eurad

European Joint Programme on Radioactive Waste Management

# NEAR FIELD: TEMPERATURE AND GAS

## Introductory course on EURAD and Radioactive Waste Management

14 September 2020 • Markus Olin

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  - Wetting → stress formation
  - Corrosion → gas production stress → formation
- **Methods to study**
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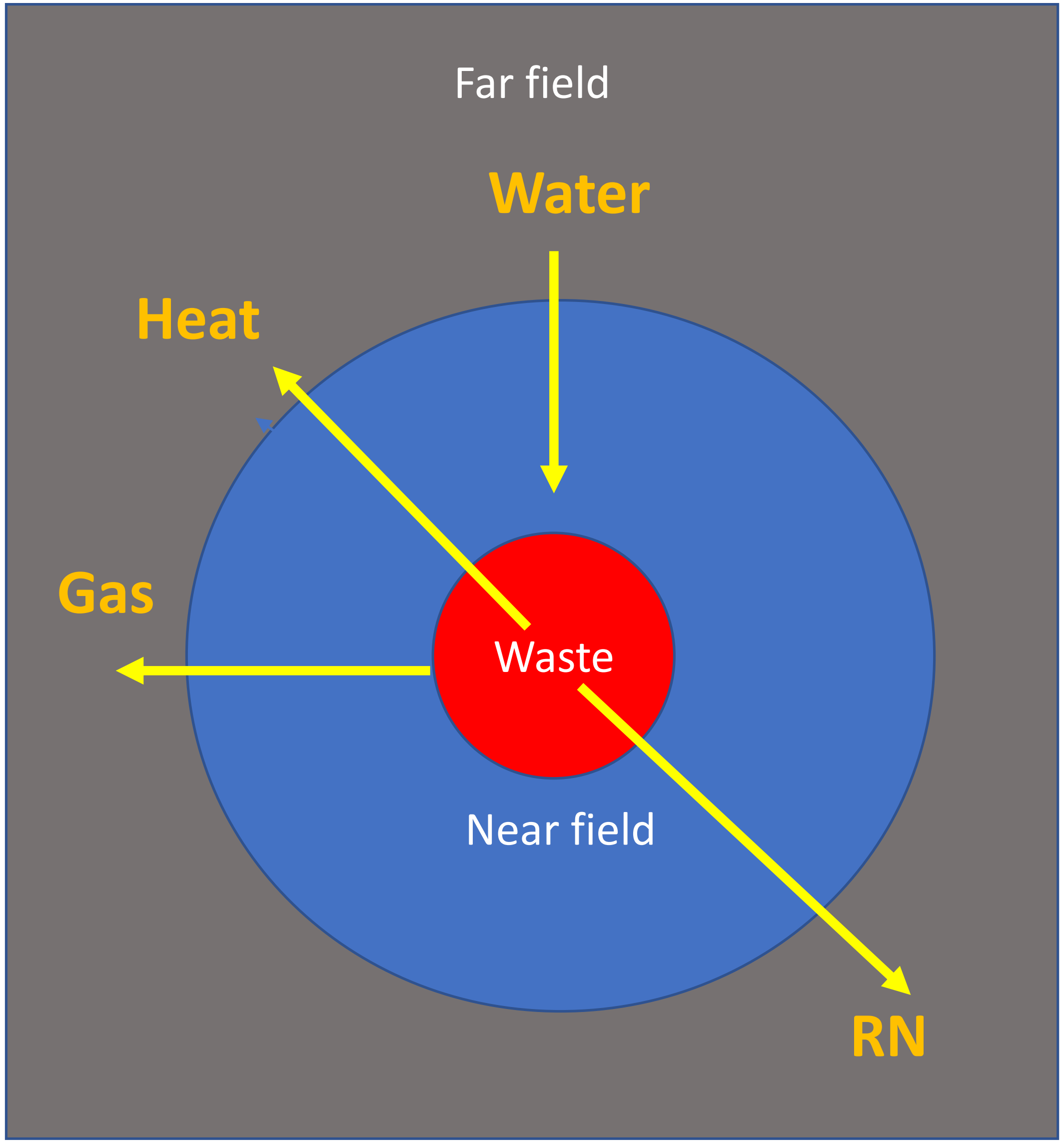
- **GAS and HITEC WPs**



# NEAR FIELD

- **Definition near field**
  - The excavated area of a *repository* near or in contact with the *waste packages*, including filling or sealing materials, and those parts of the *host medium/rock* whose characteristics have been or could be altered by the *repository* or its content. See also
  - https://www-pub.iaea.org/MTCD/publications/PDF/Pub1155_web.pdf
- **Three components**
  - Waste packages: often copper or steel coverage
  - Filling or sealing materials like bentonite buffer
  - Altered host/rock
- **far field.** The *geosphere* beyond the *near field.*
- Both EURAD HITEC and GAS study effects on near and far field (or near field just around the near field)

