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Supplement of

Compaction of crushed salt for safe containment – a summary of the KOMPASS projects

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Compaction of Crushed Salt for Safe Containment

A summary of the KOMPASS projects

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Outline

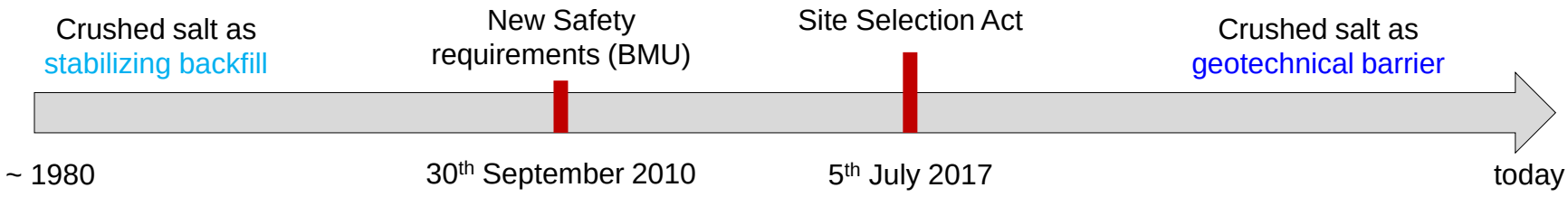
1. The Origin
2. Evolution of the KOMPASS projects

3. Experimental studies
4. Microstructural investigations
5. Numerical modelling

6. Conclusion & outlook

1. The Origin

- Investigations on crushed salt have been performed during the last decades
  - Focus on the mechanical evolution
  - Crushed salt as stabilization for the host rock
- Important paradigm shift in repository design with the Site Selection Act (2017)
  - Shift from limited release to safe containment
  - Crushed salt as **geotechnical barrier**
  - Focus on the evolution of hydraulic properties



Ref: Korthaus, Callahan, Hansen, Hunsche, Spiers, Stührenberg, WIPP Site, Asse mine, Gorlegebn mine…

DAEF state-of-the-art report (2017)

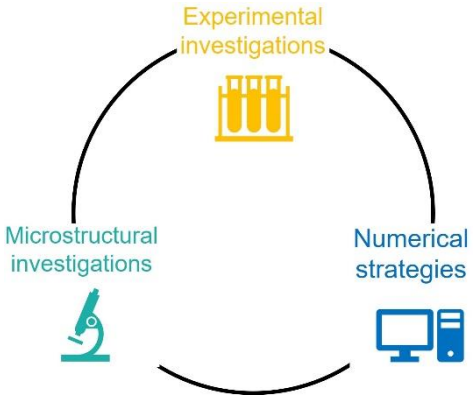
➥ Need for future R&D work

2. Evolution of the KOMPASS projects

KOMPASS-I	→	KOMPASS-II	→	MEASURES
09/2018 – 08/2020		07/2021 – 06/2023		XX/2024

- Improve scientific database behind using crushed salt for long-term isolation of high-level nuclear waste
- Improve prediction of crushed salt compaction process

- Work with relevance for long-term safety of HLW repository in rock salt



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3. Experimental studies – The KOMPASS reference material

Aim: Choice of an easy available & permanent reproducible crushed salt material for generic investigations (also beyond the projects)

