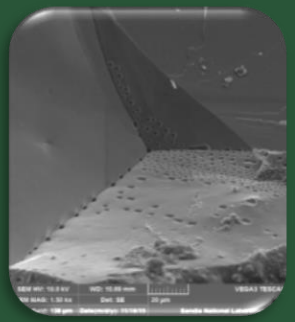
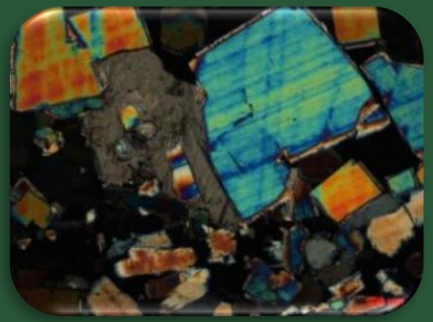



11th US/German Workshop on Salt Repository Research, Design, and Operation

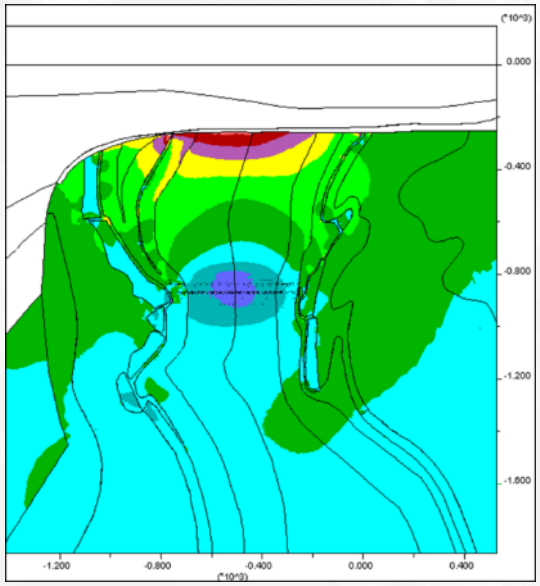
Role of crushed salt in the repository concept

Nina Müller-Hoeppe
Christian Lerch
BGE TECHOLOGY GmbH

Part 2 of the online workshop
June 17, 2021

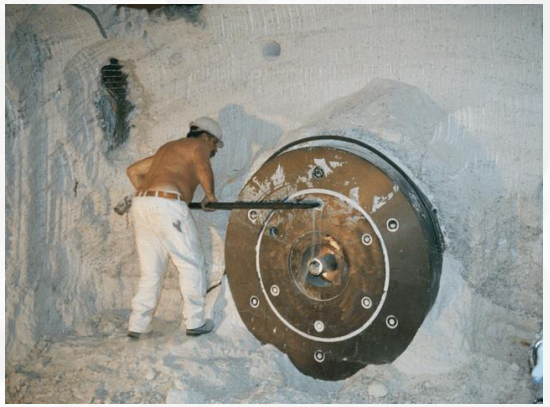
Isolation of Radwaste in Salt

Intact salt rock



EDZ

Crushed salt backfill



Sandia National Laboratories | GRS | TU Clausthal | BGR | IfG Institut für Gebirgsmechanik GmbH Leipzig | BGE TEC

Role of crushed salt

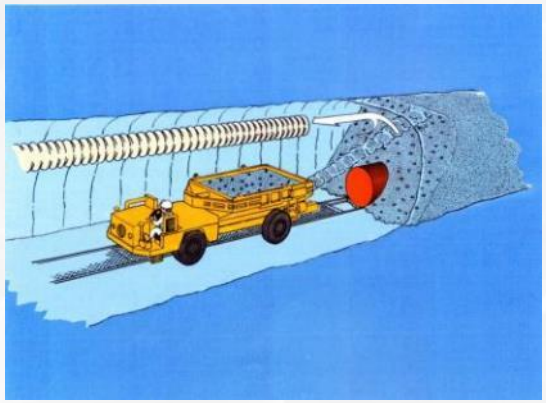
- In the operational phase
  - (1) Radiation protection
  - (2) Fire and explosion protection (prevents propagation)
- In the operational and post operational phase
  - (3) Transfer of decay heat from the heat generating waste to the host rock
  - (4) Improving stability of repository mine and supporting integrity of geological barrier
- Post closure phase
  - (5) Reduction of void volume in the repository mine (limiting amount of brine and constituting a barrier of $k \sim 1 \cdot 10^{-14}$ m²)
  - **(6) New: Recovery of the salt barrier´s tightness comparable to the host rock in order to achieve isolation of radwaste**

