Large scale in-situ experiments on sealing constructions in underground disposal facilities –

Examples of recent BfS and GRS activities

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Part 1, R. Mauke: BfS in-situ experiments related to the closure concept and sealing measures of the low- and intermediate-level radioactive waste disposal facility Morsleben (ERAM)

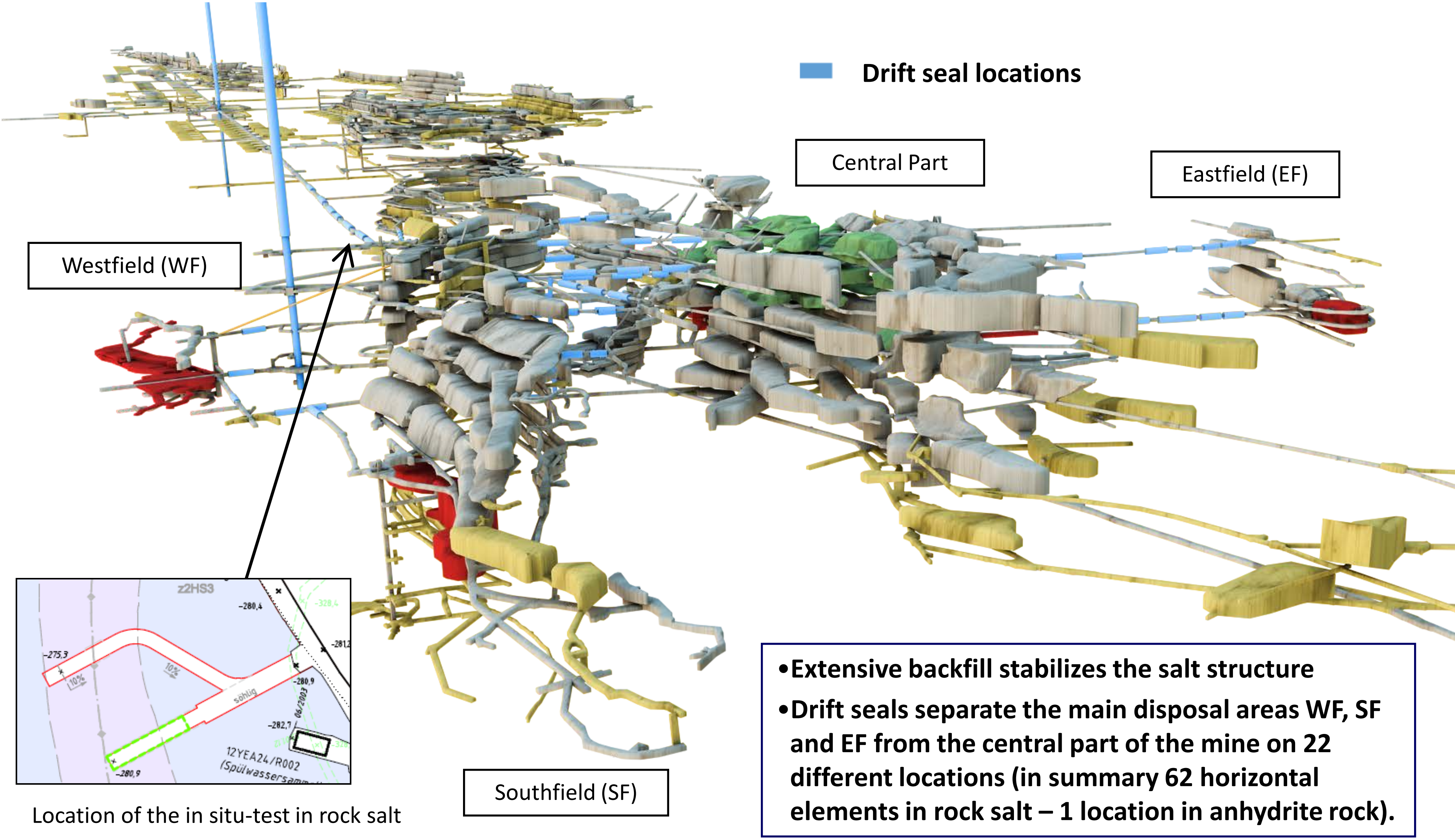
Part 2, H.-J. Herbert: GRS contributions to sealing concepts

Background

- Radioactive waste disposal facilities in deep geological formations must safely be sealed for long time periods
- Based on the site specific knowledge of the geological situation and possible evolution scenarios of the disposal system, safety concepts must be developed which verify that the goal of containment and isolation can be achieved.
- Before construction of a disposal facility, a long-term safety analyses must prove that no hazardous impact on the biosphere may occur
- Closure concept for underground disposal facilities include detailed planning for specific sealing constructions
- The extensive verification management in waste disposal uses natural analogues, modelling calculations, laboratory and large scale in-situ experiments as well as different prediction procedures, in order to also consider unavoidable uncertainties and inadequate knowledge.

This paper gives an insight into the respective work of BfS and GRS.

Closure concept and sealing measures of the low- and intermediate-level radioactive waste disposal facility Morsleben (ERAM)



Location of the in situ-test in rock salt

- **Extensive backfill stabilizes the salt structure**
- **Drift seals separate the main disposal areas WF, SF and EF from the central part of the mine on 22 different locations (in summary 62 horizontal elements in rock salt – 1 location in anhydrite rock).**

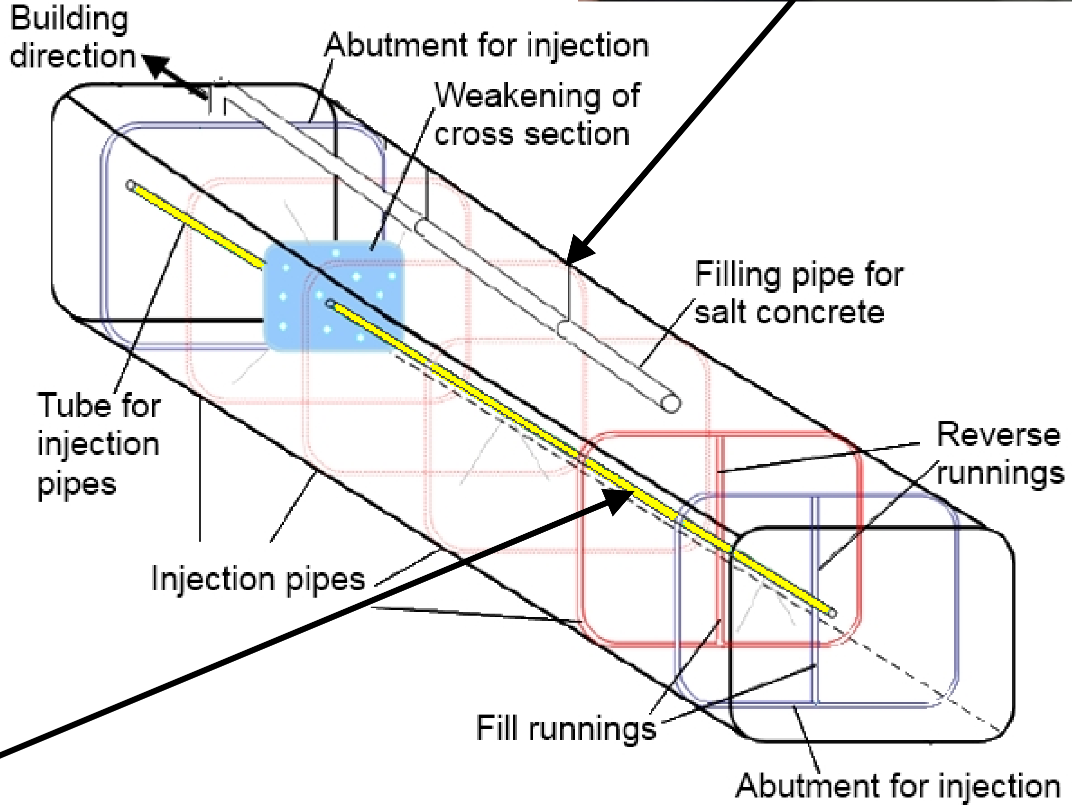
In-Situ Test - Proof of Drift Seals Performance

