Evaluating the Performance of Engineered Barriers

Outcomes of the PEBS project

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Introducing PEBS

„Long-term Performance of Engineered Barrier Systems“

Project duration: 2010 - 2014

Coordinator: BGR

Partners: nagra, SKB, TK, GRS, JAEA, CIMNE, ANDRA, Golder Associates, enresa, UAM Universidad Autonoma de Madrid, Clay Technology AB, Universidade da Coruña, Gobierno de España Ministerio de Economía y Competitividad / Ciemat, 中核集团核工业北京地质研究院 CNNC Beijing Research Institute of Uranium Geology, Aitemin Centro Tecnológico, Solexperts

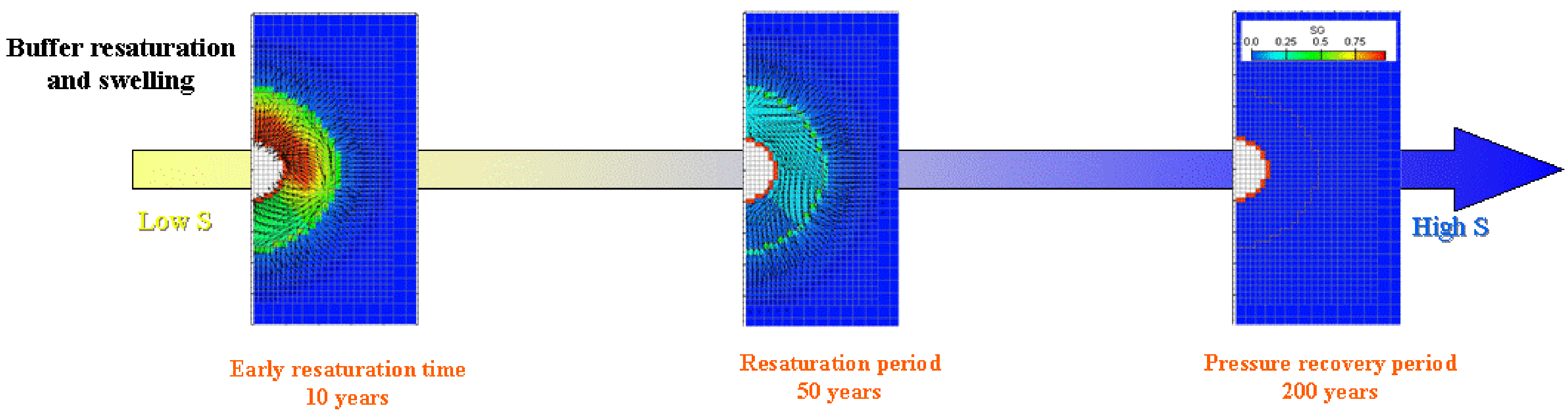
Long-term Performance of Engineered Barrier Systems

Introducing PEBS

Objective

Improve understanding of the **early resaturation phase** of the bentonite barrier

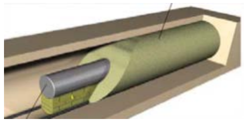
Reducing associated uncertainties in **long-term safety** assessment



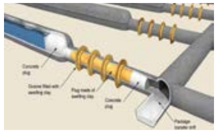
Introducing PEBS

Procedure

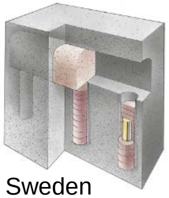
Identification of **uncertainties** during early evolution of EBS for different disposal concepts → Laboratory and in-situ **experiments** on THMC processes in bentonite → Numerical **modelling** of short-term effects and **extrapolation** to long-term evolution → Analysis of **impact on long-term safety** and guidance for repository design