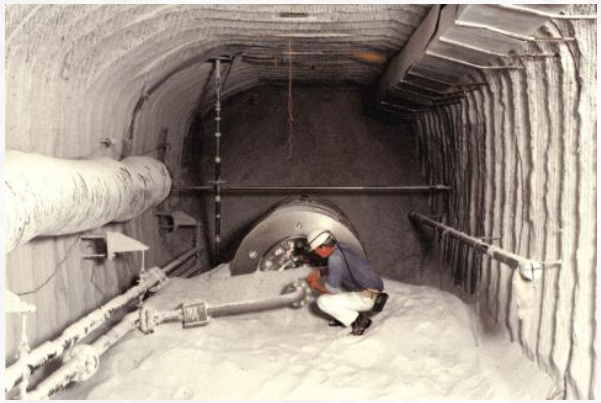
Functional Requirements

- High initial density and placeable without gap in the roof is sufficient to fulfil functions (1) to (5)

Furthermore

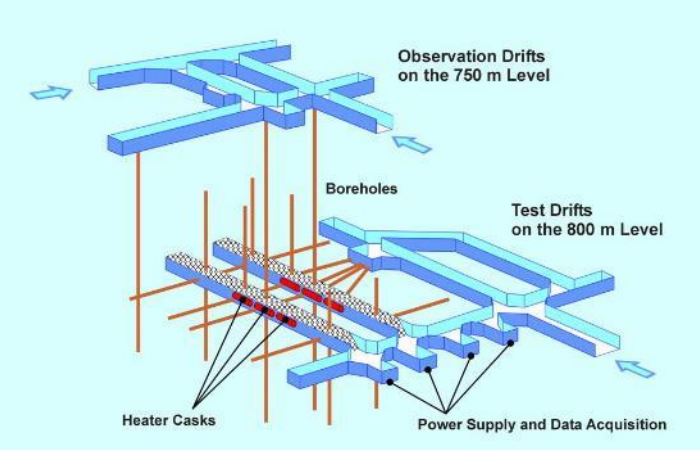
  - Dry crushed salt close to the metallic containers to limit corrosion effects (natural moisture content ~ 0.02 M%)
  - Possible emplacement technologies to achieve this goal considering additionally staff´s radiation protection (neutrons!)
- Slinger truck technology appeared to be the best option