Technical feasibility
- Structural manufacturability
- Requirements for the salt concrete

Proof of functionality
- Integral permeability
- Connection of concrete to the rock salt
- Injectability of the contact zone

Short test period in comparison to the real drift seal

More detailed design with injection measures



<u>More objectives:</u> improved understanding of up scaling effects on material behavior, building technology and flow processes

In situ-experiments related to sealing measures in horizontal drifts in rock salt – Construction Design and Geotechnical Measurements

Measurements on in-situ test

Requirements of concrete technology (e. g. Temperatures, Stresses, Displacements Strength, Young-Modul, Porosity, Permeability)

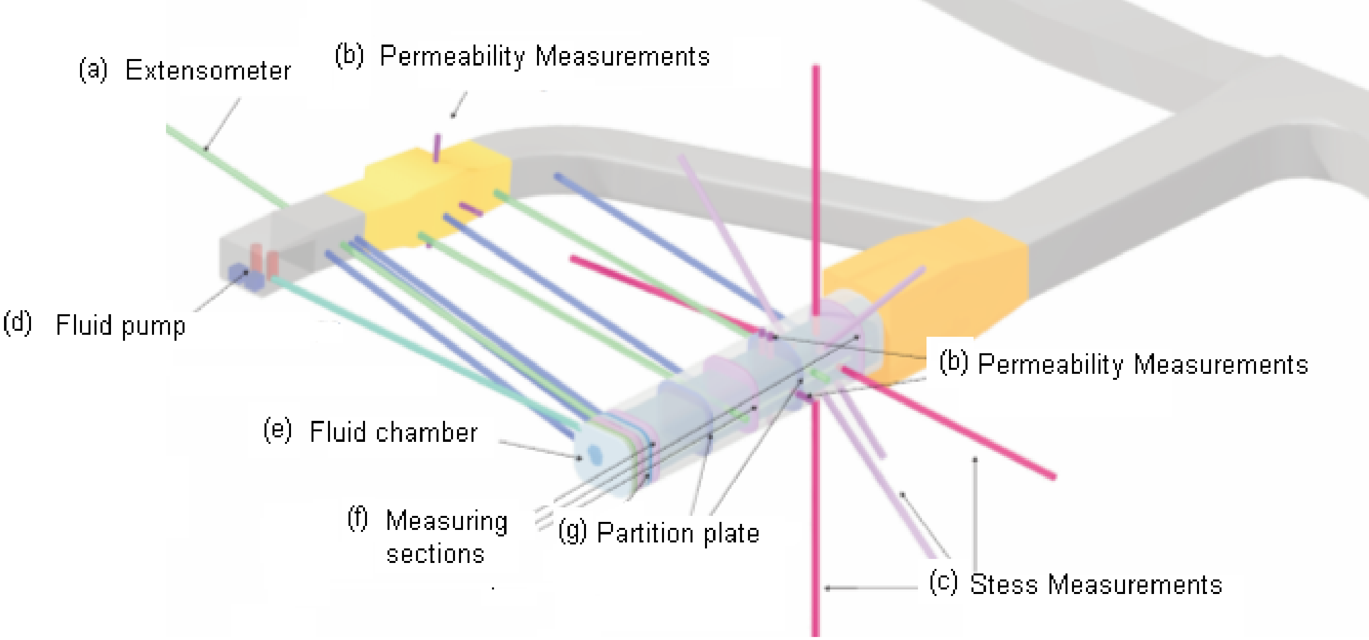
Connection of concrete to the rock salt (e. g. Cores from the contact zone)

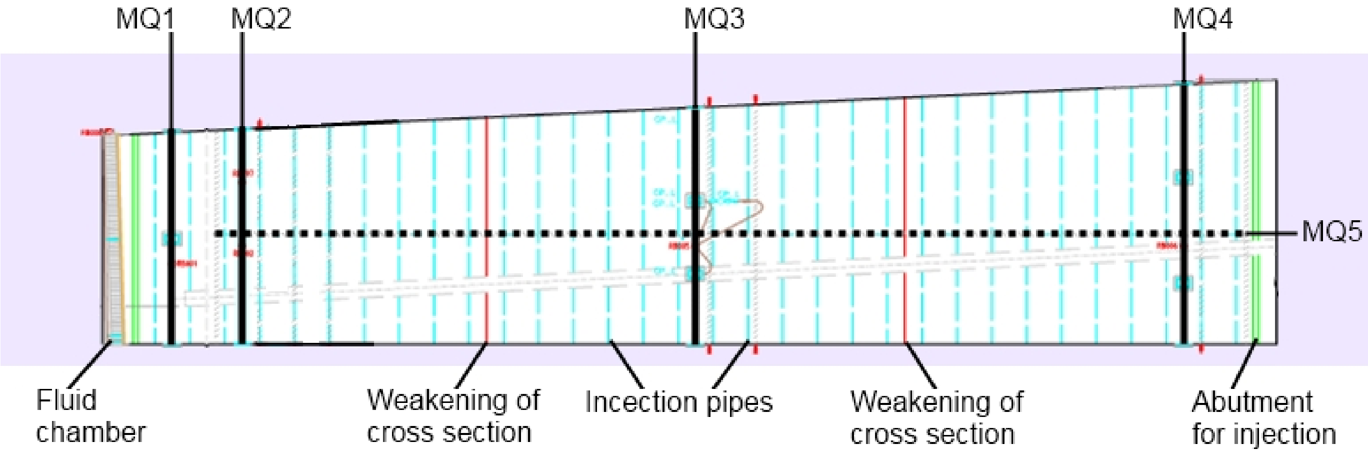
Integral permeability (Tests to determine the permeability for gas and solution, loading the fluid chamber with pressure)