Switzerland



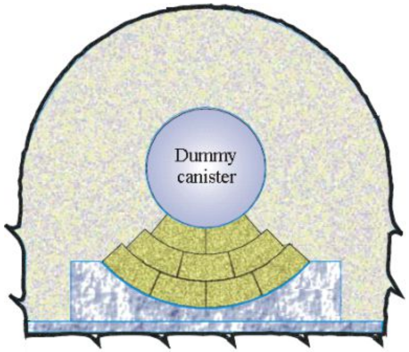
France



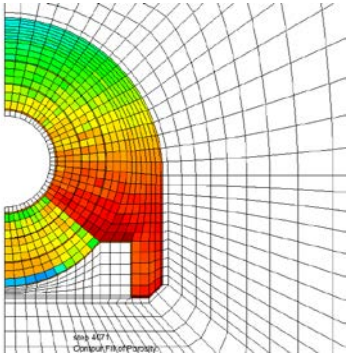
Sweden

Spain

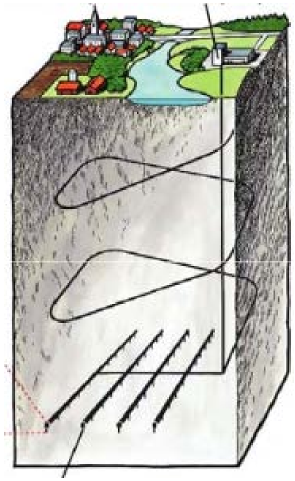
Germany



[Source: PEBS D3.1-1]



[Source: PEBS D3.1-1]



[Source: PEBS D1-1]

PEBS Long-term Performance of Engineered Barrier Systems

Introducing PEBS

Identified uncertainties – cases

Cases: areas of process-based understanding that need to be evaluated to improve the integration in long term safety assessment

Uncertainties associated with **water uptake** in bentonite for early evolution (**T<100°C**)	Uncertainties associated with **bentonite performance** for early evolution (**T>100°C**)
Hydro-Mechanical evolution of bentonite barrier	**Geochemical** evolution of bentonite barrier

Outcomes of PEBS

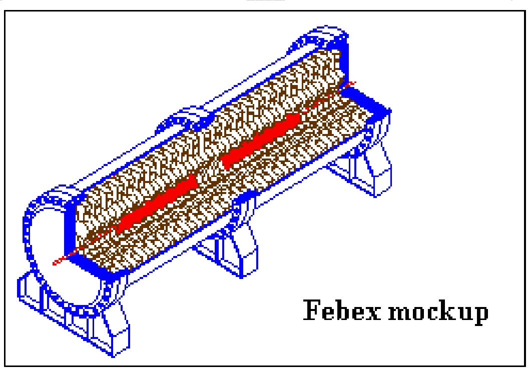
Selected results of analysed cases

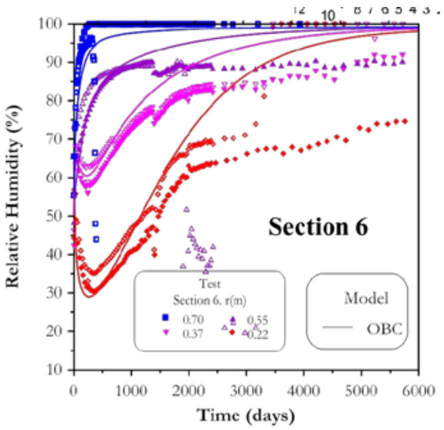
1

Uncertainties associated with **water uptake** in bentonite for early evolution (**T<100°C**)

– Results of **enhanced numerical models** showed good agreement to observed water uptake in large-scale heater experiments
– **Uncertainty regarding late stage resaturation** predicted with models
– Observations show that safety function of the buffer is fulfilled by **sufficient swelling pressure even prior to full liquid saturation**
⇒ Existing model uncertainty not significant from long-term safety perspective

