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Shaft seal systems of VSG

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Outline

- Status at US-German Workshops 2010 & 2011
- Technical design procedure
- Selected steps of design procedure
- Results
- Conclusions & outlook

Status at US-German Workshops 2010 & 2011

- Decision to use European Standards in civil engineering (Eurocode) as design basis for the VSG sealing system on a trial basis
  - to derive and apply appropriate technical specifications and procedures
  - to link “long-term SA” and the proof of safety function of sealing systems
  - to assess the consequences of different working lives for sealing systems required in “long-term SA” and Eurocode by decoupling actions and resistances in “short-term” and “long-term” processes as a first approach

➢ As a result, corrosion due to geochemical conditions was identified as a “long-term” acting process on sealing systems causing degradation that is not sufficiently covered by Eurocode

Status at US-German Workshops 2010 & 2011

- The conceptual VSG sealing system (shaft & drift seals) is based on prototypes
  - availability of data for technical specifications (minimize expert judgment)
  - constructability is guaranteed (proof of constructability)

- The sealing system is constructible and the proof of safety function shows a high degree of reliability
- But as a draft not yet optimized

Technical Design Procedure

(1) Conceptual design
(2) Preliminary dimensioning
(3) Basic Design
(4) Dimensioning
(5) Detailed Design

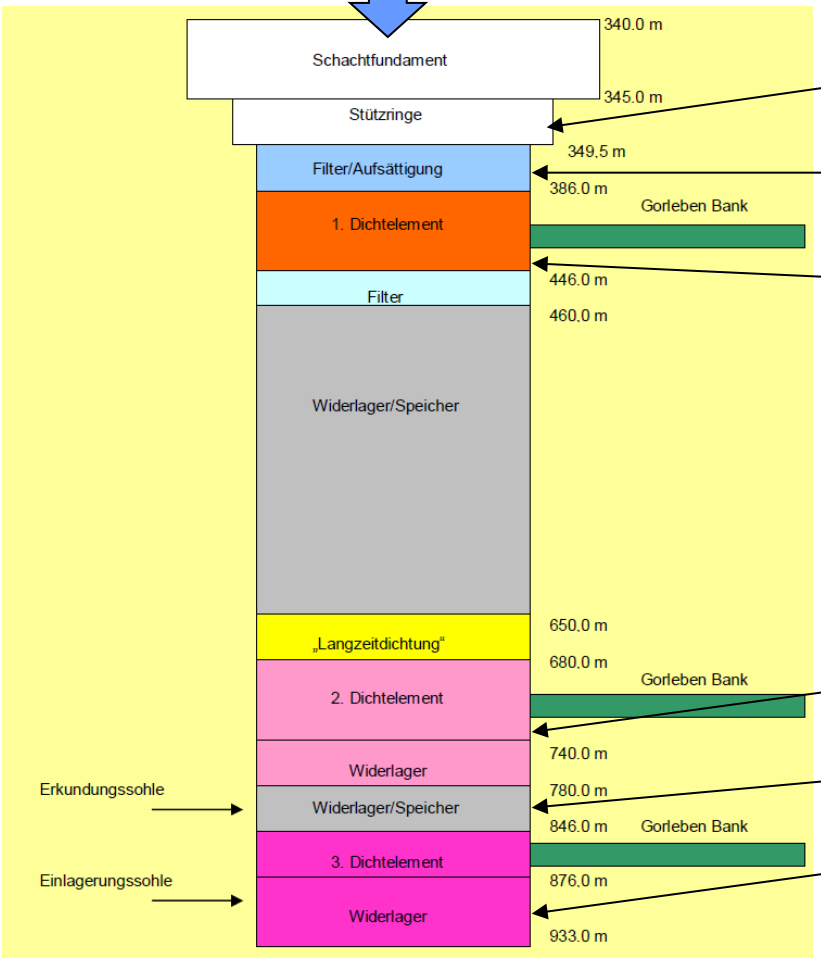
Focus on selected actions (impacts) with high risk for significant design modifications regarding the „unkowns“