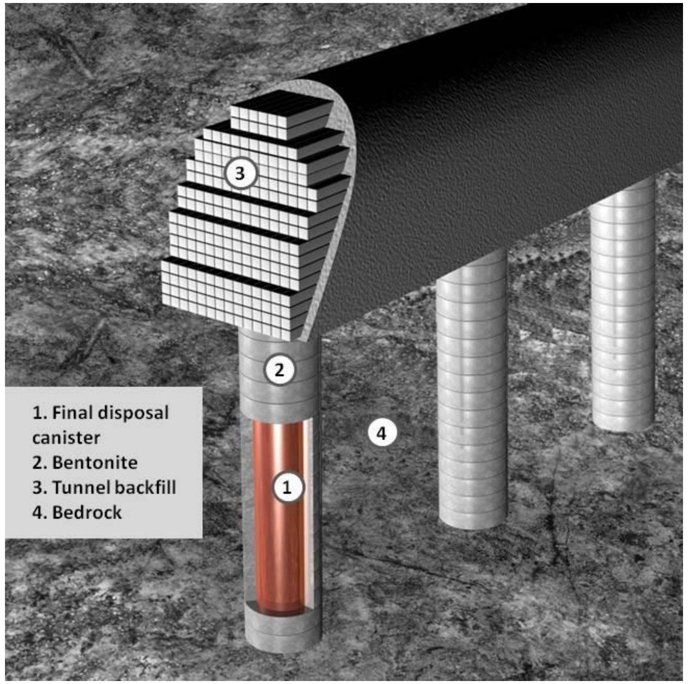
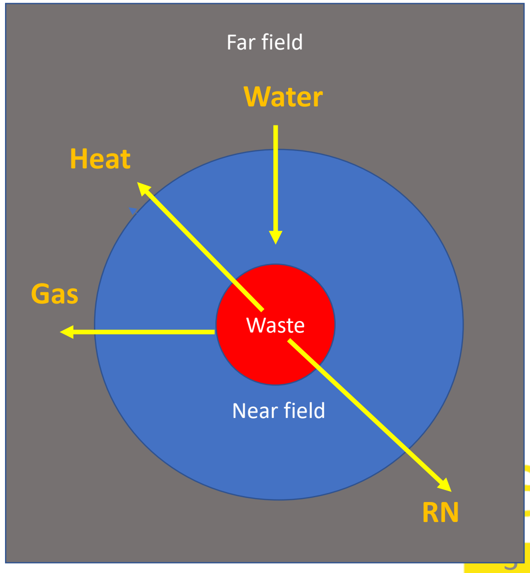
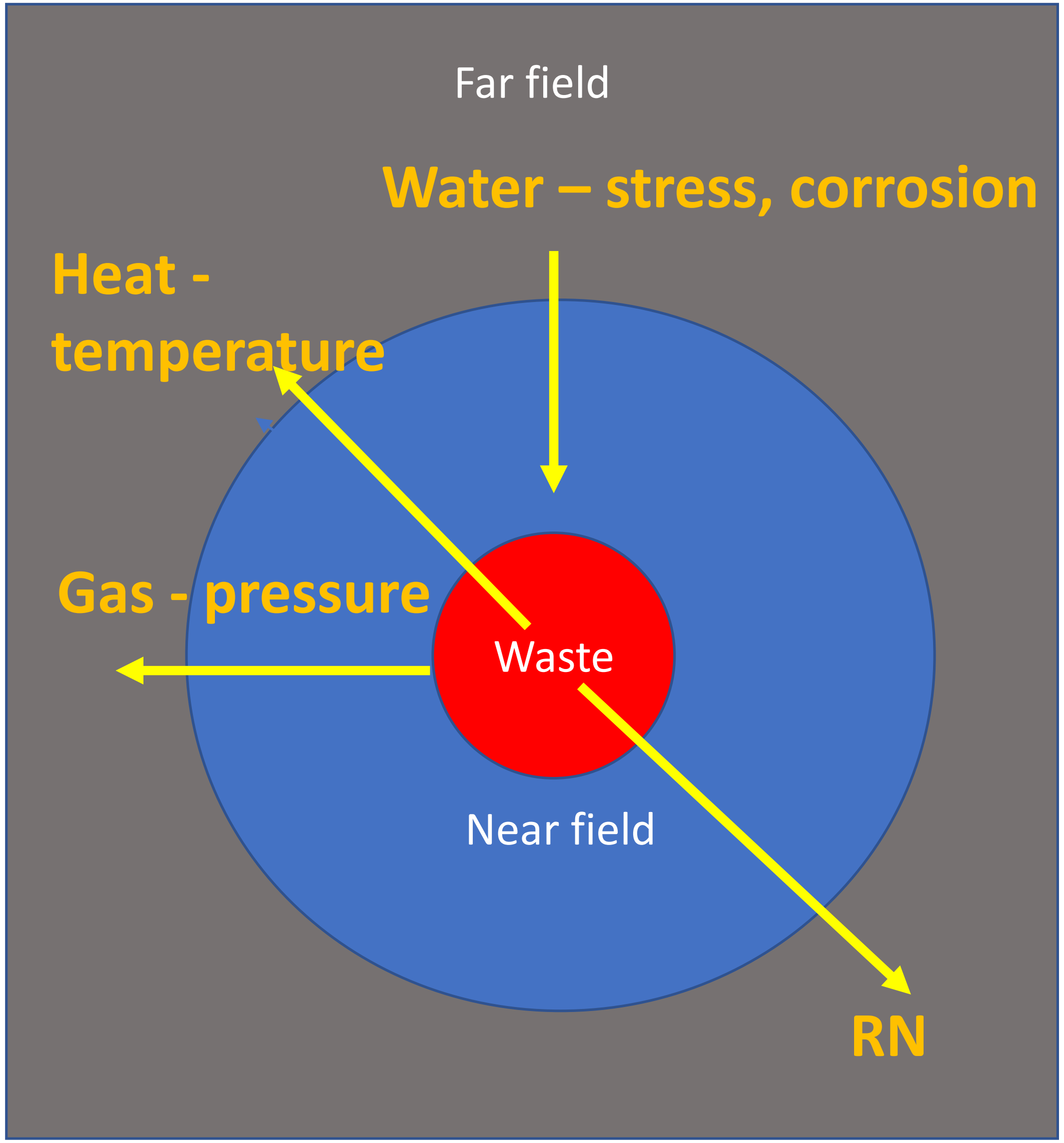



