THE ROLE OF STRUCTURAL RELIABILITY OF GEOTECHNICAL BARRIERS OF AN HLW/SF REPOSITORY IN SALT ROCK WITHIN THE SAFETY CASE

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SAFETY CASES FOR THE DEEP DISPOSAL OF RADIOACTIVE WASTE:
WHERE DO WE STAND?
PARIS, 23-25 JANUARY, 2007

Structural reliability according to technical standards

One geotechnical barrier

- Failure probability: $p_f \leq 10^{-4}$ / working life

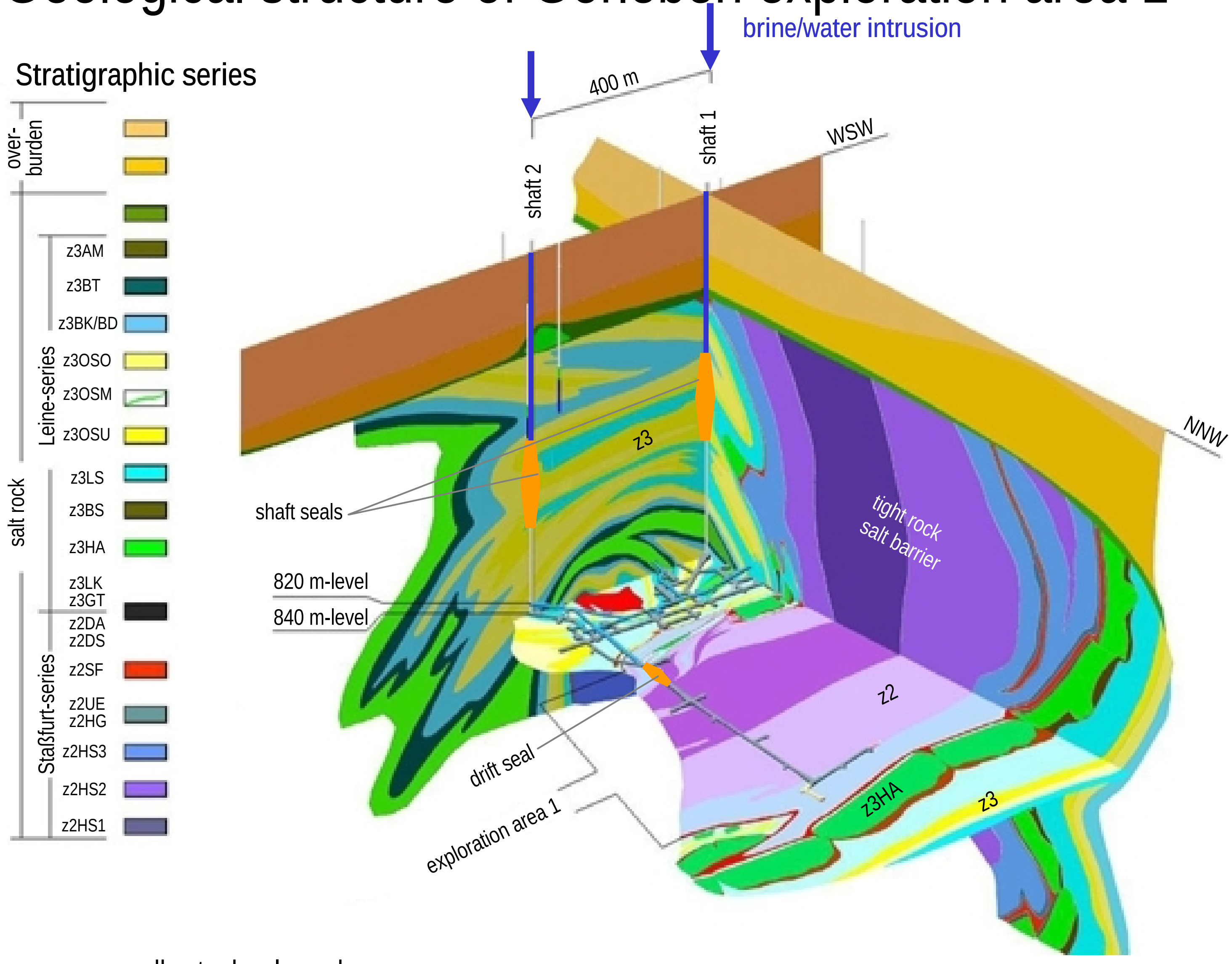
A system of two independent geotechnical barriers