Design working life (functional lifetime)
Actions (impacts)
Resistances (depending on design)
Design situations

- As a result, geochemical actions (corrosion) were analysed first due to lack of knowledge on quantitative effects of a long-term impact

(1) Conceptual design – shaft seal (VSG)

Cap rock solution



GS + standard concrete = G1

G1 + salt top = G2

G2 + bentonite = G3

Brine sequences and sealing materials are compatible. Due to limited amount of $MgCl_2$, only small amounts of salt concrete may be corroded.

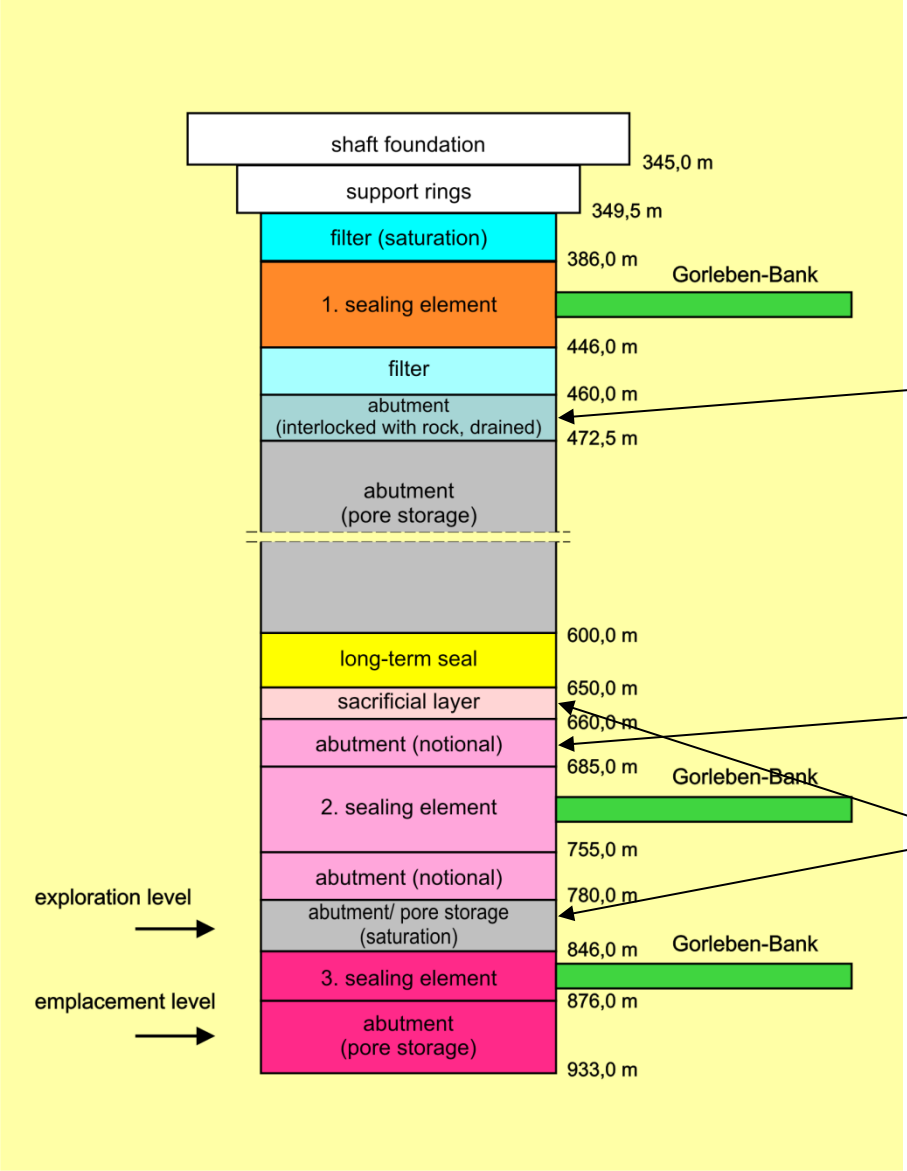
G3 + salt concrete = G4

G4 + technical bischofite = G5

G5 + Sorel concrete = G6

(2) Preliminary dimensioning → basic design

(3) Basic design – shaft seal (VSG)