Figure by Posiva Oy.



# EVOLUTION

- **Heat production → temperature increases, temperature gradients appear**
- **Wetting → stress formation (swelling pressure in the case of bentonite)**
- **Corrosion by anoxic water or microbes → gas production**



# HEAT PRODUCTION → TEMPERATURE INCREASES, GRADIENTS TOO

- **High level waste and especially spent nuclear fuel, which is planned to dispose of without any pre-processing, produces heat**
- **This heat production is not that high after typical intermediate prepository period (tens of years):**
  - Maximum (KBS3) less than 2 kW/tU

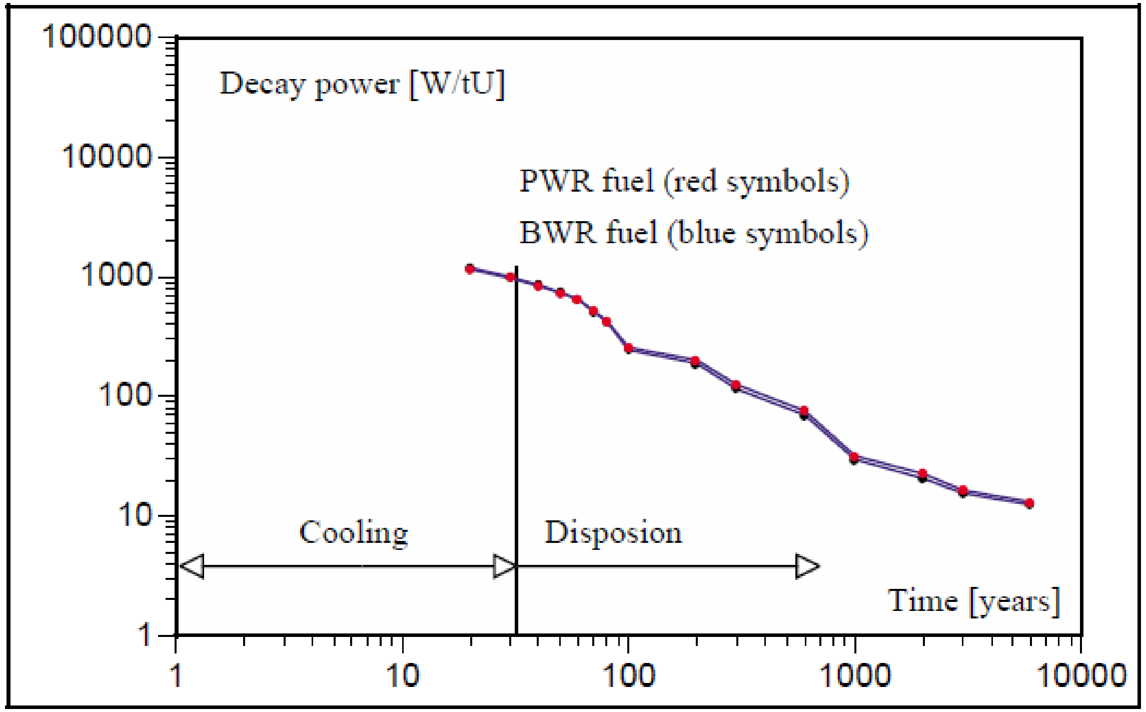



*Figure 7. Decay power of BWR and PWR fuel, burn-up 40 MWd/kgU according to M. Anttila.*

Ikonen, POSIVA 2003-04

- However, heat production is always on, and finally temperature starts to increase
- After few tens of year the maximum is obtained, and then T deceases
- Most often max T is planned to be 100 ºC
- The nearer the waste packages are each other the higher the temperature
- Therefore, heat production affects very much on dimensioning (and costs) of any repository

