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TIMODAZ

Thermal Impact on the Damaged Zone Around a Radioactive Waste Disposal in Clay Host Rocks

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General project scope and objectives

Editor: **Xiangling li**

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1 General project scope and objectives

Spent nuclear fuel and long-lived radioactive-waste management is an important environmental issue today. Disposal in deep clay geological formations is one of the promising options to dispose of these wastes. An important item for the long-term safety of underground disposal is the assessment of the damaged zone extent induced both by the excavation process and the thermal impact.

The TIMODAZ project studies the Thermo-Hydro-Mechanical and Chemical (THMC) processes occurring around a repository. It focuses on the study of the combined effect of the EDZ and the thermal impact on the repository host rock. The influence of the temperature increase on the EDZ evolution as well as the possible additional damage created by the thermal load is investigated. The knowledge gained within the TIMODAZ project will allow to assess the significance of the TDZ (Thermal Damaged Zone) in the safety case for disposal in clay host rock and to provide direct feedback to repository design teams.

The project is broken down in 7 Workpackages (see Figure 1).

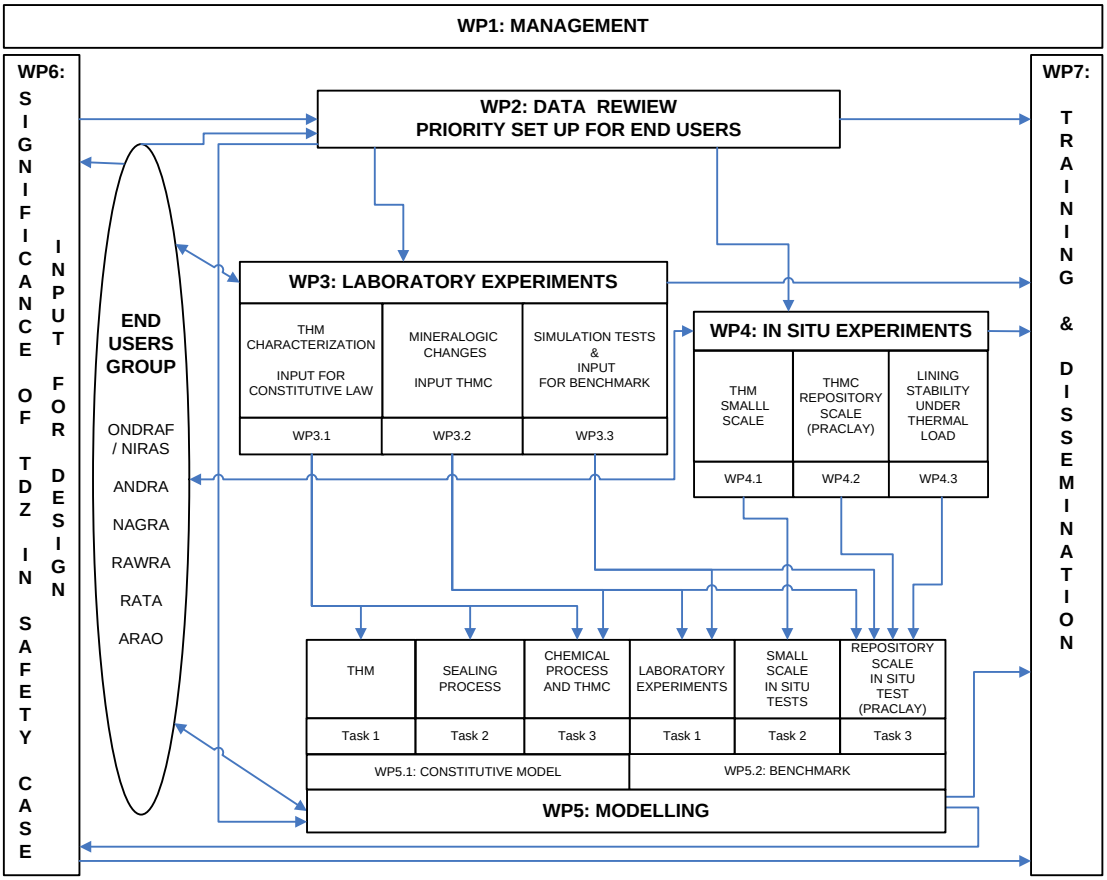

Figure 1: Structure of the TIMODAZ project

Three types of clay are investigated: the Boom Clay, the Opalinus Clay and the Callovo-Oxfordian argilitte. Even if the characteristics of these clays are different, the THM processes governing the fracturing and the sealing present some similarities. Therefore, the first

