



TIMODAZ

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

(Contract Number: FI6W-CT-2007-036449)

Executive Summary of the activities (Mid Term)

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Reporting period: **01/10/2006 - 30/09/2008**

Date of issue of this report : **10/12/08**

Start date of project : **01/10/2006**

Duration : **48** Months

**Project co-funded by the European Commission under the Sixth Framework Programme Euratom
Research and Training Programme on Nuclear Energy (2002-2006)**

Dissemination Level

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Executive summary

1 Nature and scope of the project

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.

Three types of clay are investigated: the Boom Clay, the reference Belgian host formation, the Opalinus Clay, that of Switzerland and, the Callovo-Oxfordian argillite (COX), the host formation of France.

1.1 Consortium

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 SOLEXPPTS (CH).

1.2 Priorities of project

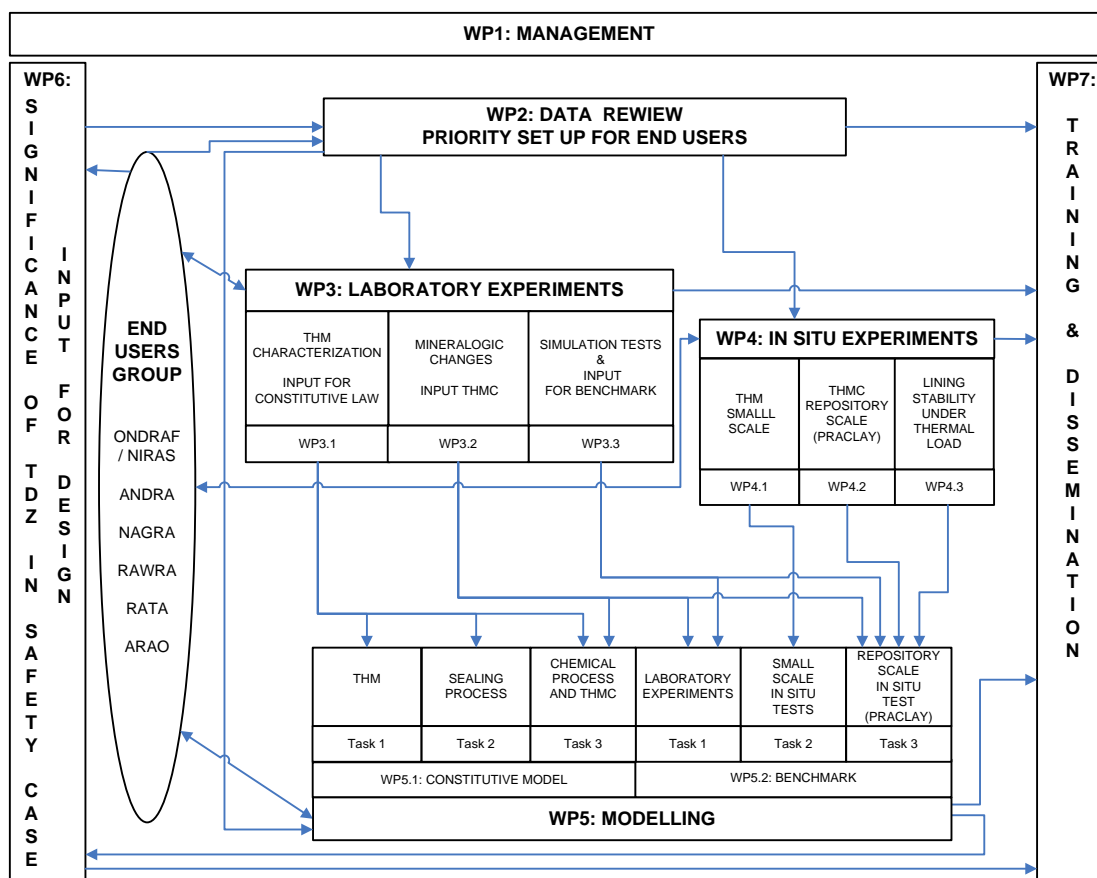
An important item for the long-term safety of underground disposal is the proper evaluation of the Damaged Zone (DZ) in the clay host rock. The DZ is defined here as the zone of the host rock with Thermo-Hydro-Mechanical and Chemical (THMC) modifications induced by the repository, with major changes in the transport properties of radionuclides. These transport properties are the low permeability of clays, a slow diffusive transport combined with the absence of preferential migration pathways for solutes and some sealing capacity.