- Staßfurt-sequence in a bedded Zechstein
- Optimized grain size distribution

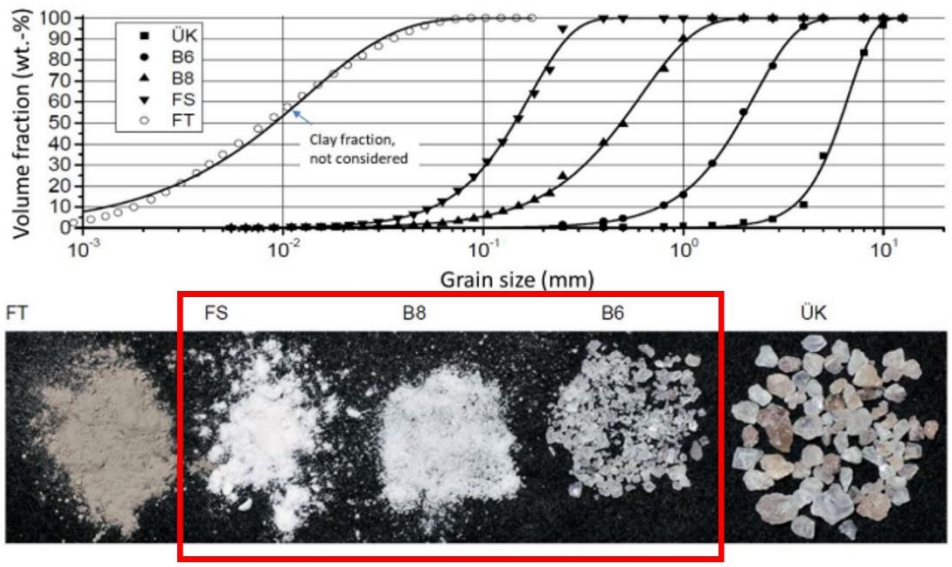


Fig. 4.3 Salt grain fractions and grain size distributions

[KOMPASS-I, 2020]

Tab. 4.1 Grain size fractions in the raw salt material and the optimized mixture

Material-fraction	Grain size distribution d_5-d_{95} [mm]	d_{50} [mm]	m [-]	Optimized mixture [wt.-%]
Überkorn (ÜK) – oversized grains	3 - 10	6.03	3.44	-
Band 6 (B6) – production line 6	0.4 - 4	1.90	2.06	65.6
Band 8 (B8) – production line 8	0.1 -1	0.49	1.58	20.2
Feinsalz (FS) – fine salt	0.03 -0.3	0.14	2.01	14.2
			sum	100.0
Materials from other investigations or sources				
REPOPERM	0.1 - 30	2.35	0.81	
ESCO - salt	0.1 - 8	1.48	1.02	

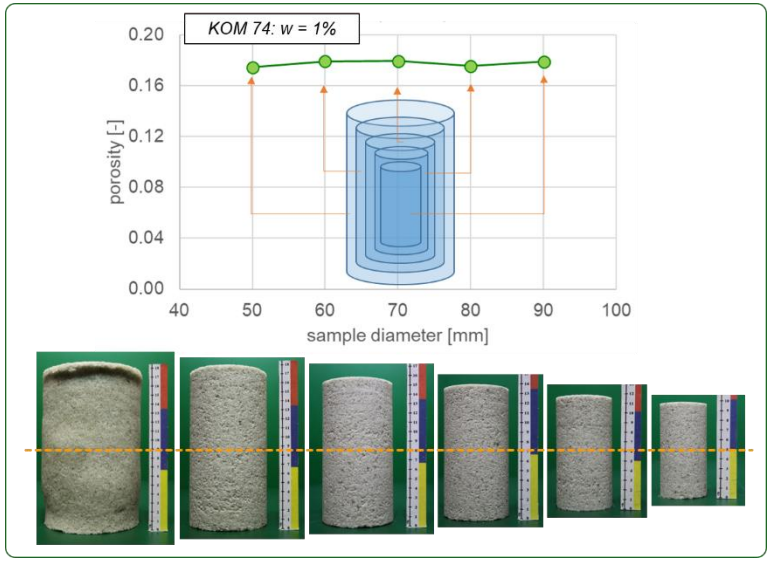
[KOMPASS-I, 2020]

3. Experimental studies – Pre-compaction methods

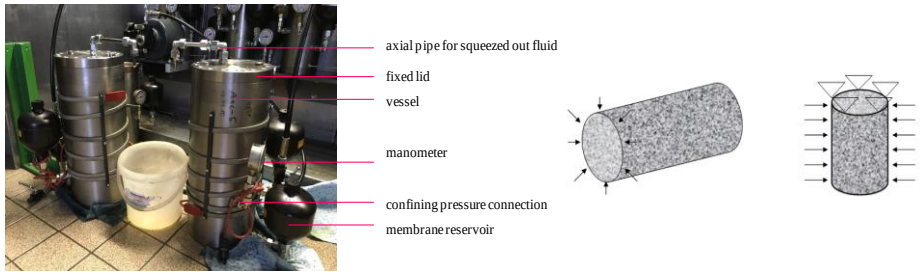
Aim: Produce samples for long-term compaction tests