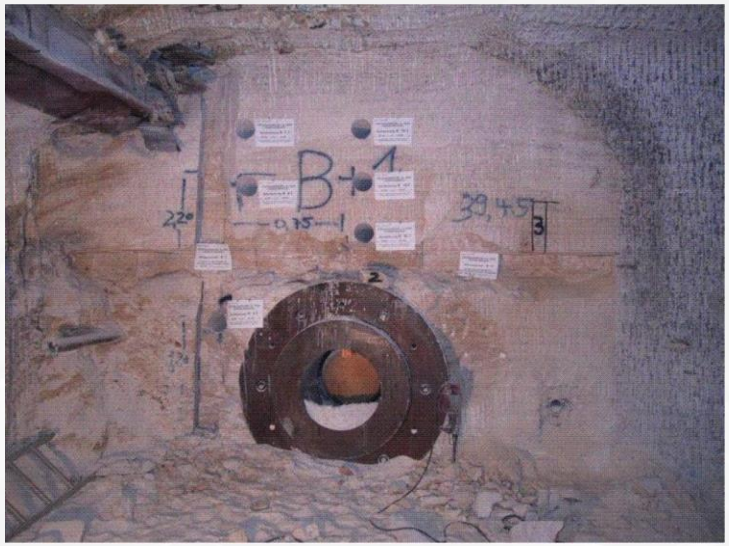


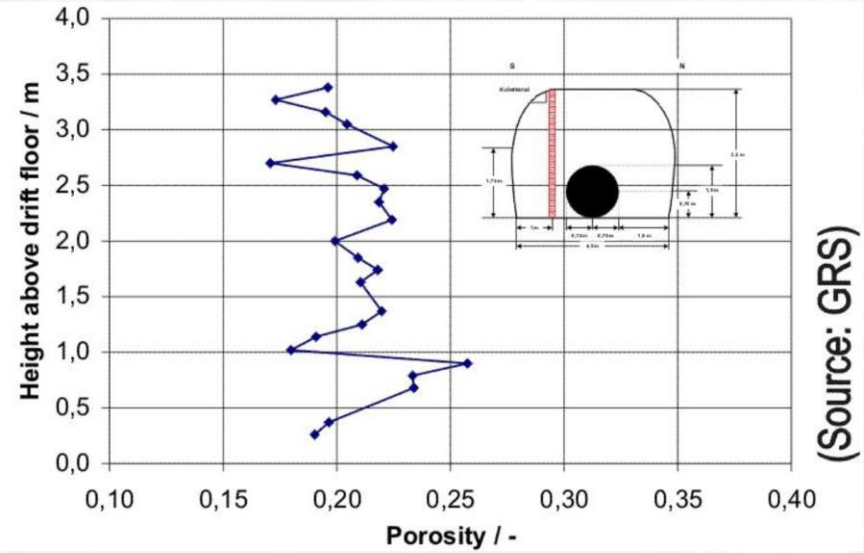


Functional Requirements

- Compliance with functional requirements (1) – (5) was demonstrated by the TSS/BAMBUS R&D projects
- No gap in the roof (1), (2), (4)

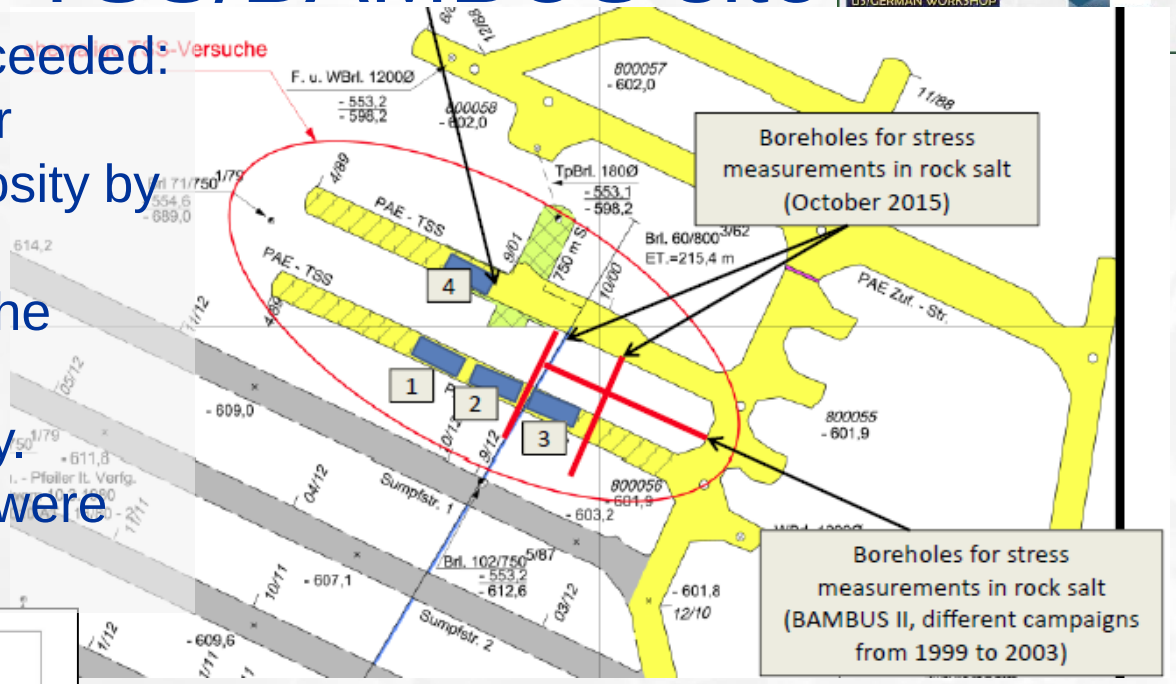


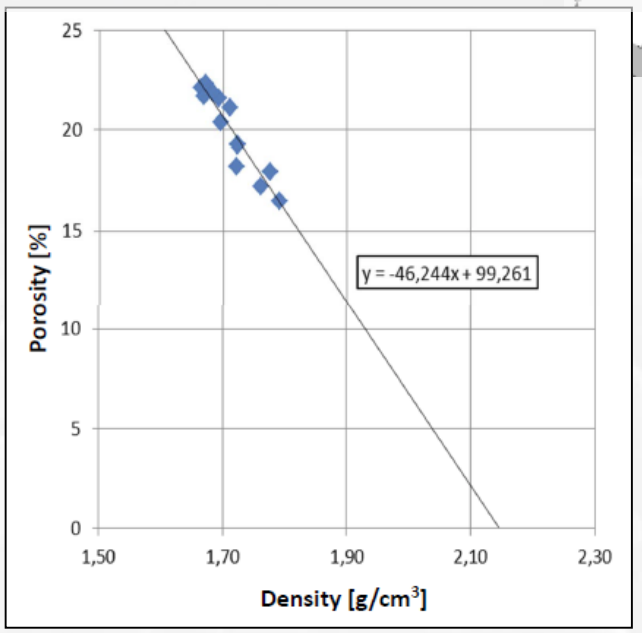




Revisitation of TSS/BAMBUS site

- Backfill compaction proceeded:
- Within 15 years a further reduction of backfill porosity by 3 – 5% was observed (~ drift convergence at the 800-m-level).
- The backfill was very dry.
- The working conditions were warm-cold.