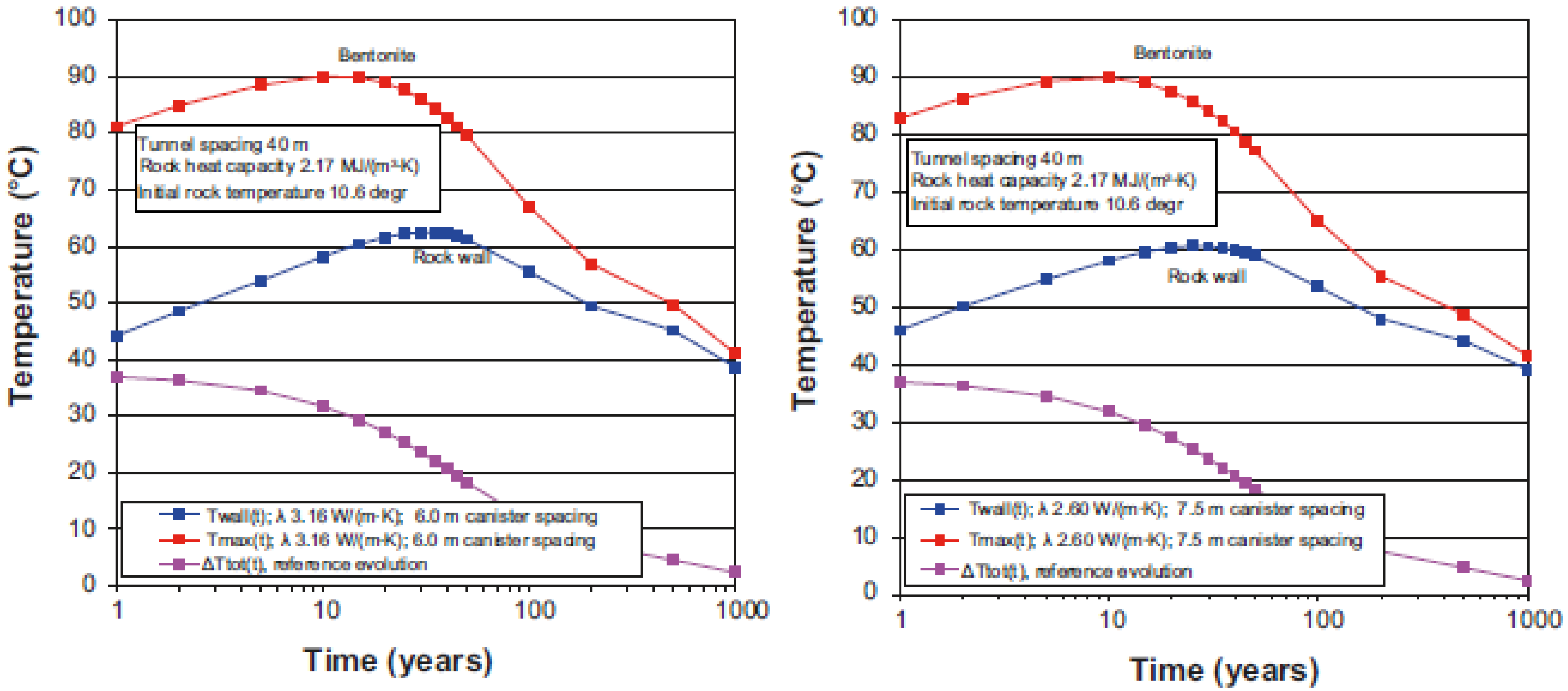



*Figure 4-15. Result examples. Peak buffer temperatures for two combinations of rock conductivity and canister spacing.*

SKB R-09-04

# WETTING → STRESS FIELD (OF BENTONITE)

- **Initially only partially saturated clay host or buffer starts to saturate (wetting)**
- **This is most often much lower process than heat transport**
  - May take even a few thousand year in bentonite
- **Wetting together with elevated temperature initiates a complex set of reactions and phenomena**
  - Dissolution/precipitation of minerals
  - Transport of chemical species
  - Stress formation
    - Bentonite swells
    - In clay host rock water expands thermally more than rock