- Low initial porosity (15 – 20 %)
- Natural grain structure
- Short-term, but under in-situ relevant stress/strain

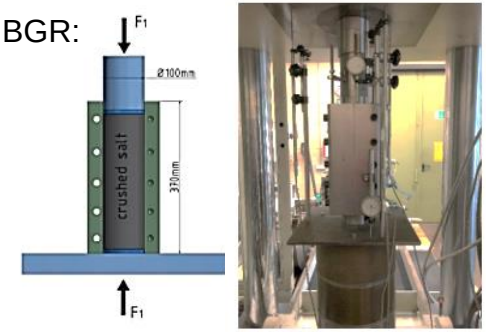
[KOMPASS-II, in preparation]



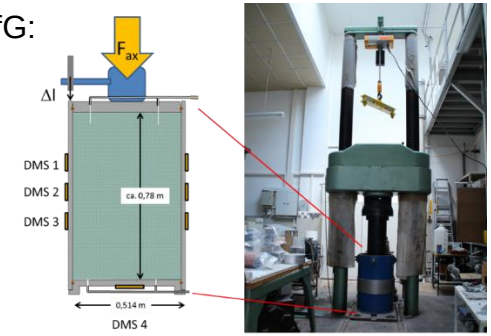
TUC:

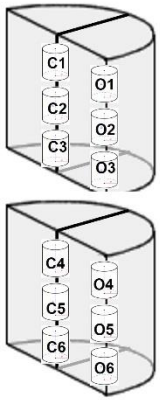


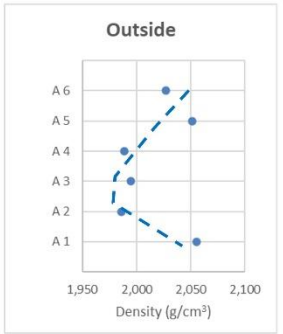
BGR:

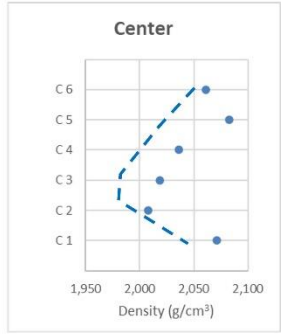


IfG:









[KOMPASS-I, 2020]

Friction effect on compaction:

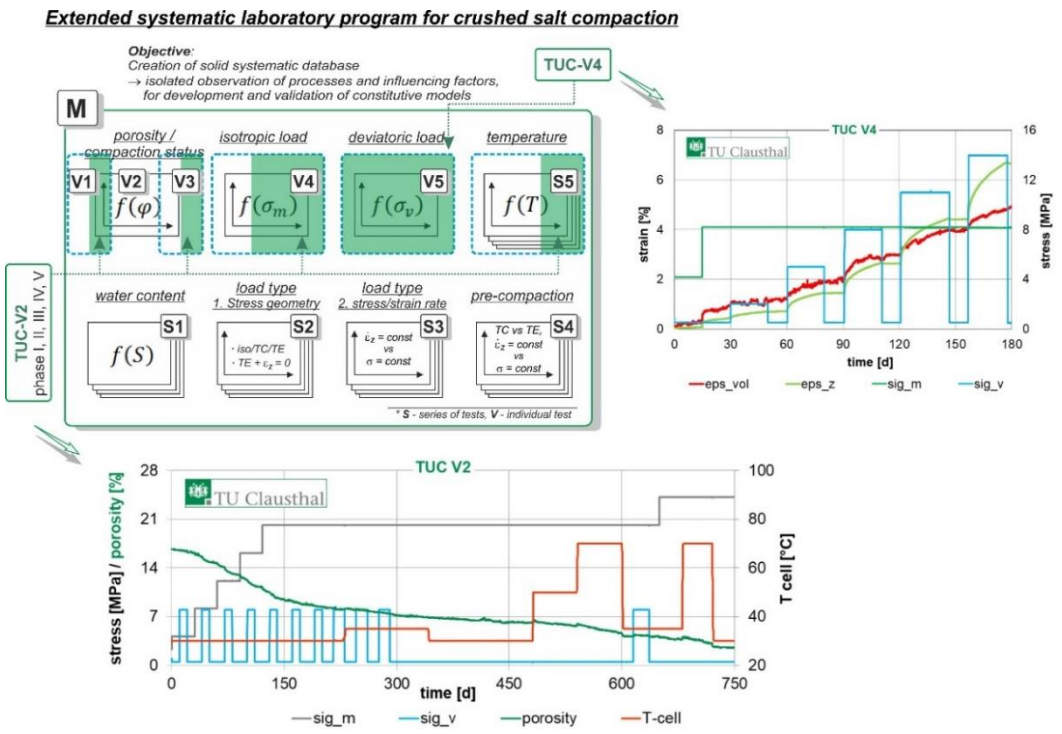
- End effects bottom /top: higher
- Center of the cylinder is higher consolidated than the outsides

