European Partnership
on Radioactive Waste Management

DOCTORAL SCHOOL
EURAD2 WP ANCHORS
27 August – 29 August 2025, Liège (BE)

THMC behaviour of bentonite and bentonite mixture:
From the experimental investigation to the numerical modelling.

OVERVIEW

We are happy to invite you to the ANCHORS training course, which will be held in Liege between 27 August and 29 August 2025.

This school is organized within the framework of EURAD2 - European Joint programme on Radioactive waste management (grant agreement No 101166718) – whose one of its objectives is to develop, maintain and consolidate the scientific and technical basis of radioactive waste management. This doctoral school focuses on the ANCHORS Work Package of the EURAD2 Joint Programme.

The main objective of the WP ANCHORS is to increase the optimisation potential of bentonite barrier systems: buffer, backfill and seals, and the Safety Case resilience. The activities of the WP are twofold:

1) qualifying the Hydro-Mechanical (HM) behaviour of various kinds of bentonite types and mixtures through laboratory experimental programme focused on heterogeneity, chemical effects and friction at different scales

2) 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.

Geomechanics plays a significant role in the understanding of the relevant thermo-hydro²-chemio-mechanical couplings taking place around the disposal. The objectives of the school is therefore to provide the state-of-the-art on basic concepts related to the THMC(G) couplings, the experimental investigation of complex hydro-mechanical behaviour of various bentonite types and mixtures, and the numerical modelling of the multiphysical phenomena.

TARGET AUDIENCE

- (Early-career) researchers involved in the EURAD2 WPs
- (Early-career) researchers on the bentonite behaviour
- Members of waste management organisations and technology support organisations

LEARNING OUTCOMES

At the end of the school, participants will have a broad view of the state-of-the-art and of the challenges related to the ANCHORS WP research programme. They will meet a number of key researchers on these questions, and will therefore be in contact to further develop their research project.

In particular, the attendees will be able to:

- Understand the Thermo-hydro²-chemo-mechanical (multi-physical) couplings in geomaterials
- Catch the fundamentals on constitutive modelling of the relevant phenomena
- Identify the challenges in numerical modelling of these physical processes
- Perceive the experimental evidences at the laboratory scale
- Figure out the physical processes thanks to in situ tests.

VENUE

The PhD school will be held in the '*Amphithéâtres de l'Europe*' buildings of the **ULiege (Sart-Tilman campus)**, Liège, Belgium.

Liege is well connected with a range of public transport options and offers plenty of options for accommodation.

PROGRAMME

Wednesday 27 August	
9.00 – 10.15	Introduction Lessons learned from BEACON WP P. Sellin, SKB Challenges addressed by ANCHORS WP N. Mokni, ASNR
10.30 – 12.30	Basics of thermo-hydro-mechanical processes in geomaterials F. Collin, ULiège
Lunch	
13.30 – 15.30	Basics of experimental testing of geomaterials A. Ferrari, EPFL
16.00 – 17.00	Exploring the mineralogy and physico-chemical properties of bentonites to understand their response to CHM loads A-C Dieudonné (TUDelft)
Thursday 28 August	
8.30 – 10.00	Investigating the microstructure of compacted bentonite-based materials O. Cuisinier, ULorraine
10.30 – 12.30	In situ experiment on bentonite plug P. Sellin, G. Armand, J. Svoboda
Lunch	
13.30 – 15.30	THMC(G) laboratory testing on bentonite Y.J. Cui, ENPC
16.00 – 17.00	Constitutive modelling for thermomechanical behaviour of bentonite D. Masin, Charles University
17.00 – 17.30	Thermo-Hydro-Mechanical and Chemical (THM-C) modelling of bentonite clay in nuclear waste disposal (Han Ming LAI - Clay Conference 2024 poster award winner)
17.30	Challenges and open questions
Friday 29 August	
Departure to Mol at 8.00	
9.30 – 12.00	Group 1 visits Tabloo expositions (Gravenstraat 3, 2480 Dessel) Group 2 visits EURIDICE_HADES underground research laboratory (Boeretang 200, 2400 Mol)
12.15 – 13.15	Sandwich lunch
13.15 – 15.30	Group 2 visits Tabloo expositions (Gravenstraat 3, 2480 Dessel) Group 1 visits EURIDICE_HADES underground research laboratory (Boeretang 200, 2400 Mol)
Return from Mol at 15.45	

SYNOPSIS

Basics of thermo-hydro-mechanical processes in geomaterials (F. Collin)

