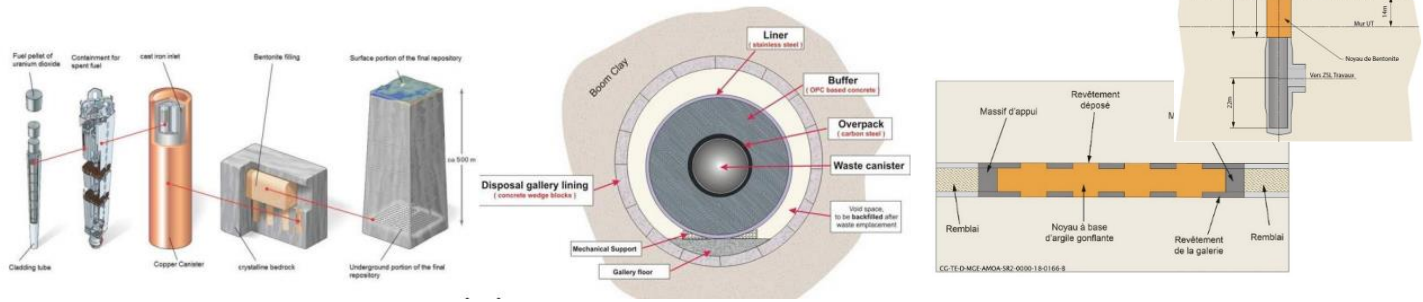
- Context
- Objective
- Impact and added value
- WP structure: Tasks breakdown and participants
- Expected outcomes linked to SRA drivers

CONTEXT

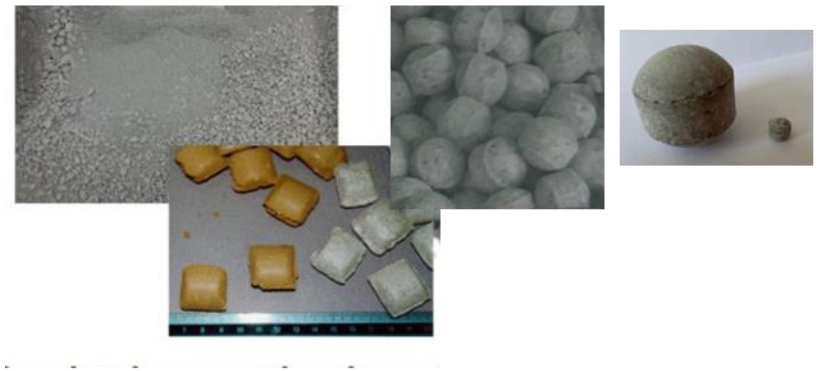
Deep Geological disposal Repositories (DGR)

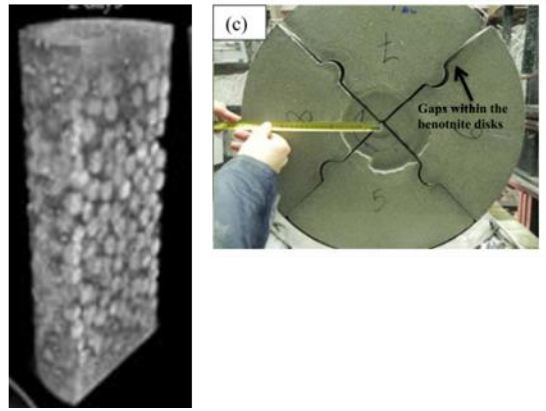


Engineered Barrier Systems (EBS)



Bentonite is used as the principal sealing element





The Knowledge of long-term THMCG behaviour of bentonite-based components contributes to safety improvement, design, and optimisation of the EBS.