Injectability of the contact zone

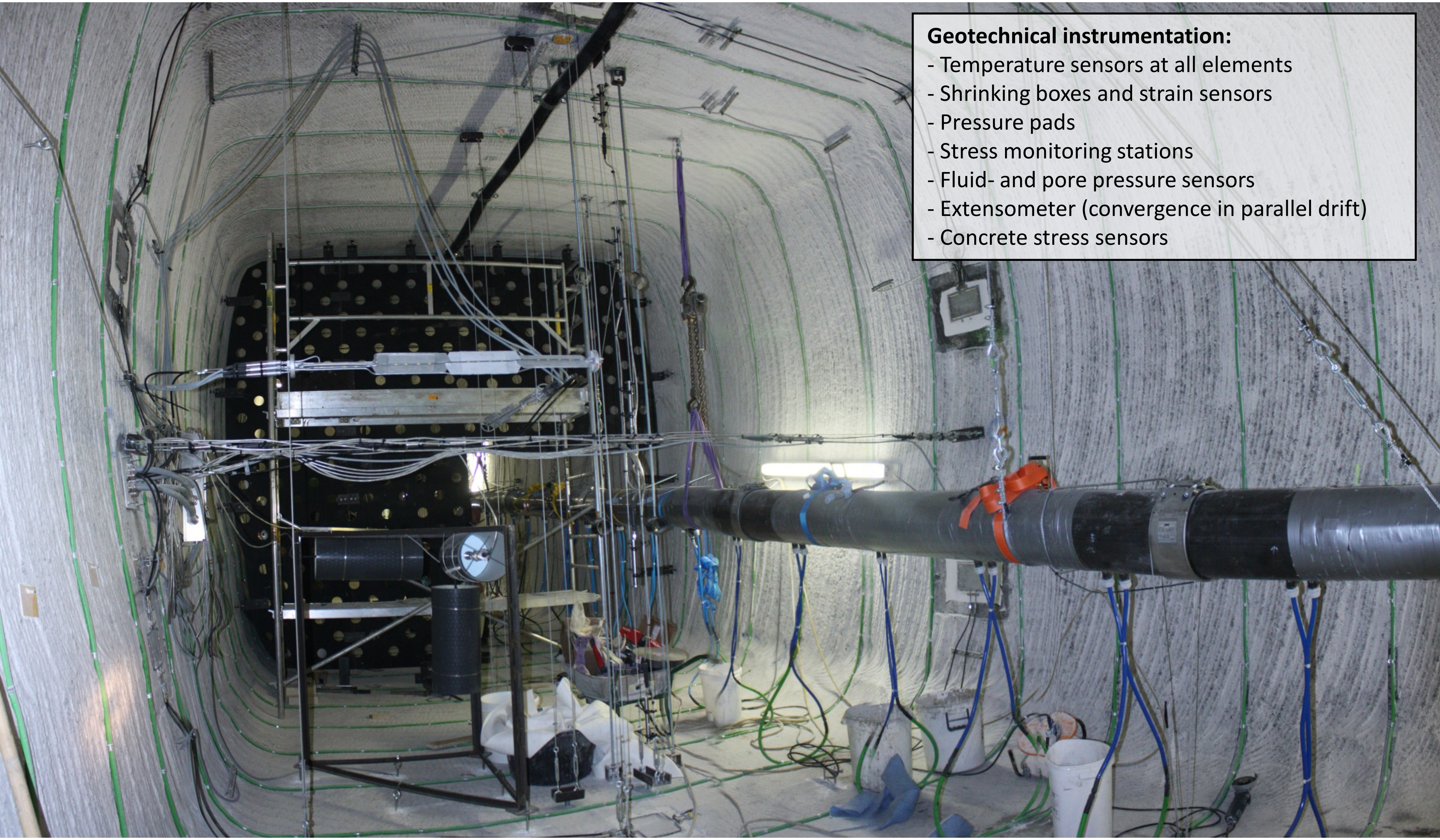
Mechanical Stability of location

Prediction of stresses and deformations with calibrated numerical analysis





In-situ Test - Impression of Construction - Instrumentation

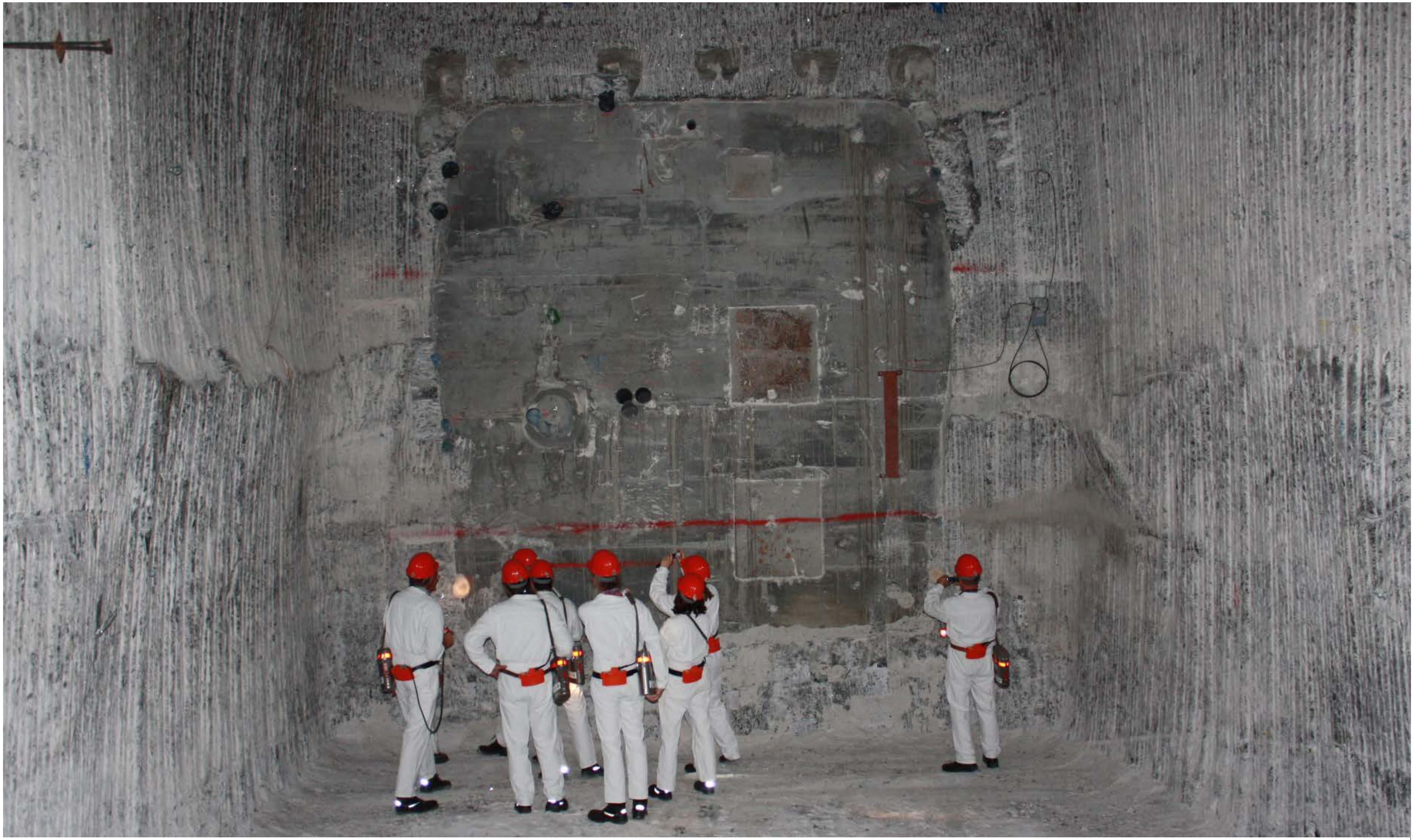


Geotechnical instrumentation:
- Temperature sensors at all elements
- Shrinking boxes and strain sensors
- Pressure pads
- Stress monitoring stations
- Fluid- and pore pressure sensors
- Extensometer (convergence in parallel drift)
- Concrete stress sensors