The DZ is first initiated during the repository construction. Its behaviour is a dynamic problem, dependent on changing conditions that vary from the open-drift period to the initial closure period and the entire heating-cooling cycle of the decaying waste.

The early THMC disturbances created by the excavation, the operational phase and the thermal load might be the most severe transient that the repository will undergo on a large spatial scale and in a relatively short period of time. Consequently the priorities of the TIMODAZ project have been set on the study of the combined effect of the excavation and the thermal impact on the host rocks around a radioactive waste disposal.

1.3 The project structure

The project is broken down in 7 Workpackages as shown below.



Structure of the TIMODAZ project

Starting from WP2-Data review and priority set-up for end-user, participants in TIMODAZ will situate their results in the long-term performance contexts, with the constant support of WP6-Significance of TDZ in safety case. All experimental works to be performed in TIMODAZ in WP3-Laboratory experiments and WP4- In-Situ experiments 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-Modelling is an essential step in meeting the Safety Case requirement of adequate understanding of the long-term evolution. Knowledge management and the dissemination of results are also key elements of the TIMODAZ project. Trainings, workshops and international conferences are managed within WP7-*Training and dissemination*.

2 Results achieved at mid term

WP1 - Management

This workpackage consists in the technical, administrative and financial management as well as the co-ordination and administration at all levels between the parties and the EC, including communication.

The organisation of the first **end-users workshop** in 13th of June 2007 in Paris is a **milestone** of the project for this reporting period. The general framework of the project and the specific scientific topics were communicated to the end-user group. The end-user group agreed with the continuation of the project according to the work programme presented and didn't suggest a reorientation (detail information on the first end-user workshop was given in *the executive summary of the activity of first year of TIMODAZ project*).

Besides, a series of coordination meetings, technical meetings are organised during the reporting period to strengthen the communication of the information between the TIMODAZ project and other European projects of interest. The web-based TIMODAZ portal is also created and stays operational,

WP2 - Data review and Priority set up for End-user

D2: "The state of the art on THMC processes" in three studied clays has been reported. The report gives a synthesis of the relevant works previously performed on three clays (Boom Clay, Opalinus Clay and Callovo-Oxfordian Argillite) in surface laboratories and in in-situ facilities. It constitutes a database and a reference document to carry on the calculations and to optimise the testing procedures of the laboratory experiments and the in-situ experiments to be performed in the present project.

D3 : "Summary of the end-user needs for the project" : The end-user needs were discussed with the end-user group during the first end-user workshop held at the 13th of June 2007. The end-user group confirmed that the objectives of the TIMODAZ project fit the end-user needs. Therefore the end-user group agreed with the continuation of the project according to the work programme presented and didn't suggest a reorientation. However, several recommendations were put forward by the end-user group, mainly in order to

- Strengthen the interaction between experimentalists, modellers and performance assessors
- Increase the possible direct use of the final outcome of the TIMODAZ project for a safety case.

As a first recommendation, the end-user group proposed to check, in the course of the project, to what extent the processes concerning TDZ are really similar for all three types of clays.

A second recommendation focused on the integration of the three domains of expertise (experimental, modelling and PA) present within the project. A possible way of integration

might be achieved by making joint presentations at meetings, conferences and certainly end-user meetings of the project.

A third recommendation focused on the integration of the different disciplines in order to make the outcome of the project directly useful for a safety case.

WP3 - Laboratory experiments

Based on the state of the art report, the objectives of the test programme have been reviewed, the protocols of the tests were established and approved by end-user.