- Failure probability: $p_f \leq 10^{-8}$ / working lives

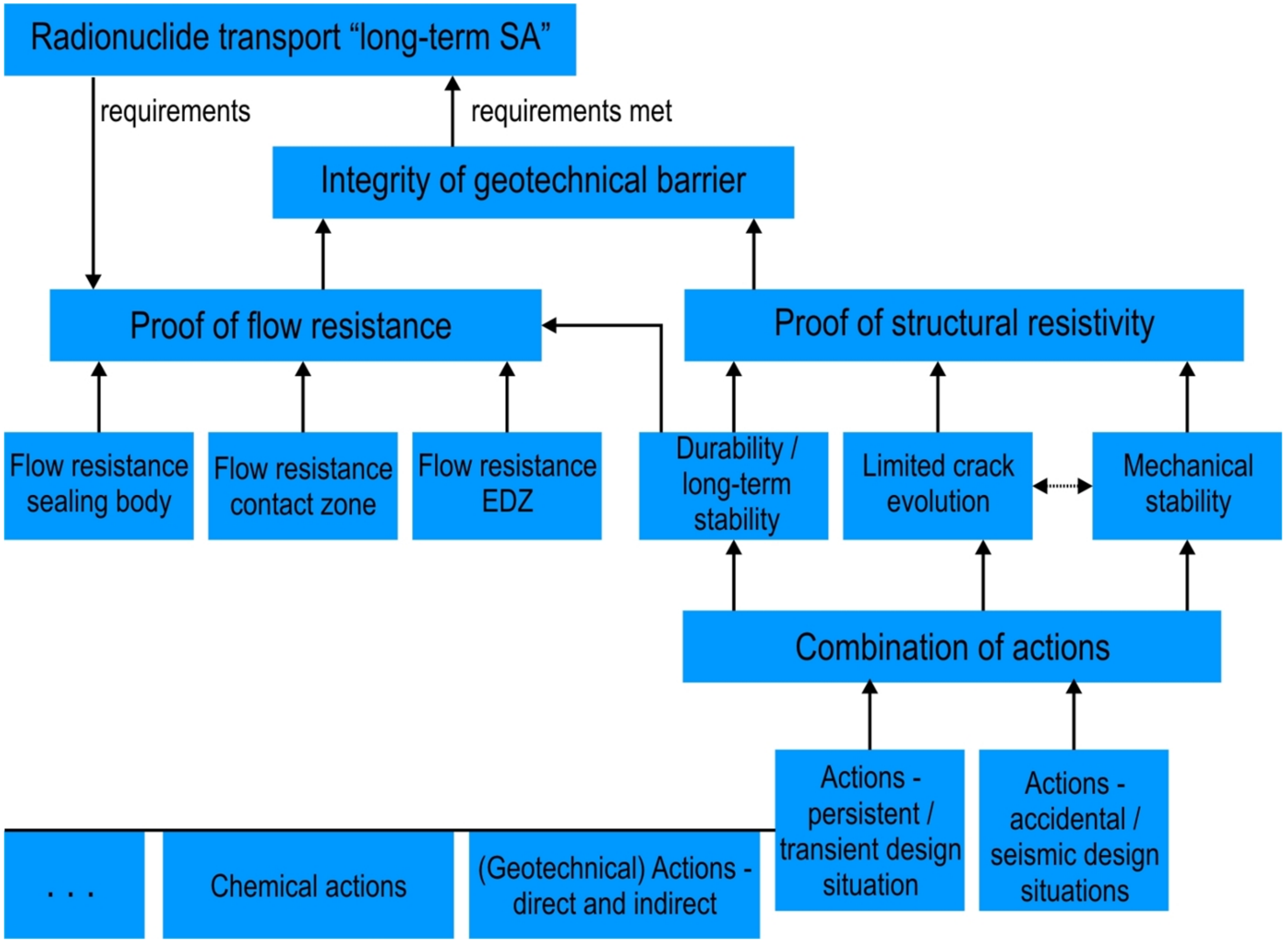
→ 2 effective geotechnical barriers – undisturbed evolution
→ 1 effective geotechnical barrier – disturbed evolution
→ 0 effective geotechnical barrier – excluded, because of low probability

Structural reliability of geotechnical barriers (combined with an intelligent repository design) is decisive for dry/wet repository evolution in salt rock