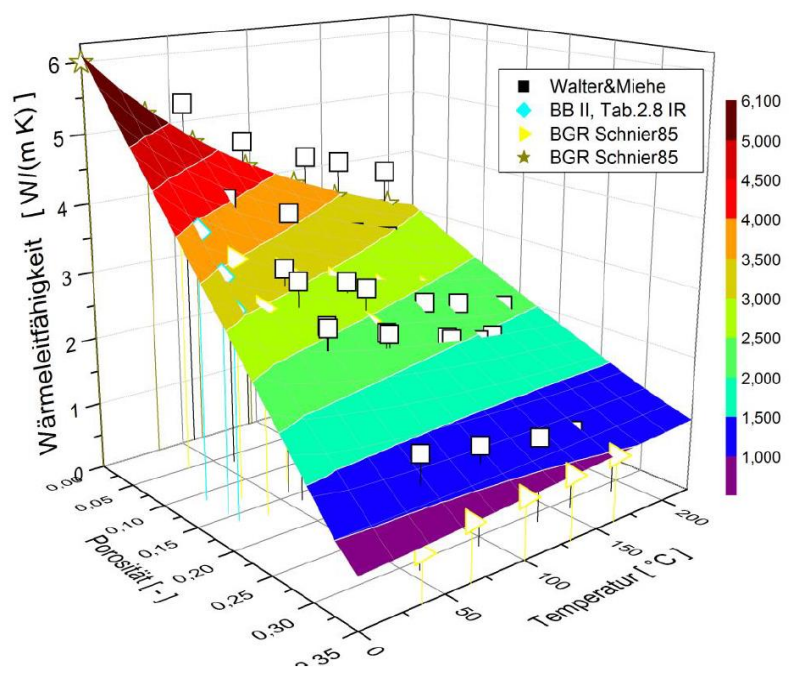


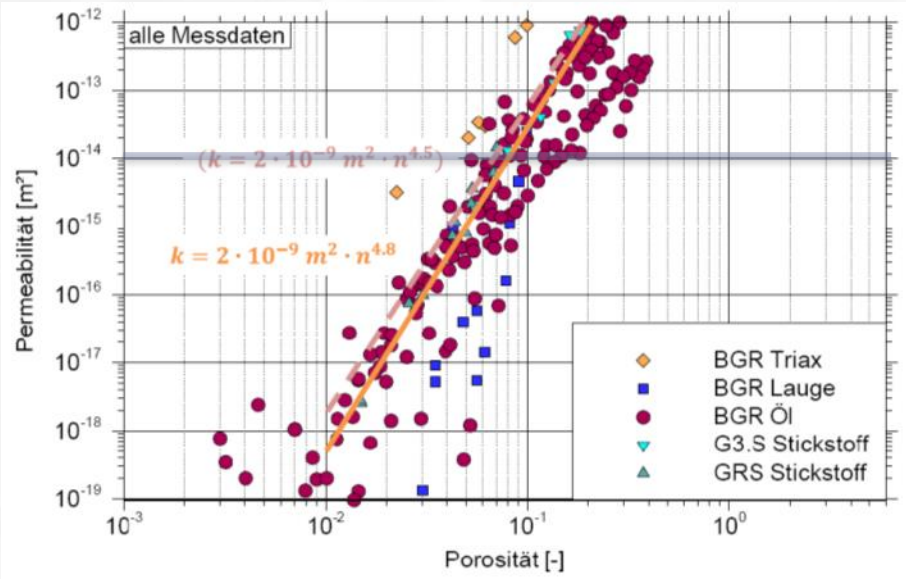
- Porosity: 23 – 17%
- Thermal conductivity: 2.3 W/(m·K)
- Gas permeability: ca. $5 \cdot 10^{-13}$ m²

SANDIA, 2016
IfG, 2016

Functional Requirements

- Compliance with functional requirements (1) – (5) was demonstrated by the TSS/BAMBUS R&D projects
- Considering heat transfer properties (3) and limitation of void volume (5) early stage at high porosity is decisive

