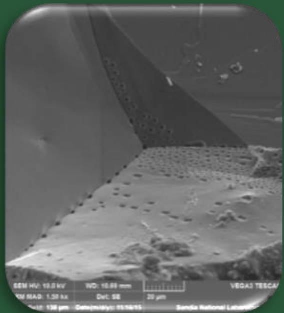
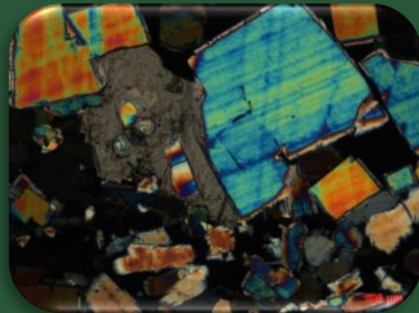
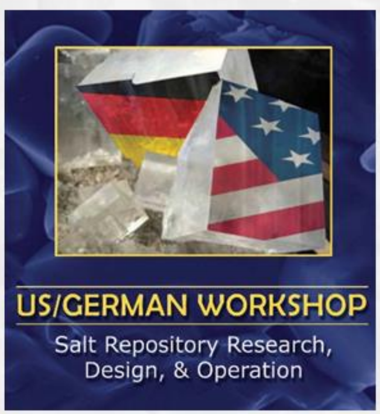



RANGERS:
Methodology and Numerical Applications

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



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The research work that is the basis of this report was funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) represented by the Project Management Agency Karlsruhe (Karlsruhe Institute of Technology, KIT) under contract number FKZ 02 E 11839. The authors alone, however, are responsible for the contents of this study.

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What is RANGERS?

- **RANGERS stands for:**
  - (german) Entwicklung eines methodischen Ansatzes zur Auslegung und zum Nachweis von geo-technischen Barrieren für ein HAW Endlager in Salzformationen Design
  - (english) Methodology for design and performance assessment of geotechnical barriers in a HLW repository in salt formations
- **Joint-Project between BGE TECHNOLOGY and SANDIA National Lab**
- **Project duration: 2020 - 2022**

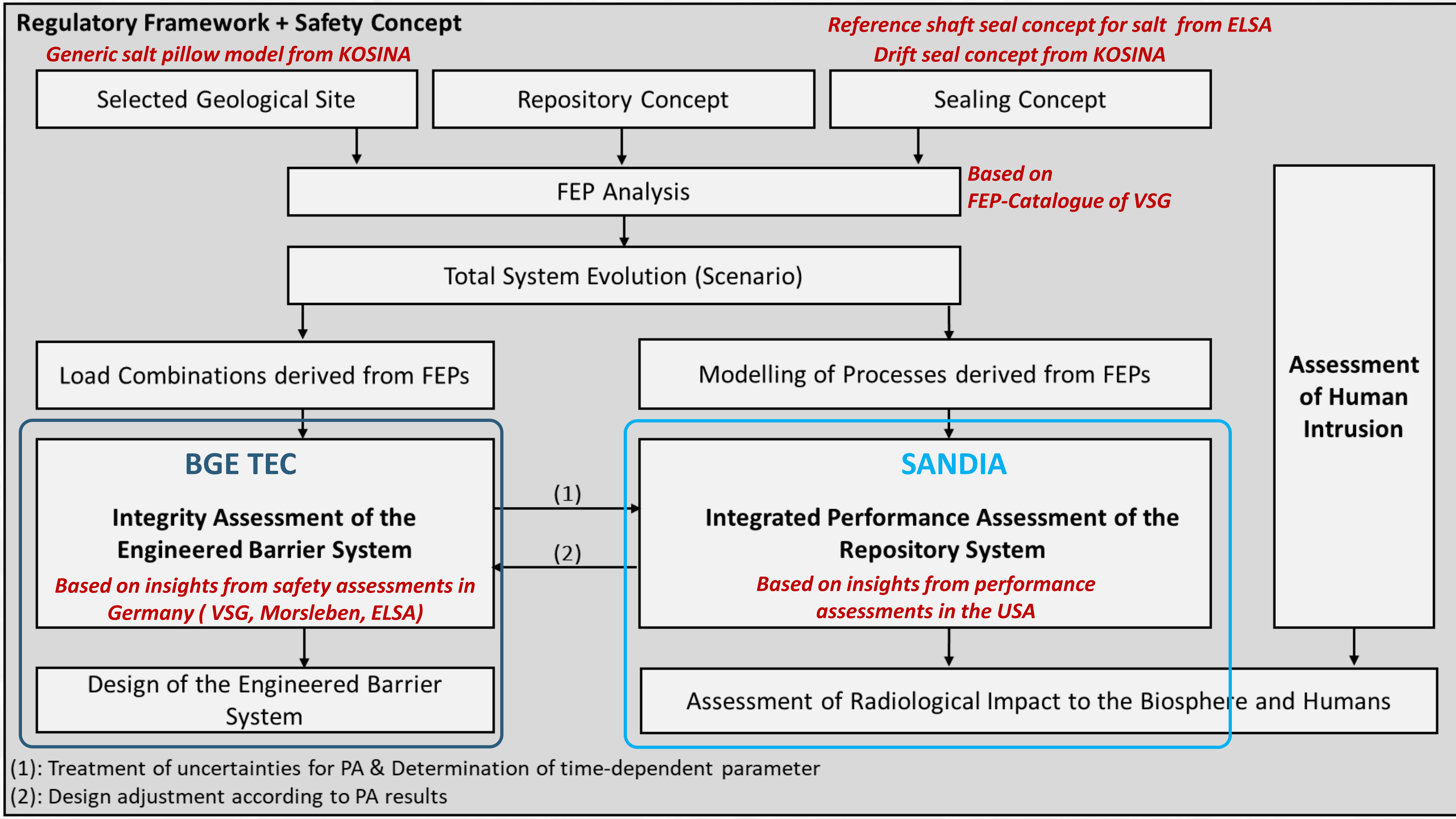
Project Goals

- **Main goals:**
  - Compilation of existing knowledge and experience for the design geotechnical barriers and compilation of new concepts and technologies on the subject of geotechnical barriers.
  - Development of a methodology based on the state of the art in science and technology for the design and verification of geotechnical barriers.
  - Preliminary design and verification of the geotechnical barrier system for the selected repository system based on the developed methodology.
  - Comparison of design results according to the new methodology with results of previous design and assessment.

