



DEEP.KBB

Recommendations for long-term safe abandonment of brine-filled salt caverns

DR. DIRK ZANDER-SCHIEBENHÖFER

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1. Planning process for cavern abandonment
2. Principal goals of abandonment
3. Processes and phenomena during abandonment
4. Geotechnical investigations
5. Assessment geotechnical investigations
6. Conclusions

1 Planning Process for Cavern Abandonment

Planning process for cavern abandonment

Steps of the Planning Process

The planning process consists of the following parts

- I. Definition of **long-term goals** and setting of **targets** (operator, authorities)
(time period, stability, containment of the brine, subsidence)
- II. **Data acquisition** (geology, operation, material behaviour)
- III. Evaluation of **in-situ observations**
- IV. **Modelling**, verification and simulation
(operation...post-operation...closure...abandonment)
- V. **Technical planning** in accordance with modelling
(workovers, measurements, tests, plugging, monitoring, waiting time)

Objectives

- (1) Demonstration that **targets can be achieved** and
- (2) Development of a technical **concept** that **can be implemented in practice**

2 Principal Goals of Cavern Abandonment

Principal goals of cavern abandonment

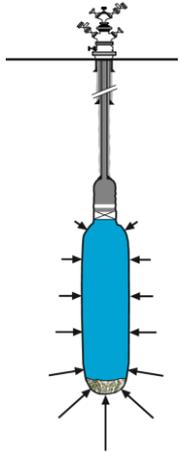
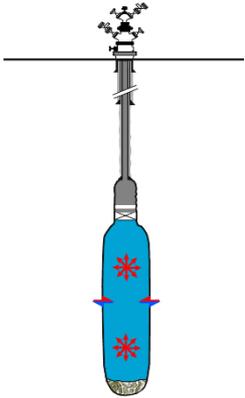
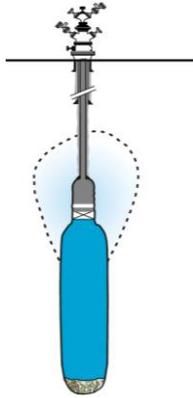
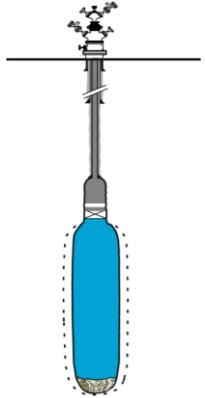
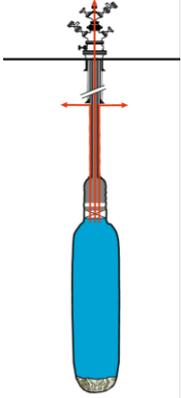
Goals and Targets

- Protection goal: Proof of long-term safety
 - Long-term **integrity** of the host rock
 - Long-term **protection of the environment**
- Agreement on targets to reach the goals
 - **Stability** of the rock mass surrounding the cavern(s)
 - Permanent **containment of brine** in the salt rock
 - **Ground water** protection
 - **Subsidence** within limits
- Achievement of targets is limited to a reasonable period to be defined

3 Processes and Phenomena during Abandonment

Processes and Phenomena during Abandonment

Relevant Processes in-situ

					
Process	Creep closure	Brine thermal expansion	Brine infiltration	Salt dissolution	Leaks
Impact on cavern pressure					
Duration	Permanent with a decreasing tendency	Relevant in the first years to decades after cavern operations	Begins (normally) after cavern pressure approaches lithostatic stress, afterwards permanent	Ends after a few months	Leakage through wellbore system to be excluded