In-Situ Test - Impressions of Construction - Concreting

Concreting of the drift seal (484 m³ - continous construction time: 20 h – 15. / 16. Dez. 2010)

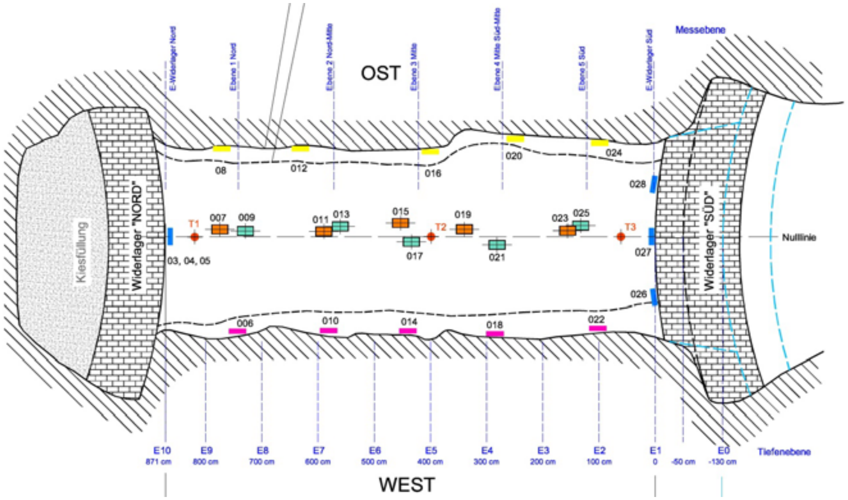
In-Situ Test – Actual View of the finished Construction



Dimension of the construction: height: 4 to 5m, width: 4,5m, length: 25m
(This real full scale experiment represent a typical drift seal profile.)

In situ-experiments related to sealing measures in horizontal drifts in anhydrite rock

Laboratory medium scale tests



In situ-Test site before concreting
(nearly full scale: length: 8 m)

In situ-experiments related to vertical sealing systems for vertical drifts and shafts

Laboratory small scale tests (hight: 60 cm)

Real scale for shaft sealing elements (diameter: 8 m)

Conclusions Part 1 – BfS large scale in-situ exeriments

- Reliable 1:1 scale in-situ data on sealing structures are essential (particularly for the plan approval procedure).
- In-situ experiments are important to demonstrate the technical feasibility.
- However in in-situ experiments only the initial state of these structures can be built according to plan and can be monitored (often only limited proof of functionality).
- In addition, not all possible system states (e.g. increase pressure with different, particularly slow rates, corrosion effects in the case of different compositions of solutions, influence of saturation, …) can be simulated in situ.
- Furthermore the characteristics of the in-situ sealing test structures’ can be influenced by the measuring equipment and the measurements themselves.
- The target value for the parameters to be determined is frequently in the range of the limits of detection of the measuring systems used.
- Within a realistic period of measurement, no stationary behaviours can be expected.
- These considerations do not diminish the great value of in-situ tests. They are as important as forecast models.
- Such models are needed for the extrapolation of the results in long term safety assessments.
- The extrapolation quality of such models also is subject to uncertainties which must be evaluated.

Part 2 – GRS contributions to sealing concepts

GRS contributions to sealing concepts in rock salt and potash salt formations

Analyses on issues related to the long term behaviour of construction materials

- **Materials investigated:**
  - Salt concrete
  - Sorel concrete
  - Self Sealing Backfill (SVV)

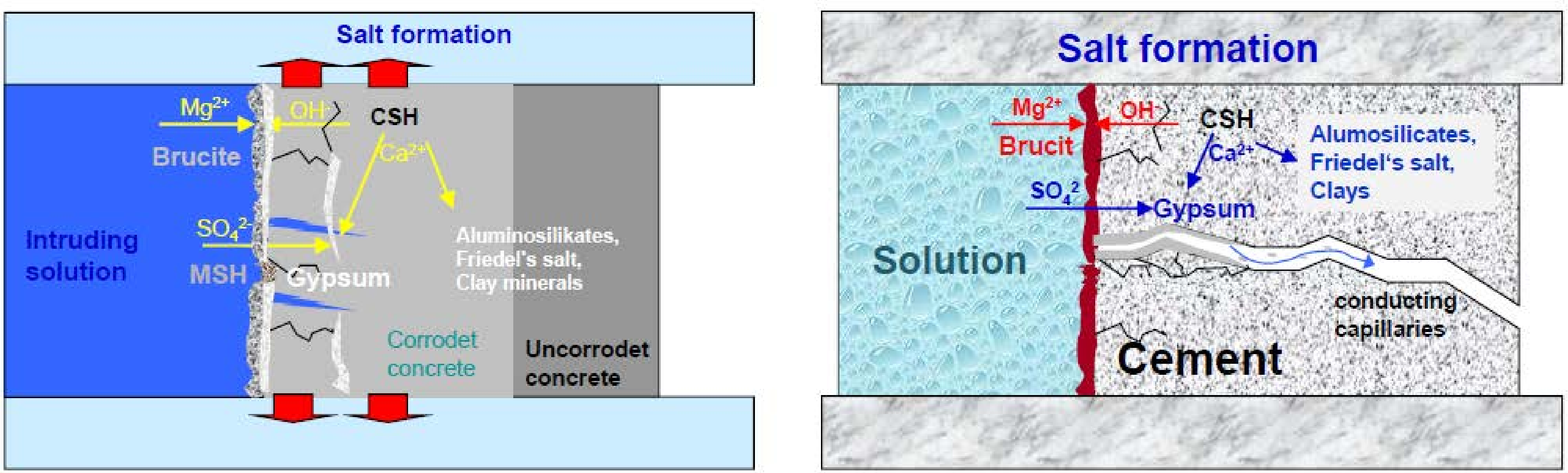
- **Investigation methodology:**

  - **Laboratory investigations**
    - Geochemical experiments
    - Hydromechanical experiments