Project Goals

- **Secondary goals:**
  - Estimation of the optimization potential of EBS in salt repositories
  - Analysis of the impact of gases on EBS in salt
  - Exploiting synergy effects between BGE TEC and SANDIA in the numerical treatment of EBS in the course of the overall safety assessment of salt repositories:
    - The expertise of BGE TEC on numerical based design of EBS will be used for the dimensioning of the components of the EBS.
    - The expertise of SNL in the performance assessment of large repository systems will serve to analyze the geochemical evolution and radionuclide transport through the EBS

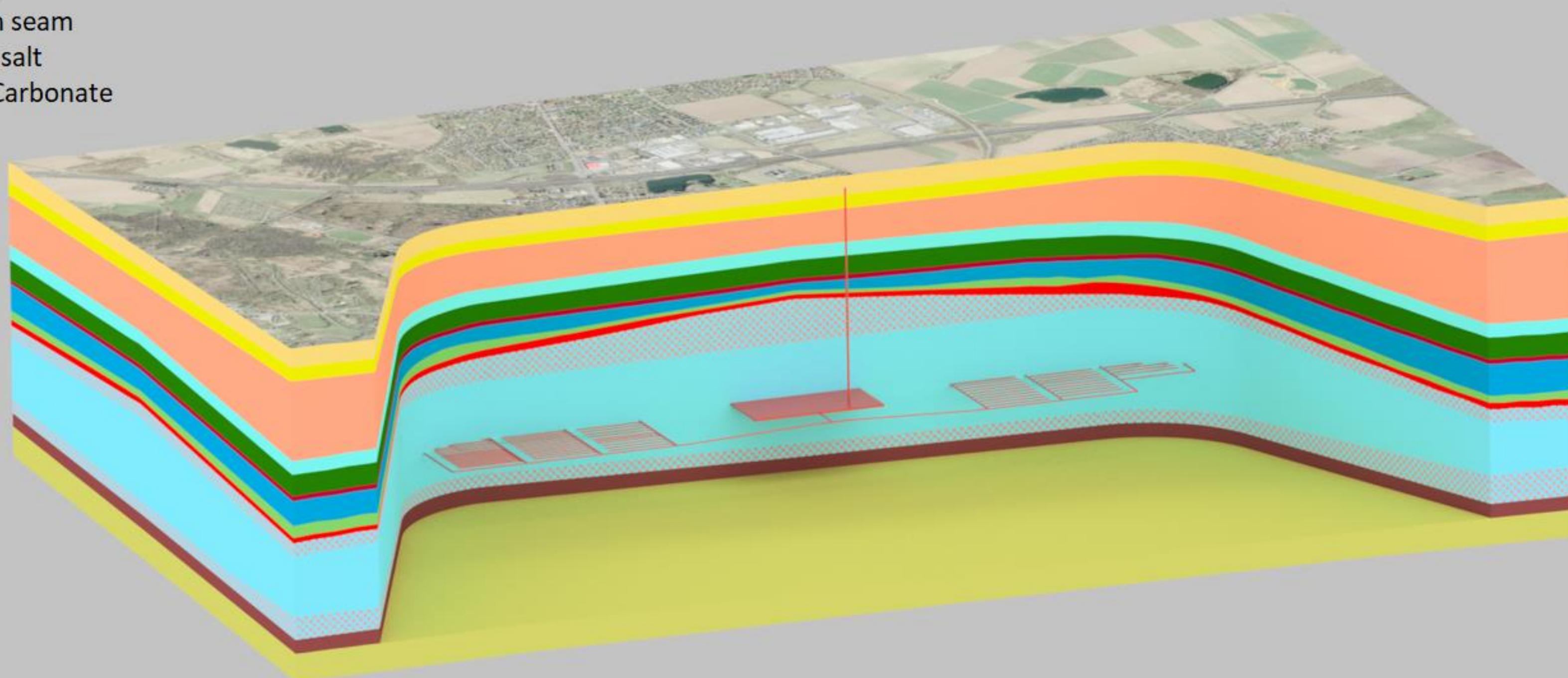
RANGERS Methodology



Repository in the selected geological site

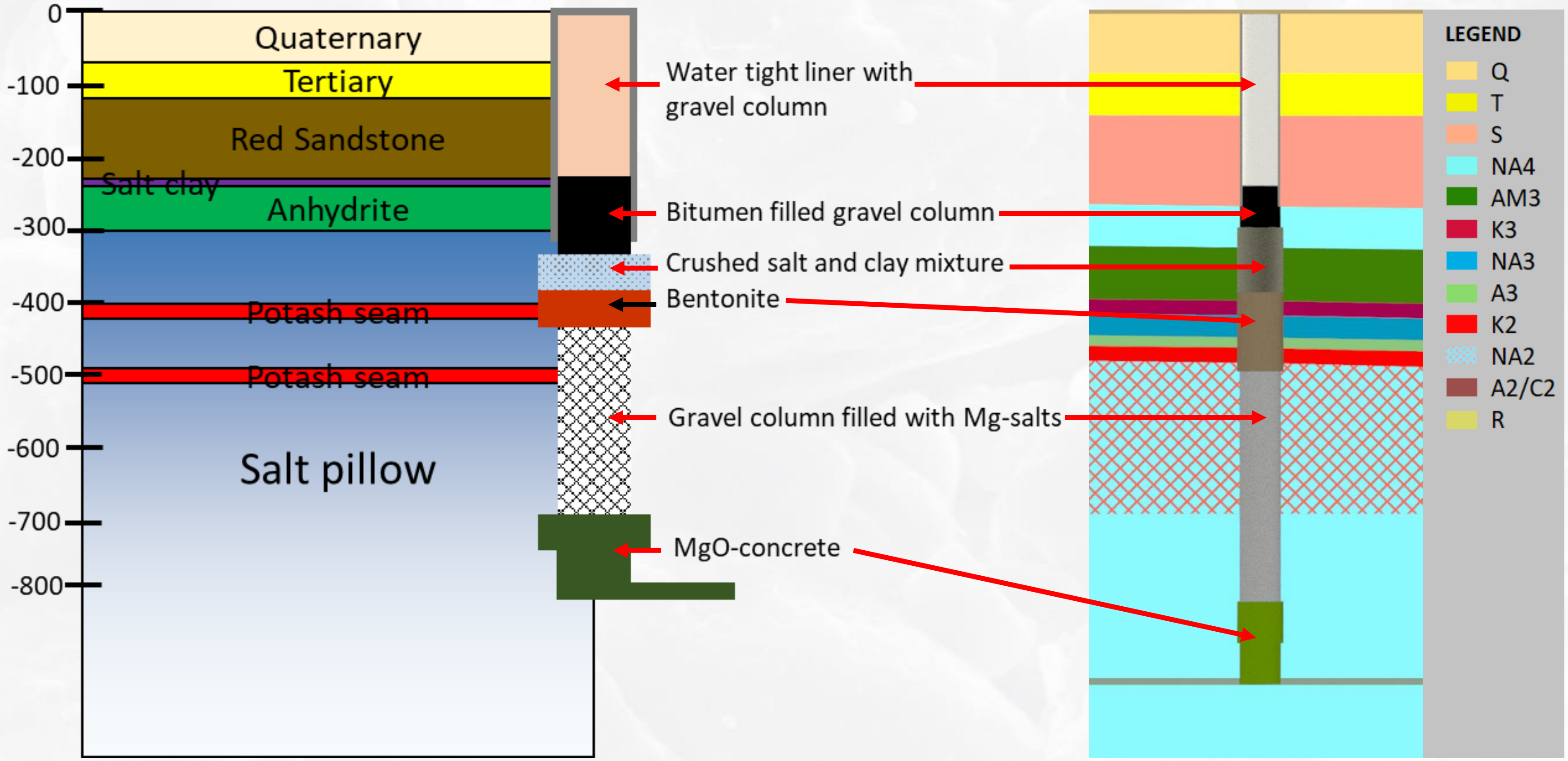
LEGEND

- Q - Quaternary
- T - Tertiary
- S - Bunter Sandstone
- NA4 - Aller rock salt
- AM3 - Anhydritmittelsalz
- K3 - Ronnenberg potash seam
- NA3 - Leine rock salt
- A3 - Main Anhydrite
- K2 - Staßfurt potash seam
- NA2 - Staßfurt rock salt
- A2/C2 - Anhydrite/Carbonate
- R - Underlying Red

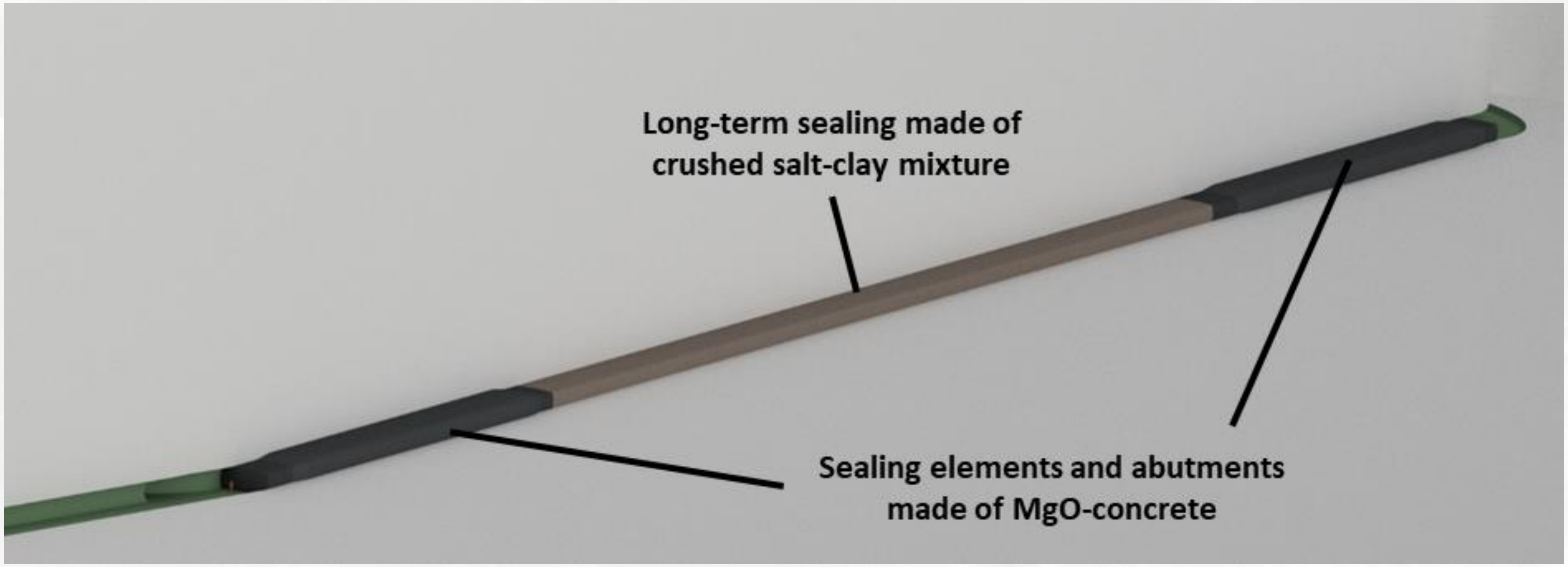


with courtesy of BGR

Sealing concept: Shaft seals



Sealing concept: Drift seals



Preliminary FEPs for EBS in salt formation

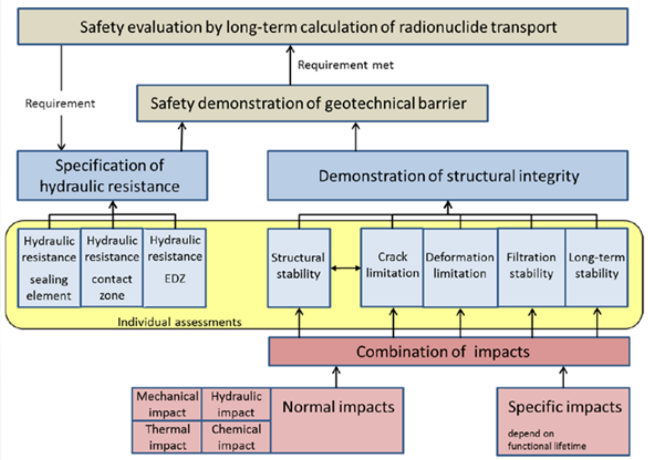
					Components affected by process														
Sub-system: Drift	Process Group	FEP	Description	Impact on EBS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Components		1: Drift seal																	
		3: Drift Backfill																	
		10: Concrete injection																	
		7: EDZ																	
		XX: …																	
Processes/ Events	Mechanical	Example: Earth quake	The release of accumulated geologic stress via rapid relative movements within the earth's crust usually along existing faults or geological interfaces.	tectonic movements resulting from an earth quake may yield in fractures in the drift seal. The drift lining may collapse.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Hydraulic	Example: Gas flow processes	Describes the gas flow due to potential gradients. Gas flow is responsible for transport of volatile compounds.	Gas flow transport is important for chemical processes and radio-nuclide spreading.									x						x
	Thermal	Example: Heat flow	Means the energy transport as a result of temperature differences. There are 3 main sources for heat flow: climate, geothermic and radionuclide decay of the waste	The impact of waste produced heat on geotechnical barriers depends on the distance between barrier and empla-cement field.	x	x	x	x	x		x	x	x	x	x	x	x	x	x
	Chemical	Example: Concrete corrosion	Describes the chemical degradation of concrete	The corrosion processes will impair the function of all concrete components in the drifts	x	x	x	x				x		x	x				