FEBEX mock-up





Modelling of relative humidity in FEBEX mock-up

Outcomes of PEBS

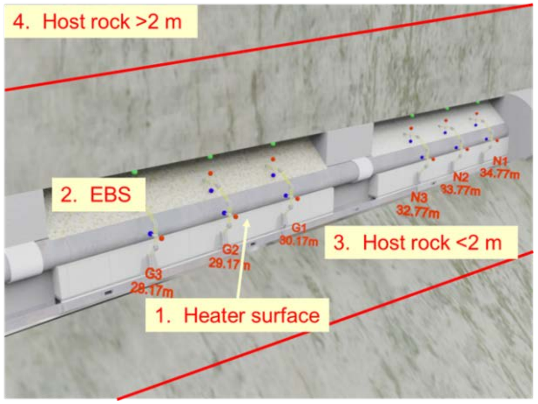
Selected results of analysed cases

2

Uncertainties associated with **bentonite performance** for early evolution (**T>100°C**)

- New in-situ experiment (HE-E)**: good agreement between models and measurements** for **thermo-hydraulic** processes in EBS and host rock
- Resaturation is slow → **several years of monitoring required** to adequately test models for resaturation
- Further studies on effects of heating bentonite **above 100°C** in partially saturated state **suggest no significant changes** in performance in the considered **high temperature** range (up to ~ 150°C)

⇒ **uncertainties** remain regarding swelling and hydraulic properties of bentonite for peak **temperatures above approx. 125 °C**



[Gaus et al., 2014]

HE-E heater test at MT URL

Outcomes of PEBS

Selected results of analysed cases

3

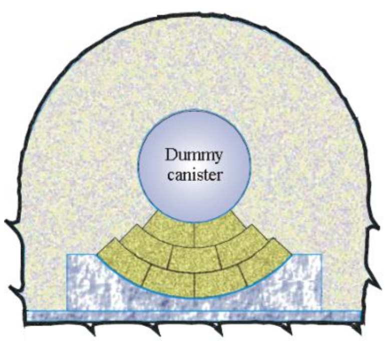
Hydro-Mechanical evolution of a bentonite barrier

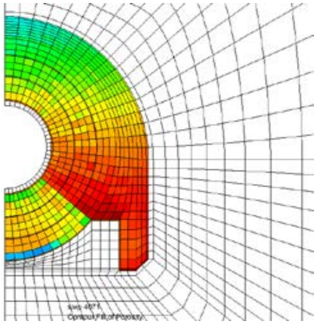
– EB experiment: **effective sealing through swelling of bentonite blocks and pellets** with large initial density differences
– Even though homogenization in the EB was reasonably efficient, some **heterogeneities remain over the cross-section** of the test
– Numerical **modeling proved capable of predicting heterogeneities** in the barrier after hydration, but involved coupled processes are complex

⇒ **Uncertainties** remain regarding evolution of heterogeneities in the EBS

Concept of the EB experiment at MT URL

[Source: PEBS D3.1-1]





THM modelling of the porosity distribution in the EB experiment

[Source: PEBS D3.1-1]

Outcomes of PEBS

Selected results of analysed cases

4

Geochemical evolution of bentonite barrier

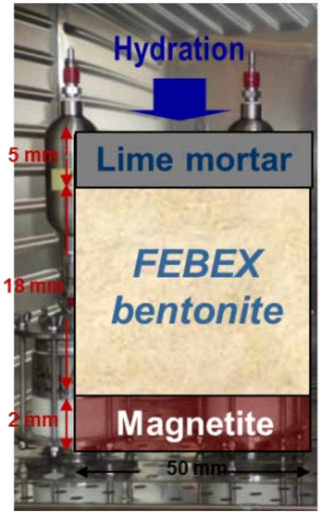
– **Limited bentonite alteration** at the **interfaces** (both steel-bentonite and cement-bentonite) **over years** (few cm reaction zone over very long term), **porosity** evolution requires **further work**

– below about 130 °C, **limited alteration of smectite** is expected within the main part of the barrier based on alteration models and natural analogues (for short thermal phase)

– Geochemical modelling provides valuable insights but uncertainties exist regarding extrapolation to the long term

⇒ **further model testing** and supporting information needed

⇒ abstraction for PA purposes should be performed cautiously



Long-term Performance of Engineered Barrier Systems

Outcomes of PEBS

Conclusions

- **Constraining uncertainties** related to **resaturation period →** associated uncertainties in **long-term performance of bentonite barriers** reduced in some important areas.