Tests under well controlled temperature/stresses/pore pressure conditions with different loading paths are planned 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. During the tests, different techniques will be used to evaluate the sealing/healing processes. Some tests consist in simulating the excavation of a gallery in hollow cylinders and the impact of temperature on the excavation damaged zone.

The experimental challenges faced in the TIMODAZ project to tackle coupled THM phenomena in relation with damage evolution in the EDZ are significant. The very low permeability of the clays investigated also involves quite long testing periods and specific experimental precautions (both in the shearing and heating phases). In this regard, the close coordination between the WP3.1 partners and the mutual scientific exchanges made (both on experimental and constitutive points of view) in close relation with WP5 devoted to constitutive behaviour (most groups are involved in both WPs) have been quite fruitful to solve the technical issues necessary to perform the ambitious experimental programme.

One can now consider that the delicate technical problems related to temperature control and testing of low permeability clays in the saturated and unsaturated domains (a field not so developed in the literature) are well controlled by the partners, most of the new equipment being now operational. Various THM tests have already been performed and the testing programmes will be completed by the end of the project. Some test programs were modified in order to provide the necessary information not foreseen initially in the project plan for the THM modelling, such that the water retention properties determination done in EPFL.

All testing equipments developed in the TIMODAZ are carefully tested and calibrated in order to get valuable test results. Figure 1 shows an example of a hollow cylinder triaxial cell developed by ENPC and associated testing/calibration curves (figure 2).



b) sample on cell base



c) cell on 25 t press

Figure 1 : The hollow cylinder triaxial thermal cell developed in ENPC

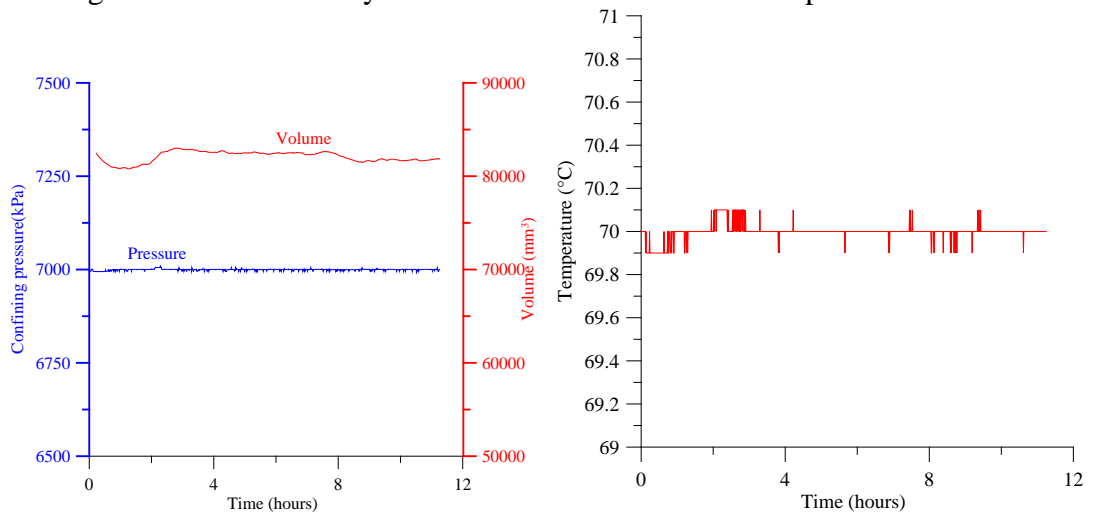


Figure 2: Test of water tightness (7 MPa) and temperature regulation (70°C)

Figure 3 illustrate the sorption bench developed in EPFL to determine the water retention properties at different temperatures. Figure 4 shows the water retention curve of Boom clay at ambient temperature.