Scenario relevant for EBS

- **Reference Scenario**: The EBS retains its function over 50000 years
  - Case 1: Water flow from overburden through the shaft to the disposal zones
  - Case 2: Gas production inside the repository from corrosion of the casks
  - Case 3: Water source inside the repository from inter-/ intragranular salt solutions
- **Alternative Scenario 1**: Shaft seal loses its function and drift seals retain their function
  - Same cases
- **Alternative Scenario 2**: Shaft seal retains its function and drift seals lose their function
  - Same cases

Modelling Concept

- **Integrity assessment:**



Modelling Concept

- **Integrity assessment:**

	Hydraulic resistance -sealing element	Hydraulic resistance -contact zone	Hydraulic resistance -EDZ	Structural stability	Crack limitation	Deformation limitation	Filtration stability	Long-term stability
Reference Scenario: The EBS retains its function over 50000 years								
Case 1: Water flow from overburden through the shaft to the disposal zones	**H**: determination of flow rate and passing time. **HM:** including compaction of crushed salt, swelling of bentonite (shaft) and related kf-development **THM:** compaction and kf-development at drift seal			**TM:** structural analysis of components inside the shaft (gravel column, concrete elements)			No numerical modelling needed, design and assessment based on existing standards	**Geochemical analysis:** determination of geochemical stability of the sealing elements against water/brine, a) theoretically unlimited water reservoir b) limited reservoir or in combination with kf-development
Case 2: Gas production inside the repository from corrosion of the casks	**H:** gas pressure development inside repository (backfill)/at the drift seal, permeation condition pg<sig min **HM:** Interaction between gas pressure evolution and compaction of crushed salt in the drifts			Not relevant			Not relevant	Not relevant
Case 3: Water source inside the repository from inter-/ intragranular salt solutions	**H:** determination of flow rate and passing time. **HM:** including compaction of crushed salt, swelling of bentonite (shaft) and related kf-development **THM:** compaction and kf-development at drift seal			**TM:** structural analysis of components inside the drift (concrete abutments)			Not relevant	**Geochemical analysis:** determination of geochemical stability

BGE TEC (purple) **SANDIA** (green)

Modelling Concept

- **Performance assessment**

$$RGI = \frac{\sum_i S_i \cdot DKF_i}{W \cdot K_{RGI}}$$

Modelling Concept

- **Performance assessment**

	Processes							Target Criteria
	Nuclide decay	Advection	Diffusion	Convection/ conduction	2-Phase-flow	Boiling	Recon-densation	Dose constraints
Reference Scenario: The EBS retains its function over 50000 years								
Case 1: Water flow from overburden through the shaft to the disposal zones								
Case 2: Gas production inside the repository from corrosion of the casks								
Case 3: Water source inside the repository from inter-/ intragranular salt solutions								

BGE TEC

SANDIA

Modelling Concept

- **Interactions between integrity and performance assessment**

Interaction with performance assessment: Determination of permeability/porosity-functions of EBS-components for the PA simulations

	Hydraulic resistance -sealing element	Hydraulic resistance -contact zone	Hydraulic resistance -EDZ	Structural stability	Crack limitation	Deformation limitation	Filtration stability	Long-term stability
Reference Scenario: The EBS retains its function over 50000 years								
Case 1: Water flow from overburden through the shaft to the disposal zones	**H**: determination of flow rate and passing time. **HM:** including compaction of crushed salt, swelling of bentonite (shaft) and related kf-development **THM:** compaction and kf-development at drift seal			**TM:** structural analysis of components inside the shaft (gravel column, concrete elements)			No numerical modelling needed, design and assessment based on existing standards	**Geochemical analysis:** determination of geochemical stability of the sealing elements against water/brine, a) theoretically unlimited water reservoir b) limited reservoir or in combination with kf-development
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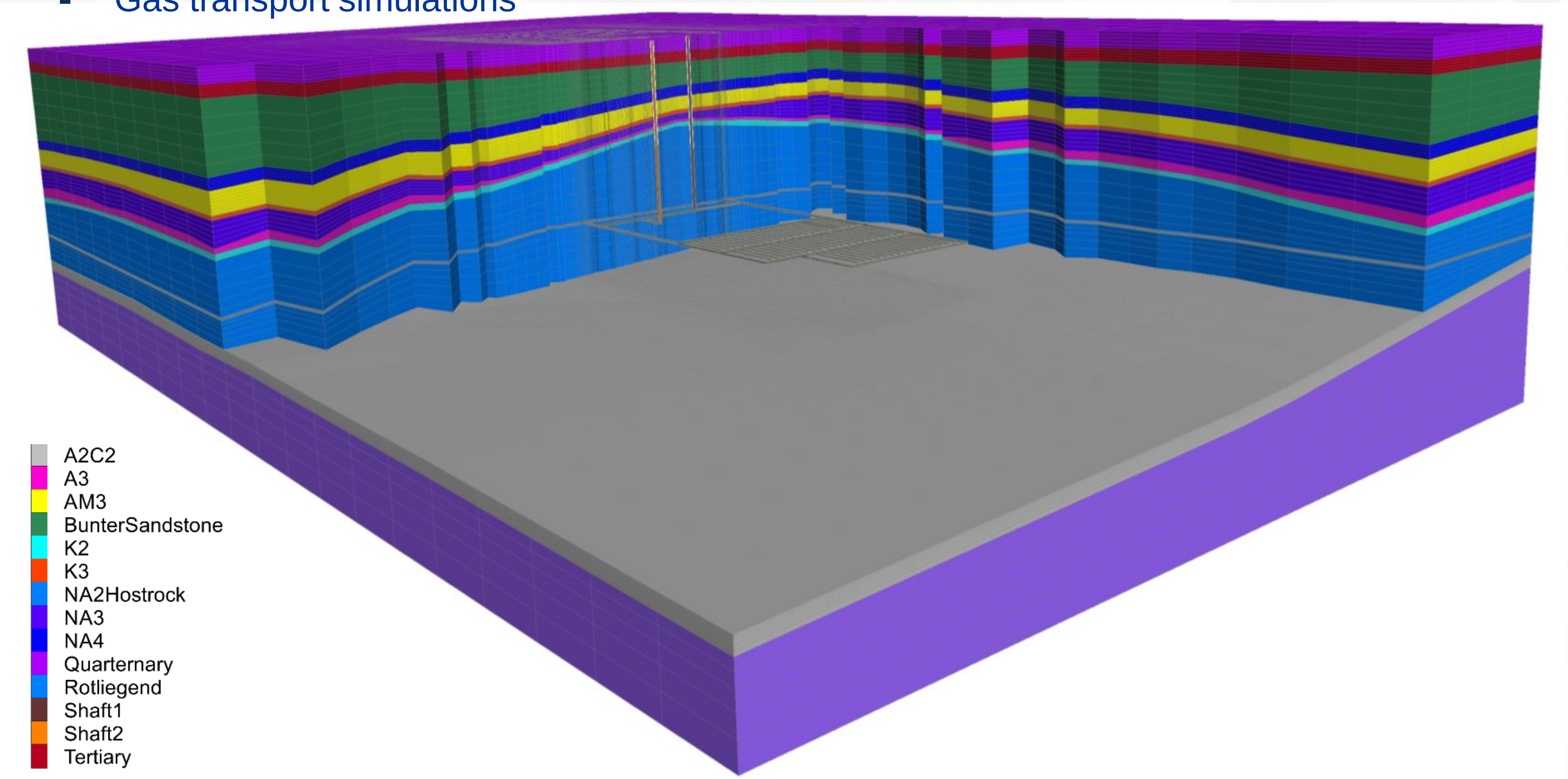
Case 2: Gas production inside the repository from corrosion of the casks								
Case 3: Water source inside the repository from inter-/ intragranular salt solutions								