3. Experimental studies – Long-term compaction tests

Aim: Systematically investigation of crushed salt compaction behaviour

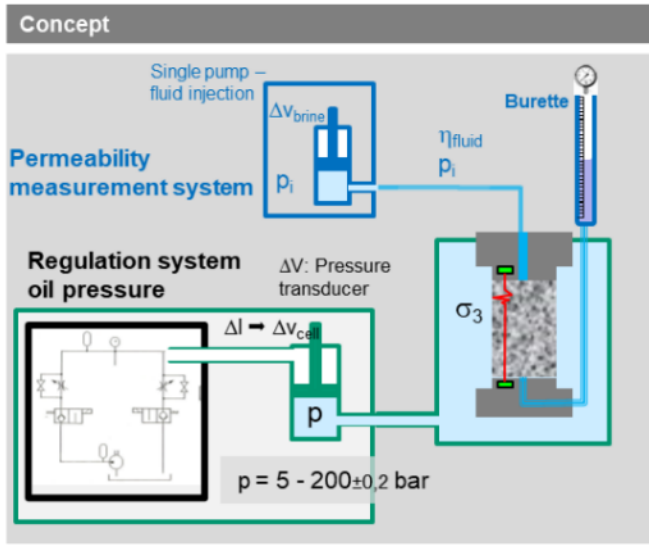
- ➢ Addressing influencing factors

TUC test program:



[KOMPASS-II, in preparation]

New IfG crushed salt compaction cell:



- ❖ Well controlled hydraulic pressure
  - Reliable pressure accuracy: p = 5 - 200±0,2 bar
  - Oil volume measurement via pressure transducer
- ❖ Indirect pore space parameters
  - P- and s- wave velocities
  - Permeability measurements / gas porosmetry

[KOMPASS-II, in preparation]

3. Experimental studies – Long-term compaction tests

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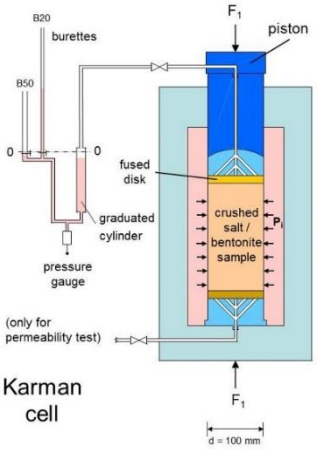
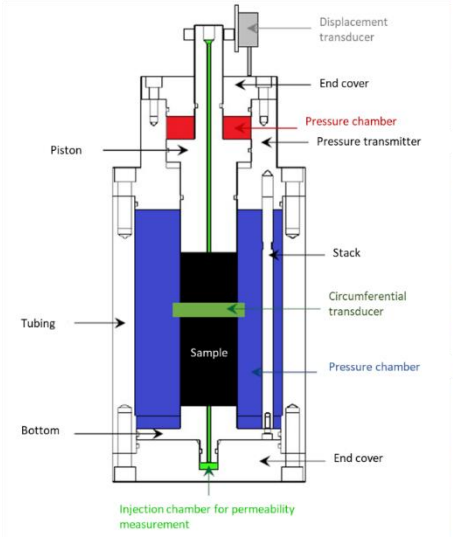
BGR test program:

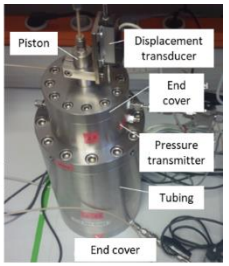


	Moisture	Temperature	Duration	Pressure steps
TK-038	0.1 w.-%	50 °C	34 d	5, 10 MPa
TK-041	0.35 w.-%	50 °C	145 d	5, 10, 15, 20 MPa
TK-042	0.35 w.-%	50 °C	72 d	10, 15 MPa
TK-044	0.5 w.-%	33 °C	144 d	4, 8, 12, 16, 20 MPa
TK-045	0.5 w.-%	50 °C	220 d	4, 8, 20 MPa

[KOMPASS-II, in preparation]

GRS triaxial compaction tests:





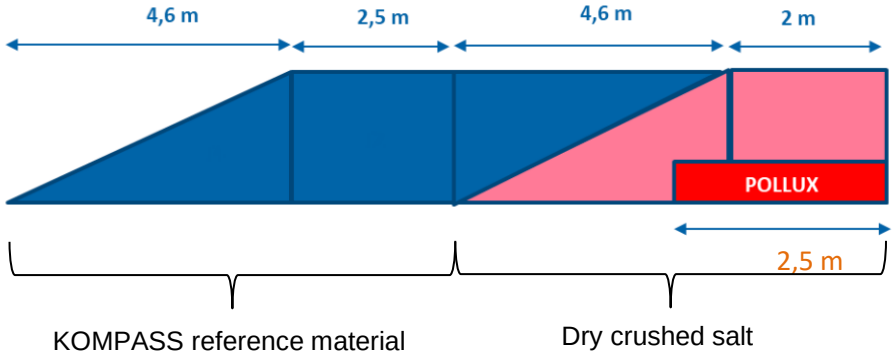
	BGR sample	IfG sample	TUC sample
Vol. strain [%]	4 – 7	8 – 11	9 – 14
Porosity [%]	6 – 9	4 – 8	4 – 9
Permeability [m^2]	$5.4*10^{-16}$	Gas tight	Permeable

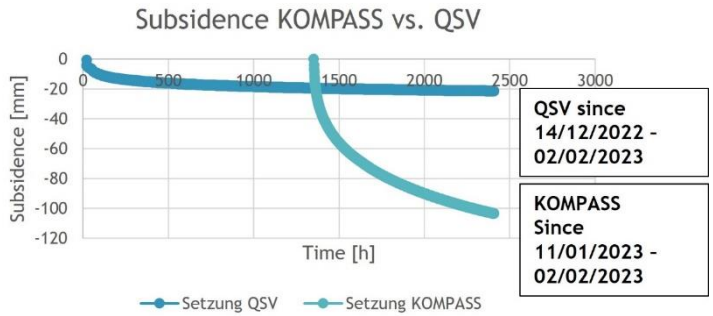
[KOMPASS-II, in preparation]

3. Experimental studies – In-situ experiment

Aim: Test the KOMPASS reference material under in-situ conditions

- Collaboration with the SAVER project (TU BAF)
- KOMPASS backfill body in the Sondershausen mine