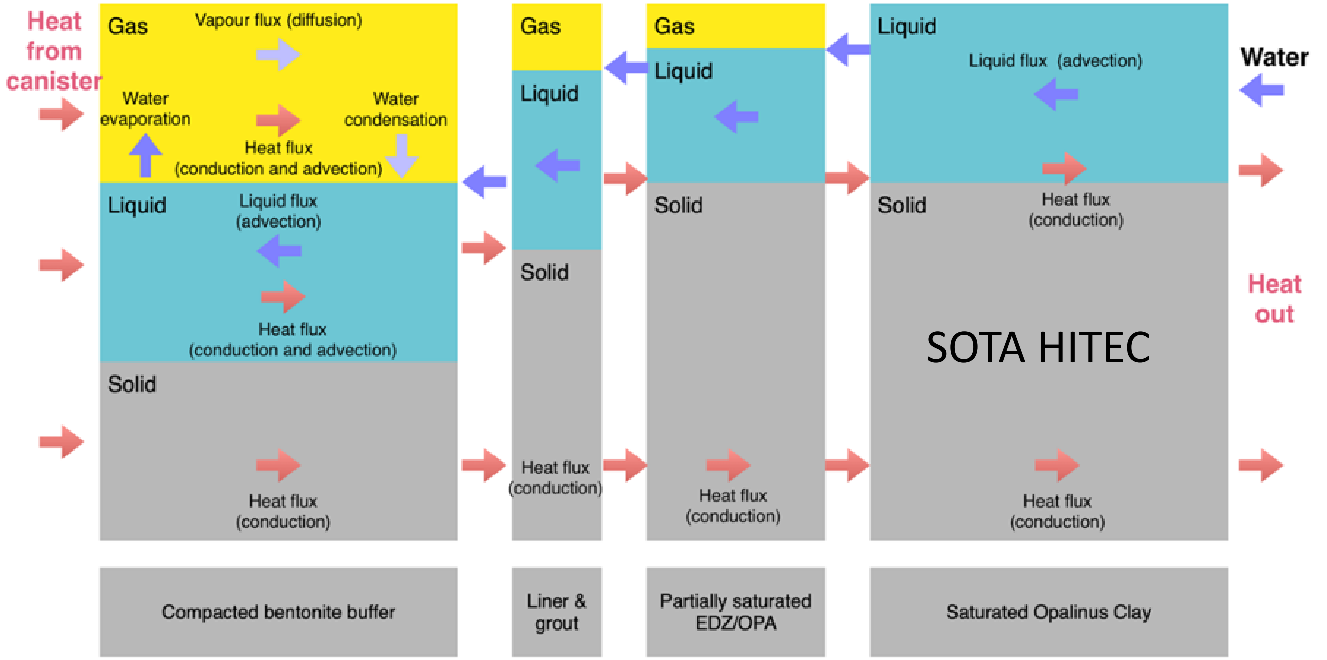



Figure 2-13. Schematic illustration of coupled processes associated with vapour transport (adapted from Gens 2003). The schematic is simplified and shows the initial state

# WETTING → CORROSION (AND OTHER PROCESSES) → GAS PRODUCTION

- **Finally, water start to react with the waste canister enabling corrosion**
  - In the case of copper canister, corrosion is very slow, but there is steel insert inside, which may have much quicker corrosion → possibility to gas production
  - However, steel canister corrode a bit faster and produce more gas → the pressure in repository increases → this may damage the host rock and flowing gas may transport radionuclides
- **GAS SOTA:**
  - In a deep geological repository gases are generated as a result of **anaerobic corrosion** of metals (which produces $H_2$), microbial and chemical degradation of organic matter (which may produce gaseous compounds $CO_2$, $CH_4$, which may incorporate $^{14}C$ and other volatile radionuclides) and radiolysis of water (which principally produces $H_2$). If the production rate of gas is higher than can be removed by dissolution and diffusion, a free gas phase will form and accumulate, building up gas pressures, which will be eventually released along the backfilled underground structures and the host rock.

# METHODS TO STUDY

- Modelling
- Lab experiments
- Large scale experiments
- Some equipment

# MODELLING

- **Due to the long or very long periods of time modelling is the ”final tool” to support Safety Case**
  - Few hundred year for thermal issues
  - Tens of thousand year for gas transport
- **However, modelling cannot be based totally on theories, but requires experimental support**
  - Models must ”validated” against shorter term experiments (complete validation is however impossible → uncertainty analysis)
  - All models of practical applicability require experimental parameters or constitutive functions
- **Complete model should included mechanics (M), transport of heat (T), water (H) and other chemical species, chemical reactions (C), and is come cases microbes (B) and radiation: THMCBR-model**
- **However, it is common (due theoretical and numerical issues and lack of data) to have only part of these, like: THM (HITEC WP) or HM (GAS WP)**
- **<u>Note</u>: these selections are simplifications, and in natural systems chemical reactions (like microbes, too) are going on, included in our models or not**
- **Sometimes is possible to work in not that much changing chemical conditions**

# LAB EXPERIMENTS

- **Laboratory scale experiments can be used for many purposes (in the field of mechanics and water transport)**
  - Determination of single parameter values (often as function of others: like heat conductivity as a function of temperature)
  - Finding constitutive functions and relations like water conductivity as a function of saturation (or suction)
- **In many cases the lab scale is spatially too small and times too short, which means that results must be upscaled by modelling to field experiment or repository scale**

# LARGE SCALE EXPERIMENTS

- **Possible to work in real (spatial) scale, if not temporal, but experiments are often quite long, at least tens of years**
- **Some examples (utilised in HITEC):**
  - Äspö: Alternative Buffer Materials (ABM) and Long term test of buffer material (LOT): https://www.skb.com/research-and-technology/laboratories/the-aspo-hard-rock-laboratory/
  - FEBEX in situ test (Grimsel): https://www.grimsel.com/gts-phase-v/febex/febex-i-in-situ-testing/febex-i-layout-test-design-
  - HADES URL Boom Clay: https://science.sckcen.be/en/Facilities/HADES
  - Bure underground research laboratory (URL): https://www.andra.fr/mini-sites/lille2007/abstract_lille2007/donnees/pdf/007_008_O_01_1.pdf
- **EURAD can apply results from these types large scale laboratories, but is not financing them – too expensive even for a big EC project like us**

EURAD Deliverable 7.4 – Specific GAS/HITEC technical report on self-sealing processes

CNRS(Ulorraine)