4 Geotechnical Investigations

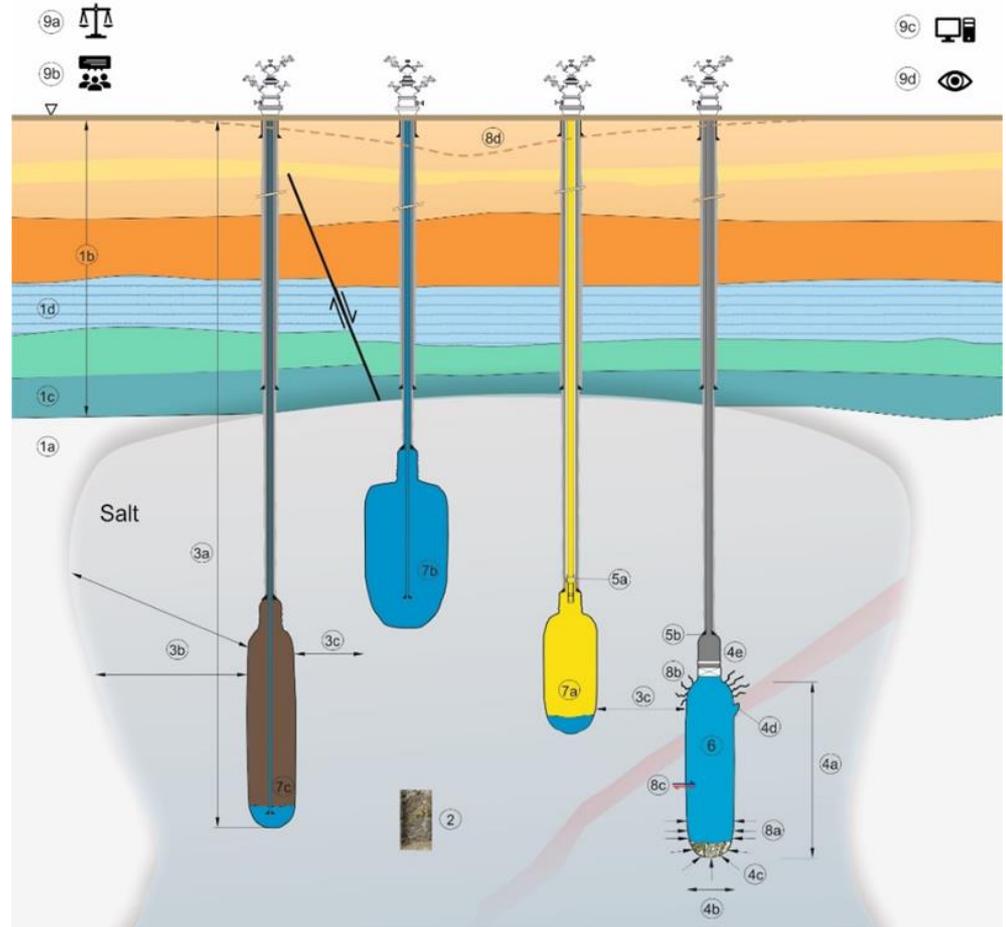
Modelling Assumptions and Simulations

Basic Information for Modelling

Basic Information for Modelling

Initial Questions

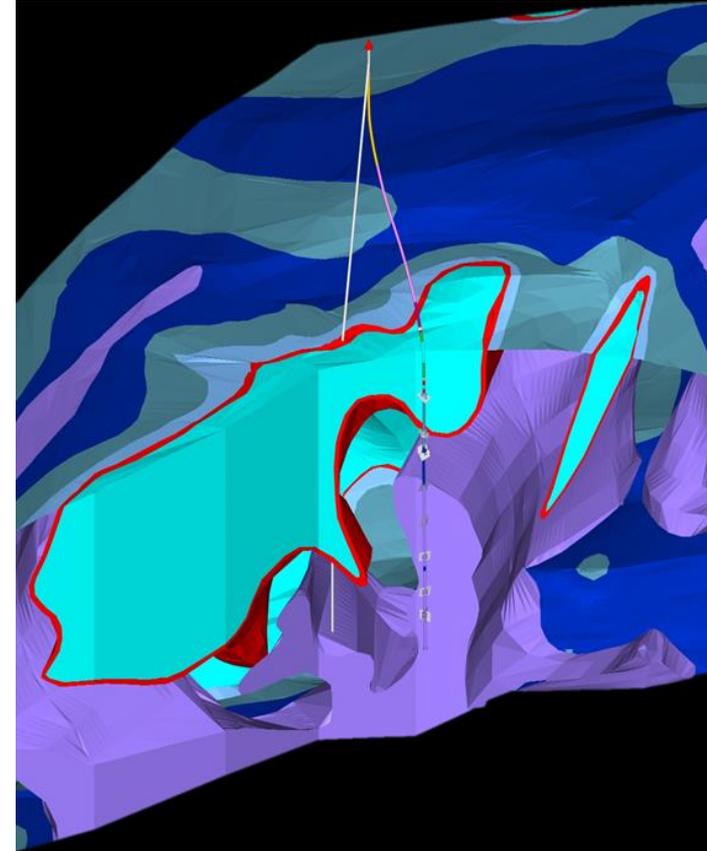
- Do we know enough about the specific location?
- Are further tests / investigations indispensable necessary for abandonment planning?
- Which degree of detail is necessary to fulfil the goals?