MX 80 bentonite,
Febex,
Czech Ca-Mg,
FoCa, Kunigel,
Calcigel…

Blocks, pellets, granular, pellets powder mixture, bentonite/ sand mixture…

OBJECTIVE

- The objective of this WP is to increase the **optimisation potential of bentonite barrier systems:** buffer, backfill and seals, **Performance Assessment** and the Safety Case resilience

    1) **by qualifying the HM behaviour of various kind of bentonite types and mixtures** through laboratory experimental programme focused on heterogeneity and **chemical effects** at different scales and

    2) **by improving the numerical tools** that are necessary to carry out performance assessment of bentonite barriers in a **THMC(G)** repository environment.

IMPACT – ADDED VALUE

- **Qualification of multiple bentonite types and mixtures** as alternative sealing materials in different repository concepts.
- **Investigation of chemical effects** (e.g., alkaline and saline conditions) **on the HM behavior** of bentonite and bentonite-based mixtures and how it affects the disposal performance.
- **Study of the consequence of bentonite and bentonite mixtures heterogeneities** in long term sealing performance under repository boundary conditions.
- **Improvement of THMCG constitutive models** related to the micro/macro interactions of the bentonite structure and the heterogeneity.
- Establishment of a comprehensive **database** containing THMCG material properties and representative numerical tests results for various kinds of bentonites and bentonite mixtures.
- Elaboration of recommendations for better **quality control** of bentonite.

OUT OF SCOPE

- **Biological effects.**
- **Complex chemical interactions.**
- **Corrosion.**
- **Radionuclide migration.**
- **New model development.**

WP STRUCTURE

WP and Task leader: **IRSN (TSO)**

Task 1
Management / Coordination of the WP

- **Scientific-technical coordination**
- **Dissemination of the results**
- **Quality control**

Task leader: **SKB (WMO)**

Task 2
Knowledge Management

- **Subtask 2.1** Knowledge capture
- **Subtask 2.2** Knowledge transfer
- **Subtask 2.3** Development of a database