- Improvements **in process understanding** and **model development**

- Arguments have been further developed concerning:
  - Development of swelling pressure during slow wetting – **target swelling pressure** reached **before full saturation**
  - General **minor impact of higher temperatures** – for short periods
  - Performance of heated bentonite
  - Swelling of bentonite blocks and pellets
  - Constraining the impact of **geochemical interactions** at the **EBS interface**

Outcomes of PEBS

Recommendations

- Existing and new **in-situ experiments** will play an important role in further confirming bentonite performance over periods of **10-20 years**
- For concepts anticipating **temperatures above 100 °C further data collection** will be needed for certain aspects , e.g. swelling pressure, strength
- Further work on the **geochemical processes at material interfaces** is required
- **potential evolution of density heterogeneities** requires further research, especially for concepts where a heterogeneous inflow is expected

Progress in scientific domain

Guidance by HLEC

The High Level Expert Committee (HLEC) with

- members from regulators (Belgium, Sweden), research (Belgium) and academia (Germany)
- Focus on analysis of impact on long-term safety (WP1 & WP4) but also interfaces with experimentation (WP2) and modelling (WP3)
- Outcome: recommendations concerning WP4 (HLEC Report)

Progress in scientific domain

Guidance by HLEC

Conclusions and recommendations:

- Good science
- Linkage to safety-related questions not always obvious, though
- Address impact of uncertainties on safety functions more explicitly!
- Consider system as a whole (e.g. impact on canister corrosion), discuss how safety functions and barriers works together to ensure safety and robustness
- PEBS cases: choices driven by
  - Most important uncertainties in terms of phenomenology / scientific understanding
  - Common interest

  ⇒ Good, but also discuss significance for the various repository concepts covered by PEBS!

  ⇒ Address safety relevance more comprehensively in WP4!

⇒ HLEC recommendations were addressed in WP4 and final reporting

Long-term Performance of Engineered Barrier Systems

Contribution to the IGD-TP vision and strategic research agenda

Irina Gaus (Nagra)

Long-term Performance of Engineered Barrier Systems

Contribution to the IGD-TPs vision.

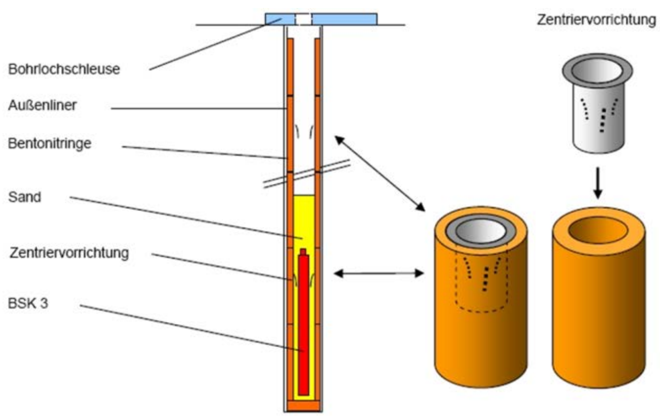
– PEBS was born before IGD-TP!