Interaction with Integrity assessment: Sensitivity analyses – Optimization of the EBS-parameters in the PA simulations

(purple)	BGE TEC
(green)	SANDIA

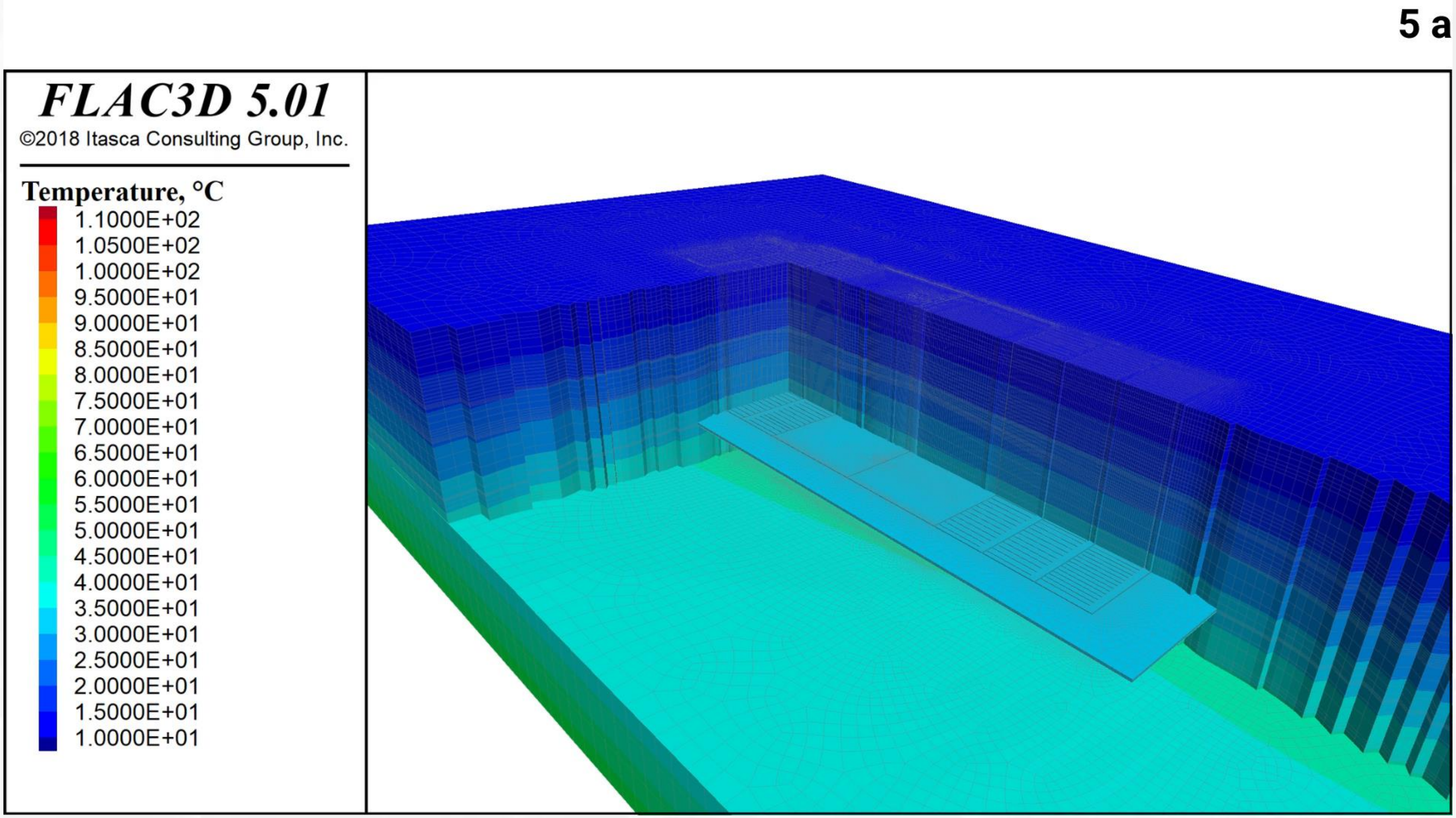
Numerical Model

- **BGE TEC:**
  - T: Analysis of the thermal evolution in the EBS components
  - H: 1-phase hydraulic evolution of the repository
  - TM-compaction of crushed salt in the repository – determination of permeability function
- **SANDIA:**
  - Performance Assessment Simulations
  - Gas transport simulations