Geological structure of Gorleben exploration area 1



Scheme of proofs to demonstrate barrier integrity



Methods to prove structural reliability

Two options to prove structural reliability

- By calculation

→ Safety criteria, modelling tools, validated models, and a method to manage uncertainty are required

- Design assisted by testing

→ E.g., if modelling tools resp. validated models are not available

ERAM drift seals:

- Structural resistivity is proved by calculation
- Flow resistance is proved by testing

Salzdetfurth Shaft II seal:

- Structural resistivity is proved by testing
- Flow resistance is proved by testing

→ Validation of models as a by-product

Example: ERAM drift seals

Design requirements and constraints

Design requirements from long-term safety: $k \leq 10^{-18}$ m^2 initially

5,000 – 30,000 years working life

Site-specific constraints: Limited length of seals

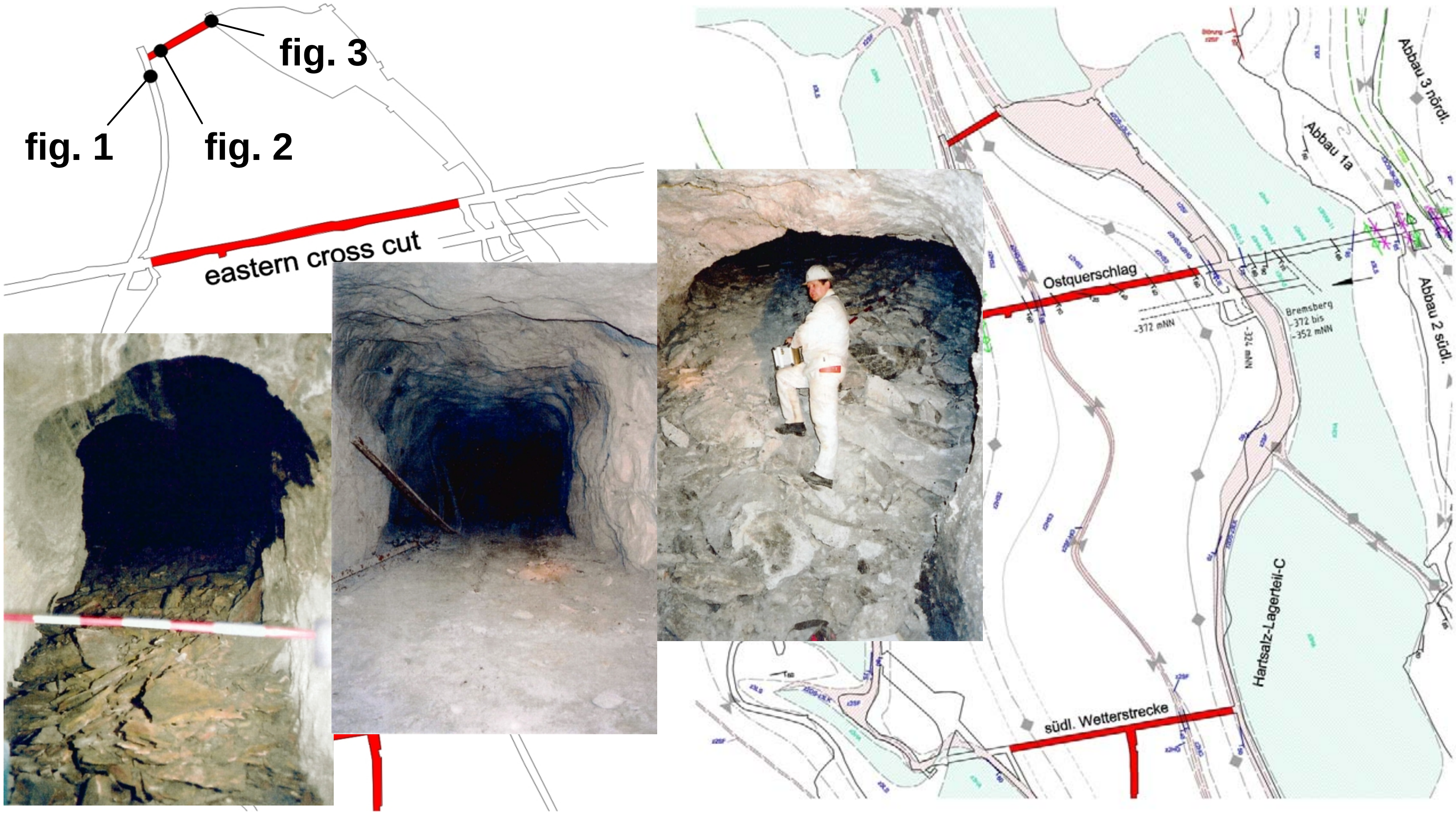
Difficult / limited access of seal locations