# TRIAXIAL CELL

- **Even Wiki knows:**
  - https://en.wikipedia.org/wiki/Triaxial_shear_test )
- **Multipurpose equipment**
  - Cylindrical sample under pressure and axial stress: deviatoric stress, shear stress
  - Offers many ways to measure mechanical properties from elastic to plastic deformations until failure of the sample
  - Water transport, self healing etc
  - Possible to combine with tomography

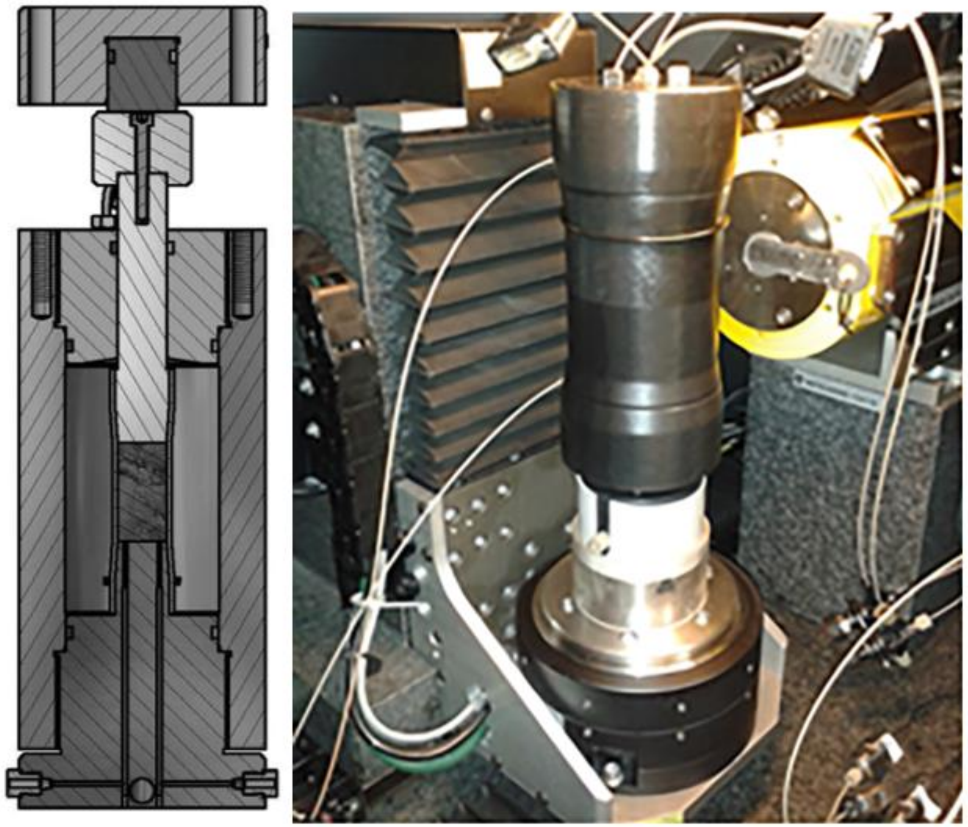
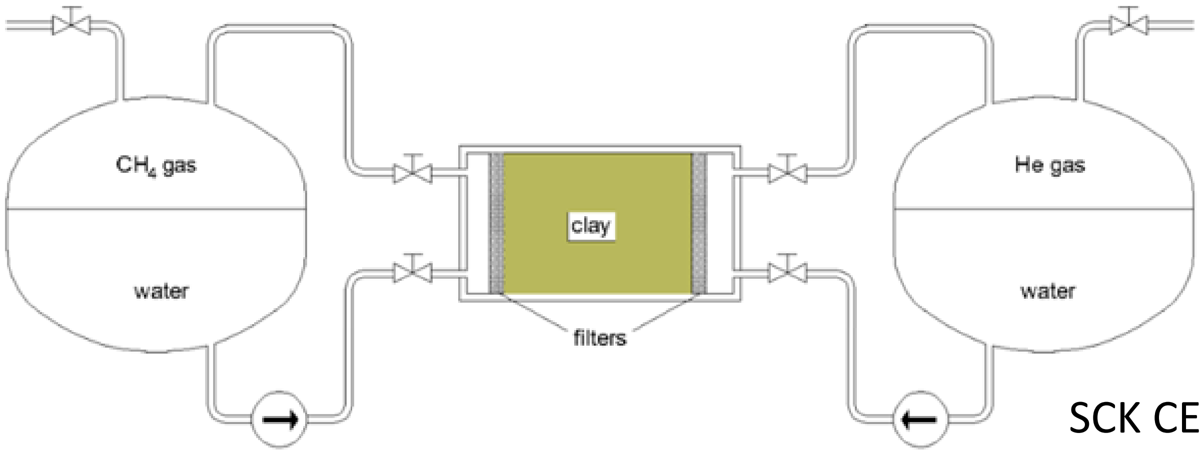


*Figure 4 – Left: schematic representation of a triaxial compression cell made of PEEK with a cylindrical sample of 20 mm diameter for self-sealing and fracturing tests. Right: the triaxial compression cell in a X-ray nano-tomograph.*