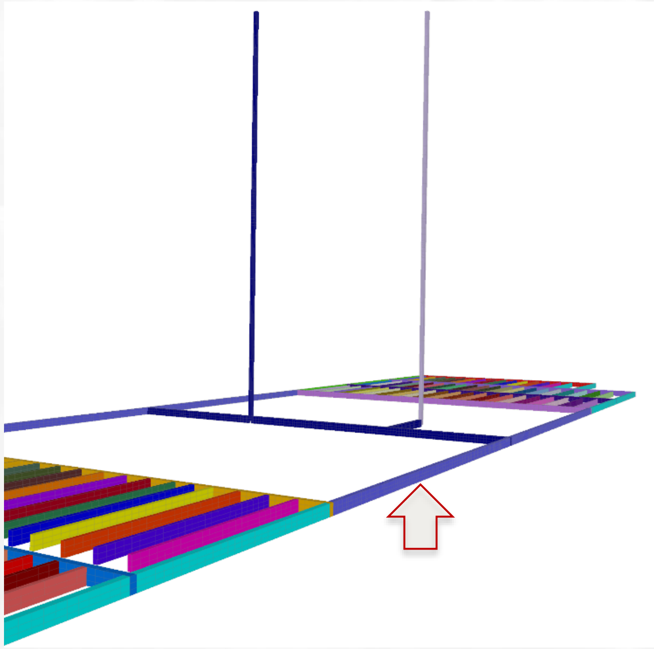
Thermal evolution in the repository (BGE TEC)

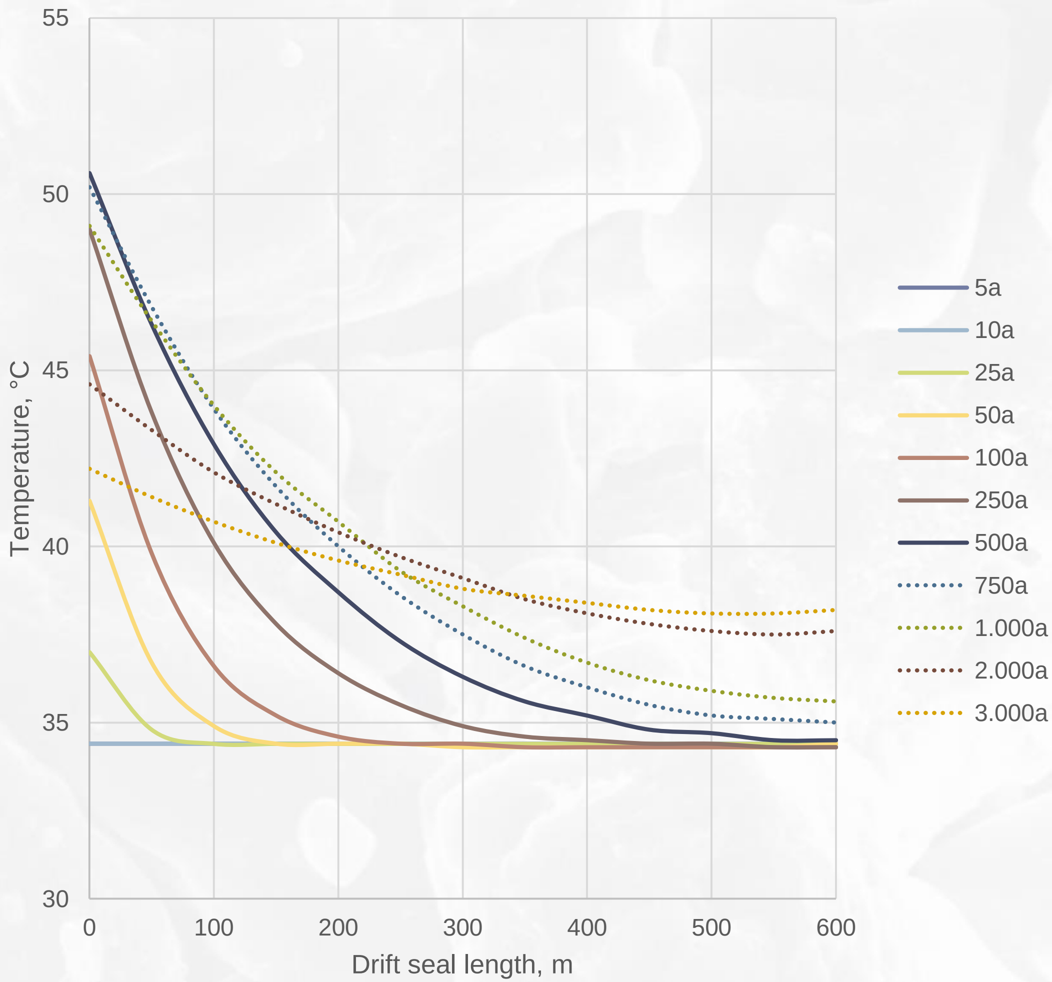
- Goal: Determination of the temperature increase in the EBS



Thermal evolution in the repository (BGE TEC)

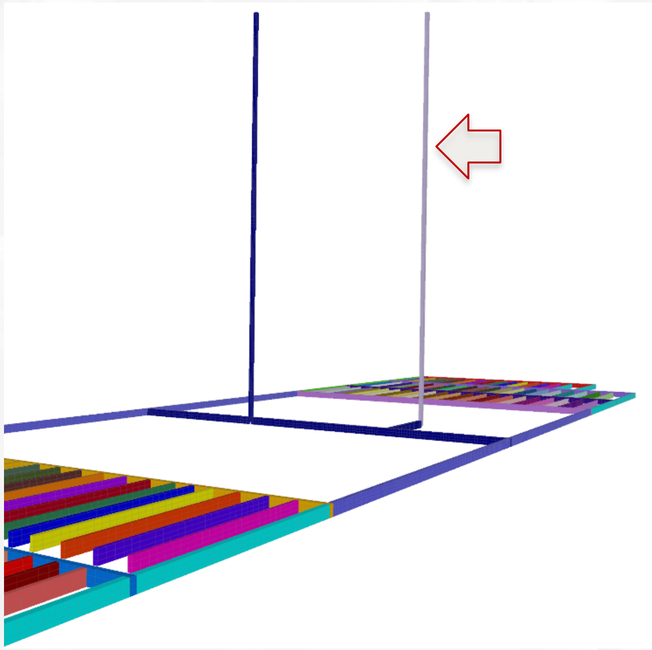
- Temperature evolution in the drift seal