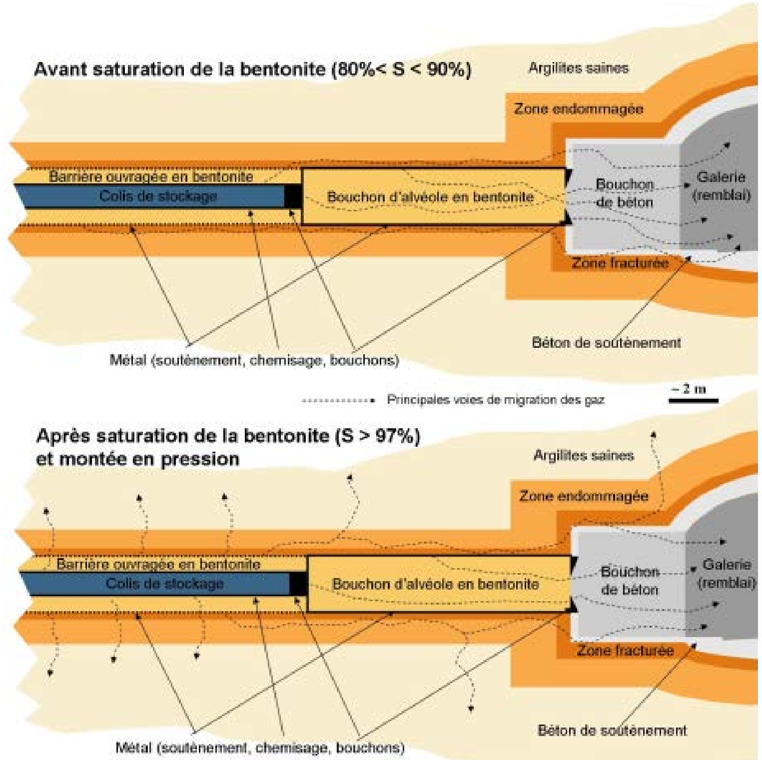
– But – Strategic Research Agenda:

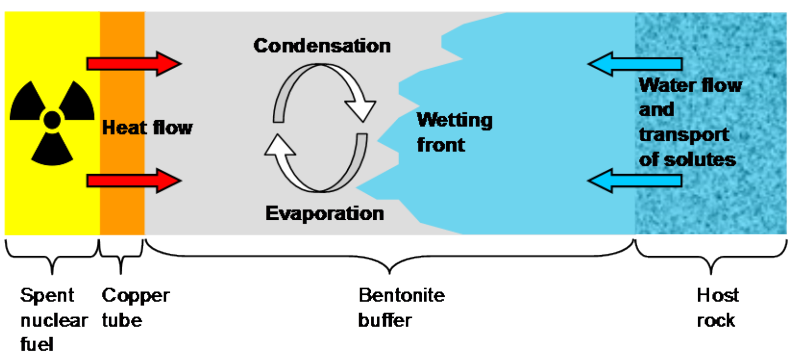
Buffer and Backfill materials: The choice of buffer and backfilling materials is partly dependent on the chosen disposal concept. Buffer and backfilling have important safety functions in some disposal concepts and shall therefore fulfil the requirements and specifications set for them. As these depend on the disposal concept under consideration and the geological environment of the site their importance varies between the different waste management programmes.

IGD-TPs Strategic research agenda

– Recognized in the projec t→ WP1 Describes the treatment of the early barrier evolution and in the safety assessments of a number of countries