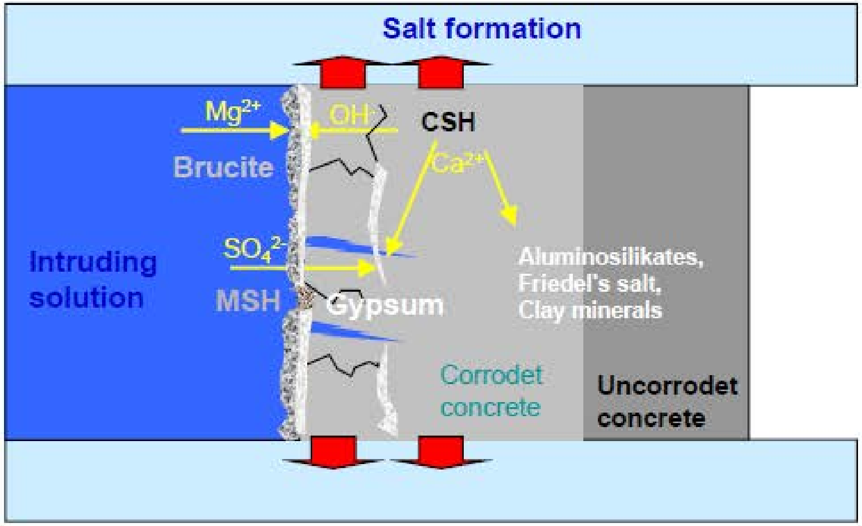
  - **In-situ experiments**

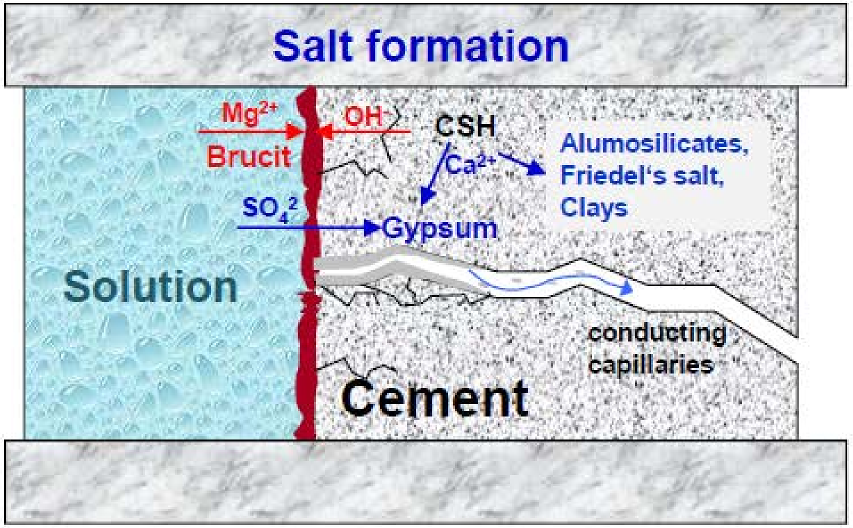
  - **Modeling**
    - Geochemical modeling
    - Reactive transport modeling

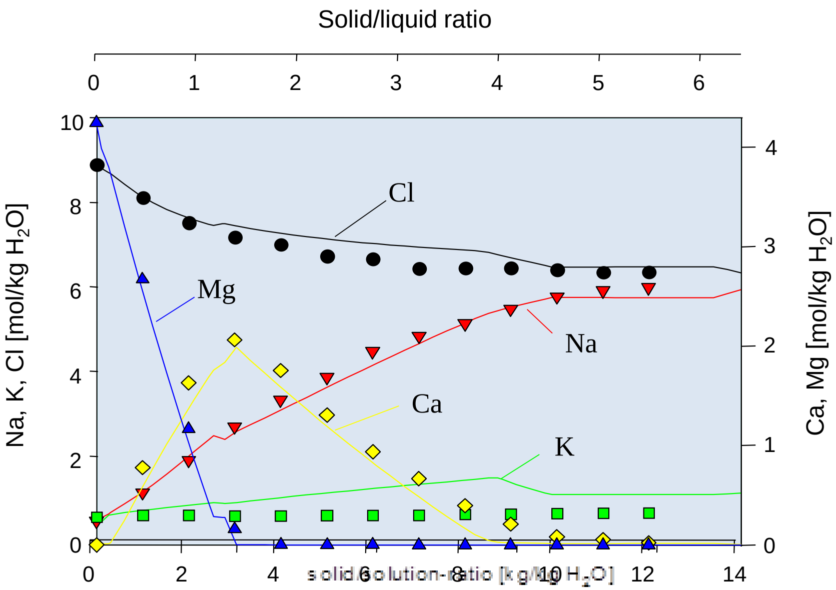
Corrosion of salt concrete by a Mg-rich (IP21) brine

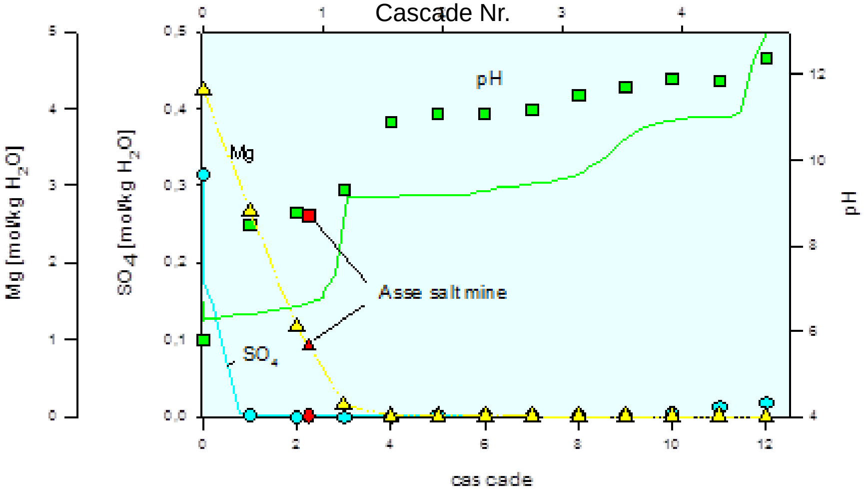


Schematic representation of corrosion processes in salt concrte due to the interaction with brine (left) matrix corrosion, diffusive magnesiumsulfate attac and (right) advective magnesiumsulfate attac


Salt formation
Mg^{2+}
OH$^-$
CSH
Brucite
Ca^{2+}
SO$_4^{2-}$
Intruding solution
MSH
Gypsum
Aluminosilikates,
Friedel's salt,
Clay minerals
Corrodet concrete
Uncorrodet concrete