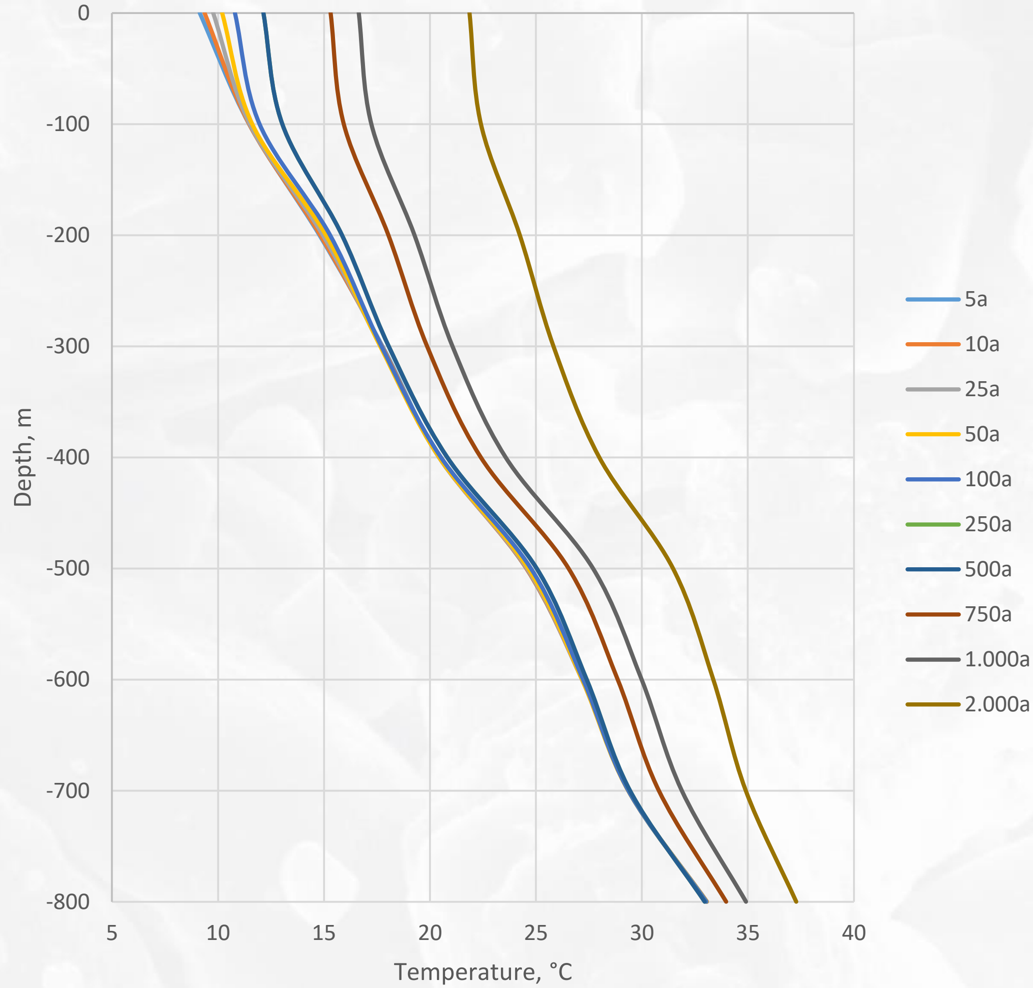




Thermal evolution in the repository (BGE TEC)

- Temperature evolution in the shaft





Thermomechanical compaction of crushed salt in the repository (BGE TEC)

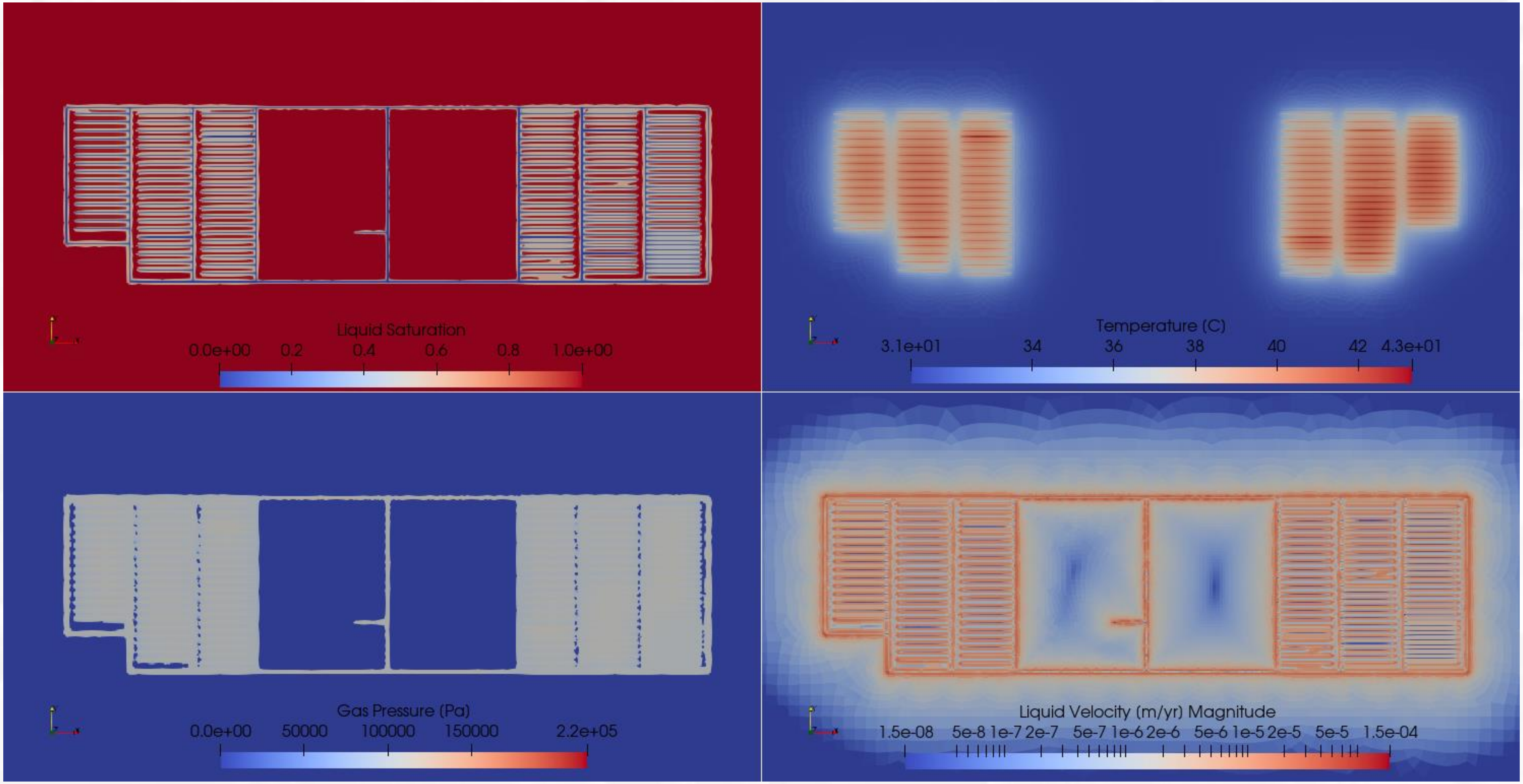
- Goal: Determination of porosity/permeability-function for PA