IGD-TPs Strategic research agenda

Common uncertainties over the programmes

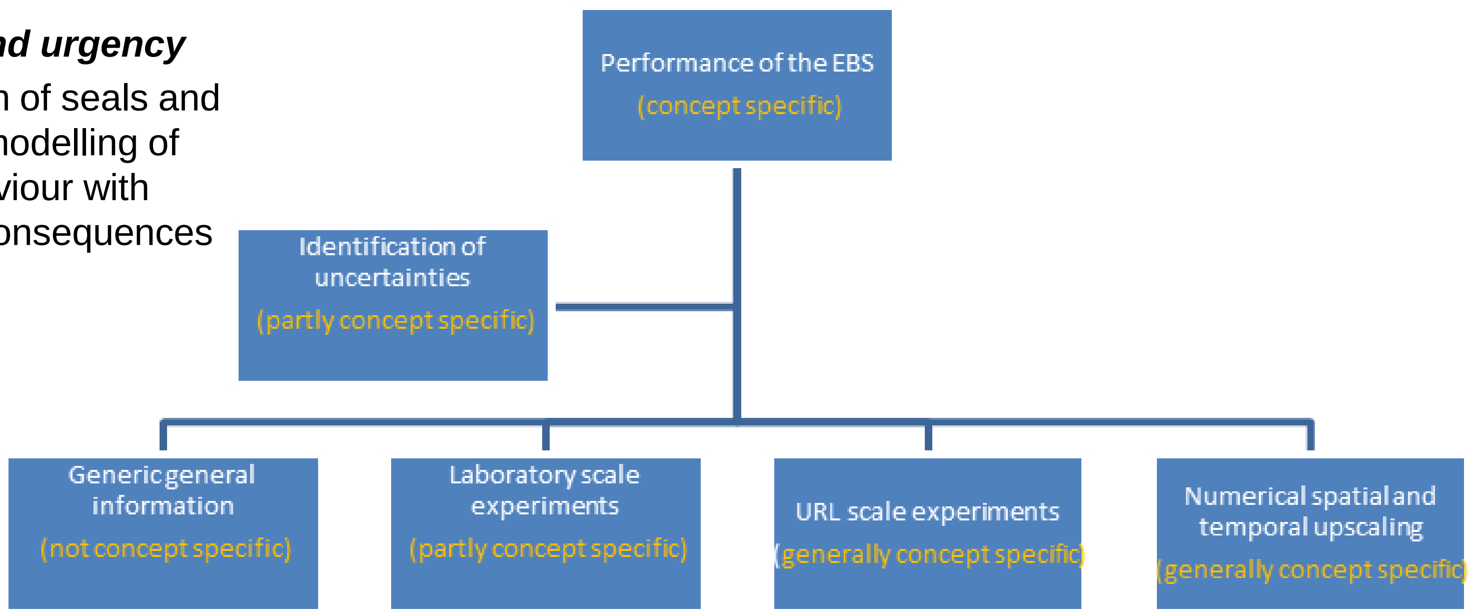
- Mass loss due to piping and erosion in the very early evolution
- Swelling and homogenisation of components with different density and sealing after losses of mass
- The importance of friction within the bentonite and between bentonite and other materials – also in the unsaturated state
- Effects of temperature on the mechanical properties
- Hydraulic processes
- Mechanical behavior in contact with the metal elements
- Mechanical effect of gases inside Argillites and swelling clay
- Thermo-mechanical effects
- Technologies implemented in the repository: swelling clay seals and engineered barriers
- The effect of temperatures exceeding 100°C on the hydraulic properties of the buffer
- The evolution of swelling pressure with time and the interaction with the convergence of the host rock
- Chemical Interaction between bentonite and Fe and the low pH liner
- Discrepancy in the water saturation process of the buffer between predicted hydration rates and experimental values

IGD-TPs Strategic research agenda

Buffer and Backfill materials: The processes occurring during repository evolution are similar for many materials and repository environments (e.g. compaction, diagenesis, changes in hydraulic characteristics), which makes comparisons meaningful, even though the impacts on disposal system performance may be significantly different.

High importance and urgency

Topic 10. Description of seals and plugs systems and modelling of their long-term behaviour with assessment of the consequences on long-term safety.



IGD-TPs Strategic research agenda

4 CASES: advanced through experiments (WP2) and modelling (WP3)

WP 1 – Current treatment in PA

- Analyis of issues per repository concept
- Consolidation in cases

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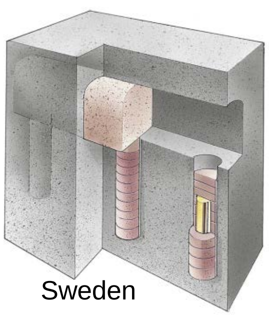
Case 2 :

Case 1:

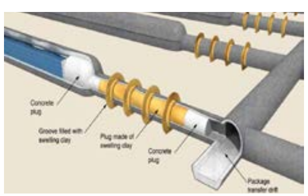
WP 4 – Improvements

- Integration of new findings in national programmes, impact for specific concepts
- Feedback to design
- Remaining uncertainties

Switzerland



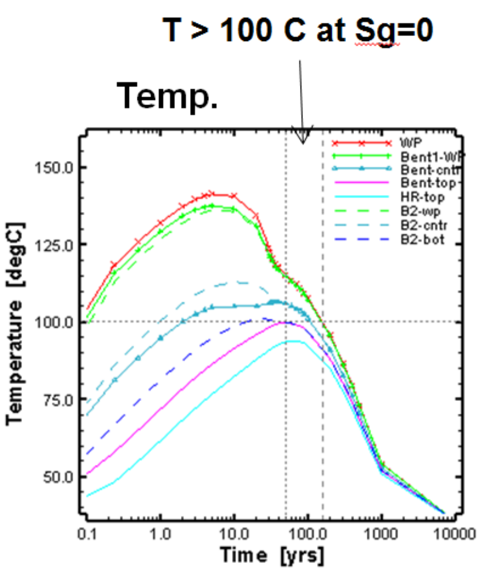
Sweden



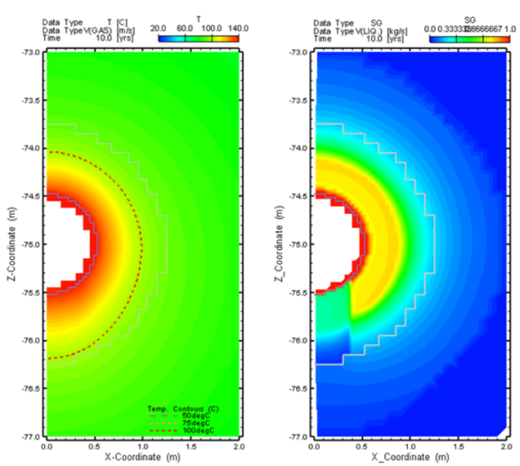
France

***CASES:** areas of process-based understanding that need to be evaluated to improve the integration in long term safety assessment*

IGD-TPs Strategic research agenda



Temp – Gas Sat. @ 10 yrs



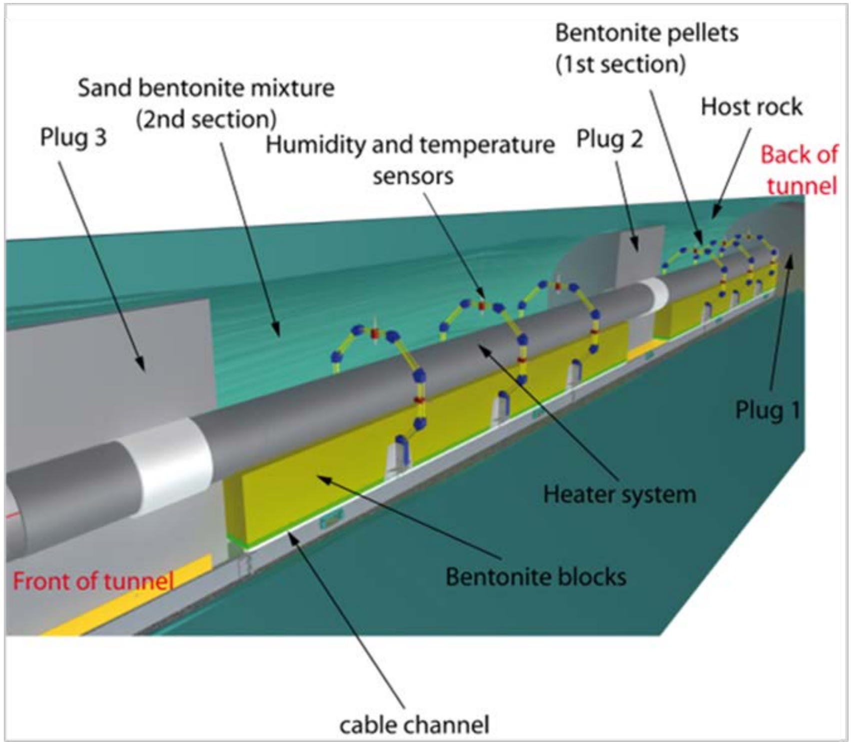
Feedback to performance assessment: Nagra case