# TECHNIQUE TO MEASURE DIFFUSION COEFFICIENTS OF DISSOLVED GASES

- **Some details (see more in SOTA of GAS):**
  - First, the sample is embedded in a constant volume cell.
  - Next, it is resaturated and hydraulic conductivity is measured.
  - Then, both sides of a test core are connected to a water vessel filled with circa 500 ml oxygen-free synthetic pore water and pressurised with a specific gas (circa 500 ml gas at 1 MPa).
  - Both vessels are filled with a different gas, but the total pressure is the same. In this way, no advective flux can occur and the clay sample remains fully water saturated. According to Henry's law, equilibrium is obtained between the free gas in the gas phase and the dissolved gas in the water. The water at both sides is then circulated over the filters, which are in contact with the clay sample, allowing the dissolved gases to diffuse through the clay sample, towards the reservoir on the opposing side




SCK CEN , GAS SOTA

*Figure 2-2 – Schematic overview of the developed setup to measure diffusion of dissolved gases.*

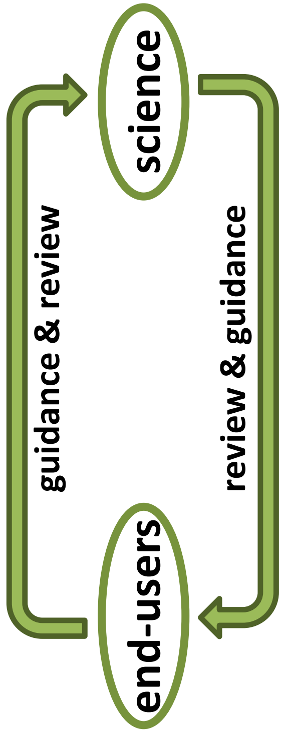
# GAS AND HITEC OBJECTIVES

- **GAS**
  - Objective 1:  Improve the mechanistic understanding of gas transport processes in natural and engineered clay materials, their couplings with the mechanical behaviour and their impact on the properties of these materials
  - Objective 2:  Evaluate the gas transport regimes that can be active at the scale of a geological disposal system and their potential impact on barrier integrity and repository performance

- **HITEC**
  - The overall objective is to evaluate whether an increase of temperature is feasible and safe by applying existing and within the work package produced novel knowledge about the behaviour of clay materials at elevated temperatures

# WP GAS – HOW?

**T1 Coordination**




**+ training & KM**

Process-level modelling embedded with tasks 2 & 3!

**T2 Transport mechanisms**

2.1 Diffusion & retardation
2.2 Advection (liquid phase displacement vs dilatant gas flow)

**T3 Barrier integrity**

3.1 Gas-induced impacts
3.2 Pathway closure & sealing
3.3 Model-based interpretation

**T4 Repository performance aspects**

4.1 Conceptualisation of gas migration at the scale of the repository
4.2 Model-assisted assessment of gas-induced effects

*Interactions at each step to ensure close cooperation between experimentalists, process-level modellers and those involved with the evaluation of system performance*

*Foster the transfer of knowledge between scientific community (RE's) and the end-users (WMO's and TSO's)*

# WP GAS – WHO?

**SCK•CEN** (BE, RE)

**ONDRAF/NIRAS** (BE, WMO)
- **ULiège** (BE, RE)

PSI (CH, RE)

**NAGRA** (CH, WMO)
- **EPFL** (CH, RE)
- **ZHAW** (CH, RE)
- **CIMNE** (ES, RE)

**SÚRAO** (CZ,WMO)
- **CTU** (CZ, RE)
- **UJV** (CZ, RE)

FZJ
- **UFZ** (DE, RE)

KIT-PTKA (RE, DE)
- **GRS** (DE, RE)
- **BGR** (DE, RE)

**BGE** (DE, WMO)

**CIEMAT** (ES, TSO)
- **UPC** (ES, RE)

University of Helsinki
- **Aalto Uni** (FI, RE)

CNRS (RE, FR)
- CNRS / **ISTerre**
- CNRS / **GeoRess.**
- CNRS / **IC2MP**
- CNRS / **Subatech**

**IRSN** (FR, TSO)

**Andra** (FR, WMO)

CEA
- **EDF** (FR, RE)