Basic design includes

- necessary design modifications
- dimensions

seismic event (earthquake)

Brine pressure from overburden

Chemical impact (corrosion)

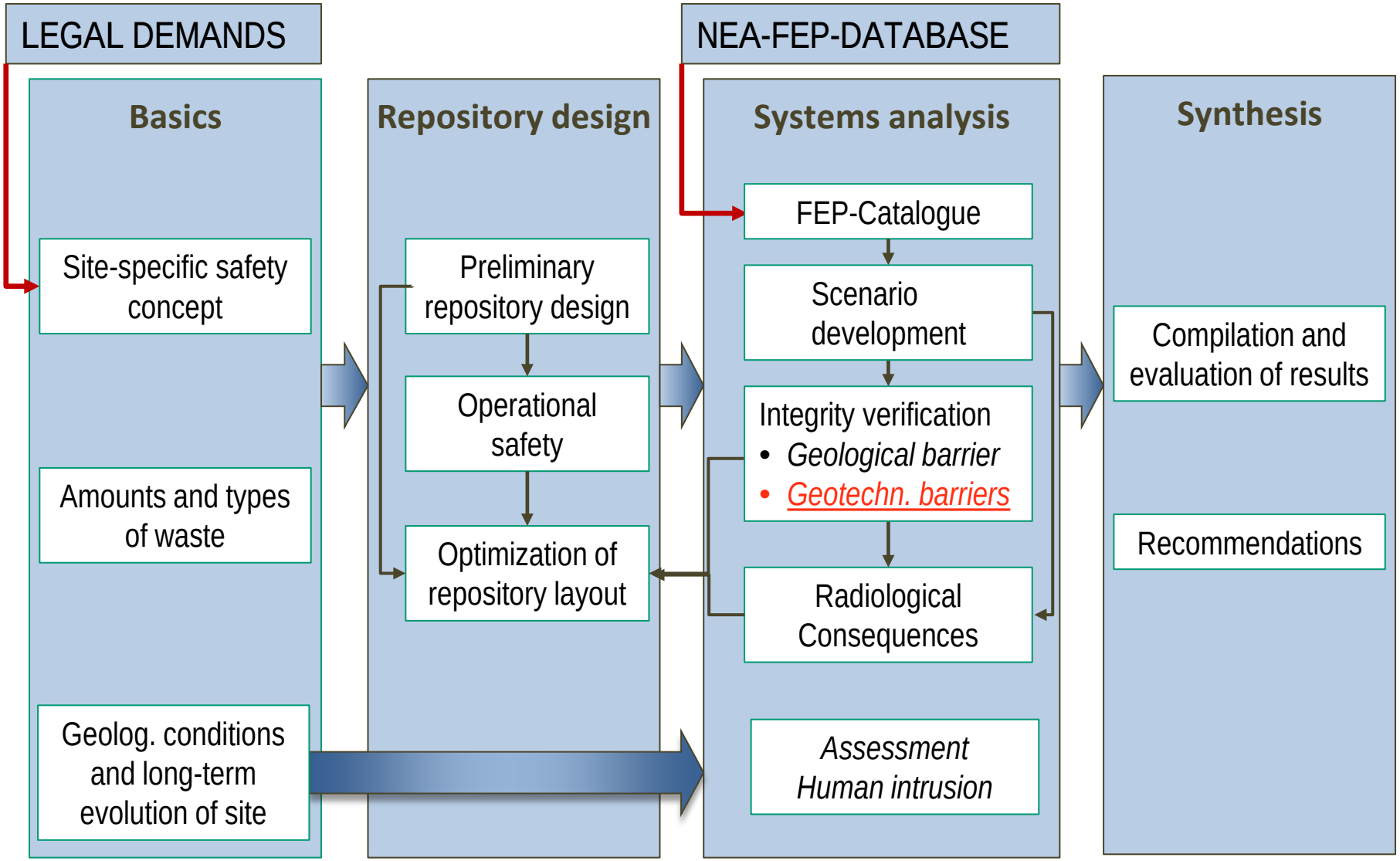
(4) Dimensioning