Task leader: **MITTA (RE)**

Task 3
Laboratory testing
Multiscale experimental characterization

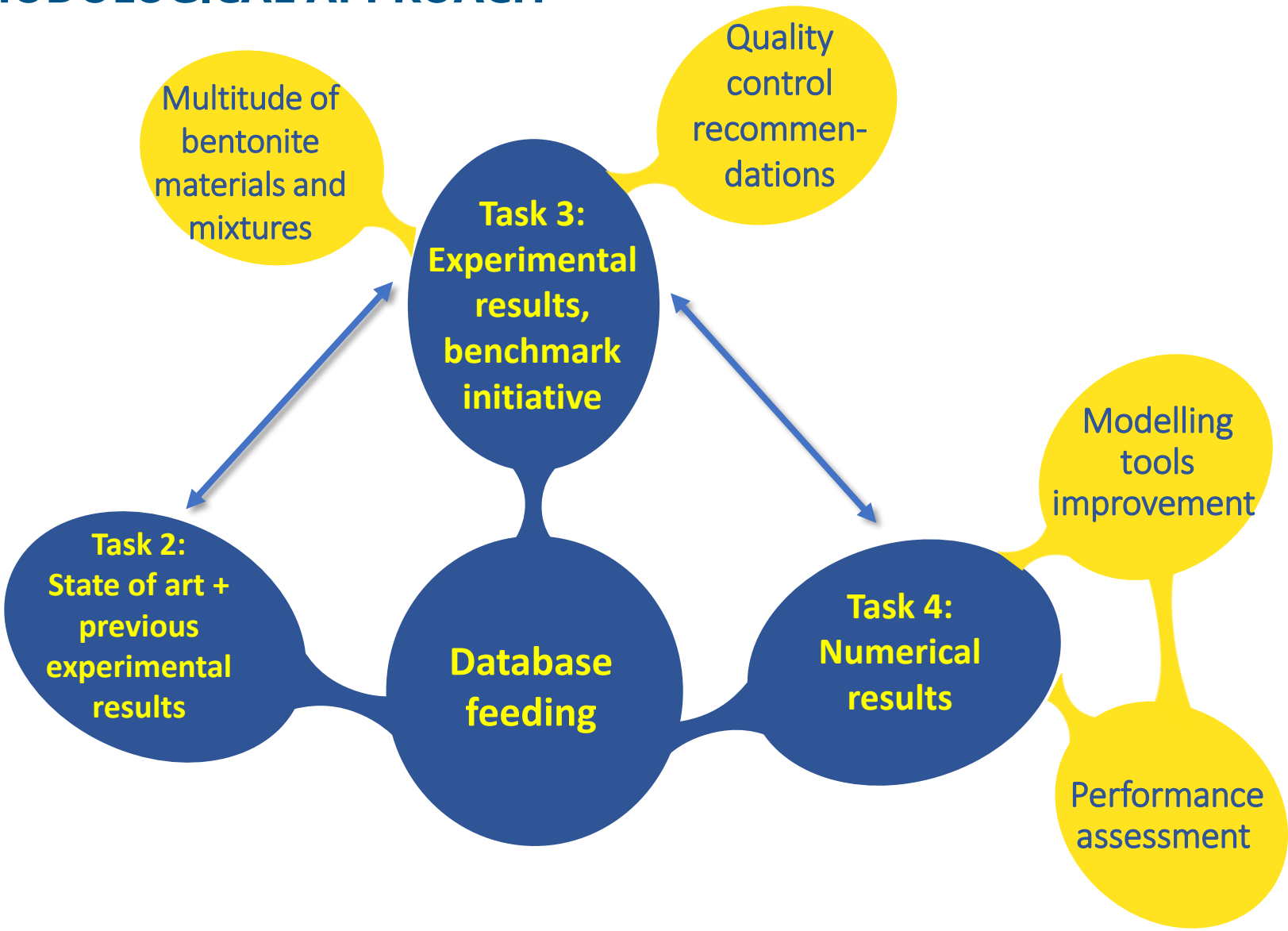
- **Subtask 3.1** Micro scale testing
- **Subtask 3.2** HMC (G) laboratory testing
- **Subtask 3.3** Quality control

Task leader: **BGE (WMO)**

Task 4
Bentonite Barrier modelling and Performance assessment

- **Subtask 4.1** Enhancement of existing constitutive models and numerical tools
- **Subtask 4.2** Application to assessment cases

METHODOLOGICAL APPROACH



TASK 1 MANAGEMENT / COORDINATION OF ANCHORS

WP leader IRSN (TSO)

- Responsible for Scientific/Technical WP coordination and follow-up, fostering interactions within the WP, with other EURAD 2 WPs (e.g. HERMES, OPTI, KM).
- WP Board : IRSN, MITTA, BGE, SKB.
- Timely production of deliverables. In particular, State-of-the-art report (Subtask 2.1): baseline against which WP progress can be measured.
- Review of milestones and deliverables, as well as assessing how the WP is achieving the KPI targets. The aim is to ensure the conformity to the Grant Agreement and high-quality outcomes that meet the objectives of the WP and overall programme.
- Implementing data management and open access link with task 2.3.

TASK 2 DESCRIPTION-KNOWLEDGE MANAGEMENT

Coordination team: SKB (Task leader) ; SKB (ST2.1)**;** ULiège (ST2.2), UCLM (ST2.3)