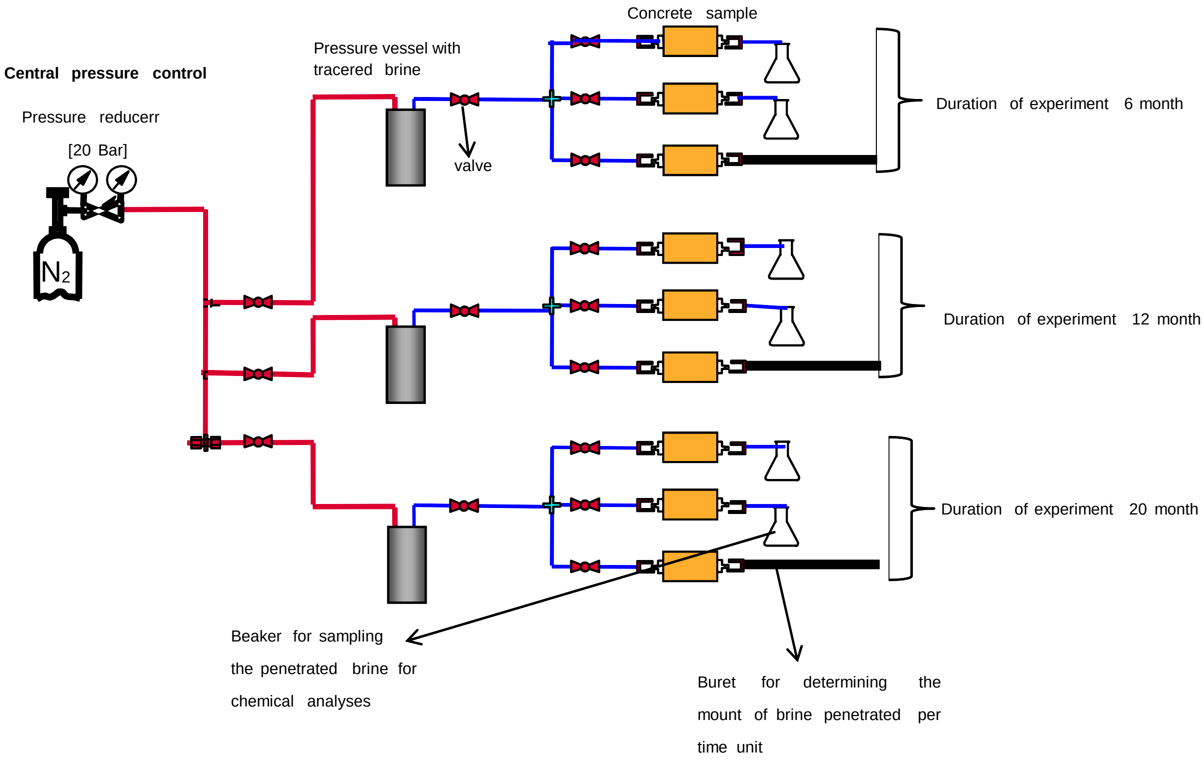

Salt formation
Mg^{2+}
OH$^-$
CSH
Brucit
Ca^{2+}
Alumosilicates,
Friedel's salt,
Clays
SO$_4^{2}$
Gypsum
Solution
conducting capillaries
Cement





salt concrete / main elements	mol / kg H_2O
Na	8,77
K	0,208
Ca	1,54
Mg	0,415
Cl	8,74
SO_4	0,187
water content [mg/kg$_{solid}$]	5,16
total carbon [mg/kg$_{solid}$]	0,80

mol/kg H_2O	IP21$_{mes}$	ReacSol 41d zi=0,33
Na	0,467	0,582
K	0,543	0,544
Ca	0,001	0,006
Mg	4,18	4,13
Cl	8,68	8,76
SO_4	0,280	0,130
Density [g/cm³]	1,291	1,280



Central pressure control

Pressure reducerr

[20 Bar]

N_2

Pressure vessel with tracered brine

valve

Concrete sample

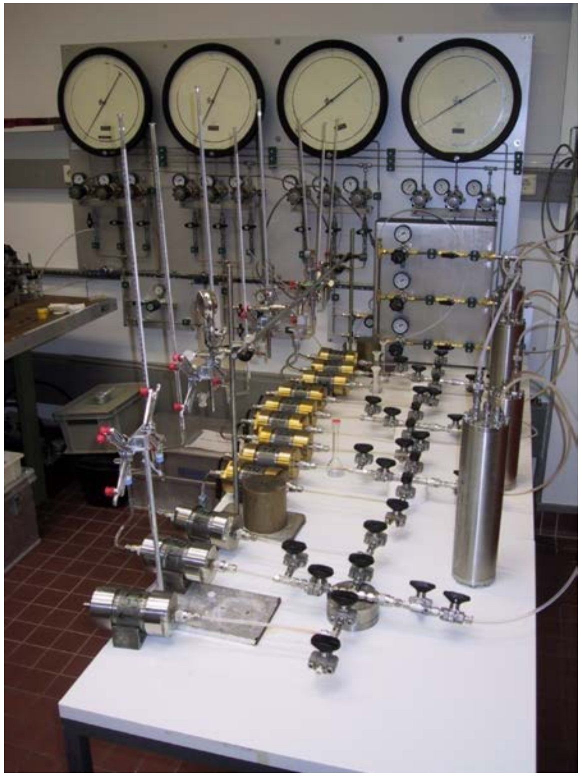
Duration of experiment 6 month

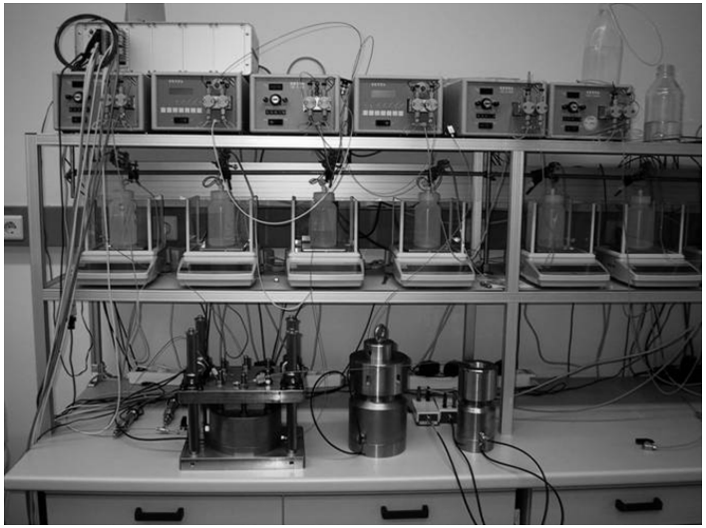
Duration of experiment 12 month

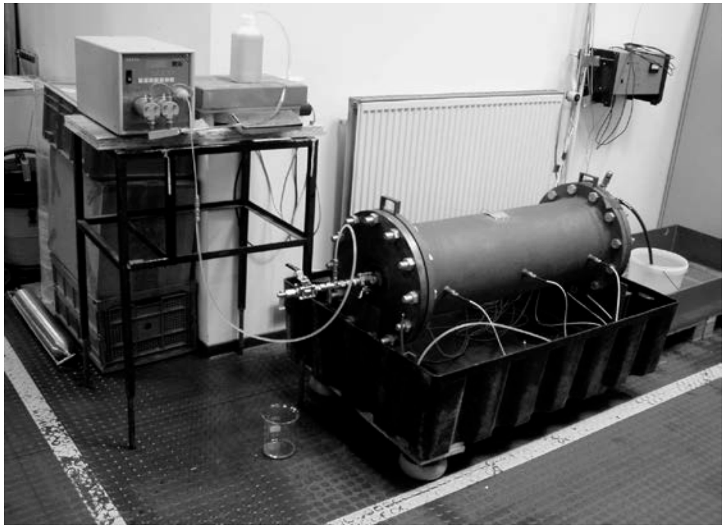
Duration of experiment 20 month

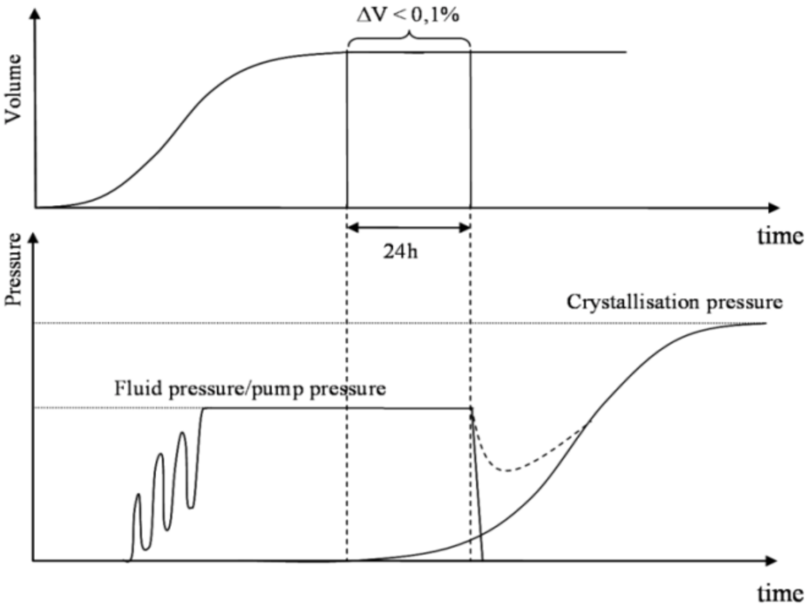
Beaker for sampling the penetrated brine for chemical analyses

