How THMC processes are handled in Performance Assessment

-

focus on the Damaged Zone (DZ)

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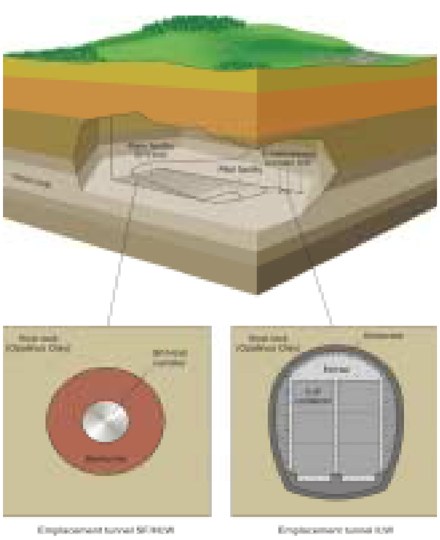
Objectives of this presentation

- **Closing the loop...**
  - **As we come near the end of this training course, you already know a lot about the THM(C) behaviour of clays and the principles of radioactive waste management**
- **...by bringing the pieces together**
  - **Provide a back-ground on the stakes associated with the damaged zone (DZ) in the working of a complete disposal system**
    - **How a repository in clay is supposed to work (& evolve)**
  - **Illustrate how the DZ has been handled in previous performance assessments (PA) exercises**
    - **Results of past assessments**
    - **Typical PA needs**

Plan

- Objectives of this presentation ✓
- Repository systems in clay
  - Typical layouts
  - Long-term safety
  - The roles of clay
  - Expected temperature evolution (current designs)
- Handling of a damaged zone in performance assessment
  - Performance assessment
  - The damaged zone (DZ)
  - How the DZ has been handled until now
- How to ensure seamless integration of DZ / THM(C) research & PA ?

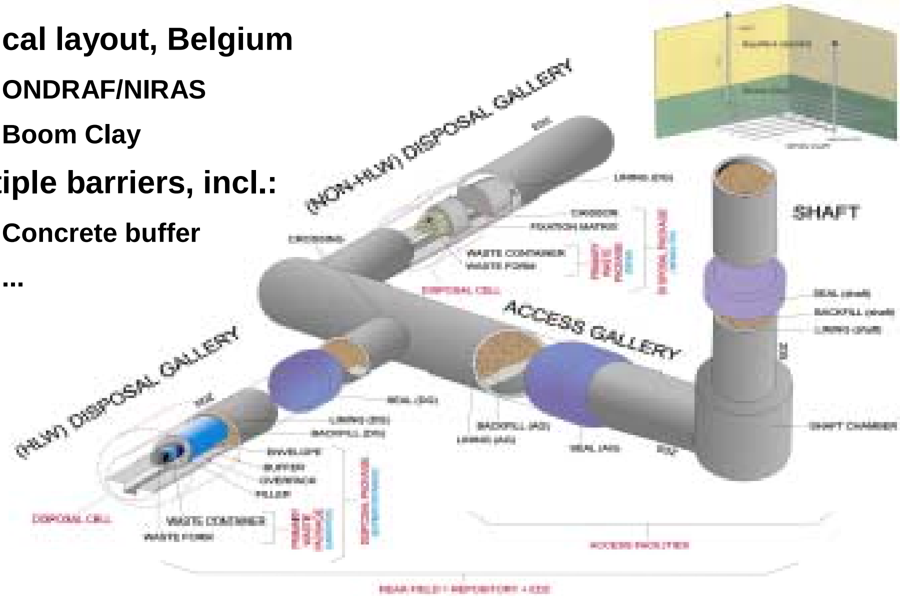
Repositories in clay



- Typical layout, Switzerland
  - SF/HLW and ILW
  - from Opalinus Clay project (NAGRA NTB 02-05, 2002)
- Multiple barriers, incl.:
  - Canister,
  - Bentonite,
  - Opalinus Clay,
  - ...

Repositories in clay

- Typical layout, Belgium
  - ONDRAF/NIRAS
  - Boom Clay
- Multiple barriers, incl.:
  - Concrete buffer
  - ...