Basic Information for Modelling

Characterization of the relevant Rock Mass Volume

- In-situ status
(stress, temperature, creep behaviour)
- 3D geological model describing
 - internal structure of the salt and the surrounding host rock
 - Inhomogeneities
- Identification of potential preferred pathways for brine infiltration



Basic Information for Modelling

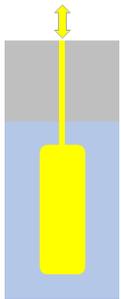
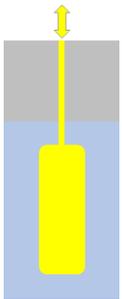
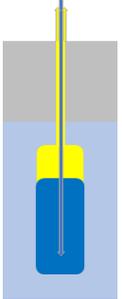
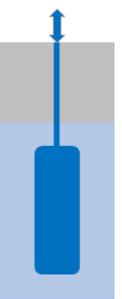
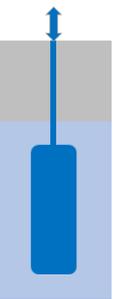
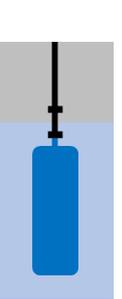
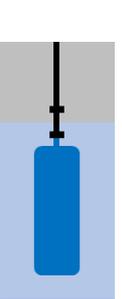
Knowledge regarding Material Behaviour

- Information about principal material behaviour (material science) (stress, temperature, composition, grain size, moisture content, etc.)
- Challenge: Transfer to real complex structures
Practical solution: Parameter studies and worst case scenarios
- In-situ tests support the interpretation of the integral behaviour of the rock mass (e.g. creep behaviour, permeability compared to lab-test results)

➤ **Consequences must be discussed**

Basic Information for Modelling

Sequence of Phases and Time Scale to be considered

Phase	Operation	Planning Phase	Product Withdrawal	In-situ tests	Potential Waiting Time	Plugging the Well	Pressure Increase	Brine Infiltration	Brine leaving the Salt
									
Duration (estimate)	~50 years	~ 0.5 year	~1.5 years	~2 years	x * 10 years	~1 year	x*10 years	x*1,000 years	x*1,000 years
Investigations	Field observations  ?								
	Subsidence prognosis  ?								
	Geotechnical study  ?								