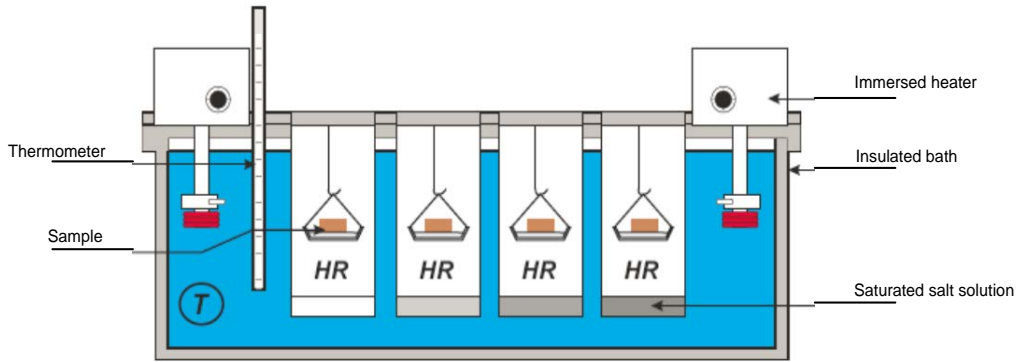


Figure 3: General schemes of the sorption bench developed by EPFL

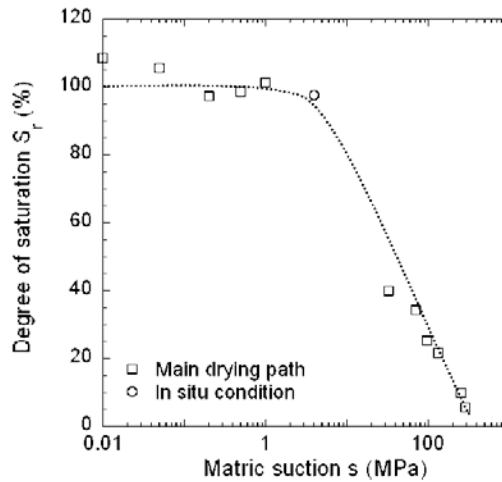


Figure 4 : Water retention curve of Boom clay

At UJF, a series of triaxial test has been performed to study the effect of a thermal loading (heating/cooling process) on the already damaged clay, i.e., to evaluate the impact of the thermal loading on the process of localisation and/or fracturing. Systematic X-ray CT and the permeability measurement on sample at the different testing phases are performed to assist the investigation. Figure 5 shows the X-ray scan of a Boom clay specimen before (left and center) and after testing.

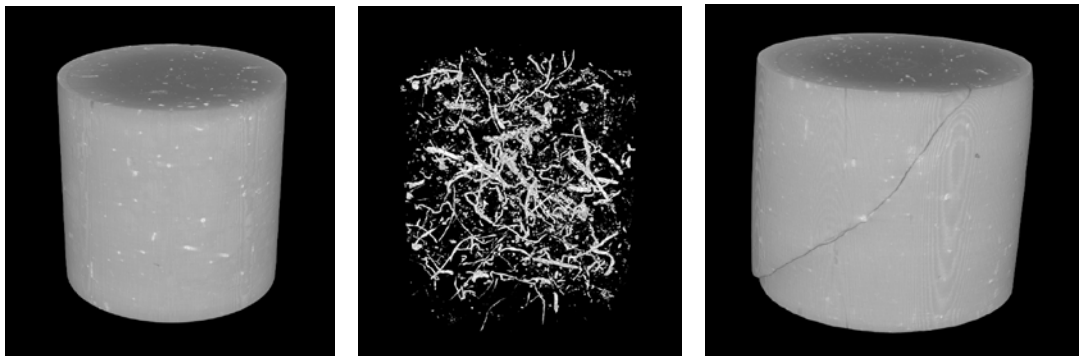


Figure 5 : X-ray scan of a Boom clay specimen before (left and center) and after testing

Middle-scale hollow cylinder triaxial cell is developed in EPFL to perform the simulation tests with mechanical and thermal loadings fairly similar to the evolution that will be encountered around disposal galleries for heat emitting radioactive waste in laboratory in order to study 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 (figure 6). The test results will be served as the numerical benchmark exercise to validate the numerical tools to be developed in the TIMODAZ project.