SOTA & Training

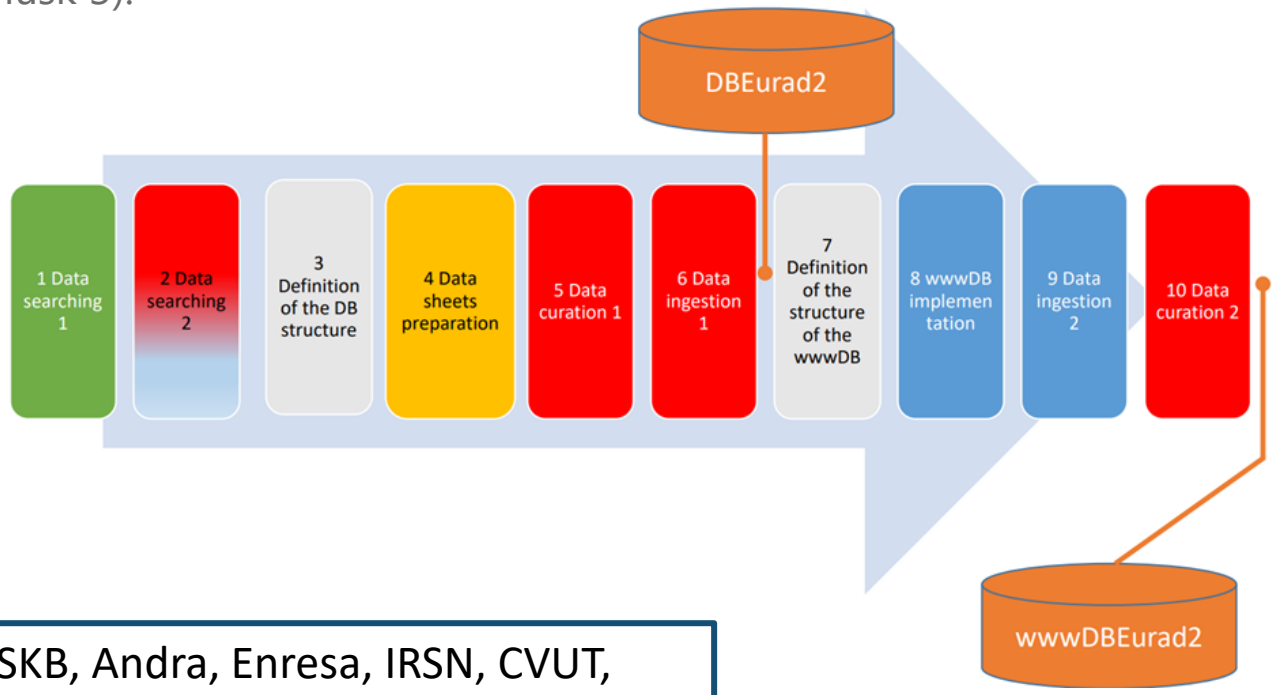
- **Subtask 2.1 Knowledge capture (SKB)**
  - ❑ Capture knowledge relevant to the WP, gained prior to EURAD-2 and extended during this WPs progress.
  - ❑ State-of-the-art report: Initial version of the SotA : month 6, Update SotA: month 60.
- **Subtask 2.2 Knowledge transfer (ULiège)**
  - ❑ 2 doctoral schools Y1 M12 (Sept 2025) and Y5 M54 (Mars 2029)
  - ❑ Target audience: participants of EURAD2+ open to international community in geomechanics.
  - ❑ TOPICS:
    - Impact of chemical loadings on HM behavior of bentonite-based barriers.
    - Laboratory testing and constitutive modelling of bentonite-based materials.
    - Innovative microstructural characterization methods.

Associated Partner (AP): EPFL.

TASK 2 DESCRIPTION-KNOWLEDGE MANAGEMENT

Coordination team: SKB (Task leader) ; SKB (ST2.1)**;** ULiège (ST2.2), UCLM (ST2.3)

- **Subtask 2.3 Development of a database (UCLM)**
  - ❑ Database on the characterization and THMC(G) behaviour of different kind of bentonite and mixtures based on the compilation of previous experiments and from new experiments to be carried out in this project (Task 3).



Data will be accessible to all data base users. Non-published data could also be part of the database but with the permission of the owner and the intellectual owner.

Partners: UCLM, JYU, SKB, Andra, Enresa, IRSN, CVUT, UFZ, Ciemat, Mitta, BGE.
AP: EPFL, LBNL, Nagra, NDA.