Refinement of the early evolution placed in the correct spatial and temporal context to assess the consequences → confirmation of assumptions of latest safety case (2002), input for the next (2022)

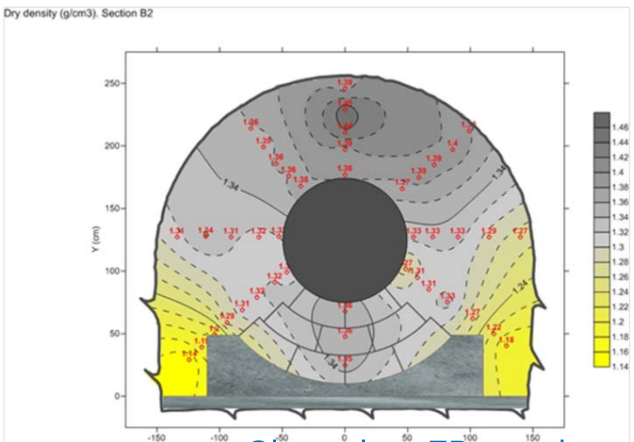
Extrapolation modelling based on HE-E results

(Kuhlmann et al., 2014)

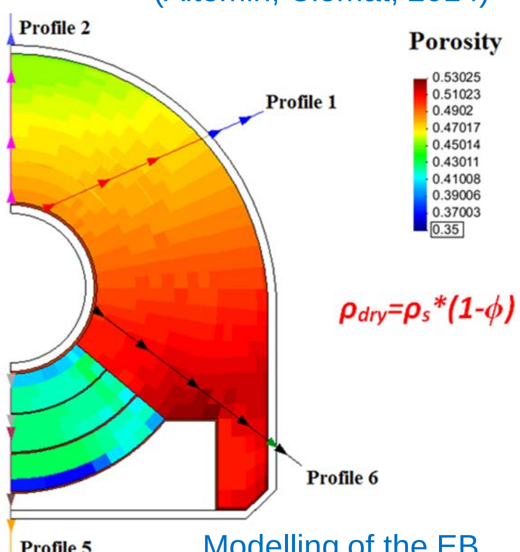
1:2 Scale Heater Test at Mont Terri URL (Nagra, 2014)



Contribution to the IGD-TPs vision.



Obervations EB experiment
(Aitemin, Ciemat, 2014)



Modelling of the EB
experiment. (CIMNE, 2014)

Feedback to performance assessment: SKB

SR-Site assessment (SKB 2011): if the buffer and backfill is installed as envisaged buffer density and swelling pressure will homogenise to a situation where the relevant safety functions will be upheld.

PEBS confirmed that:

- even if installed as a mixture of high density blocks and low density pellets a highly saturated bentonite barrier was able to seal all the initial voids.

- FEBEX mock up shows that the buffer achieves the required performance over time as saturation increases, and will perform long before full saturation is reached.

Contribution to the IGD-TPs vision.

Remaining uncertainty at the end of PEBS:

For concepts where a heterogeneous inflow is expected, evaluation of the potential evolution of density heterogeneities during saturation might need further attention → locked in heterogeneities.

September 2015: bentonite swelling into liner-heater gap after 18 years – results from the FEBEX-DP project at the Grimsel Test Site (Kober et al., 2015)

IGD-TP at work …

Working Group in this Exchange Forum

"HOMOBENTO"

… next HORIZON2020 project ?

Thank you!

Thanks to the PEBS partners for the input to this presentation.

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