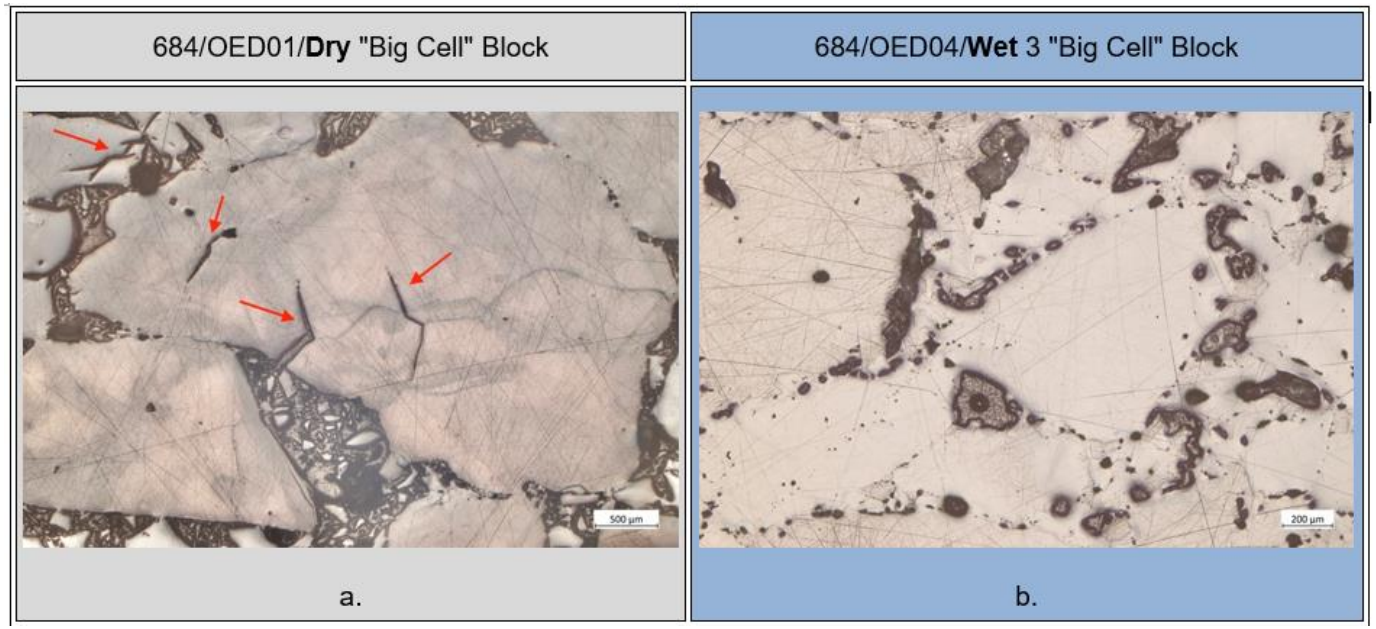


[KOMPASS-II, in preparation]

4. Microstructural investigations

Aim: Reduce the uncertainties regarding the actual contribution of microstructural deformation mechanism to the overall compaction

- Establishment and improvement of microstructural investigation methods
- Relating the abundancy of indicators for microscale deformation mechanism to compaction conditions
- Focus on comparison of different pre-compaction methods
- Investigation of different influencing factors on the microscale deformation mechanism (grain size, humidity)