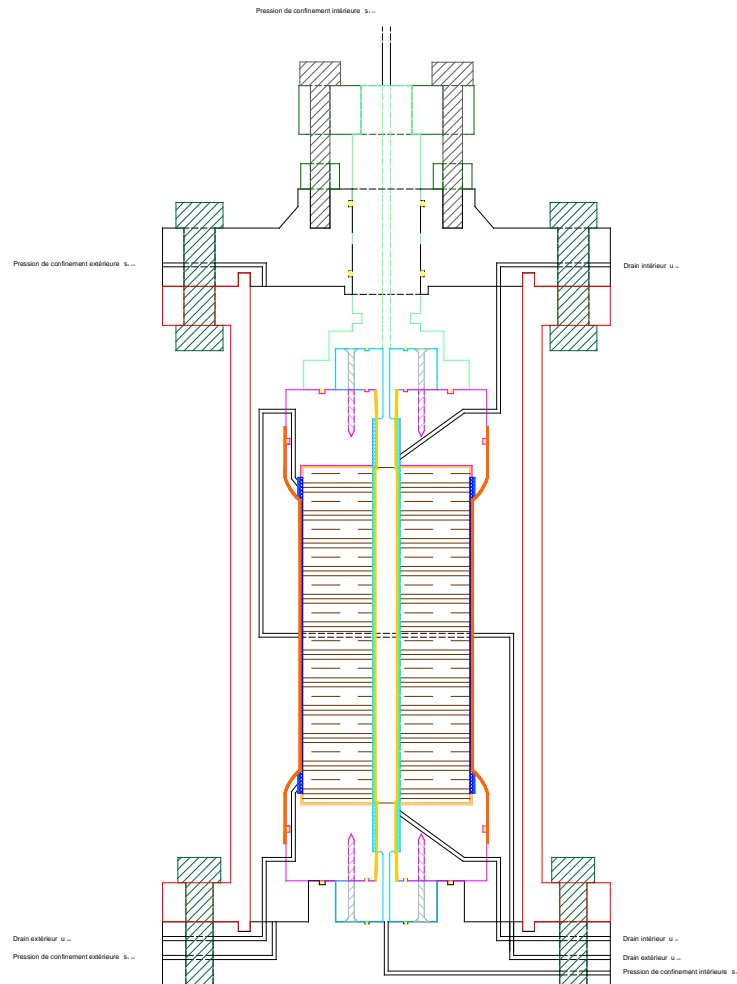


Figure 6 : EPFL's Testing device for the simulation tests on hollow cylinder samples (June 2007)

At GRS, a set of triaxial compression tests were conducted on COX samples at elevated temperature up to 150°C to study thermal impact on deformation, damage and strength, as well as response of pore-water pressure under drained and undrained conditions. Figure 7 presents two thermal expansion tests on COX samples at a deviatoric stress of $\sigma_1 = 15 \text{ MPa}$ / $\sigma_3 = 3 \text{ MPa}$ in drained and undrained conditions, respectively.