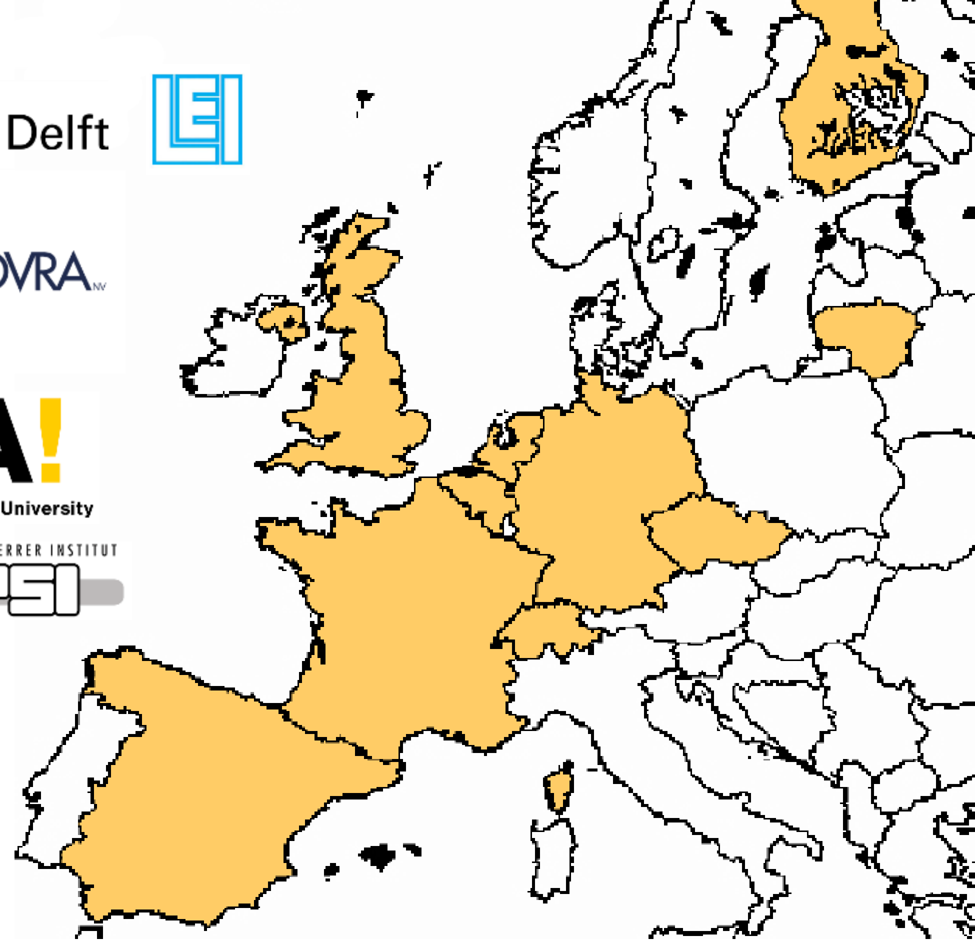
**LEI** (LT, RE)

**COVRA** (NL, WMO)
- **TU Delft** (NL, RE)

**UKRI-BGS** (UK, RE )

**RWM** (UK, WMO)

Key: **Full participant in GAS**
*Participating through LTP(s)*



# HITEC STRUCTURE

- **Task 1 – S/T coordination, State-of-the-art and training material**
  - Task Leader: VTT – Markus Olin
  - SoA: CIEMAT – Maria Villar
  - Training: Uliège – Robert Charlier
- **Task 2 - Clay host rock <120°C**
  - Task Leader: Ulorraine – Dragan Grgic
  - T2.1: Ulorraine - Dragan Grgic
  - T2.2: BGS – Katherine Daniels
  - T2.3: Andra – Gilles Armand
- **Task 3 - Clay buffers >100°C**
  - Task Leader: CTU – Jiří Svoboda
  - T3.1: SKB - Daniel Svensson
  - T3.2: BGS - Katherine Daniels
  - T3.3: CIEMAT - Maria Victoria Villar
- **Task 4 - Impacts and deployment of results**
  - Task Leader: VTT – Markus Olin
  - T4.1: NAGRA – Olivier Leupin





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## WP 7 – HITEC: WHY?

- **T2 Clay host rock**
  - The overpressure generated by the difference between thermal expansion coefficient of pore water and the solid rock skeleton may have deleterious consequences.
  - In far field, this could induce rock damage and reactivate fractures/faults.
  - In near field characterized by a fractured zone, this could induce fracture opening or propagation in this fractured zone, altering the permeability.
- **T3 Buffer bentonite**
  - Proving that higher temperatures than presently accepted are suitable is very relevant even for current concepts.
  - It increases safety margin and gives greater credibility to the design (e.g. if it is proven to work for 130°C then for 100°C it is definitely safe).

# WP HITEC - WHO?

VTT
ANDRA
La maîtrise des déchets radioactifs
BGE BUNDESGESELLSCHAFT FÜR ENDLAGERUNG
cea
Ciemat

CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE
LEI
LIÈGE université
POSIVA
Radioactive Waste Management

enresa soluciones ambientales
nagra
Geoscience for a sustainable Earth brgm
UAM UNIVERSIDAD AUTONOMA DE MADRID
eDF

SKB Svensk Kärnbränslehantering AB
SÚRAO
JYVÄSKYLÄN YLIOPISTO UNIVERSITY OF JYVÄSKYLÄ
cnrs
GTK

UNIVERSITY OF HELSINKI
BGS 1835
UPC UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
ÚJV

Euridice, Siignasu
CHARLES UNIVERSITY
BGR

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# FINAL COMMENTS

- **Near field processes are almost always strongly coupled**
  - Not that easy to take care of all couplings: both lack of data and numerical issues
  - Mechanics and chemistry often (partially) separated
  - Some processes like wetting and heat transport long lasting processes (less than thousands of years)
  - Some processes like corrosion, and gas production and transport may take much longer
- **Reading**
  - There is very much literature available (sometimes oldest ones are thin and easy to read like R. Pusch's reports by SKB)
  - If available to you, see the SOTA-reports of GAS and HITEC (they will be updated in the end of EURAD)
    - They couple science and technology to Safety Case, and needs in nuclear waste management, very well
    - Written by very experienced experts