Compatibility of seal material with salt concrete backfill

Low convergence rates of rock salt at seal locations

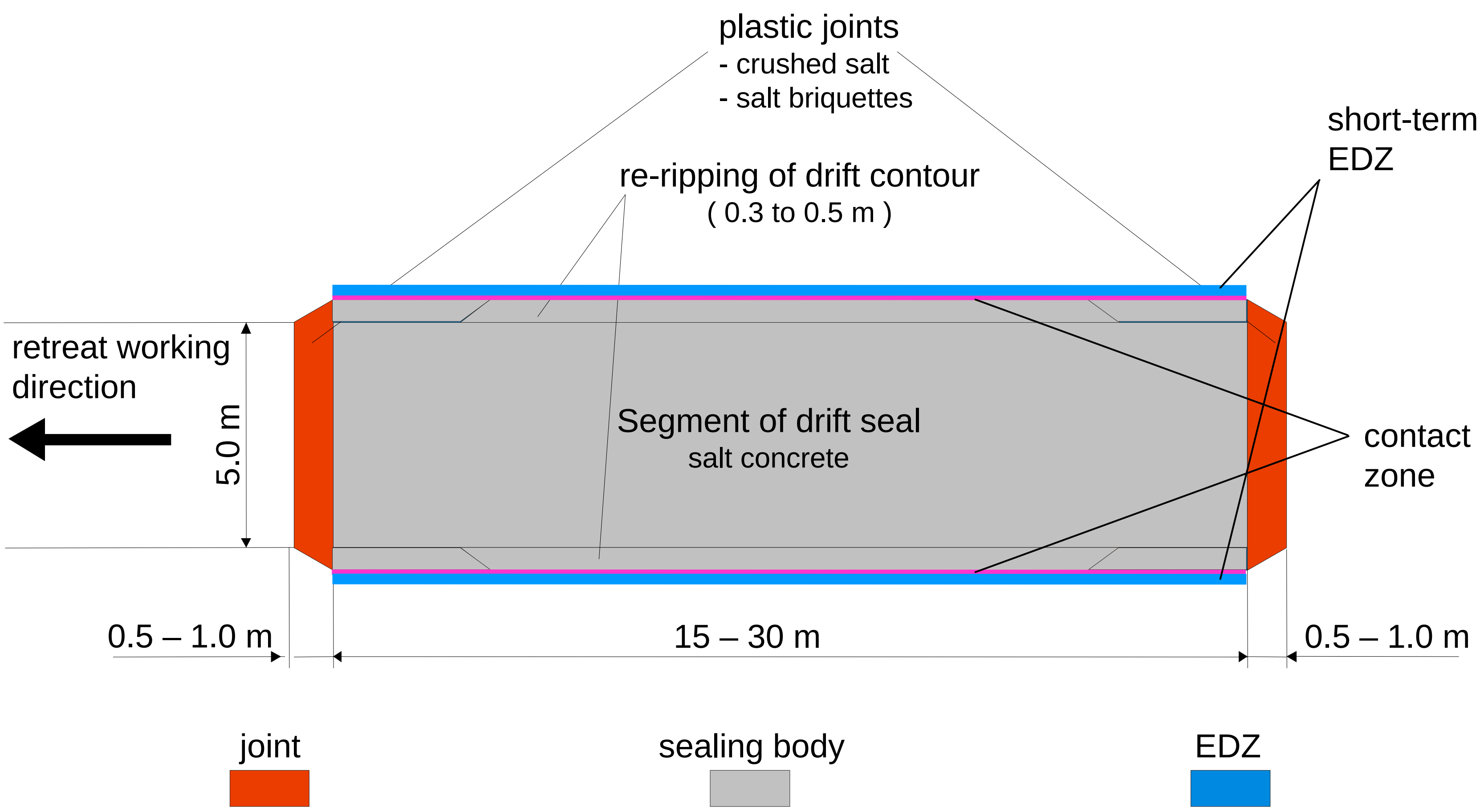
Source: BfS / DBE

Position of drift seals – 3rd level



Source: BfS / DBE

Schematic overview – drift seal segment



Source: BfS / DBE

ERAM drift seals – proof of structural resistivity

- Safety criteria, modelling tools, validated models, and a method to manage uncertainty were applied according to state-of-the-art

→ Adequate level of structural reliability was shown

→ Cooling of salt concrete to avoid temperature-induced cracking

- New question: Cooling of salt concrete avoidable?