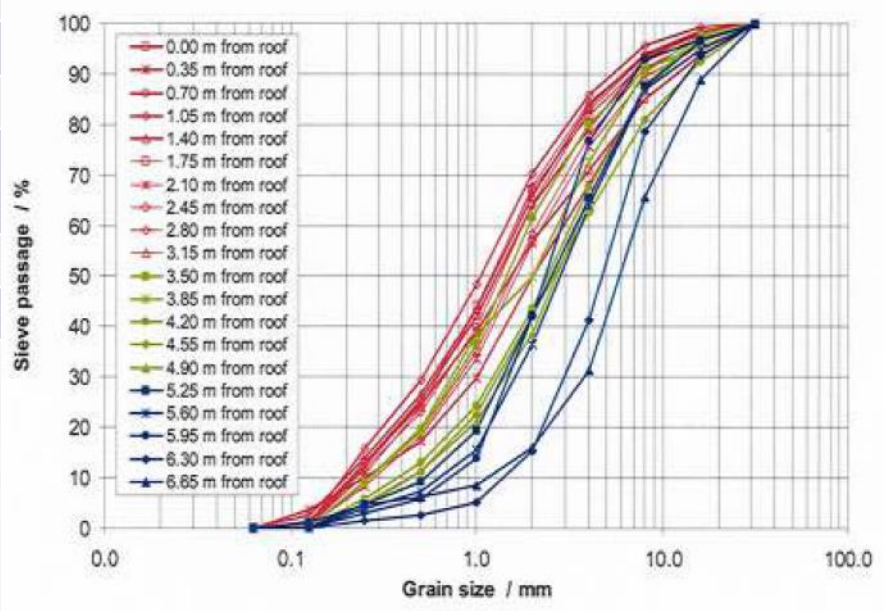




QA-measures

- QA-measures considering functions (1) to (5)
  - Initial porosity by recording mass of emplaced crushed salt and volume of cavity
  - Grain size distribution within a drift´s cross-section

	Southern drift	Northern drift
Backfill material [10^3 kg]	1,347	1,363
Drift volume [m^3]	963	966
Initial bulk density [kg/m^3]	1,399	
Specified deviation [%]	+2 … -2.6	
Range of initial density [kg/m^3]	1,363 …1,427	
Porosity [-]	0.34 … (0.35) … 0.37	
Void ratio [-]	0.52 … (0.54) … 0.58	