deliverable of the project consists in a synthesis integrating the work previously performed on these three types of clay in surface laboratories and in-situ facilities.

Specific laboratory tests will be performed to strengthen our knowledge of the fracturing and the sealing processes under evolving thermal conditions. In particular, the effects of the temperature on damaged clay as well as on the clay properties are investigated. Special attention is drawn to the possibility of creating irreversible damage. The tests include the study of the desaturation/resaturation processes at ambient and at different temperatures. Recent developments in transmission/emission tomography appears to be promising to study the density and water content of the studied samples and the heterogeneities and fractures in these samples during temperature-controlled geomechanical tests. Some tests are complemented with a radionuclide migration test to evaluate any possible relict of preferential migration along the sealed fracture. Different chemical conditions are considered: chemical undisturbed, oxidised and alkaline environment. Mineralogical analyses are performed and linked to the hydromechanical observations. These laboratory tests provide the necessary data for the numerical models to be used in TIMODAZ.

Results from previous and current THM in-situ tests are available for the project. An additional small-scale in-situ THM test is conducted at Mont Terri as an extension of the SELFRAC test configuration. The results of these in-situ tests are very useful to link pure lab testing and full scale tests. Different numerical codes modelling THM processes in clays are evaluated by participation in Benchmark tests. Sealing and chemical processes induced by THM phenomena are also incorporated in some computer codes.

The thermal impact on the stability of the lining is also investigated. This issue is particularly important in term of operational safety when the retrievability of the radioactive waste is considered.

The modelling work together with the results of the lab and the in-situ tests should give clear indication on the evolution of the DZ with time upon temperature evolution. After such an independent validation, a good prognosis is expected for the application of the codes in simulations at spatial and time repository scale. In this perspective, an important objective of the project is to perform predictive simulations of the large-scale heater test PRACLAY that will be performed in the HADES underground laboratory at Mol. If the Praclay heater test starts as initial planned, the first results of the PRACLAY heater test should be available within the TIMODAZ project period.

A single temperature limit may not account for the full potential of a given host rock. The use of such a single temperature may however be legitimate as long as its conservativeness can be supported by adequate, hard evidences. Therefore it is important to at least estimate what the ultimate thermal limits (maximum temperature and maximum temperature increase rate) of the clay could be in the context of the long-term performance of the repository system. While such an estimate may use softer data, it should still rest on well-documented phenomenological descriptions. Also such information could be used for optimization purposes in future designs for spent fuels with higher burn-up or heat-emitting wastes arising from alternative fuel cycles.

Starting from WP2, participants in TIMODAZ will situate their results in these design and long-term performance contexts, with the constant support of WP6 and under the watch of the End-User Group. All experimental works to be performed in TIMODAZ in WP3 and WP4 will contribute to a better understanding of the processes occurring within the clay around a disposal system for heat-emitting waste during the thermal transient phase. As this transient should span over several centuries, the development and testing of sound, phenomenology-based models in WP5 is an essential step towards meeting the Safety Case requirement of adequate understanding of the long-term evolution.

Particular attention is given to determine which conditions and phenomena could lead to irreversible modifications of the clay properties, which directly affect the safety functions of the disposal system. These properties are the watertightness or low permeability of clays, a slow diffusive transport combined with the absence of preferential migration pathways for solutes and sealing capacity. The TIMODAZ project assesses under which conditions these basic properties of clay can be altered during a thermal transient phase and to what extent the required basic safety functions of the repository system can be affected.