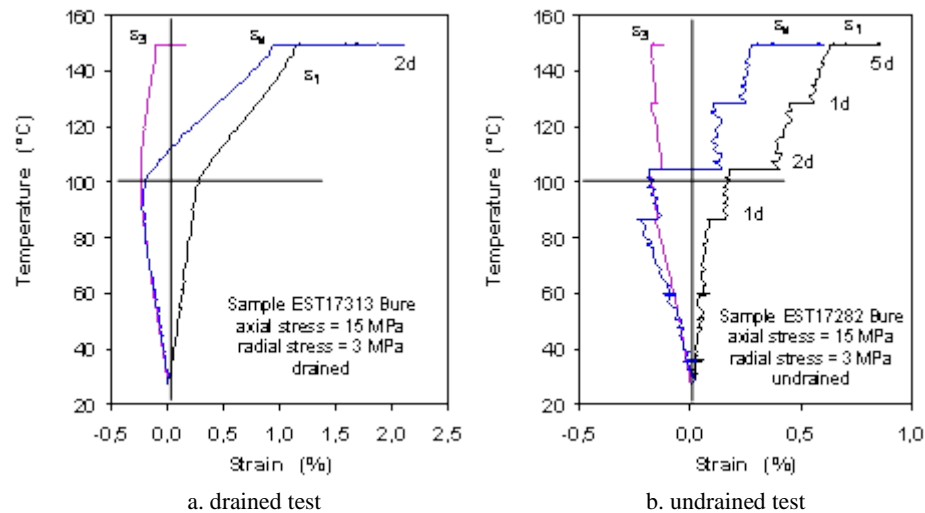


Figure 7 : Thermal deformation of COX samples at deviatoric stress in drained and undrained

In addition, special well controlled drying device was designed in ULg to study the effect of the hydraulic transfer properties through the tunnel face and through fractures on the HM behaviour of the studied clays during the open-drift phase.

SCK•CEN has tried to perform the real-time XRD experiment of step-heated Boom Clay to check the effects of a broader range of thermal loadings on clay mineralogy, due to some technical problems (difficulty to maintain the anaerobic conditions while heating at the same time), it's realised that it's impossible to perform this step-wise heating test.

Mineralogical analyses are running in SCK•CEN both for Opalinus Clay and Boom Clay to study if combined effect of increased temperature and oxidising or alkaline plume conditions during the permeability tests may result in an increased precipitation of non-clay minerals (e.g. carbonates and sulphates). Results show that both Boom Clay and Opalinus Clay have a good buffering capacity. A good buffering capacity is exhibited by the stable, circum neutral pH values already after 90 days of the batch experiment irrespectively of the starting pH (12.5 for the Evolved Cement Water reacted with Boom Clay and 12.6 for the Alkaline Pearson Water reacted with Opalinus Clay).

WP4 - In-situ experiments

Small and large scales in situ tests are performed in different underground laboratories within the TIMODAZ project:

- Small scale In situ ATLAS heater test in Hades, Mol : to study the THM behaviour of Boom clay
- Small scale In situ SE-H test (Self sealing with Heating) in Mont Terri: this test includes two phases : Phase A : overcoring of a previously tested borehole (EU Project SELFRAC) to improve the understanding of EDZ geometry and formation in bedding parallel boreholes as a small-scale equivalent to repository tunnels. Phase B: a heated experiment is planned to investigate the effects of temperature on the self-sealing of the EDZ.

- Large scale in situ heater test: Praclay experiment in HADES, Mol: to study the thermal impact on EDZ evolution and large scale THM behaviour of Boom Clay.
- In situ test in UEF Josef (Mokrsko) to study the lining stability under thermal loading

Figure 8 shows the pore pressure evolution accompanied by the temperature variation observed in Boom clay during the ATLAS heater test, which shows clearly the THM coupling behaviour of Boom clay.

Figure 9 gives a section of the overcore of SELFRAC borehole in Mont Terri under UV light, which allows to create a conceptual model of the borehole EDZ.

Figure 10 gives the observed fracturation pattern around the Praclay gallery in Boom Clay.