The basic thermo-hydro-mechanical (THM) phenomena occurring in saturated and unsaturated porous media are reviewed, with special attention to their interactions. A theoretical formulation that encompasses the most relevant THM phenomena and their couplings is developed. The description of the formulation is divided into balance equations, constitutive equations and equilibrium restrictions. Governing equations include solid mass balance, water mass balance, air mass balance, energy balance and momentum balance (equilibrium). Constitutive equations are proposed for the various THM phenomena that are deemed most relevant. The specific form of each constitutive equation generally includes information on the nature of the interactions between different phenomena. Equilibrium restrictions provide conditions for processes that are considered fast with respect to the characteristic times of the overall THM problem, notably phase changes.

Basics of Experimental Testing of Geomaterials (A. Ferrari)

This lecture introduces the principal experimental strategies for investigating the hydro-mechanical behavior of geomaterials, with particular focus on materials relevant to nuclear waste repositories. Classical test setups will be reviewed, with emphasis on the challenges posed by the specific characteristics of these materials—such as unsaturated conditions, significant swelling pressures, and strong stress-path dependency. The discussion will also cover the definition of a representative volume element for testing and the use of experimental results to derive parameters for constitutive modeling.

Exploring the mineralogy and physico-chemical properties of bentonites to understand their response to CHM loads (**A-C Dieudonné**)

The lecture will explore the mineralogy, physico-chemical properties, and microstructural characteristics of bentonites, aiming to provide a deeper understanding of the mechanisms underlying the material's response to chemo-hydro-mechanical (CHM) loads. The discussion will begin with a description of the material's mineralogy, followed by an exploration of the structure and processes occurring in bentonites, starting from the smallest relevant scale—the scale of the clay minerals. The structure and physico-chemical properties of these clay minerals will be presented first. As the scale of observation increases, the structure of bentonites and its evolution under mechanical and environmental loads will be addressed. Special attention will be given to the hydration and swelling mechanisms, as well as the impact of water chemistry.

Investigating the microstructure of compacted bentonite-based materials (O. Cuisinier)

The thermo-hydro-mechanical-chemical (THMC) behaviour of compacted bentonite-based materials is closely linked to their microstructure. Analysing the microstructure is therefore essential to interpret and predict their macroscopic properties. However, microstructure is a broad concept encompassing various aspects such as particle arrangement, interparticle interactions, particle organization, and pore size distribution. Multiple experimental methods are available, and defining the appropriate investigation strategy can be challenging.

In this context, this lecture will begin with a brief overview of the main techniques used to investigate microstructure, and to quantify microstructural features. Emphasis will then be placed on how to select the most suitable technique. Case studies will highlight the value of combining multiple techniques, particularly when quantitative analysis is required. The lecture will also address limitations inherent to each method.

In situ experiment on bentonite plug (**P. Sellin**, **G. Armand, J. Svoboda**)

- *In-situ experiments with bentonite in crystalline rock* (**P. Sellin**)

This will include a discussion on:

- The purposes of large-scale field tests and a brief history of tests that have been undertaken.
- The processes the are relevant for a clay engineered barrier in the safety case for a nuclear waste repository and how they can be studied in field tests.
- Validation of numerical models based on observations from field tests

- *In-situ experiments on bentonite plug* (**G. Armand**)

Andra has been conducting large scale experiments in its underground research laboratory on the closure system for the radioactive waste repository for many years. These tests have both scientific and technological objectives. The aim is to demonstrate Andra's operational capacity to build seals or backfill galleries, and also to check that the expected performance with regard to water and gas flow and compressive strength has been achieved. Various types of materials were tested, including pure bentonites, bentonite/sand mixtures and mixtures based on excavated crushed clay. Different shaping methods were also used, with the preparation of pre-compacted blocks, bricks, pellets or in-situ compaction. These experiments are accompanied by intensive campaigns of tests on samples and simulations to design and understand the hydromechanical-gas behaviour of these components over the long term. Feedback from these large scale experiments will be presented, from material qualification to performance testing.

- *DOPAS EPSP plug experiment* (**J. Svoboda**)

Since 2014, Experimental Pressure and Sealing Plug is in operation at Josef Underground Research Laboratory. The plug has been erected as part of DOPAS project and is still in operation. The lecture will present the EPSP from design, erection and operation including lessons learned.

THMC(G) laboratory testing on bentonite (Y.J. Cui)

After a short introduction and a presentation of different forms of bentonite investigated, advanced THMC(G) testing is presented for characterising different key bentonite property/behaviour including thermal conductivity, water retention property, hydraulic conductivity, swelling pressure, volume change/damage behavior and gas transfer.