The knowledge gained within the TIMODAZ project will allow to assess the significance of the TDZ (Thermal Damaged Zone) in the safety case for disposal in clay host rock and to provide direct feedback to repository design teams. To ensure appropriate and continuous linkage between the end-user needs and the priorities of the TIMODAZ project, the following end-user group has been constituted: ONDRAF/NIRAS, NAGRA, ANDRA, RAWRA, ARAO and RATA

The research activities covered by TIMODAZ calls for multidisciplinary expertise involving both European radioactive waste management organisations together with the main nuclear research institutes supported by other research institutions, universities, industrial partners and consultancy companies (SME's).

The TIMODAZ consortium is composed of 15 participating organisations representing in total 8 countries: ESV EURIDICE GIE (BE), NAGRA (CH), SCK•CEN (BE), GRS (DE), NRG (NL), CIMNE (ES), EPFL (CH), ULG (BE), UJF (FR), ENPC (FR), CEG-CTU (CZ), ITASCA (FR), ASC (UK), ITC (CH) and SOLEXPERTS (CH).

2 Objectives and measurable results for each workpackage

2.1 WP1: Management

The overall objective of this work-package is to manage the project effectively to ensure the integration of the results within the safety case and the set-up of recommendations for repository design. Strong co-operation within the TIMODAZ consortium and information flow with the end-user will be stimulated.

The measurable results are:

- Set-up of an end-user group to define the end-user needs and to integrate the research results of the TIMODAZ project in a broader, safety case-oriented context, i.e. performance assessment and repository design studies. The contribution of the end-user group will start from the on-set of the project.

2.2 WP2: Data Review and Priority Set up for End Users

The objective of this workpackage is to integrate the knowledge acquired in previous European projects and national activities about the THM behaviour of clays (especially Boom Clay, Opalinus Clay and Callovo-Oxordian Clay) and the influence of the temperature on the chemical properties. Within this workpackage priorities for end-user will be set-up, so that researchers understand the specific problems for which their research is targeted. The review work and the definition of the end-user needs will allow to optimise the experimental programme and to chose the most appropriate constitutive laws for modelling. The review will also include the existing information and results concerning the acceptable thermal limits that the host rock could sustain during the thermal period.

The measurable results are:

- A review on the state of the art on THMC for Boom Clay, Opalinus Clay and Callovo-Oxfordian Argilitte and priority set-up for end users – Month 12

2.3 WP 3.1: THM characterization / Input for constitutive laws

The general objective of this sub-workpackage is to perform the tests in laboratory under well controlled temperature/stresses/pore pressure conditions with different well defined loading paths in order to determine the parameters of the Thermo-Hydro-Mechanical constitutive models used for the numerical modelling. More specifically, the thermal effects on the damaged clay and the possible damage induced by the thermal loading itself will be investigated. The tests include the study of the desaturation/resaturation processes at ambient and at different temperatures. Specific attention will be given to the possibility of the creation of an irreversible damage. During the tests, different techniques will be used to evaluate the sealing/healing processes (water/gas permeability measurements, µCT, etc.). Some tests will be complemented with a radionuclide migration test to evaluate any possible relict of preferential migration along the sealed fracture.

The measurable results are:

- 46 tests in laboratory under well controlled temperature/stresses/pore pressure conditions with different loading paths to determine the parameters of the THM(C) constitutive models – Month 30:

Tests to be performed	Investigated process: Influence of T on:	Boom Clay	Opalinus Clay	Callovo-Oxfordian argilitte
Triaxial shear tests upon heating/cooling	Strain localisation	UJF (4)	UJF(4)	
Triaxial shear tests upon heating/cooling	Damage for various	EPFL(4)	EPFL(4)	

at different saturation states Oedometer drying/wetting tests at different temperatures	degrees of saturation Saturation/desaturation process	EPFL(6)	EPFL (6)	
Triaxial shear tests upon heating/cooling under different constant temperature	Coupling between damage and water&gas transfer properties	ENPC(4)	ENPC(4)	GRS(4)
Triaxial shear tests with different loading rates under different constant temperatures	Viscoelastoplasticity	ULG(10)		
Permeability tests in permeameter	Sealing by swelling	SCK(3)	SCK(3)	
Permeability tests in isostatic cell	Sealing by consolidation	SCK(1)	SCK(1)	

2.4 WP 3.2: Mineralogical changes / Input for THMC

This workpackage aims to determine the possible thermally induced modifications of clays mineralogy which is a dominant factor influencing the key properties of the clays and THM behaviour. The investigation in this sub-workpakage provide thus key elements to answer the following questions: Specific attention will be given to the possibility of the creation of irreversible changes.