→ Applying a more sophisticated salt concrete constitutive model

→ Using cracking index to rate crack evolution

- New question: Autogenous shrinking of salt concrete

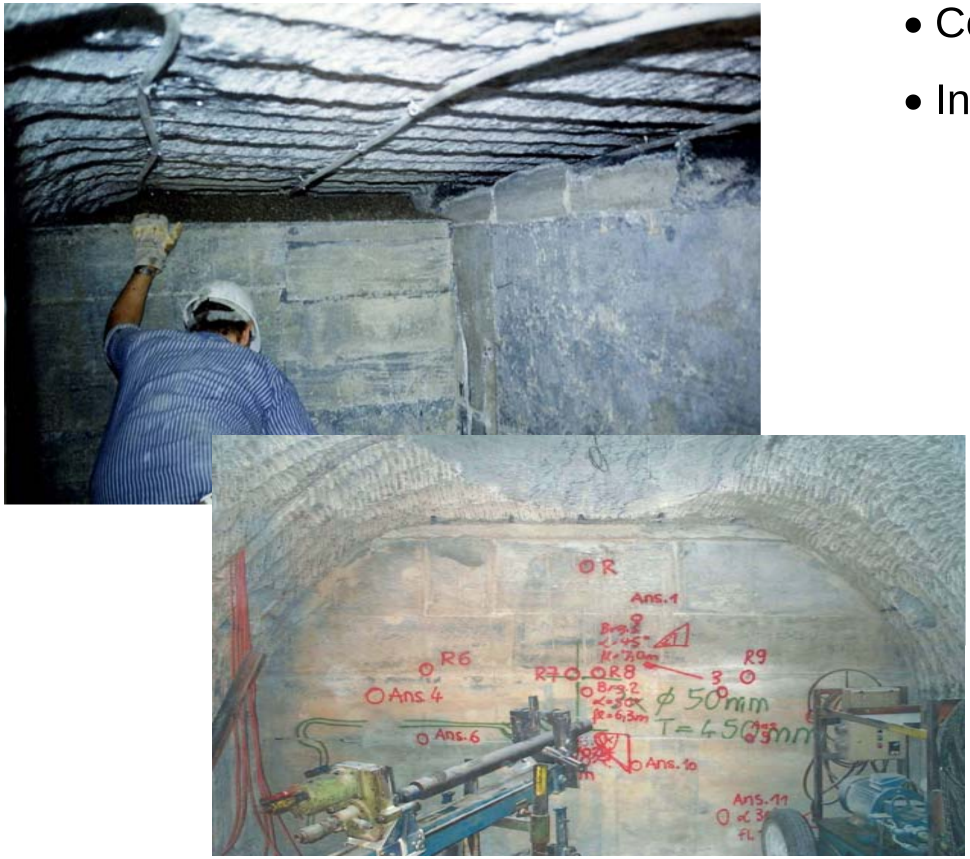
→ Presently, further investigations

Source: BfS / DBE

Flow resistance

Assessing flow resistance of contact zone

Data basis to prove adequate hydraulic resistance of contact zone must be obtained by testing from comparable, existing structures



- Comparable structure: Asse seal
- Investigation:

  Permeability test in situ

  Hydraulic fracturing in situ

  Ultrasonic fault analysis in situ

  Lab tests using core samples from Asse seal

Source: GSF / BfS / DBE

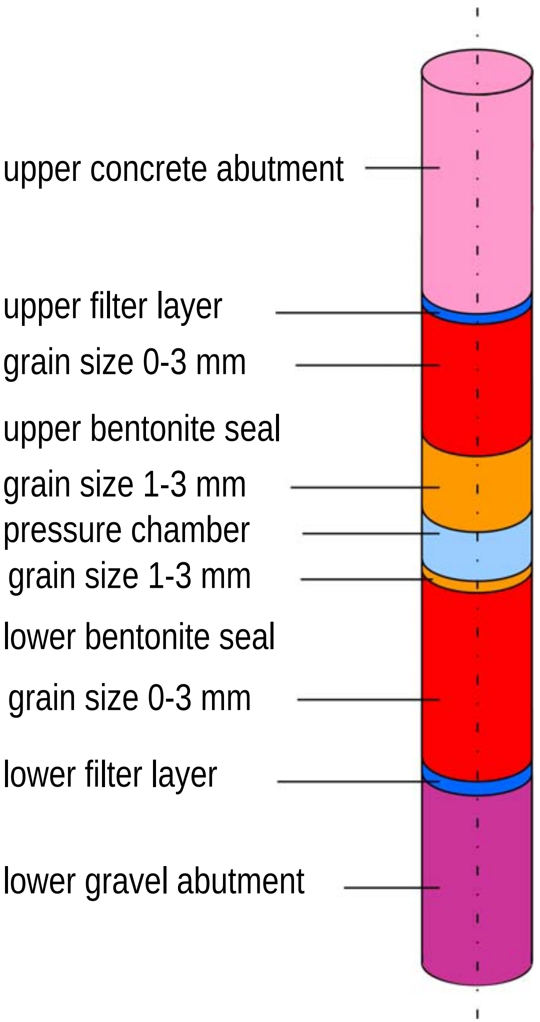
Asse seal – rating investigation results

- The construction process must be improved resp. the structure modified construction-compatible
- The salt concrete sealing body shows a suffiently low permeability
- Basically, the contact zone being a weak spot is avoidable
- The EDZ shows a permeability equivalent to intact rock salt
- Healing of EDZ is uncertain
  → High pore pressure may increase permeability
  → Meeting the fluid pressure criterion is important

Source: BfS / DBE

Example: Experimental shaft Salzdetfurth

Schematic test arrangement

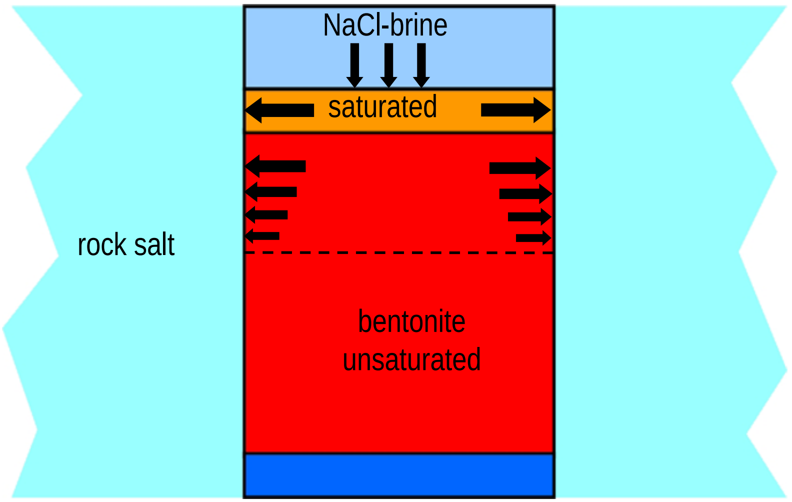


Design requirements from long-term dry closure:

$k_f \leq 5 \bullet 10^{-10}$ m/s

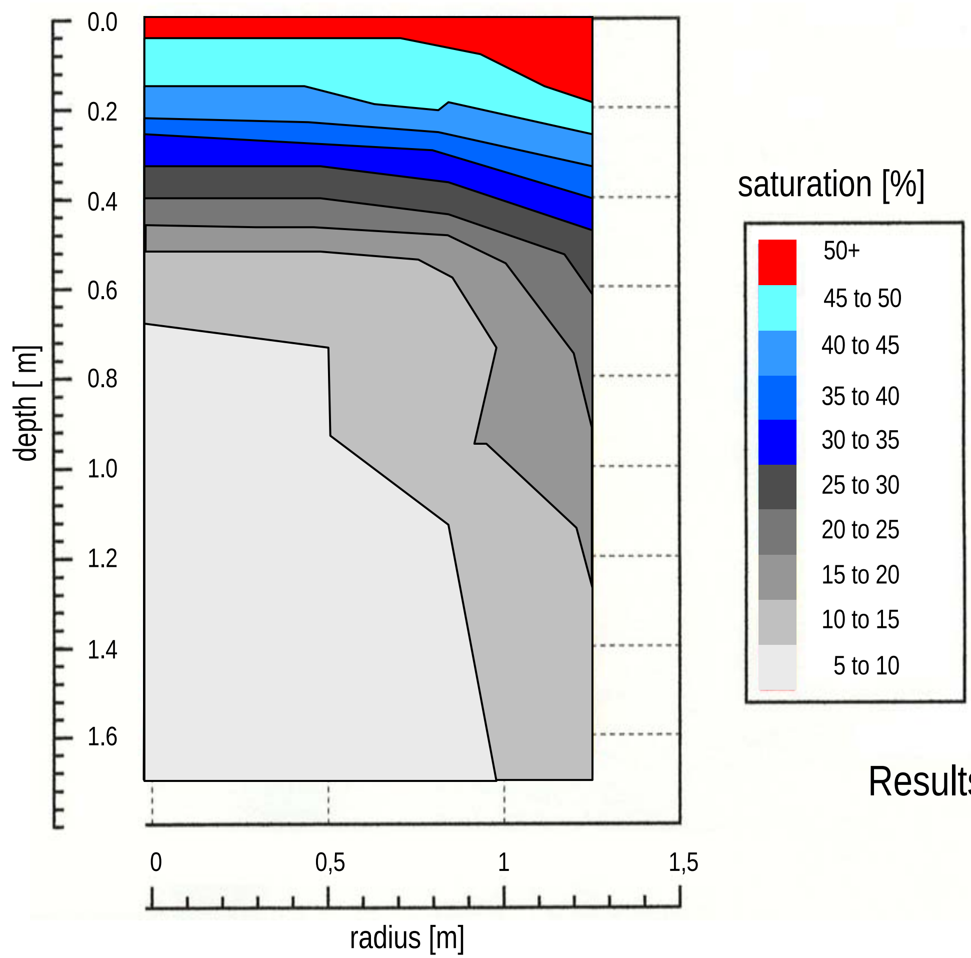
$p_{qo} \geq 1$ MPa (NaCl-brine)

Long-term durability

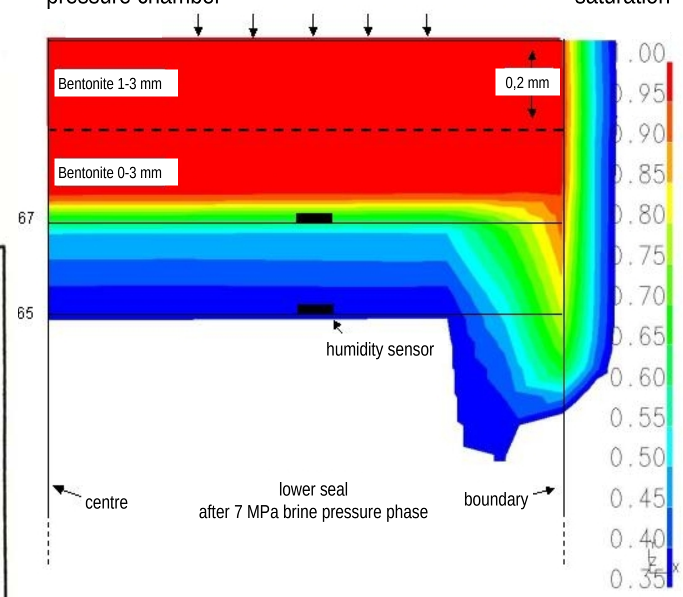


Experimental shaft – saturation of bentonite seal

dismantled seal



calculation results



Results: $k_f = 4,4 \bullet 10^{-11}$ m/s $< 5 \bullet 10^{-10}$ m/s

$p_{qo} \simeq$ 1-1.2 MPa $\geq$ 1 MPa

Long-term durability: natural analogue

Summary and conclusion

ERAM drift seals:

→ Advanced state of proof of structural reliability

→ Main uncertainty: Assessing state of EDZ

Salzdetfurth Shaft II seal:

→ Advanced state of proof of structural reliability

→ Validity is restricted due to initial, boundary, and loading conditions of testing

→ Initial, boundary, and loading conditions might be comparable to Gorleben shaft seals

In the case of an HLW/SF repository in salt rock, proving structural reliability of two independent geotechnical barriers is a realistic option → dry repository evolution