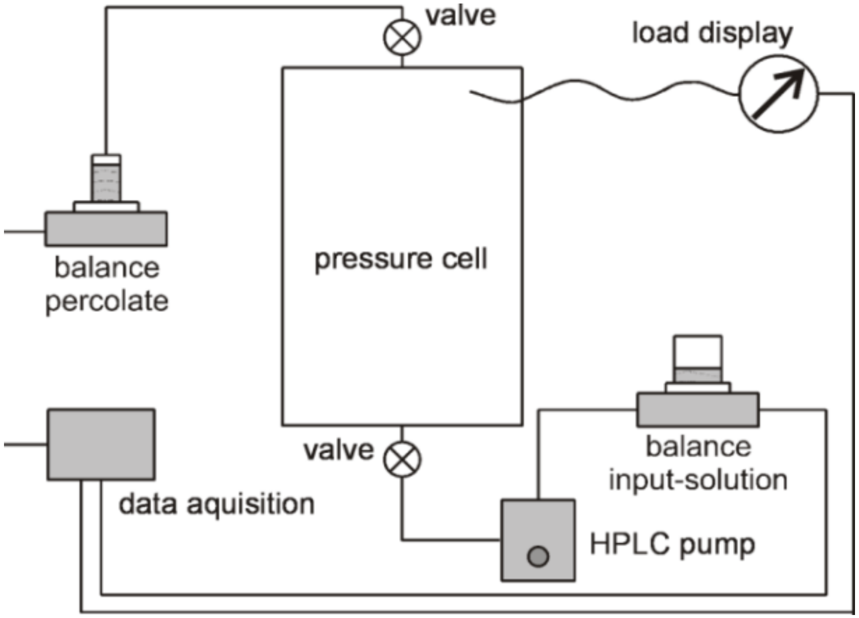
Buret for determining the mount of brine penetrated per time unit