Long-term safety of a repository system

- Multiple, passive, safety barriers
  - Internationally recognized requirement (IAEA, NEA,...)
  - Man-made barriers, the "engineered barrier system" (EBS)
  - Natural barriers: geological setting (TIMODAZ: clay)
- Thus, barriers are parts of a repository system
  - Redundancy
  - Interactions
    - **+ :** concrete buffer → High pH → low corrosion rate of overpack
    - **- :** concrete can perturb clay, enhance glass dissolution rate

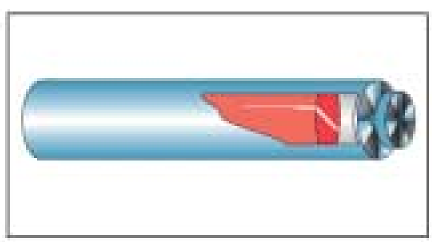
Long-term safety of a repository system

- Barriers contribute to the **safety functions**
  - **Isolation (I)**: prevent direct access, inadvertent human intrusion and limit consequences (damage to system)
  - **Confinement (C)**: as much as possible, let radionuclides decay within the disposal system
  - **Delay and attenuation of the releases** (retardation, R) to the environment of radionuclides that do not decay to insignificance within the system

multiple barriers and safety functions, example (NAGRA, 2002)

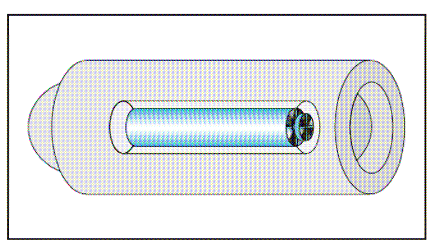
Glass matrix (in steel flask)

- Confinement
  - Containment of radionuclides in glass
- Attenuation of releases
  - Low corrosion rate of glass



Steel canister

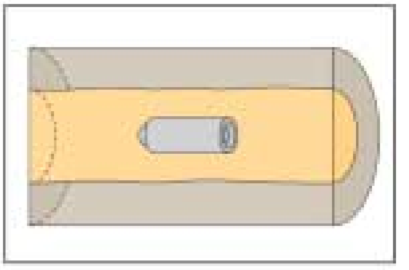
- Confinement
  - Prevents inflow of water and release of radionuclides from waste for several thousand years
- Attenuation of releases
  - Corrosion products act as reducing agent (giving low radionuclide solubilities)
  - Corrosion products take up radionuclides



multiple barriers and safety functions, example (NAGRA, 2002)

Bentonite backfill

- Confinement
  - Long resaturation time
  - Plasticity (self-sealing following physical disturbance)
- Attenuation of releases
  - Low solute transport rates (diffusion)
  - Retardation of radionuclide transport (sorption)
  - Low radionuclide solubility in pore water



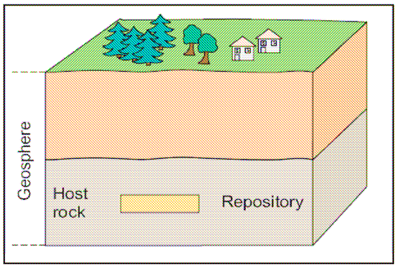
Geological barriers

Host rock

- Confinement
  - Absence of water-conducting features
  - Mechanical stability
- Attenuation of releases
  - Low groundwater flux
  - Retardation of radionuclide transport (sorption and colloid filtration)

Geosphere

- Confinement
  - Physical protection of the engineered barriers (e.g. from glacial erosion)
- Attenuation of releases
  - Retardation of radionuclide transport (sorption)
  - Dispersion



Safety functions can be detailed further, example (ONDRAF 2006)

- **Delay and attenuation of the releases (retardation, R) to the environment of radionuclides that do not decay to insignificance within the system**
  - **R1: limit the release rate from waste packages (conditions favourable to slow degradation of packaging, waste matrix)**
  - **R2: limit water flow through the system (diffusion is dominant transport mechanism for radionuclides)**
  - **R3: retard contaminant migration (precipitation, sorption)**
  - **Note: safety functions come in different flavours, but always closely related to the concentrate and confine strategy**