Demonstration PFLOTRAN Simulations (SANDIA)

- **Goal: Test of the capacity of PFLOTRAN to simulate the relevant processes considered in the scenario evolution**
- Assumption for the test case:
  - Two-phase flow of air and water
  - Drifts, seals, and shafts are initially air-filled
  - Host rock is initially water-filled
  - 20 years pressure equilibration, then heating
  - Small inventory: 765 Pollux-10 and 279 Pollux-9 canisters
  - Individual waste packages not resolved
  - Assumed fuel 100 years out-of-reactor
- Next step: more realistic scenarios

PFLOTRAN Simulations (200 yr)

- Seals re-saturating and gas pressure increasing
- Flow in hostrock confined to near repository



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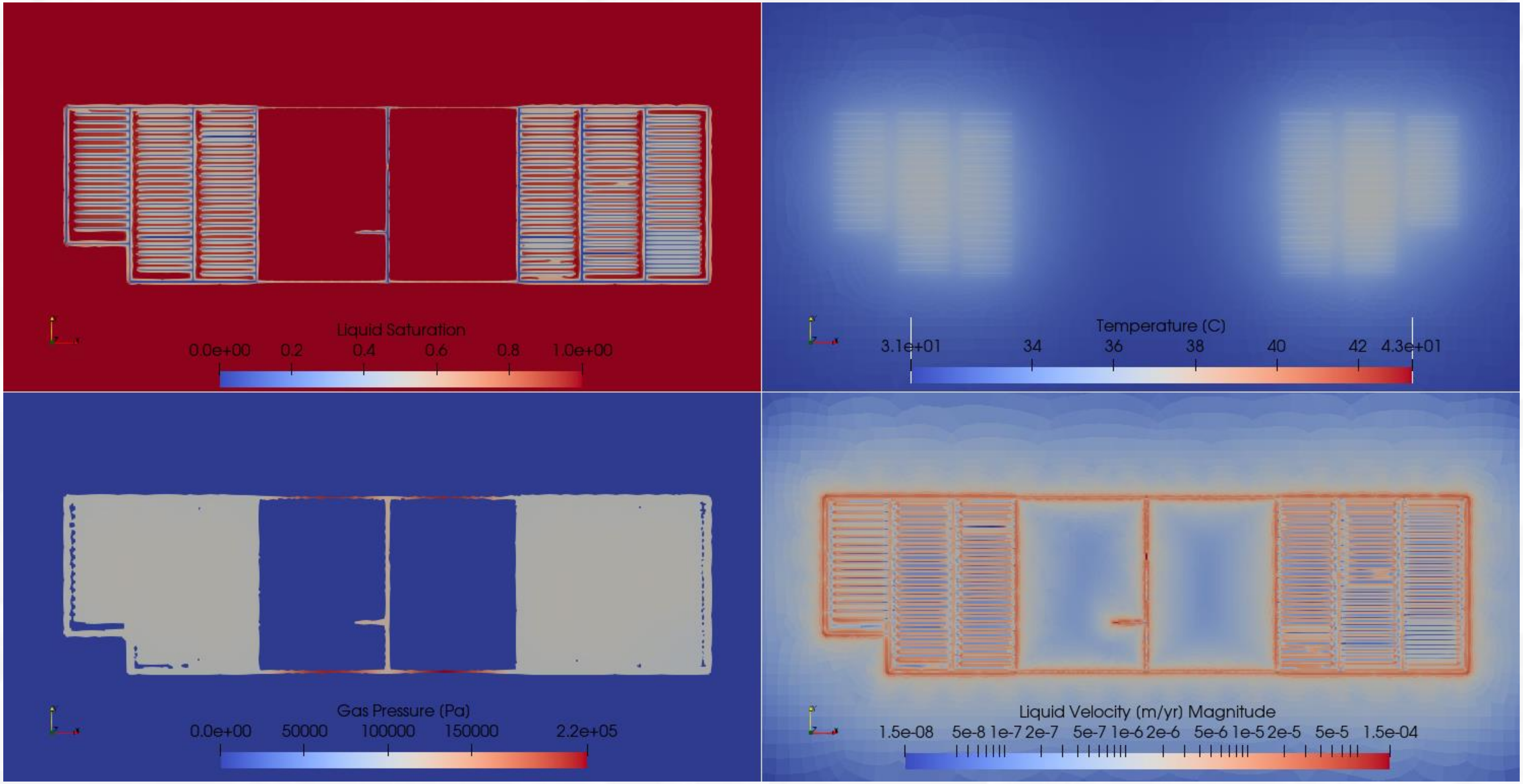

Conclusions

- A methodology for the for design and performance assessment of EBS in a HLW repository in salt formations has been developed
- The methodology has been applied for the preliminary design of the EBS of a generic repository system in Germany based on the generic salt pillow model developed in the KOSINA project
- The methodology is now being used to assess the integrity of the EBS and the long term evolution of the repository system:
  - A unique numerical model used at BGE TEC and at SANDIA has been developed for this purpose
  - First results show that the temperature evolution in the EBS remain transient in the first 2000 years
  - The evolution of the compaction of crushed salt in the repository will be used to derive the time dependent permeability in the repository mine
  - The capabilities of PFLOTRAN to analyze all relevant processes occurring in the near- and far-field of the repository system have been successfully shown

Next steps

- Structural integrity of the drift seals
- Structural integrity of the shaft seals
- Performance Assessment Simulations of the whole repository using the realistic geological material parameters and the actual waste inventory available in Germany
- Model optimizations and several case studies

Questions?

Thank you for your attention!