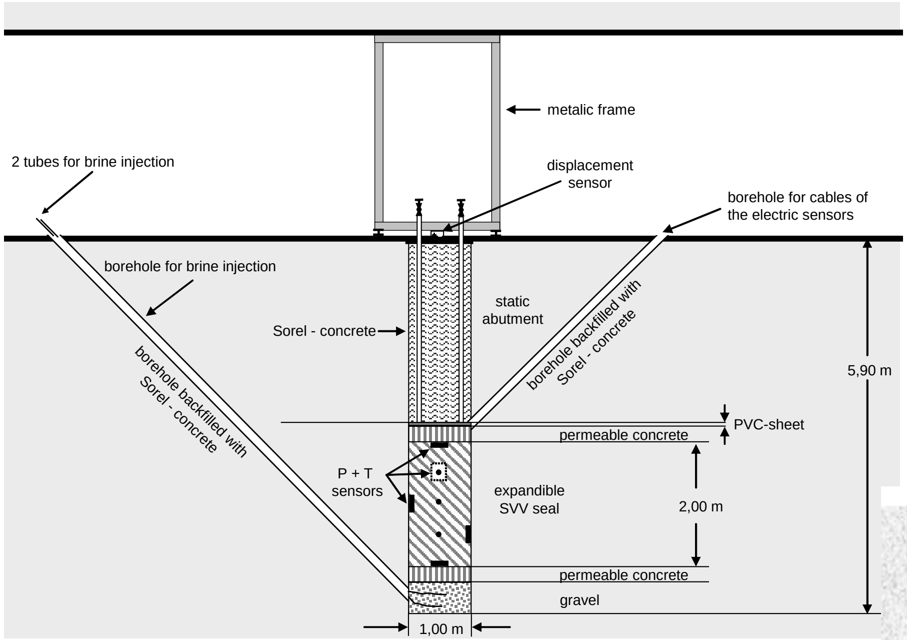


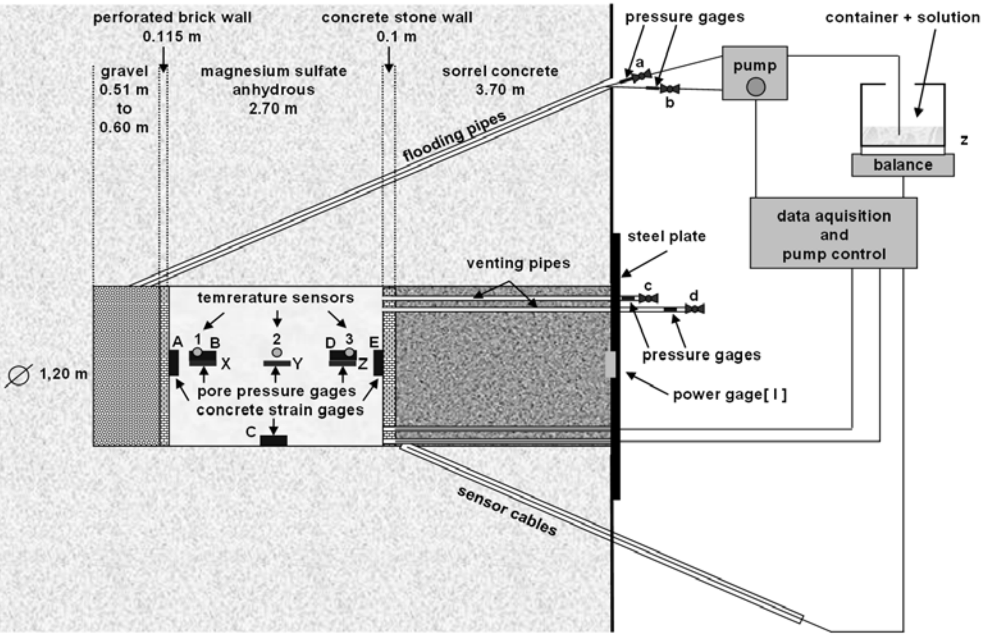


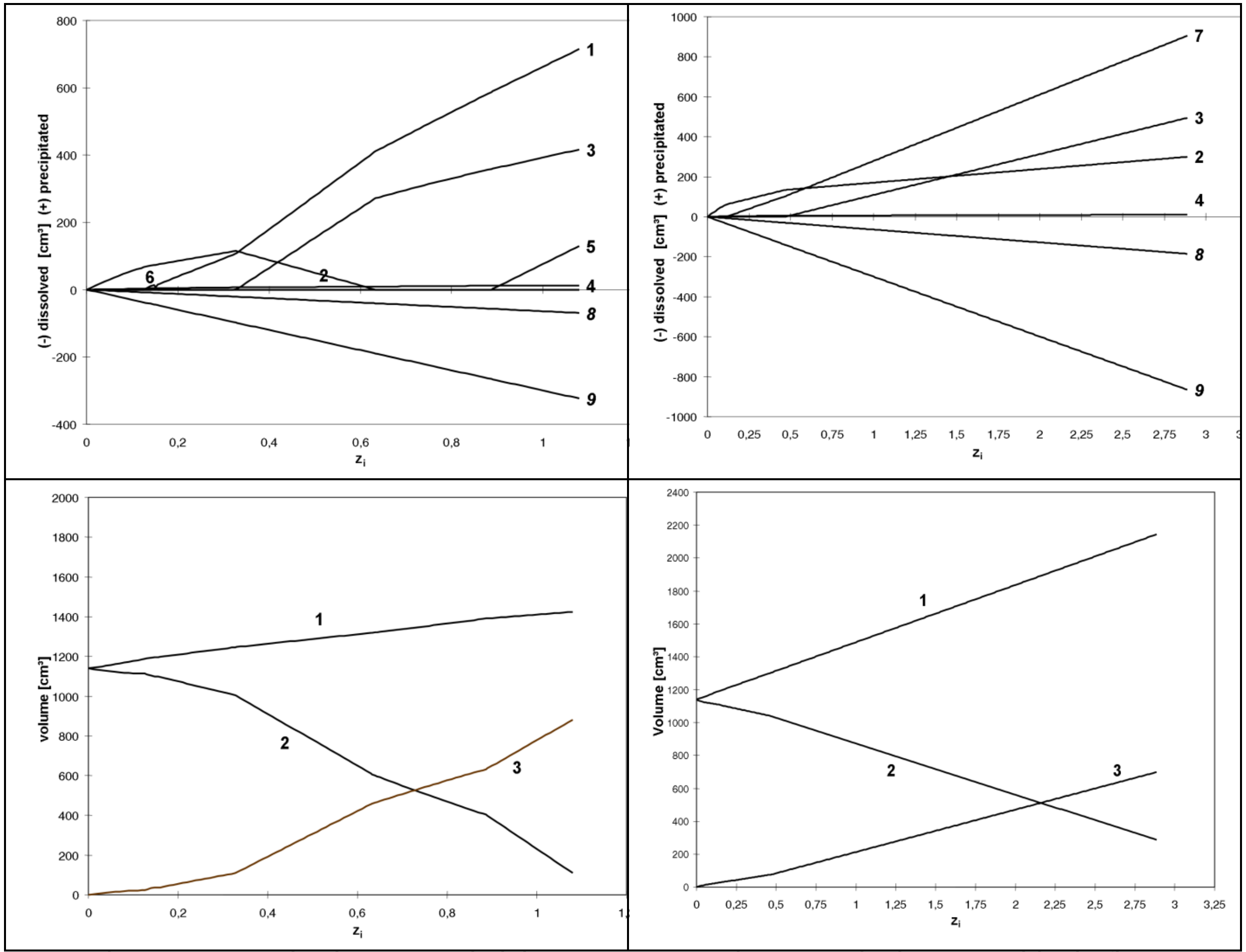



ΔV < 0,1%
Volume
time
24h
Pressure
Crystallisation pressure
Fluid pressure/pump pressure
time


valve
load display
balance
percolate
pressure cell
valve
data aquisition
balance
input-solution
HPLC pump


metalic frame
2 tubes for brine injection
displacement sensor
borehole for cables of the electric sensors
borehole for brine injection
static abutment
Sorel - concrete
borehole backfilled with Sorel - concrete
borehole backfilled with Sorel - concrete
5,90 m
PVC-sheet
permeable concrete
P + T sensors
expandible SVV seal
2,00 m
permeable concrete
gravel
1,00 m

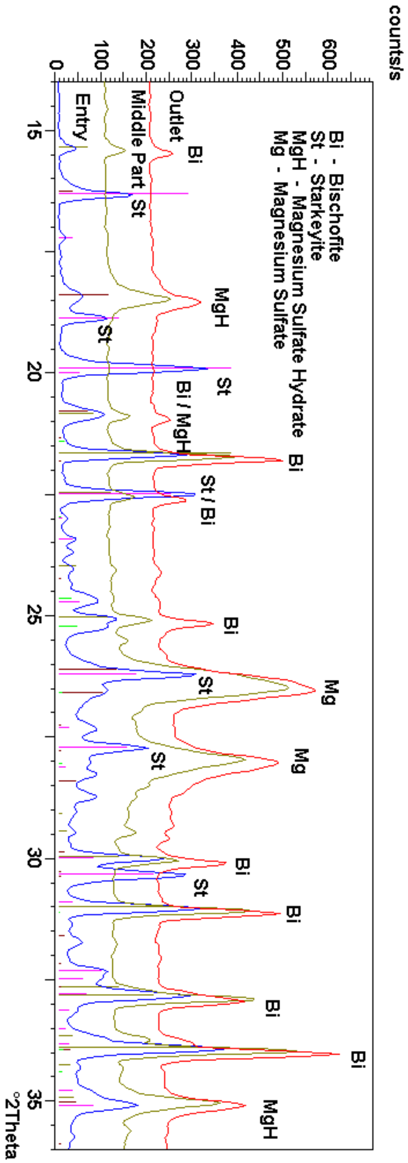

perforated brick wall 0.115 m
concrete stone wall 0.1 m
pressure gages
container + solution
gravel 0.51 m to 0.60 m
magnesium sulfate anhydrous 2.70 m
sorrel concrete 3.70 m
a
b
pump
z
balance
flooding pipes
data aquisition and pump control
steel plate
venting pipes
temrerature sensors
c
d
A
1
B
2
D
3
E
X
Y
Z
1,20 m
pressure gages
pore pressure gages
concrete strain gages
C
power gage[I]
sensor cables



Above 1 = starkeyite 2 = kainite 3 = carnallite 4 = halite 5 = bischofite 6 = hexahydrite 7 = kieserite 8 = sylvite 9 = anhydrous magnesium sulphate

Below 1 = volume of the system (difference between the sum of solution and consumed anhydrous magnesium sulphate and the sum of precipitated minerals) 2 = volume of the solution 3 = volume of precipitated minerals

Fig. 19: Geochemical modeling of the interaction of self-sealing backfill (SVV. 80 wt-% MgSO4 anhydrous + 10 wt.-% halite + 10 wt.-% sylvite) with a Mg rich (IP21) brine saturated with halite-carnallite-kainite-polyhalite-sylvite [11]



Conclusions Part 2 – GRS contributions to sealing concepts)

- Laboratory and in-situ tests contribute essentially to the understanding of the complex system of sealing structures
- For the long term safety assessment suitable forecast models are indispensable
- GRS has carried out corrosion experiments with different materials foreseen for sealing structures, (Salt Concrete, Sorel concrete and SVV)
- On the basis of the experimental results GRS has developed models for the prediction of the long term behaviour of these materials
- The results can be summarized as follows:
    - Salt concrete (based on CaO) ist stable in the presence of NaCl-brine
    - Sorel concrete (based on MgO) is stable in the presence of Mg-rich (IP21) brine
    - For Salt concrete a suitable model for the matrix corrosion exists
    - No model is still available for the corrosion of concretes on cracks
    - Self sealing Backfill (SVV) is compatible with rock salt as well as with potash rock formations and with pertinent brines, SVV is an expandable sealing material with low permeability which aslo can close the EDZ, 1:1 scale SVV seals are still required

Outlook GRS

- GRS has developed an experimental methodology for the investigation of the corrosion of Salt concrete and Sorel concrete
- Matrix corrosion and corrosion on cracks can be determined quatitatively
- Experiments with Sorel concrete have been started
- Based on the experimental results a model will be built which can predict the combined corrosion of concretes and subsequent permeability changes after interaction of these materials with different brine compositions

Thank You for Your Attention !!