The roles of clay

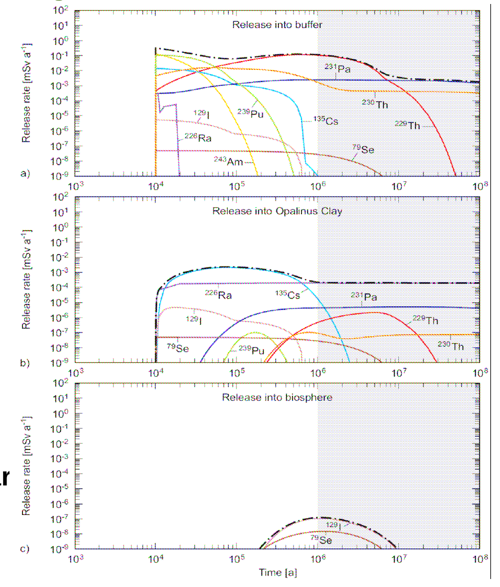
- **Intrinsically favourable properties with respect to repository safety functions:**
  - **very low permeability (➔R2)**
    - natural hydraulic gradients: small flow rates
    - solute transport is mainly diffusive (advection is very small)
  - **low pore diffusion coefficients for solutes (➔R3)**
  - **ionic sorption capacity (➔R3)**
  - **anionic exclusion (➔R3)**
  - **swelling capacity, creep (➔R2)**
    - closure of (technological) gaps
- **+ Indirect contributions to safety**
  - **Provide stable, favourable environment to EBS (➔R1, C)**
    - Mechanical, chemical stability
  - **(Self-)sealing capacity ➔robustness against disruptions**

The roles of clay

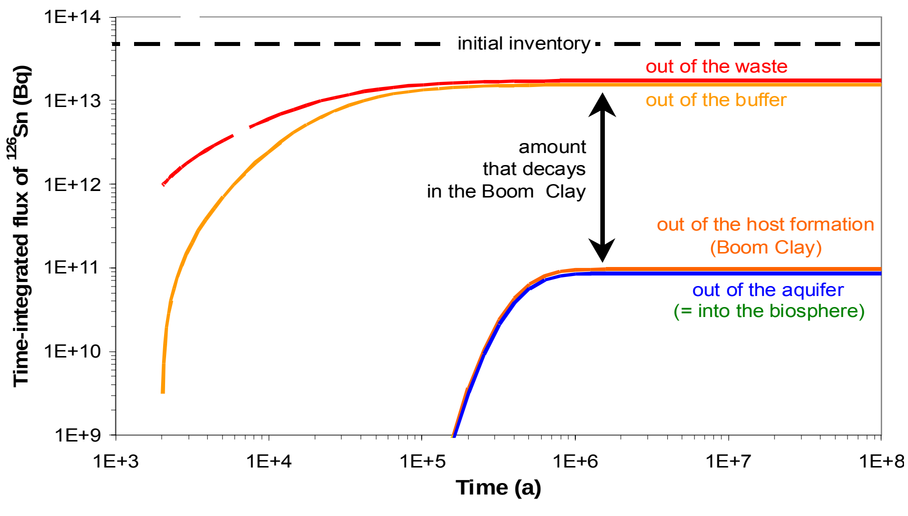
- **Evaluations of the overall performance of repositories usually stress the dominant contribution of the clay**
  - **In the "expected evolution" scenario**
  - **In some (many, most ?) "altered evolution" scenarios**
- **Examples**
  - **Computed release rates, HLW repository in Opalinus Clay**
    - delaying and attenuation of releases !
    - use of radiotoxicity units (weighting scheme, to sum over RNs)
  - **Released fraction, single radionuclide**
    - released fraction = time-integrated (or cumulated) release over [0, ∞]
    - different pictures for different radionuclides !

Computed release rates, HLW repository in Opalinus Clay

- rel. rate into **buffer**:
  - < 1 mSv/year
  - Max at 10,000 years
  - ^{239}Pu, ^{243}Am
- rel.rate into **Opa. Clay**:
  - < 0.01 mSv/year
  - Max after 65,000 years
  - ^{135}Cs
- rel. rate into **biosphere**:
  - < 0.000001 mSv/year
  - Max after 1,000,000 year
  - ^{129}I, ^{79}Se