- Basic design is a highly back coupled “input structure” for systems analysis within the safety case
- Significant basic design modifications are possible in principle

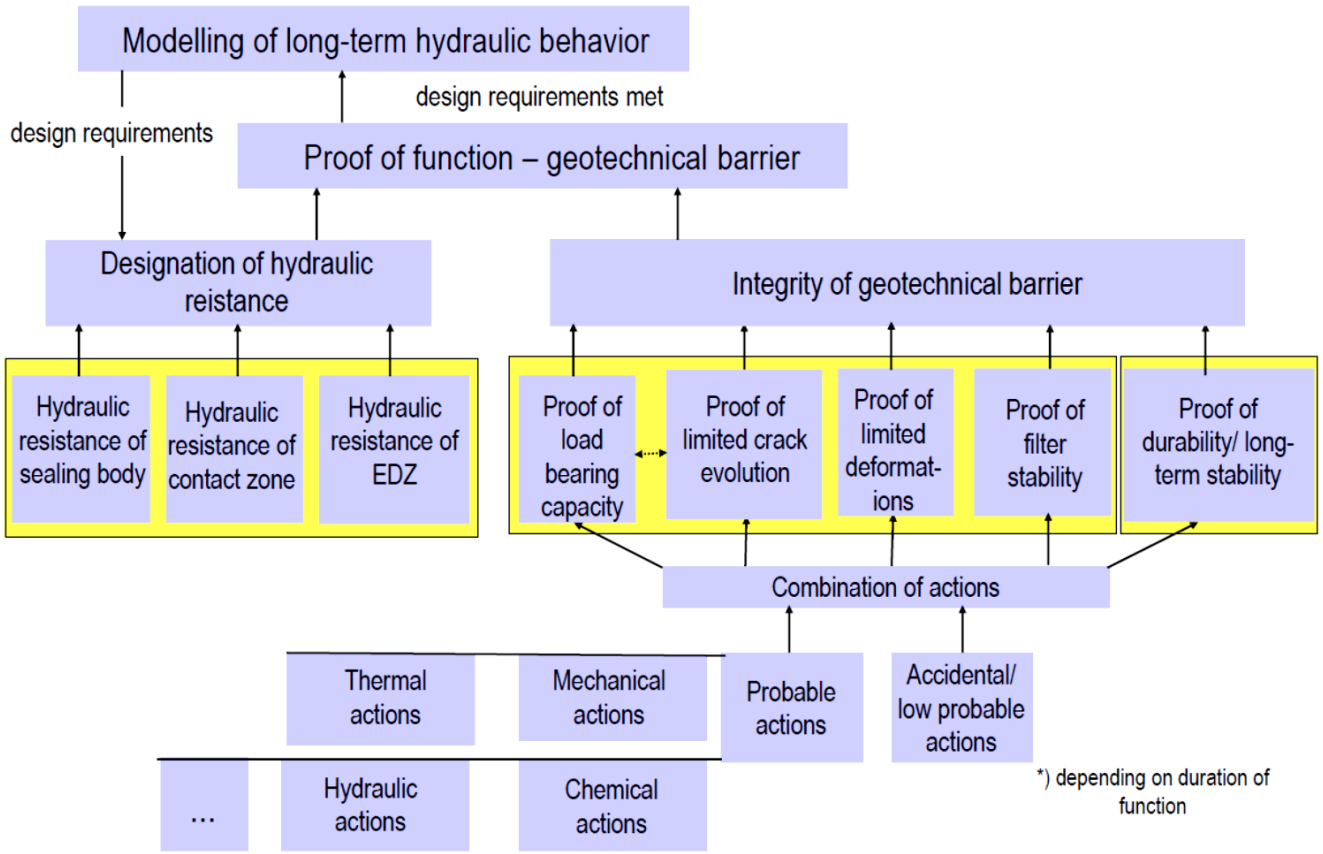
➢ But the structure of the safety case may significantly be affected