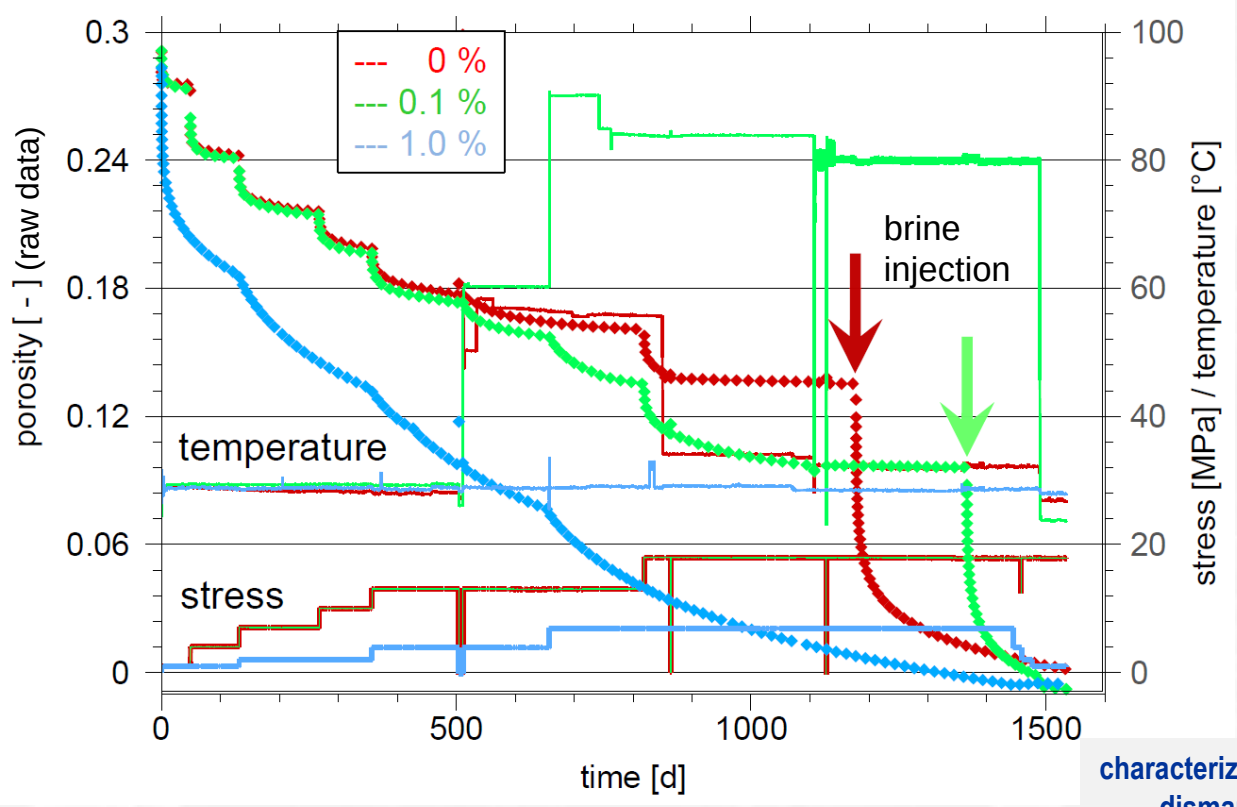


BAMBUS II project (2004)

Functional Requirement (6)