TASK 3 DESCRIPTION-LABORATORY TESTING

Coordination team: MITTA (Task leader) ; UYU (ST3.1); CVUT (ST3.2), POSIVA (ST3.3)

- **Objectives**

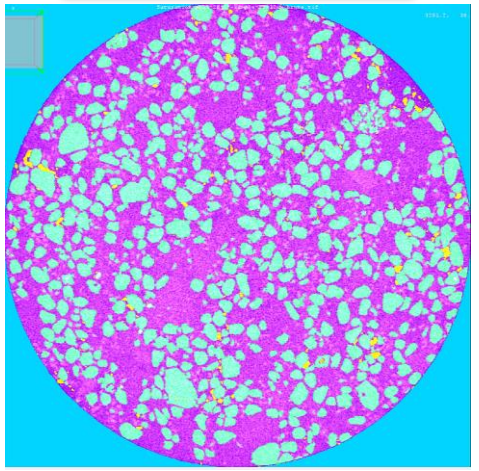
  - ❑ Multiscale experimental characterization of a wide range of bentonite types (e.g., Na and Ca bentonites from different locations) and bentonite-based mixtures.
  - ❑ Specific focus on chemical loadings, heterogeneity, role of friction in link with scale effects and mixture optimisation (influence of variations in the bentonite-based mixture components),
  - ❑ Laboratory characterization of “aged or matured” bentonite/mixtures coming from “in situ” tests or mock-up tests (if samples are available).
  - ❑ Experimental groups will be asked to analyze a different kind of bentonites or bentonite mixtures in addition to the suggested materials to achieve the WP objective on material optimization and provide supplementary data for the database.

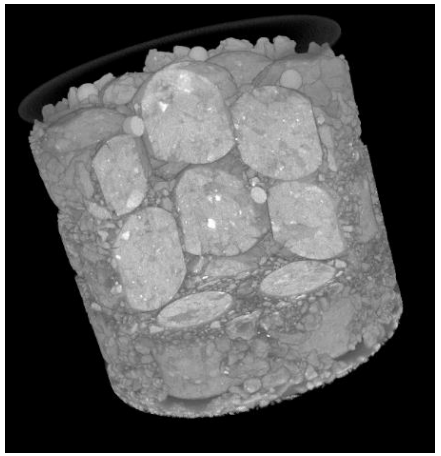
TASK 3 DESCRIPTION-LABORATORY TESTING

Coordination team: MITTA (Task leader) ; JYU (ST3.1); CVUT (ST3.2), POSIVA (ST3.3)

- **SubTask 3.1 Micro scale testing (JYU)**
  - ❑ In-depth microstructural characterization of different kind of bentonite types and bentonite-based mixtures at various conditions to improve understanding of physical and chemical mechanisms governing the material properties.
  - ❑ Improve possibilities for optimizing the EBS, to obtain more reliable data for constitutive modelling in Task 4, and to contribute to the bentonite THMCG database.

Sand/bentonite mixture





Pellets/powder mixture

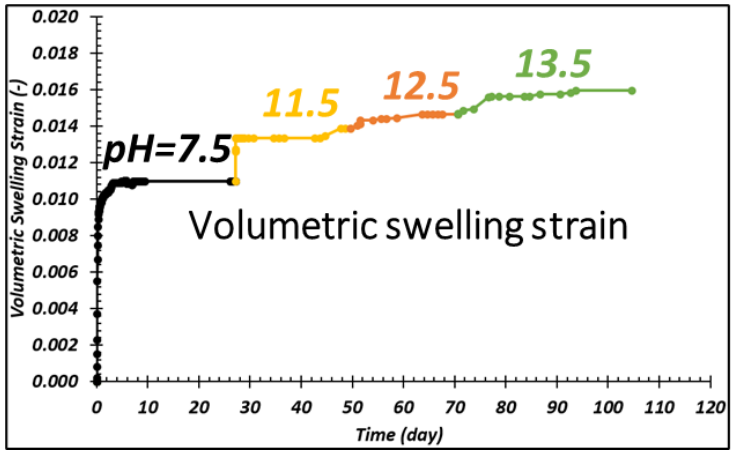
- ➢ 5 different bentonites and mixtures, clay bentonite mixtures, aged samples.
- ➢ Use of both destructive and non-destructive techniques for detailed analysis, : X-ray and neutron microtomography and radiography, WAXS, SEM, SEM-EDX, µ-Raman ,MIP…
- ➢ In-situ testing : Miniature Oeudometer tests, constant volume swelling test.