➢ “Good” basic design is essential

(4a) Structure of safety case - VSG



(4b) Scheme of technical functional proof - VSG



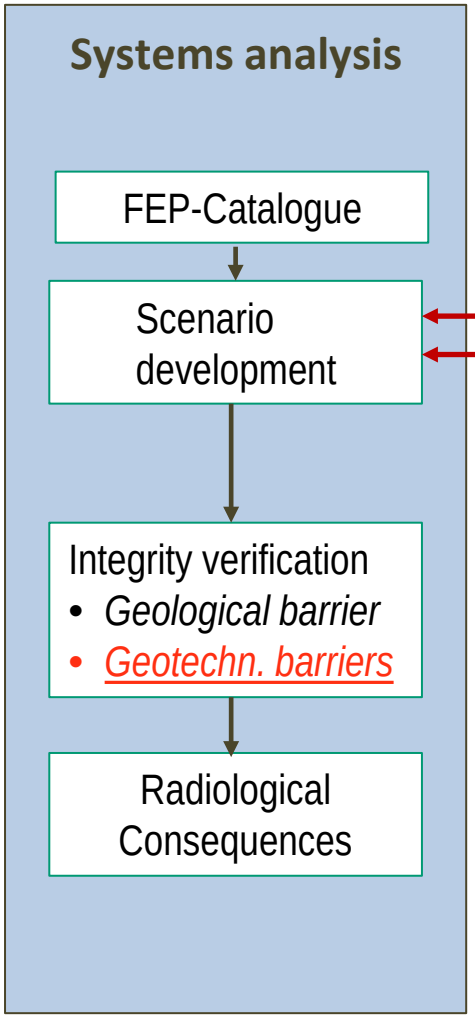
$$E_d \leq R_d$$

E_d: Design values of effects of actions

R_d: Design values of resistances

Unusual design working life: 50,000 years until next ice age

(4c) FEPs affecting geotechnical barriers - VSG



Initial FEPs

FEP-No.	FEP-Name	Affected geotechnical barrier
1.2.03.01	Earthquake	Shaft seal, drift seal
1.2.09.01	Diapirism	Shaft seal, drift
1.2.09.02	Subrosion	Shaft seal
1.3.05.03	Formation of glacial channels	Shaft seal
2.1.05.04	Alteration of drift and shaft seals	Shaft seal, drift seal
2.1.07.01	Convergence	Shaft seal, drift seal
2.1.07.02	Fluid pressure	Shaft seal, drift seal
2.1.07.04	Volume changes in materials – not thermally induced	Shaft seal, drift seal
2.1.07.07	Displacement of shaft seal	Shaft seal
2.1.08.08	Swelling of bentonite	Shaft seal
2.1.09.02	Solution and precipitation	Shaft seal, drift seal
2.1.09.06	Corrosion of materials with cement or magnesium oxychloride phases	Shaft seal, drift seal
2.2.01.01	Excavtion damaged zone	Shaft seal, drift seal
2.2.06.01	Change of stresses	Shaft seal, drift seal

Less likely FEPs

FEP-No.	FEP-Name	Affected geotechnical barrier
2.1.07.05	Early failure of a shaft seal*	Shaft seal
2.1.07.06	Early failure of a drift seal*	Drift seal
2.1.08.05	Piping in seals	Shaft seal, drift seal