BMU 2010

- From limited release to isolation of radionuclides

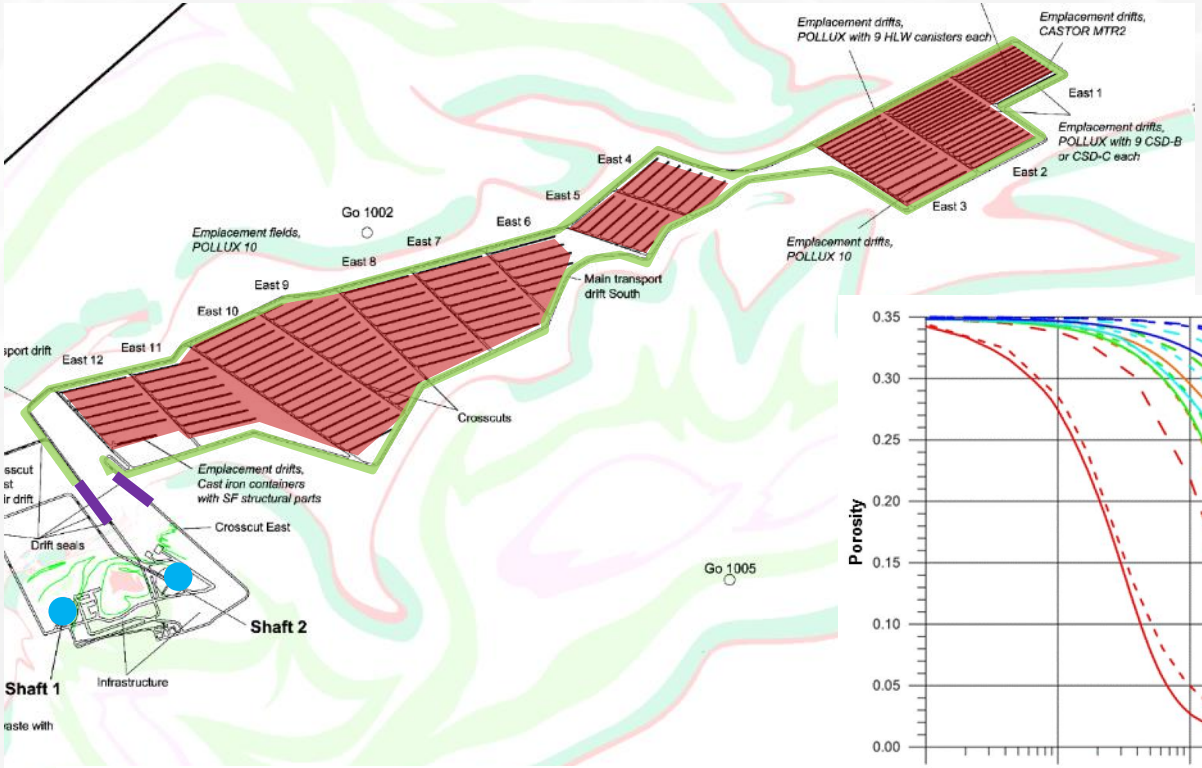


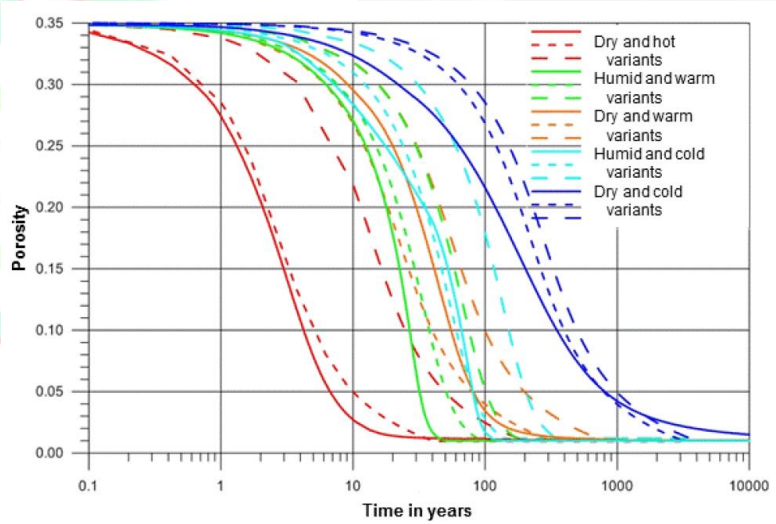
REPOPERM II, 2017

Current knowledge gives confidence that granular salt will compact to a final porosity in the order of 1±1 % within less than 1000 a, but this has to be demonstrated, reliably

characterization after dismantling yields porosities of 1 – 2%

First Application of BMU 2010 Requirements - VSG





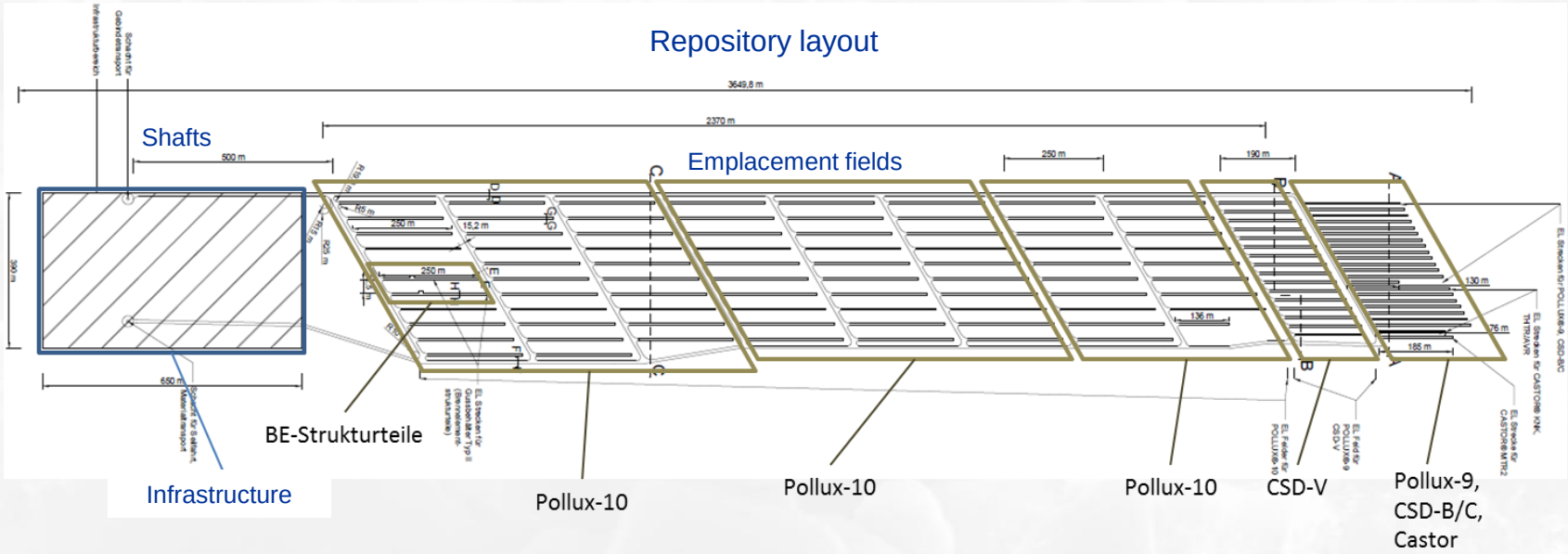
Backfill and seals:

- Dry crushed salt in emplacement drifts and cross-cuts
- Humid crushed salt in access drifts
- Drift seals (made of MgO-concrete)
- Shaft seals include humid crushed salt sealing elements