- Under which thermal condition can the favourable clay properties be modified ?
- Under which conditions do the changes in clay properties become irreversible ?

An ultimate temperature limit in terms of geochemical properties can be assessed through these analysis. The impact of these modification of the geochemical properties on the hydromechanical behaviour of the clays can be qualitatively assessed.

The measurable results are:

- A set of mineralogy analysis at higher temperature, and mineralogy analysis on all samples available after the permeability tests with permeameter cell (thus with different pore water chemistry conditions) to be performed by SCK.CEN will allow to determine the combined effects of thermal impact and geochemistry on the mineralogy. Three geochemical environments are considered, namely undisturbed, oxidised and alkaline plume – Month 30

2.5 WP 3.3: Simulation test / Input for THMC

Within Workpackage 3.3 laboratory tests will be performed simulating as close as possible the conditions in a real repository. This workpackage will also provide the experimental basis for validating the constitutive models that will be mainly built on the basis of the results of Workpackage 3.1.

Precisely, the tests performed in WP3.3 aim to study in laboratory the fracturing and sealing processes that develop in the Excavation-Damaged Zone around galleries in clayey formations and the impact of a thermal phase on their evolution. For this purpose, simulation tests will be performed on hollow cylinder samples with mechanical and thermal loadings similar to the evolution that will be encountered around disposal galleries for heat emitting radioactive waste. In order to examine the possible scale effect and to enable extrapolation of the lab results obtained on normally-sized samples to the repository scale, tests will be performed on different sizes of hollow cylinder samples. The results of these tests will be

used for modelling benchmark exercises in task 1 of WP 5.2. The hydraulic transfer properties through the tunnel face and through fractures will also be characterised in order to optimise the hydraulic boundary conditions in the benchmark exercises.

The measurable results are:

- 12 simulation tests studying the fracturing and sealing processes in the EDZ – Month 36

	Boom Clay	Opalinus Clay	Callovo-Oxfordian argillite
Hollow cylinder tests	EPFL(4)	EPFL(4)	GRS(1)
Large hollow cylinder tests	EPFL(1)	EPFL(1)	GRS(1)

2.6 WP 4.1: THM small-scale in-situ tests

The objective of this workpackage is to realise small scale in-situ tests to characterise the influence of the thermal load on the THM behaviour and the sealing capacity of clays. One experiment will be realised at Mont Terri in Opalinus Clay and another one at Mol in Boom Clay. The results of these experiments will be used for benchmark exercises.
In compensation of the technique limit in laboratory(mainly in terms of the temperature application), the in situ test at Mol site (ATLAS) will be designed specifically to be able to overheat the host rock to study the ultimate temperature limit of the Boom Clay and possible thermal induced irreversible damage of clay.
After tests, samples will be taken in the thermal affected zones for subjecting laboratory verification tests to investigate thermal effects on the key properties of the clays.
Installation and material costs of the test at Mol will not be charged to the project.

The measurable results are:

Two small-scale in-situ tests – Month 36

- One at Mt Terri as an extension of the second SELFRAC experiment (including thermal load)
- One at Mol: re-use of ATLAS. Results will be available for the project but material and installation costs are not charged to the TIMODAZ project

2.7 WP 4.2: THM large-scale in-situ test PRACLAY

A large-scale heater test will be realised in the frame of the Belgium programme. The objective of this workpackage will be to inform the partners about the progress of this test and to gather all necessary data for a "blind prediction" benchmark exercise. A part of the workpackage is also devoted to the interpretation of the seismic measurements performed around the PRACLAY experiment. As the installation of the PRACLAY experiment makes not part of the TIMODAZ project, no material and no installation costs will be charged to the project.