Partners: BGRM, GI-BAS, ULorraine, EK, BGR, GRS, Ciemat, JYU, IRSN.
AP: LBNL, ETH.

TASK 3 DESCRIPTION-LABORATORY TESTING

Coordination team: MITTA (Task leader) ; JYU (ST3.1); CVUT (ST3.2), POSIVA (ST3.3)

- **SubTask 3.2 THMC(G) Laboratory testing (CVUT)**
  - ❑ Perform small scale tests (centimetric) and mock-ups (decimetric) on alternative bentonite and bentonite mixtures to improve understanding of the micro-scale mechanism.
  - ❑ The planned tests aim to investigate mainly the scale effect, the friction, and the chemistry effects and aging



- ➢ Oedometric tests at different scales will be performed to investigate the scale effect and to analyze the hydration process with saline and cementitious waters.
- ➢ Mock-up tests will be performed in cells with different sizes.
- ➢ Mixtures, proportions and type of waters will be agreed by comparing the different resources of each laboratory
- ➢ Experimental benchmarking : These tests are going to be used for modelling validation ⟷ **Task 4.1**

Partners: IRSN ,CNRS-Navier, Mitta, Ciemat, ULorraine, Clay Tech, TUBAF, GRS ,VTT, GI-BAS, CVUT,UJV,CUNI.
AP: EPFL, U SClyde

TASK 3 DESCRIPTION-LABORATORY TESTING

Coordination team: MITTA (Task leader) ; JYU (ST3.1); CVUT (ST3.2), POSIVA (ST3.3)

- **SubTask 3.3 Assessment of measures for better quality control and testing of bentonite (POSIVA)**

  ❑ The main aim is to define a systematic quality control plans to verify the quality of the batches of bentonite that the waste management organisations can use.

➢ Phase I:
  - Collect data on currently used quality control methods (e.g. required sampling, suppliers and laboratories requirement, standards/instructions). Best practices from other material's QC can be used as basis.
  - Questionnaire to participants to see current readiness of methodologies/QC and used methods.

➢ Phase II: State of knowledge report +Task 3.2 benchmark results.

State of knowledge report

Recommendations / plans / best practices for the future

Partners: POSIVA, SKB, ANDRA, BGE, ENRESA.
AP: Nagra, NWS.

TASK 4 BENTONITE BARRIER MODELLING AND PERFORMANCE ASSESSMENT

Coordination team: BGE (Task leader) ; CIMNE/UPC (ST4.1); ANDRA (ST4.2)

- **SubTask 4.1 Enhancement of existing constitutive models and numerical tools (CIMNE/UPC)**
  - ❑ Improve existing constitutive models coupling with temperature and relevant chemistry, gas flow is not scope of this WP but it can be included. Micro/macros coupling in link with Task 3, consideration of heterogeneity and transient behavior.

- ➢ Some constitutive models are going to be extended from THM, HM or HC to THMC or HMC
- ➢ HM will be improved to include heterogeneity and friction effect or double porosity/multiple structure approaches
- ➢ Comparative benchmarking exercises.
- ➢ Model validation with reference tests.

Partners: UCLM, Amphos 21, Clay Tech, LEI, IGN, ULIEGE, TUDELFT, TUBAF, BGE, UFZ, BGR, CUNI, IGN, CUNI, CVUT, VTT, UBERN, CIMNE-UPC.
AP: PSI, EPFL, UBERN, ICL, ETH, ICL.