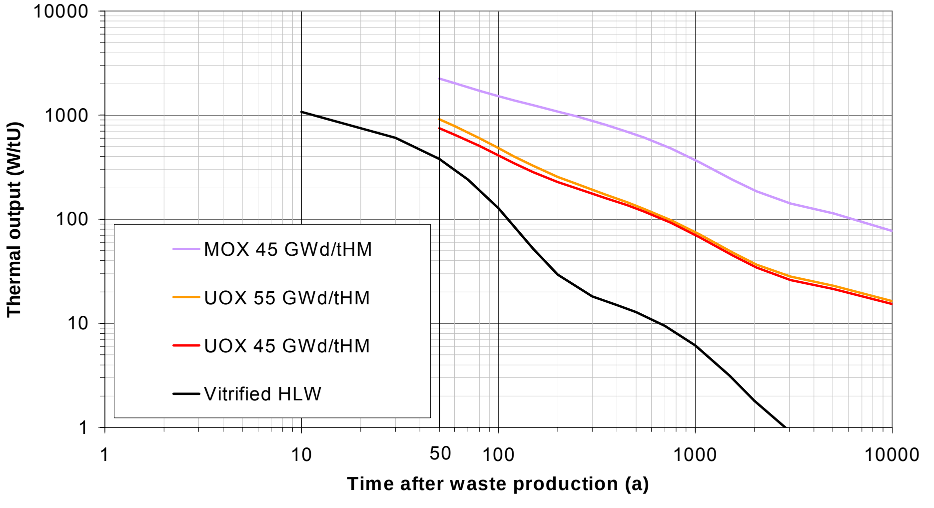


time-integrated (or cumulated) release of ^{126}Sn, SF repository in Boom Clay



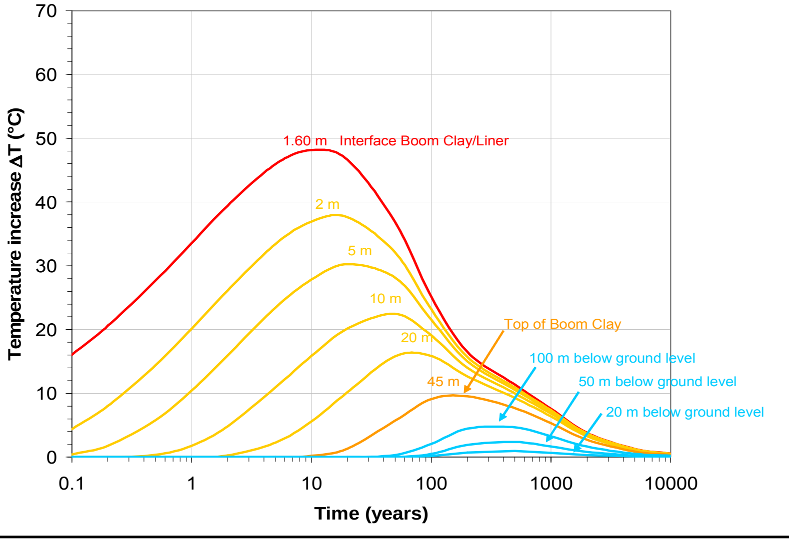
Expected temperature evolution

➢ **Source term (SF: W/ton, VHLW: W/ton reprocessed)**



Expected temperature evolution

➢ **Expected temperature increase (ΔT) above gallery, (VHLW, Boom Clay)**



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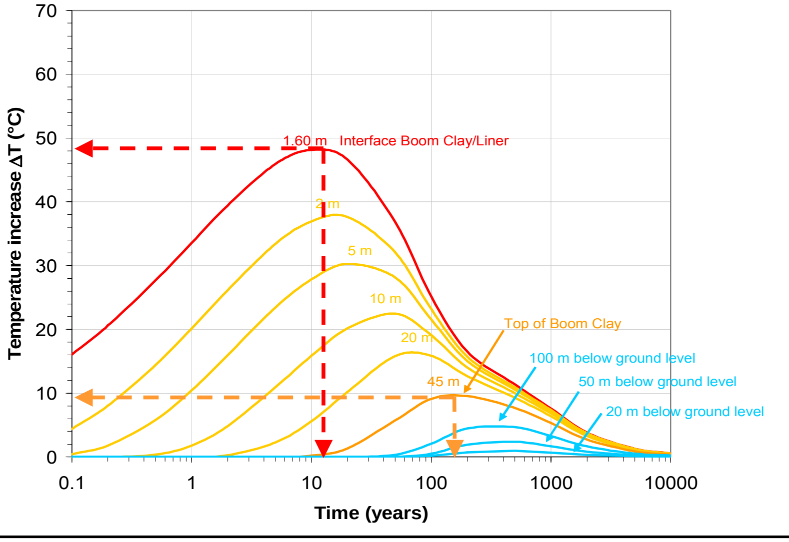