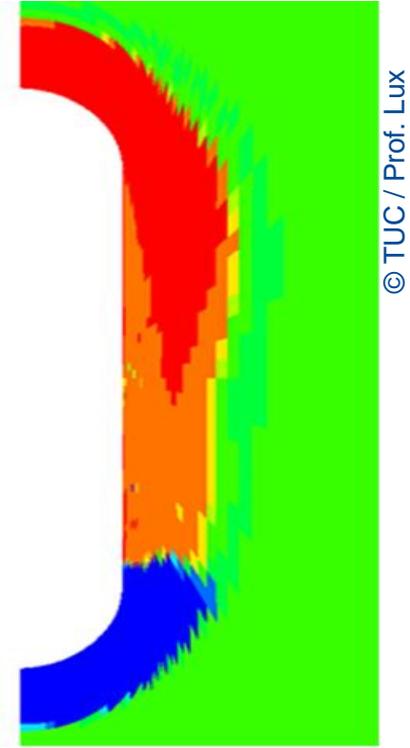
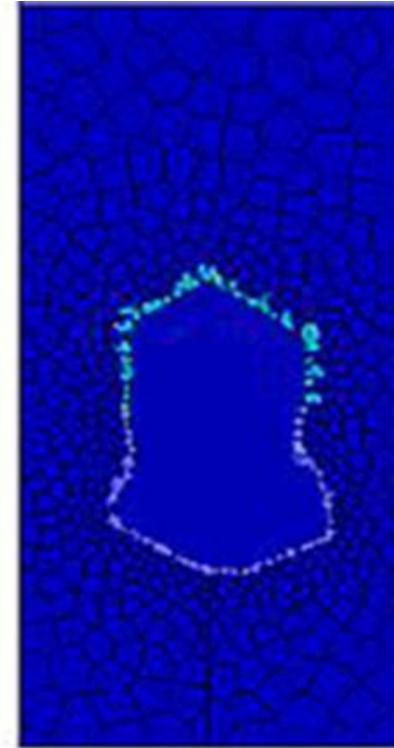
Geotechnical Modelling

- **Compromise** between requirements and resulting effort in terms of time and costs (efficiency, effectivity)
- Consideration of complex geological structure affords
 - **transfer between different scales** (micro, macro, ... , cavern, dome)
 - **trade-off between** allocation of **locally determined material parameters** and **parameter studies** with worst-case assumptions
- Importance of broad **practical experience** from cavern and mining operations

Geotechnical Modelling

Modelling Approach

- 3D Modelling preferred vs 2D
- Discontinuum and/or continuum approach
- Coupling of **T**hermodynamics, **H**ydraulics, and **M**echanics (THM approach)
- Modell verification based on observations



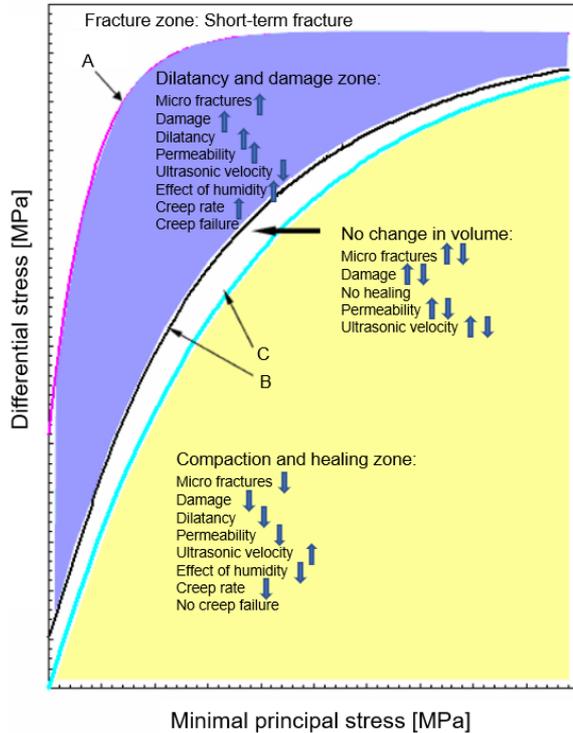
5 Assessment of Geotechnical Investigations