TASK 4 BENTONITE BARRIER MODELLING AND PERFORMANCE ASSESSMENT)

Coordination team: BGE (Task leader) ; CIMNE/UPC (ST4.1); ANDRA (ST4.2)

- **SubTask 4.2 Application to assessment cases (ANDRA)**

  ❑ Enhance confidence in numerical tools for safety case applications by focusing on large-scale bentonite barriers components. This includes investigating the sensitivity of parameters in the long-term evolution of bentonite barriers.

- Definition of a limited number of assessment taking into account the concerns of WMOs, the ability of partners to model them.
- These cases will evolve during the project, increasing the global complexity of the case by introducing more coupling between the main processes to be considered such as Mechanical, Thermal, Hydraulic, Chemical and Gas
- The role of wall friction will also be examined through these test cases.
- A focus will be also on sensitivity analysis, the quantification and propagation of uncertainties.

Partners:SKB, Clay Tech, LEI, ULIEGE, BGE, BGR,CVUT, Mitta, CIMNE-UPC, Andra, IGN.
AP: PSI, EPFL, Nagra, NDA, LBNL.

INTERACTIONS WITH OTHER EURAD-2 WORK PACKAGES

Task 1 ⟺ WP1 – Programme Office Management (PMO)

WP13 – HLW repository optimisation including closure (OPTI)

OPTI → Anchors

- ❑ What are the key challenges for the optimization of buffer and backfill?
- ❑ Give to ANCHORS the high-level needs/goals for optimization and define the information needed about bentonite to do the optimization.

Y2: Annual meeting jointly with OPTI.

Task 2 ⟺ WP2 – Knowledge Management (KM)

WP16 – High fidElity numeRical siMulations of strongly coupled processes for rEpository syStems and design optimisation with physical models and machine learning (HERMES)

HERMES → Anchors

Data and models exchange on the bentonite evolution on the repository near field. A joint workshop on THMC characterisation and modelling of bentonite behaviour.

Y3: Joint workshop with HERMES on THMC characterisation and modelling of bentonite behaviour.

EXPECTED OUTCOMES LINKED TO IDENTIFIED SRA DRIVERS

- **Innovation for Optimisation (SRA 3.3.2)**:
  - Qualification of HM behaviour of various kind of bentonite types and mixtures focusing on heterogeneity, chemical effects and friction at different scales.
  - Development of testing methods and protocols to study HM behavior of selected mixtures under coupled representative disturbances at different scales.
- **Scientific Insight (SRA 3.3.1):**
  - Enhancement of the understanding of more complex systems at laboratory scales,
  - Improvement scientific insight on key controls and performance assessment.
- **Implementation Safety (SRA 3.3.1):**
  - Improvement of current numerical tools, considering the coupling THMCG coupled processes.
  - Validation of THMCG computer codes to be used for carrying out the performance assessment.
  - Provision of accepted tests to improve the quality validations trough laboratory benchmarking .

PARTNERS

- 31 EU partners +11 AP
- From 15 countries

WMO	RE	TSO	AP
ANDRA	AMPHOS 21	CIEMAT	EPFL
BGE	CIMNE/UPC	GI-BAS	ETH
ENRESA	UCLM	IRSN	UBERN
POSIVA	BRGM	VTT	NAGRA
SKB	ENPC	GRS	PSI
	ULORRAINE		ICL
	BGR		NDA
	UFZ		NWS
	TUBAF		Uni Strathclyde
	Clay Tech		SANDIA
	CUNI		LBNL
	CVUT		
	UGN		
	UJV		
	IGN		
	HUN-REN EK		
	JYU		
	MITTA		
	LEI		
	TUDELFT		
	ULIEGE		
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THANK YOU FOR YOUR ATTENTION