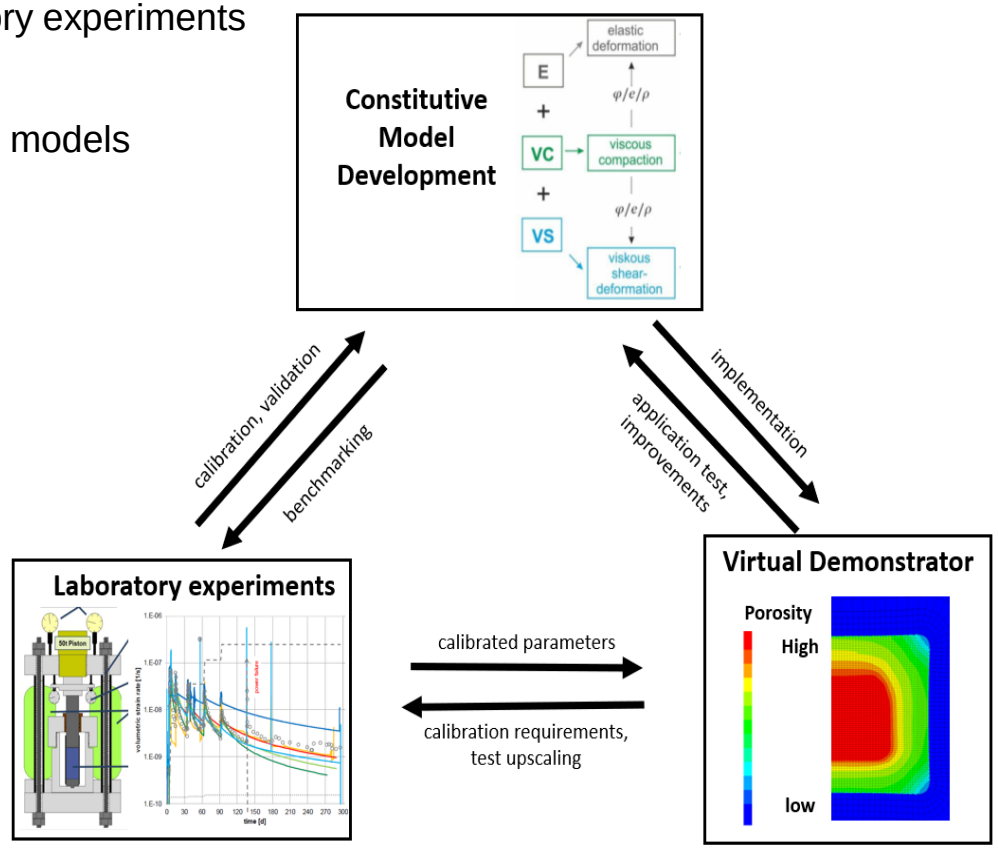
[KOMPASS-II, in preparation]

5. Numerical modelling

Aim: Improve/develop models for describing the mechanical/hydraulic property changes of crushed salt compaction over a wide range of influencing parameter

- Application of various constitutive models
- Benchmark calculations against laboratory experiments
- Application of a virtual demonstrator
- Development/optimization of constitutive models

[KOMPASS-II, in preparation]



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The KOMPASS projects contribute to the improvement of the scientific knowledge for using crushed salt as backfill for HLW containment.

B U T . . . The KOMPASS projects also identified some important shortcomings!

- Laboratory program is not completed
- Effects of laboratory shortcomings has to be addressed
- Hydraulic properties of crushed salt need to be considered
- Need for optical experiments on the activation and quantification of micro deformation mechanism
- Constitutive models are not calibrated in its entireness
- Update the permeability reduction with time for the long-term safety analysis

To be continued… MEASURES (coming 2024)

THANKS TO THE KOMPASS-FAMILY!

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Attended by:

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Karlsruher Institut für Technologie

FKZ: 02 E 11951A-D

THANKS FOR YOUR ATTENTION!

[KOMPASS-I, 2020] Czaikowski, O., Friedenberg, L., Wieczorek, K., Müller-Hoeppe, N., Lerch, Ch., Eickemeier, R., Laurich, B., Liu, W., Stührenberg, D., Svensson, K., Zemke, K., Lüdeling, Ch., Popp, T., Bean, J., Mills, M., Reedlunn, B., Düsterloh, U., Lerche, S., Zhao, J.: Compaction of Crushed Salt for the Safe Containment. KOMPASS project. Final report, GRS-608. Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Köln, August 2020

[KOMPASS-II, in preparation] Friedenberg, L., Bartol, J., Bean, J., Beese, S., Coulibaly, J.B., Czaikowski, O., De Bresser, H.J.P., Düsterloh, U., Eickemeier, R., Gartzke, A.-K., Hangx, S., Jantschik, K., Laurich, B., Lerch, C., Lerche, S., Lüdeling, C., Mills, M., Müller-Hoeppe, N., Popp, T., Rabbel, O., Rahmig, M., Reedlunn, B., Rogalski, A., Rölke, C., Saruulbayar, N., Spiers, C., Svensson, K., Thiedau, J., van Oosterhout, B., Zemke, K.: Compaction of Crushed Salt for Safe Containment – Phase 2. KOMPASS-II. Final report, in preparation, 2023