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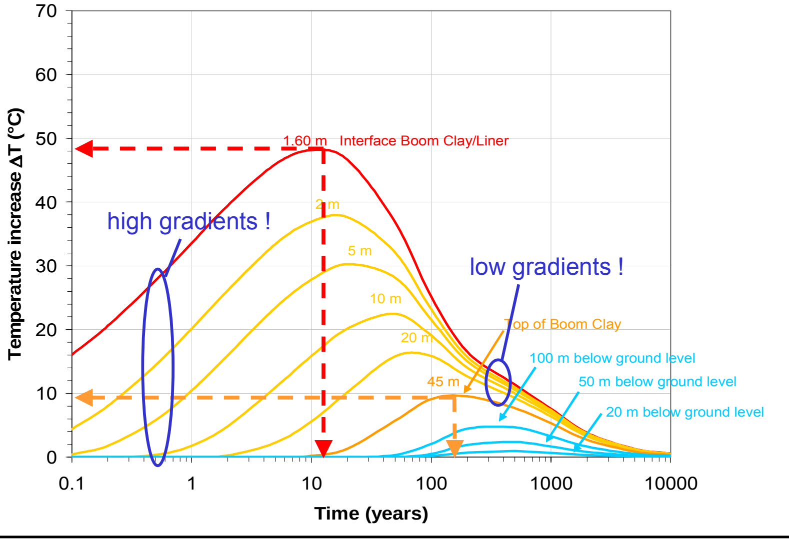
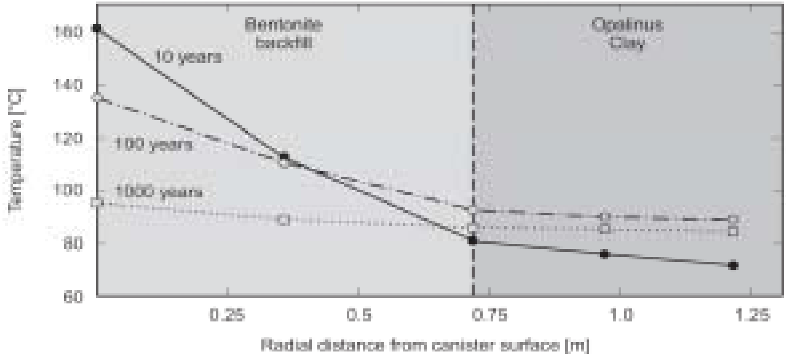


Expected temperature evolution

- Expected radial temperature profiles, (SF, Opalinus Clay)



Expected temperature evolution

- **Side note: what is more important (critical) ?**
  - Absolute (peak) T ?
  - dT/dr ?
  - dT/dt ?
  - Time-at-temperature (integral) ?
- **Beware of arbitrary T criteria...**
  - ...as evolution depends on T-controlled processes.
  - Thermal evolution is (much) more than T° evolution !

Plan

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Performance Assessment (PA)

(this slide was shamelessly stolen from Schneider & Zuidema, NAGRA)

- **Aims of analysis**
  - quality of the system → any needs to modify system?
  - quality of understanding (& confidence in conclusions) → future R+D?

  in relation to safety of system (not everything is important)
- **Phases of performance assessment**
  - phenomenological analysis (get full picture, identify the issues relevant for safety: contribution to safety, potential to undermine safety)
  - address uncertainties: variability, lack of data / understanding
  - quantification of performance (& effect of uncertainties → sensitivity)
  - synthesis: the main findings (quality of system, confidence in results)
- **Nature of the analysis: the need for …**
  - … completeness (RNs, components, phenomena) → uncertainties
  - … simplifications (not everything can be depicted in all details)
  - … justification (incl. how to deal with incomplete understanding) & compilation of independent (often imperfect) evidence

The Damaged Zone (DZ)

- **Definition:**
  - **Some variants do exist…**
    - SELFRAC (EDZ, EdZ)
    - National programmes
    - NEA
  - **"Zone around underground openings that may have altered properties relevant to the post-closure performance of the overall repository system"**
    (Zuidema, EDZ Cluster Luxembourg, 2003)
  - **Definition in a specific context !**
- **Initiated by repository construction**
  - **Can be limited by appropriate excavation technique**
  - **Cannot be completely avoided**