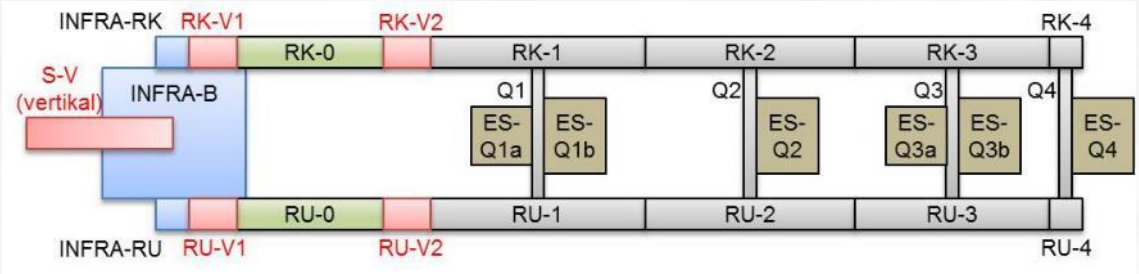
Result

Safe confinement of radionuclides within 1 million years!

Application to Bedded Salt Formation - KOSINA



Performance assessment model



Dry crushed salt in
emplacement drifts, cross-cuts, access drifts

Humid crushed salt in selected parts of access drifts

Drift seals, shaft seals

Result

Safe confinement of radionuclides within 1 million years!

Functional Requirement (6) – Knowledge Gaps

- Current knowledge gives confidence that granular salt will compact to a final porosity in the order of 1±1 % within less than 1000 a
  - but this has reliably to be demonstrated in order to show salt barrier´s recovery
- Scientific challenge
  - long lasting processes must be accelerated in order to achieve results within a reasonable time span
  - Consequently, it must be demonstrated as well that accelerated results are equivalent to that of long lasting processes
- Furthermore, to predict long-term behaviour of a repository verified and validated numerical models are required

The KOMPASS Project – Closing Knowledge Gaps

KOMPASS –

Compaction of Crushed Salt for the Safe Containment

(„Kompaktion von Salzgrus für den sicheren Einschluss“)

- The overall objective of the project is to reduce the knowledge gaps to enhance the safety case for a repository in rock salt

- This includes
  - the completion of the experimental database
  - the improvement of process understanding
  - and the enhancement and calibration of models to enable a reliable prediction of crushed salt reconsolidation

The KOMPASS Project - Phase I

- KOMPASS – Phase I (01.09.2018 – 31.08.2020) was funded by the Federal Ministry for Economic Affairs and Energy (**BMWi**) under support code 02E11708. Results of phase I are presented here
- The authors are sincerely thankful for the financial support
- The project partners would also like to express their special thanks to our colleagues from **Sandia** for fruitful cooperation

Partners

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PTKA Projektträger Karlsruhe
Karlsruher Institut für Technologie

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

BGE TEC | BGR | GRS | IfG Institut für Gebirgsmechanik GmbH Leipzig | TU Clausthal

The KOMPASS Project – Phase II

- KOMPASS – Phase II (01.07.2021 – 30.06.2023) is also funded by the Federal Ministry for Economic Affairs and Energy (**BMWi**) under support code 02E11951
- A joint project of BGE TEC, BGR, GRS, IfG, and TUC
- Cooperation with Sandia and Utrecht University as associated partners is planned
- The overall objective of the project is to reduce furthermore the knowledge gaps to enhance the safety case for a repository in rock salt

- This includes
  - Advanced experimental investigations based on results of KOMPASS I
  - Advanced microstructure investigations based on results of KOMPASS I
  - Numerical modelling aiming at to establish a virtual demonstrator
  - Evaluating of numerical models referring to the requirements of long-term safety

PTKA
Projektträger Karlsruhe
Karlsruher Institut für Technologie

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BGE TEC BGR GRS IfG Institut für Gebirgsmechanik GmbH Leipzig TU Clausthal

Remarks and Outlook

- Keep in mind that crushed salt must be emplaced by mining techniques
- Knowledge on initial conditions relies on presently available QA-measures
  - Initial porosity by recording mass of emplaced crushed salt and volume of cavity
  - Grain size distribution
  - (Surface) moisture content
  - Mineral composition
  - Temperature
- If humid backfill is used preservation of humidity distribution over time is a research issue – clay salt may act as a natural analogue

Acknowledgement

The projects are funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) and managed by the Project Management Agency Karlsruhe (PTKA)

Thank you for your attention!

ELSA II