*incl. malfunction caused by insufficient construction process

(4d) Actions & design situations - VSG

No.	Name of action
Chemical actions	
1.	Chemical actions induced by solutions and gases
2.	Chemical actions induced by temperature change
Mechanical actions	
1.	Effects due to forces and stresses
1.1	Dead load
1.2	Rock pressure
1.3	Fluid pressure
1.4	Flow forces
1.5	Restraint stresses
1.6	Mass forces (earthquakes)
2.	Effects due to impressed strains
2.1	Thermal expansion/contraction
2.2	Swelling/shrinking
2.3	Creep/relaxation
2.4	Restraint strains (deformation constraints, settling)

DIN EN 1990, DIN EN 1997 …

Design situation	Characteristic conditions
Transient situations*	Temporary, normal situations, e.g. construction process
Persistent situations*	Normal situations according to normal function and use
Abnormal (accidental) situations**	Rare, mostly extraordinary situations, e.g. accidental situations as impacts or explosions
Seismic situations (earthquakes)***	Short, limited in time, design-defining earthquakes rare

* will occur ** will probably not occur ***regional differences in occurrence

(4e) Linkage of FEPs, actions & design situations

FEP-No.	FEP-Name	Classification within the functional proof*
1.2.03.01	Earthquake	DS, seismic DS; A, mass forces
1.2.09.01	Diapirism	A, restraint strains
1.2.09.02	Subrosion	Excluded, because significance starts with next glaciation (after selected performance period)
1.3.05.03	Formation of glacial channels	Excluded, because significance starts with next glaciation (after selected performance period)
2.1.05.04	Alteration of drift and shaft seals	A, consequence of chemical action incl. temperature
2.1.07.01	Convergence	A, equivalent to rock pressure due to constitutive equation
2.1.07.02	Fluid pressure	A, fluid pressure
2.1.07.04	Volume changes in materials – not thermally induced	A, swelling/shrinking
2.1.07.07	Displacement of shaft seal	A, restraint strains or a consequence of forces/stresses
2.1.08.08	Swelling of bentonite	A, swelling
2.1.09.02	Solution and precipitation	A, consequence of chemical action incl. temperature
2.1.09.06	Corrosion of materials with cement or magnesium oxychloride phases	A, consequence of chemical action incl. temperature
2.2.01.01	Excavation damaged zone	Neither DS, A nor R but component of the seal
2.2.06.01	Change of stresses	A, dead load, rock pressure, fluid pressure, flow forces, restraint stresses