The measurable results are:

A repository scale heater test at Mol: the PRACLAY experiments – Month 48.

- Results will be available for the project but material and installation costs are not charged to the TIMODAZ project
- Interpretation performed by ASC of the PRACLAY seismic measurements build upon the work performed in the OMNIBUS project

2.8 WP 4.3: Lining stability under thermal load

The overall objective of this workpackage is to study the influence of thermal impact on the stability of linings. This issue is particularly important in terms of operational safety when the retrievability of the radioactive waste is considered. THM laboratory tests and an in-situ test at the Underground Educational Facility - UEF Josef (Mokrsko) are proposed to investigate this issue. The installation and material costs of the laboratory tests and the in-situ test will not be charged to the project.

The measurable results are:

One in-situ test at Mokrsko URL to study the stability of lining under a thermal load – Month 36

2.9 WP 5: Modelling & Benchmark

WP 5.1: Modelling

This workpackage aims to develop numerical tools allowing simulation at time and repository scale. These numerical tools are essential to address the following relevant questions:

- What is the expected evolution of the clay around a disposal system for heat-emitting waste during the thermal period?
- What are the main uncertainties about the EDZ+TDZ evolution and how can these uncertainties be dealt with?
- What the ultimate thermal limits of the clay could be in the context of the long term performance of the repository system

WP5.2: Benchmark

This workpackage will allow to better understand and quantify the thermal impact of heat emitting radioactive waste on the host-rock and the Damaged Zone, and to realise predictive modelling of a repository scale experiment (the PRACLAY experiment). The aim of the workpackage is to assess the performance of coupled THM analysis, using different codes, of proposed laboratory tests and in situ tests (available and prospective), with a main focus on the development and evolution of the DZ. The modelling work together with the results of the lab and the in-situ tests should give clear indication on the evolution of the DZ with time: What are the risks of fracturation? What are the favourable and the unfavourable effects of the thermal load on sealing? What are the THMC governing processes and parameters at repository time and spatial scale?

The measurable results are:

- WP5.1*:* Development of modelling tools allowing simulation at time and spatial repository scale – Month 36:
  - Thermal effects on the development, evolution, and sealing of the fractures/cracks
  - Thermally induced modifications in the mineralogy
  - Thermally induced modification in the properties of host rock
  - Chemical effects on the development and evolution of the damaged zone
  - Long-term creep

- WP5.2: Benchmark and predictive modelling – Month 48

	EURIDICE 1	NAGRA 2	GRS 4	NRG 5	CIMNE 6	EPFL 7	ULG 8	UJF 9	ENPC 10	ITASCA 12
Simulation tests (WP3.3)										
Boom Clay	X			X	X	X	X	X	X	
Opalinus Clay		X	X			X	X	X	X	X
Callovo-Oxfordian Argilitte		-	X		X	X	X	X	X	X
In-Situ Tests (WP4.1)										
Mt Terri (Opalinus Clay)		X				X	X			X
ATLAS (Boom Clay)	X			X			X		X	
Predictive large-scale heater test – PRACLAY experiments	X			X	X	X	X	X	X	X

2.10 WP 6: Significance of EDZ in Safety Case / Input for design

This workpackage aims to:
- assess the significance of the TDZ in the safety case for disposal in clay host rock;
- and to provide direct feedback to repository design teams especially the thermal limits that the clays could sustain

The measurable results are:

- Integration of TIMODAZ results within the safety case and recommendations for repository design Month 48

2.11 WP 7: Training and dissemination

This work-package brings together all activities concerning training including knowledge management and transfer. Knowledge management and the exploitation and the dissemination of results are key elements of TIMODAZ.

The measurable results are:

- Two training courses
- Three workshops with the end-user group
- One international workshop
- Papers and attendance at relevant conferences

- TIMODAZ web site including a knowledge management tool
- Folders