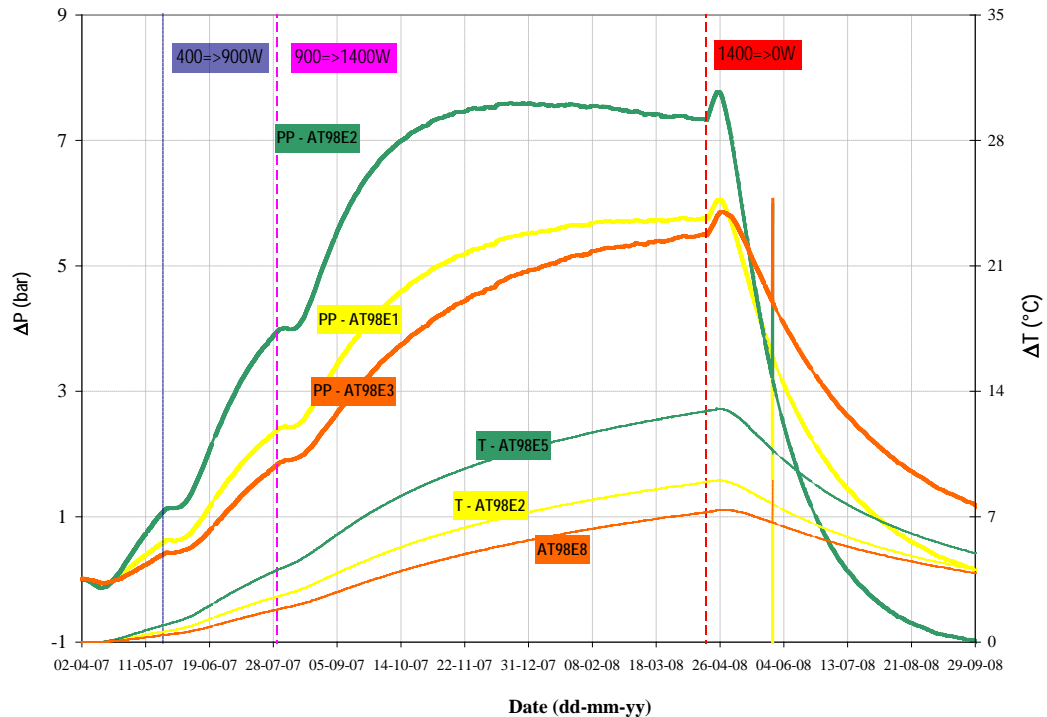


Figure 8 : Pore pressure and Temperature evolution at different boreholes observed in Boom clay with ATLAS in situ heater test
(dash line : Temperature, solid line : Pore pressure)

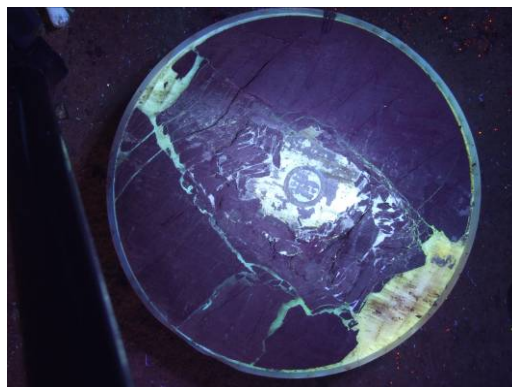


Figure 9 : Section of the overcore from 8.32 m under UV light. Bedding planes from lower left to upper right. Resin (light blue/green) delineates fracture network around the central

borehole. Note the perfect positioning of the old (diameter 101 mm) borehole in the overcore (diam. 330 mm).

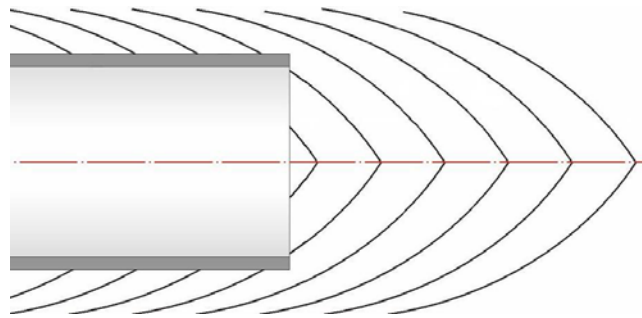


Figure 10 : Observed fracturation pattern around Praclay gallery in Boom clay

WP5 - Modelling and benchmark

This workpackage aims to develop numerical tools allowing simulation at time and repository scale. The developed numerical tools will be validated through a series of benchmark exercises.