General Background

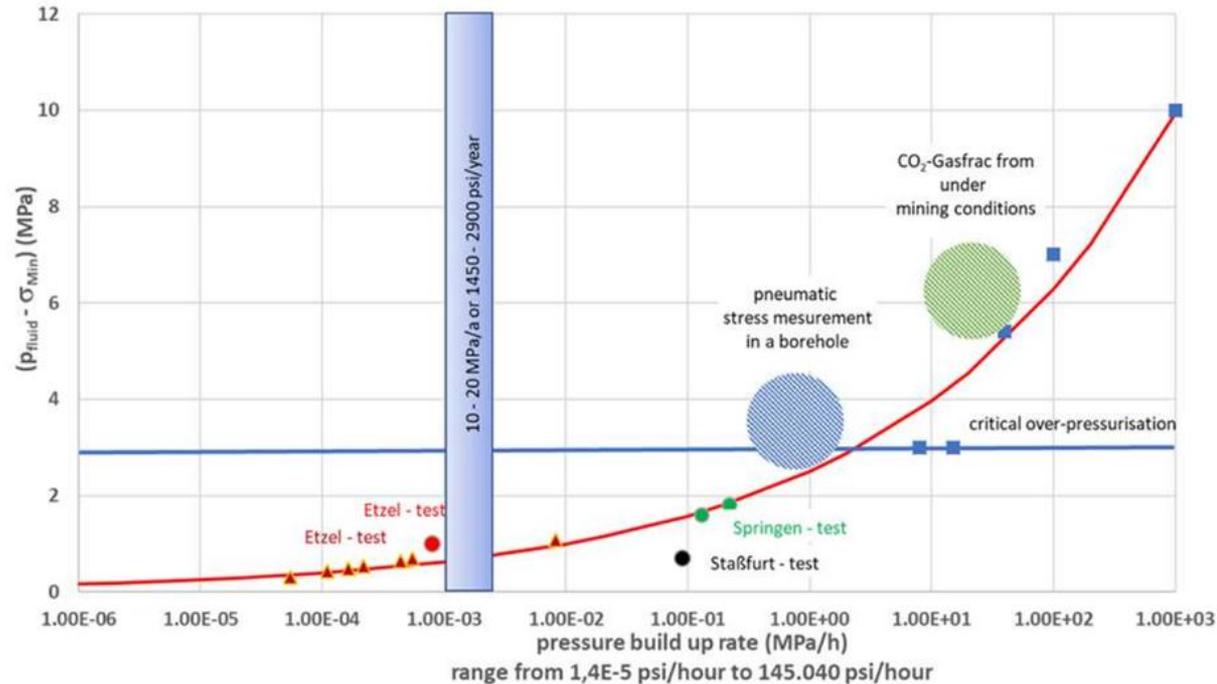
- Simulations result in **figures and graphs**
- **Need for assessment** of the simulation results
 - Statements on the long-term effects are required (operators, authorities and the public)
- **Assessment criteria** to **check** if **goals and targets** can be met
 - Adequate period to be considered (100, 1,000 10,000 years?)
 - Long-term stability
 - Occurrence of macro fracs?
 - Permanent containment of the brine in the salt rock or acceptance of brine leakage into the overburden?
 - Acceptable subsidence

Assessment of Geotechnical Investigations

Examples: Stability Assessment – Risk of Macro-Fracturing



Herchen, et al., 2016



Brückner 2023

Assessment of Geotechnical Investigations

Final Statement and further Actions

Final **key statements** of geotechnical study

- **Confirmation** of abandonment planning
- **Effects** on the environment **are within limits**
- Suggestion of **further observations**

Subsequent actions

- **Public presentation** and discussion
- Application for **permission**
- **Permission**
- **Implementation**

6 Concluding Remarks

The **State of the Art** has **improved** considerably over the last 20 years

- Materials science research in the micro range on creep and permeability
- Laboratory tests, in-situ tests on boreholes and caverns
- Research on brine infiltration mechanisms / processes
- THM simulation software
- Criteria for the occurrence of macro-fracs
- Definition of targets and evaluation criteria

General issues

- Evaluation whether or not safety is improved by more detailed knowledge
 - Safety concept is of public interest => **A practical solution is required**
- **According to the current State of the Art
salt caverns filled with brine can be safely abandoned in the long-term**

Recommendations for long-term safe abandonment of brine-filled salt caverns



Thank you for your attention!

DR. DIRK ZANDER-SCHIEBENHÖFER

dirk.zander@deep-kbb.de