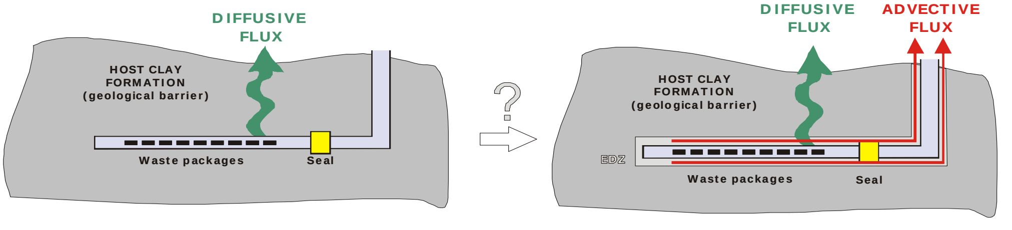
The Damaged Zone (DZ)

- **As conditions changes, the DZ evolves:**
  - **Open drift (suction, O_2 ,…)**
  - **Waste emplacement (heating starts)**
  - **Initial closure (begin of EBS saturation)**
  - **Heating-cooling period**
  - **Long-term chemical (biological ?) evolution**
  - **EBS failure, radionuclide releases**

  (Open drift through Heating-cooling period: TIMODAZ)
- **Many T,H,M,C processes !**
  - **Exhaustive Features, Events & Processes lists (FEP's)**
    - **FEP's traditionally viewed as building blocks for building scenarios**
    - **Nowadays, the trend is toward the use of FEP's as checklist**

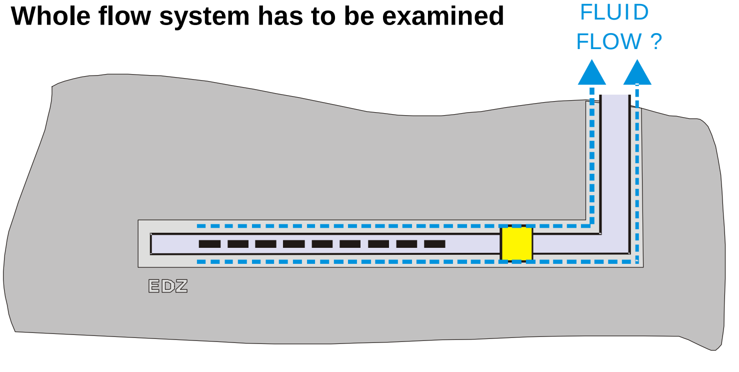
How the DZ can be handled in PA

- In previous PA exercises ('90s, early '00s)
  - (E)DZ = region of enhanced permeability
  - Concern: advection of radionuclides by water flowing through DZ, bypassing the geological barrier



How the DZ can be handled in PA

- Are concerns about a bypass through the DZ justified ?
  - High permeability is not sufficient by itself !
  - Flow requires available fluid, difference of potential
  - Whole flow system has to be examined



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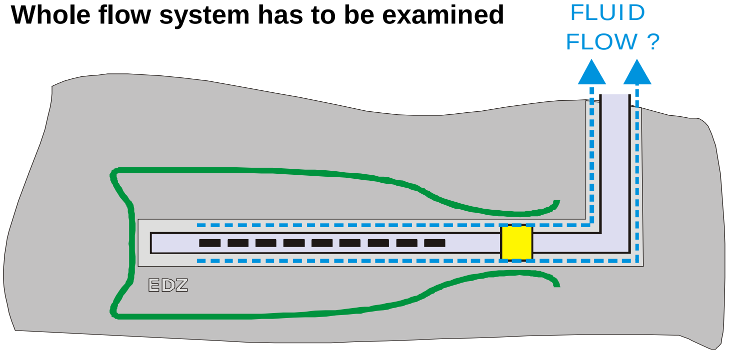
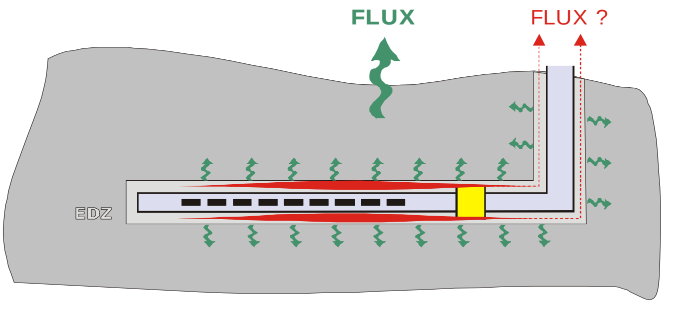