Constitutive modelling for thermomechanical behavior of bentonite (D. Masin)

The constitutive modelling of bentonite THM (thermo-hydro-mechanical) behaviour will be described from the perspective of unsaturated soil mechanics. After introducing possible stress representations for unsaturated soils (including the unsaturated effective stress concept) and outlining the basic features of unsaturated soil behaviour using simple models (such as the Barcelona Basic Model), additional layers of constitutive modelling will be presented to enhance the prediction of bentonite behaviour. This includes, in particular, the double structure approach for describing soil mechanical behaviour, the modelling of void ratio-dependent double-structure water retention behaviour coupled with the effective stress principle, and the incorporation of thermal effects on the behaviour of both macrostructure and microstructure. Finally, more advanced topics will be introduced, such as viscoplasticity (to describe rheological effects), chemo-mechanical behaviour (to account for the effects of variable pore fluid chemistry), and the triple structure concept (for modelling the behaviour of bentonite pellets).

REGISTRATION

Registration is free of charge.

A maximum of 80 participants will be able to join the school. Priority will be given to researchers involved in EURAD2 until 1 July 2025.

https://euradschool.eu/event/work-package-anchors-training-course/

EVALUATION

An evaluation on the course content will be organized for the students, that need a certificate to obtain credits. The evaluation will take place on Thursday 28 after the closure of the school.

CONTACT

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Find your way to the Doctoral School

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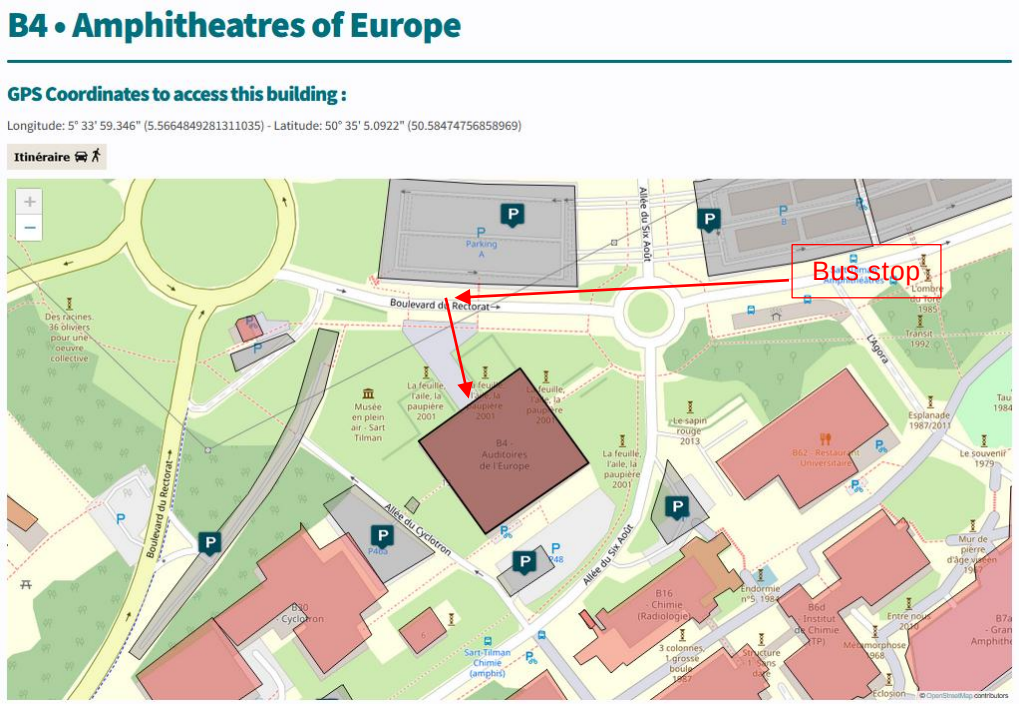
Boulevard du Rectorat, 13

4000 LIEGE

Parking PA



https://www.campus.uliege.be/cms/c_1763578/en/b4-amphitheatres-of-europe

Getting to Sart-Tilman Campus by Public Transport

Several bus and tram lines can take you to the Sart-Tilman campus, depending on where you're staying in Liège.

🚌 Direct Bus Lines

Bus 2
📍 Departure: Guillemins Station
Approximate travel time: 30 minutes

Bus 3
📍 Departure: Place de la République Française (city center)
Approximate travel time: 45 minutes