Following progress in development of the modelling tools constitutes a milestone for the project at mid term:

- GRS develops an empirical model for the description of permeability changes of clay rocks due to mechanical damage and reconsolidation
- ENPC develops a new mixed damage model, coupled to an unsaturated soil behaviour model, formulated in independent state variables (net stress and suction)
- CIMNE develops a constitutive model for argillaceous rocks considering the effects of bonding, unsaturation and temperature changes
- CIMNE has implemented osmotic flow in the THMC formulation
- EPFL – LMS has developed a constitutive model describing the soil response under non-isothermal and unsaturated conditions
- ULg has extended its cap model with suction effect to the thermal effects on the yield surface and the stress – strain relation
- UJF has developed a THM second gradient model in order to be able to extend the benchmark 1 for a description of the possible localized patterns with coupled thermal and hydraulic effects.

Moreover, a series of benchmark has been defined and performed partly:

Benchmark 1: The benchmark 1 consists in simulating the large scale laboratory simulation test to be performed within the WP3.3 (Hollow-cylinder test to be performed by EPFL). It has been clearly defined (geometry, boundary conditions, sollicitation, and constitutive laws, etc.). Different cases considering different constitutive laws were studied.

Benchmark 2.1: The benchmark 2.1 is devoted to the in situ Mont Terri dilatometer experiment performed within the previous EC supported project SELFRAC. The benchmark exercise description has been prepared, presented, discussed during the Lausanne July 08 meeting. A first prediction has been done by ULg.

Benchmark 2.2 : The benchmark 2.2 is devoted to the in situ ATLAS experiment (Mol URL). Two simulations have been presented respectively by SCK-CEN/EURIDICE, EPFL-LMS.

WP6 - Significance of TDZ in Safety Case and Input for Design

A workshop on current repository designs and the handling of the damaged zone in integrated PA was held the 13th of June 2007.

A review of the handling of the damaged zone in previous PA exercises has been carried out. The stakes associated with the DZ *in the context of a safety case* have been presented to the science teams and also during the first training course. Several integration tools have been developed and put to use within TIMODAZ ("the 5 questions", the questionnaire about expected evolution and the common "science"/PA presentations to be delivered at next end-user meeting). These integration tools comply with the end-users recommendations (detail was given in *the executive summary of the activity of first year of TIMODAZ project*).

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 TIMODAZ web site including a knowledge management tool has been developed
- Organisation of the first end-user workshop on the 13th of June 2007
- The first TIMODAZ training course was successfully carried out at EPFL in Lausanne in July, 2008. Totally 28 participants from universities, agencies, regulators and private companies attended the course. Feedback from questionnaires indicated that the training course was satisfying, an overall score of 4.11 (from scoring range 5 – 2) was obtained (from about 20 answers of the participants).
- The preparations for the International conference and workshop co-organized with THERESA project and EC were continued, title, date and location were fixed ("Impact of Thermo-Hydro-Mechanical-Chemical (THMC) processes on the safety of underground radioactive waste repositories") – An international conference and workshop in the framework of the European Commission TIMODAZ and THERESA projects, Luxembourg, 29th September – 1st October 2009). Sponsors / supporters were successfully sought. The organization committee composing of representatives of the sponsors and supporters was formed. Topic, structure of the event, Working Groups, etc. were discussed and drafted, and the rational document as well as the draft for the first call for abstracts and first announcement of the conference and workshop were prepared.

3 Social impact

Public and political perception with respect to the nuclear waste issue will play a major role in determining the future of nuclear energy. The results of the TIMODAZ project will be situated in the context of the long-term performance of a repository. All of the experimental works to be performed in TIMODAZ 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 is an essential step towards meeting the Safety Case requirement of adequate understanding of the long-term evolution.

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 provide direct feedback to repository design teams. To ensure an appropriate and continuous link between the end-user needs and the priorities of the TIMODAZ project, the following end-user group has been constituted: ONDRAF/NIRAS (BE), NAGRA (CH), ANDRA (FR), RAWRA (CZ), ARAO (SI) and RATA (LT). This group will be active throughout the duration of the project.

4 Project logo



5 Project web site :

www.timodaz.eu

6 Contact person

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