How the DZ can be handled in PA

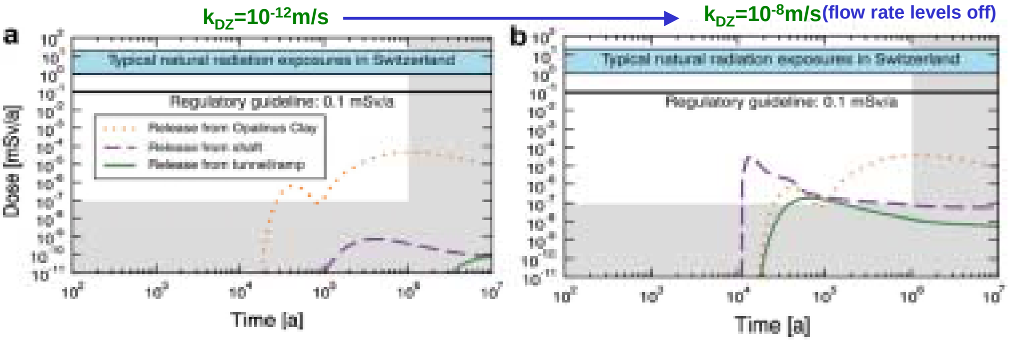
- Are concerns about a bypass through the DZ justified ?
  - An efficient bypass needs an externally- (fracture ?) or internally- (gas ?) provided driving force
  - Even then, matrix diffusion into the clay remains active !
  - A lot of radionuclides can be lost from the DZ along the way !



How the DZ can be handled in PA: example

- Several examples of calculations that hint at limited releases through the DZ are available
  - BENIPA (Poor sealing scenario)
  - Bauer et al. (EDZ Cluster 2003)
  - Nagra 2002, Smith et al., 2004

$k_{DZ}=10^{-12}$m/s → $k_{DZ}=10^{-8}$m/s (flow rate levels off)

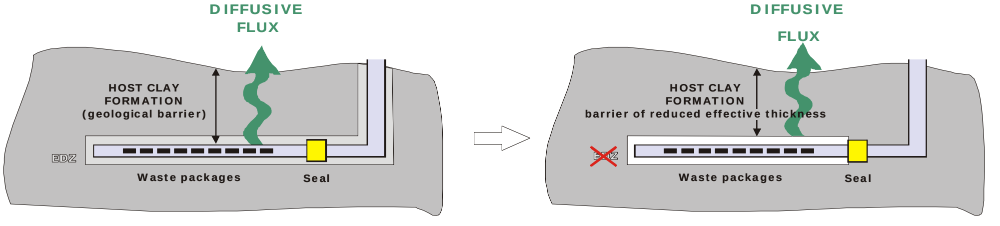


How the DZ can be handled in PA

- So, permeability increase is only part (possibly minor) of the story
- Less attention has been given to radionuclide transport properties within the DZ
  - Alheid et al., NF-PRO, 2005
  - Not easy to obtain experimentally
  - Damage → porosity, connectivity, apparent diffusion changes
  - Reactivity can be different from intact clay → sorption change
  - End result can be positive or negative
  - Concern: radionuclide transport could be enhanced within DZ

How the DZ can be handled in PA: example

- Example of handling of DZ migration parameters in a performance assessment (adapted from SAFIR-2, 2001)
  - …by ignoring the DZ altogether !
  - Effective thickness of clay barrier is reduced by DZ thickness
  - Simple, conservative…
  - …once the DZ extents are defined.



How the DZ can be handled in PA

- DZ is part of a system ➔ interactions !
  - Have been considered in the past
  - Albeit mostly from phenomenological point of view
- EBS➔DZ interactions
  - Example: alkaline plume from concrete components of EBS
    - Modify fluid flow properties
    - Modify radionuclide transport properties
    - Alter swelling & creep characteristics, self-sealing capacity
- DZ➔EBS interactions
  - Example: Mechanical
  - Example: Production and release of aggressive species
    - Sulfates, thiosulfates,... produced during open-drift period (O_2)
    - ... that could later migrate towards for metallic barriers & enhance corrosion.