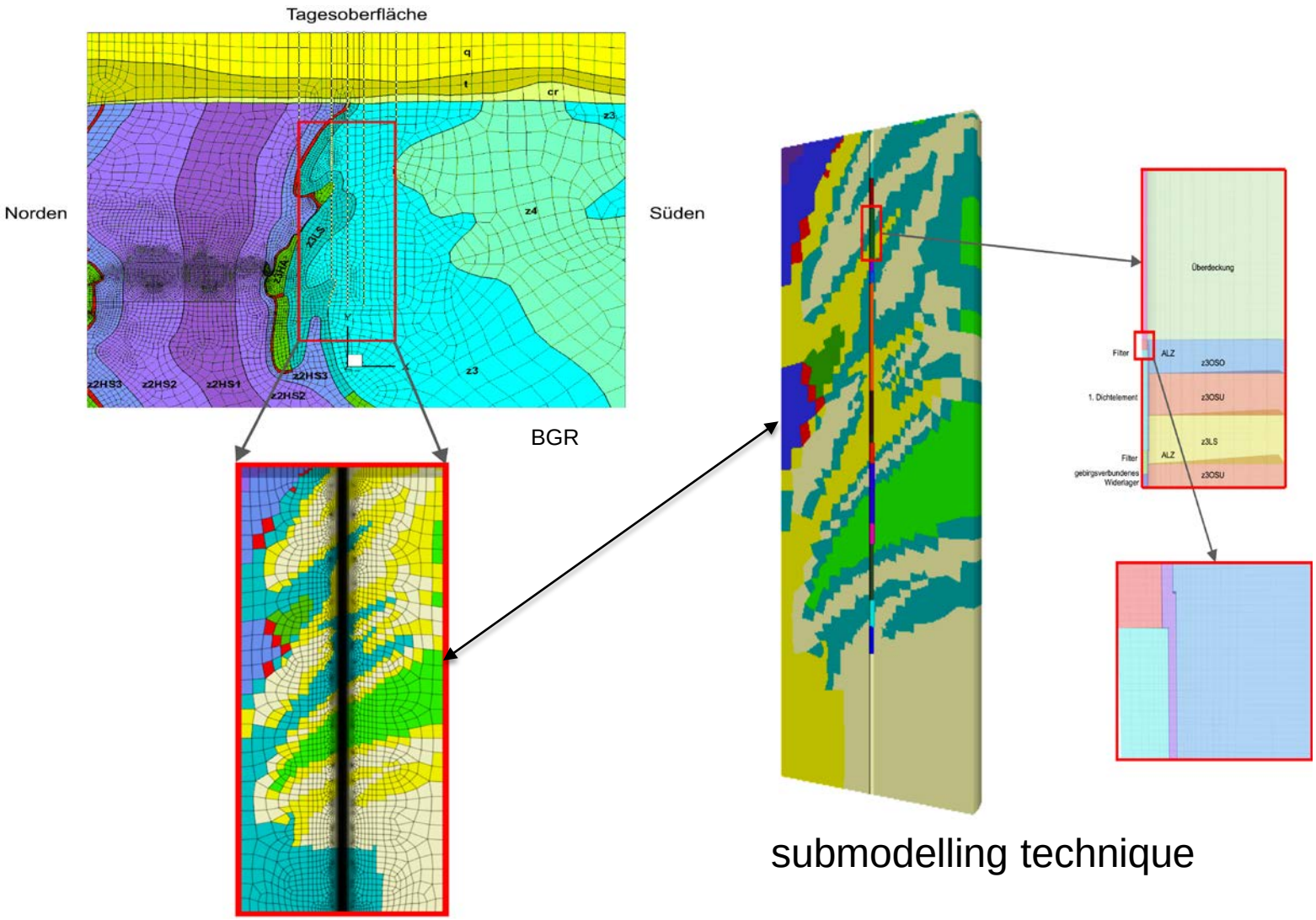
* If classification is impossible or meaningless, a comment is given

Classification of FEPs within the technical functional proof

DS = design situation
A = action
R = resistance

FEP-No.	FEP-Name	Classification within the functional proof
2.1.07.05	Early failure of a shaft seal	DS, abnormal situation
2.1.07.06	Early failure of a drift seal	DS, abnormal situation
2.1.08.05	Piping in seals	A, consequence of chemical actions or flow forces

(4f) Calculations - VSG



submodelling technique

(5) Detailed design

- Insignificant modifications of basic design

➢ Ready to start construction process

Results – Integrity of Shaft Seal

- Individual proofs to guarantee integrity were successful regarding relevant combinations of thermal, mechanical, and chemical actions

- Thus, the prognosis that hydraulic resistance as planned will really be achieved shows high level of reliability

- Pre-condition: Highly qualified construction process
- “As built” and “as planned” may be different!

Conclusions & Outlook

- Regarding VSG shaft seal linkage of safety case & technical functional proof was successfully put into practice

- Progress has been made
  - Individual technical proofs forged ahead
  - Technical specifications are available forming the basis for suitability tests
  - Technical basis to establish quality assurance procedures is available

- Open questions
  - Assessing the influence of contact zones/interfaces
  - Especially experimental data is still rare

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Thank you
for your attention!