How the DZ can be handled in PA

- **Summary: the Damaged Zone (DZ) considered...**
  - **as a pathway for RNs to bypass the geological barrier**
    - **Has been explicitly represented in PA models**
    - **Calculation results indicate (very) limited effect**
  - **as a region of the geological barrier that is less effective at attenuating and delaying releases**
    - **Data (η, D_p, Kd,…) can be incorporated in PA models**
    - **Conservative assumptions: limited effect**
  - **as interacting with the EBS**
    - **Mostly pheno. studies; may support PA assumptions, building of plausible evolution scenarios.**

Plan

- **Objectives of this presentation ✓**
- **Repository systems in clay ✓**
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  - **Long-term safety**
  - **The roles of clay**
  - **Expected temperature evolution (current designs)**
- **Handling of a damaged zone in performance assessment ✓**
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How to ensure seamless integration of DZ / THM(C) research & PA ?

- **The challenge:**

  Put together the info gathered from THM(C) / DZ research (experiment results, models,...) & Performance Assessment (system analysis, simplified models,...) in the perspective of a safety case, *i.e.* assess to which extent the results indicate that:

  - …a disposal system is **safe** (safety functions)
  - …a disposal system is **well understood** (especially its evolution)

Performance Assessment & Science

(P. Zuidema, Paris 2007)

- **For a convincing safety case, Science has to**
  - **provide process understanding (incl. quantification on relevant scales)**
  - **characterise uncertainties (alternative concepts & interpretations, data uncertainty, variability)**
  - **review the assumptions / simplifications (as proposed by PA) present in assessment models & data for consistency**
  - **accept that limitations in understanding need to (and can) be "bounded" by pessimistic or conservative assumptions**
  - **ensure that conservative assumptions are justified and explicit**
- **... and Performance Assessment has to**
  - **be open minded for the input provided by science**
  - **ensure that best use is made of the available scientific understanding**
  - **acknowledge in the synthesis the limitations of the analysis (no exact prediction but a sufficiently reliable illustration of safety)**
- **Both Science and Performance Assessment have to work together as a team**

How to ensure seamless integration of DZ / THM(C) research & PA ?

- **Work as team ✓**
- **Some practical integration tools (as used within TIMODAZ)**
  - **Safety functions of a disposal system**
  - **Questionnaire about expected evolution**
  - **The 5 questions**

Tool 1: safety fonctions

- **Several variants are possible**
  - **national programmes, system specific**
  - **Example, ONDRAF:**
    - **Isolation (I):** prevent direct access, inadvertent human intrusion and limit consequences (damage to system)
    - **Confinement (C):** as much as possible, let radionuclides decay within the disposal system
    - Delay and attenuation of the releases (**retardation, R**) to the environment of radionuclides that do not decay to insignificance within the system
      - **R1**: limit the release rate from waste packages (conditions favourable to slow degradation of packaging, waste matrix)
      - **R2**: limit water flow through the system (diffusion is dominant transport mechanism for radionuclides)
      - **R3**: retard contaminant migration (precipitation, sorption)
- **Everyone: "How does my work, my models, my experiments, my results relate to these safety functions ?"**

Tool 2: questionnaire about expected evolution

- As conditions changes, the dZ and DZ evolve:
  - Open drift (suction, O_2 ,...)
  - Waste emplacement (heating starts)
  - Initial closure (begin of EBS saturation)
  - Heating-cooling period
  - Long-term chemical (biological ?) evolution
  - EBS failure, radionuclide releases

  } TIMODAZ

- Try to "tell the story"
  - In 1 page, write your current view about the expected evolution of the clay around the engineered barriers, during the first 10,000 years, with respect to p.p., stress paths, localisation, sealing,...

Tool 3: the "5 questions"

- 5 key questions:
  - Q1: What is the expected evolution of the DZ during the thermal period ?
  - Q2: What are the main uncertainties about DZ evolution and how can these uncertainties be dealt with ?
  - Q3: Under which conditions can the favourable clay properties be modified during the thermal period and how much can these properties be affected ?
  - Q4: Under which conditions do the change become irreversible, i.e. under which conditions will the future properties of the clay differ from the currently observed properties.?
  - Q5: To which extent can temporary or permanent alterations of favourable clay properties really affect barriers and safety functions of the system, *i.e.* which alterations are significant for system performance ?

Testing of integration tools within TIMODAZ

- Together, use of the integration tools should
  - provide a set of reasoned arguments to support claims about the safety of repositories in clay
  - alternatively, highlight remaining knowledge gaps or unsolved problems
- Of particular interest
  - Fate of favourable clay properties in DZ ?
    - k, D_p, sorption, swelling, creep, self-sealing, stability,…
  - DZ evolution, at the scale of the system ?