PERFORMANCE ASSESSMENT FOR A DEEP GEOLOGICAL REPOSITORY FOR RADIOACTIVE WASTE IN SWITZERLAND

CONFIDENCE BUILDING BY MODEL-SUPPORTED SENSITIVITY AND UNCERTAINTY ANALYSES

Potsdam, Feb. 6, 2025

Abschlusstagung Forschungsvorhaben "Ungewissheiten und Robustheit mit Blick auf die Sicherheit eines Endlagers für hoch-radioaktive Abfälle"

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nagra.

SWISS PA/SA WORKFLOW FOR LICENSE APPLICATION (11/2024)

Confidence building - some guiding principles …

- **NEA (2002)**
  → *" … confidence in performance assessment approaches is established by logical, transparent assessment workflows within an auditable framework"*

- **NEA (2004)**
  → *"… the use of multiple lines of evidence to build confidence in the geoscientific understanding that underlies the safety case"*

- **IAEA (2011/2016)**
  → *"… The redundancy and diversity of the individual barrier components, a principle that is in accordance with international safety standards …"*

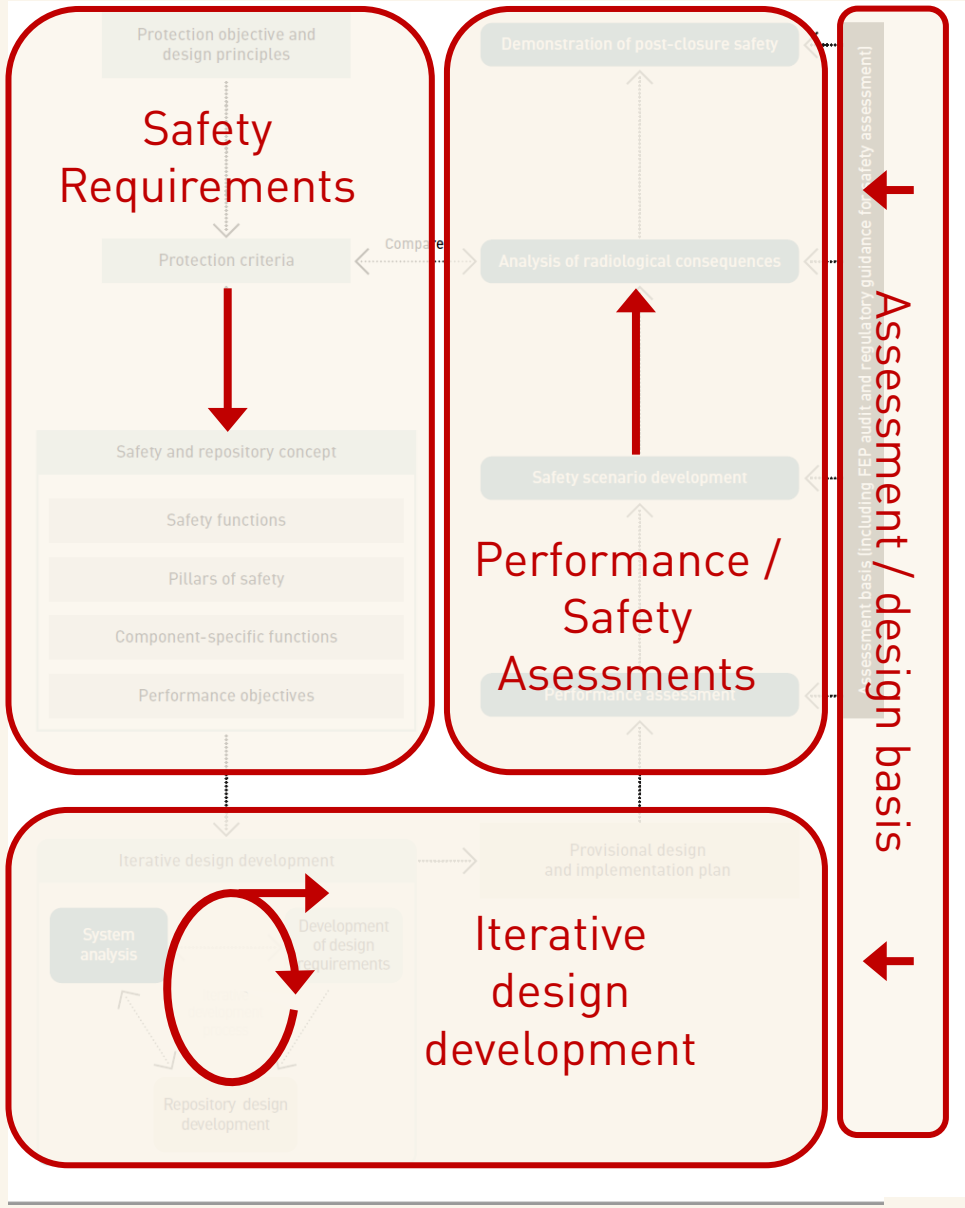
SWISS PA/SA WORKFLOW FOR LA - *A TRANSPARENT AND TRACEABLE WORKFLOW*

Swiss PA/SA workflow for License Application (LA):

PA embedded in a requirements-driven SA framework

- Top-Down safety requirements
- Iterative design development, feeding in transparent design & implementation plan
- Bottom-Up assessments
  – tailored to the Safety Case (SC)

- Supplied by an extensive assessment basis
  - updated for the safety case



SWISS PA/SA WORKFLOW FOR LA – *PILLARS OF SAFETY (MULTI-BARRIER CONCEPT)*

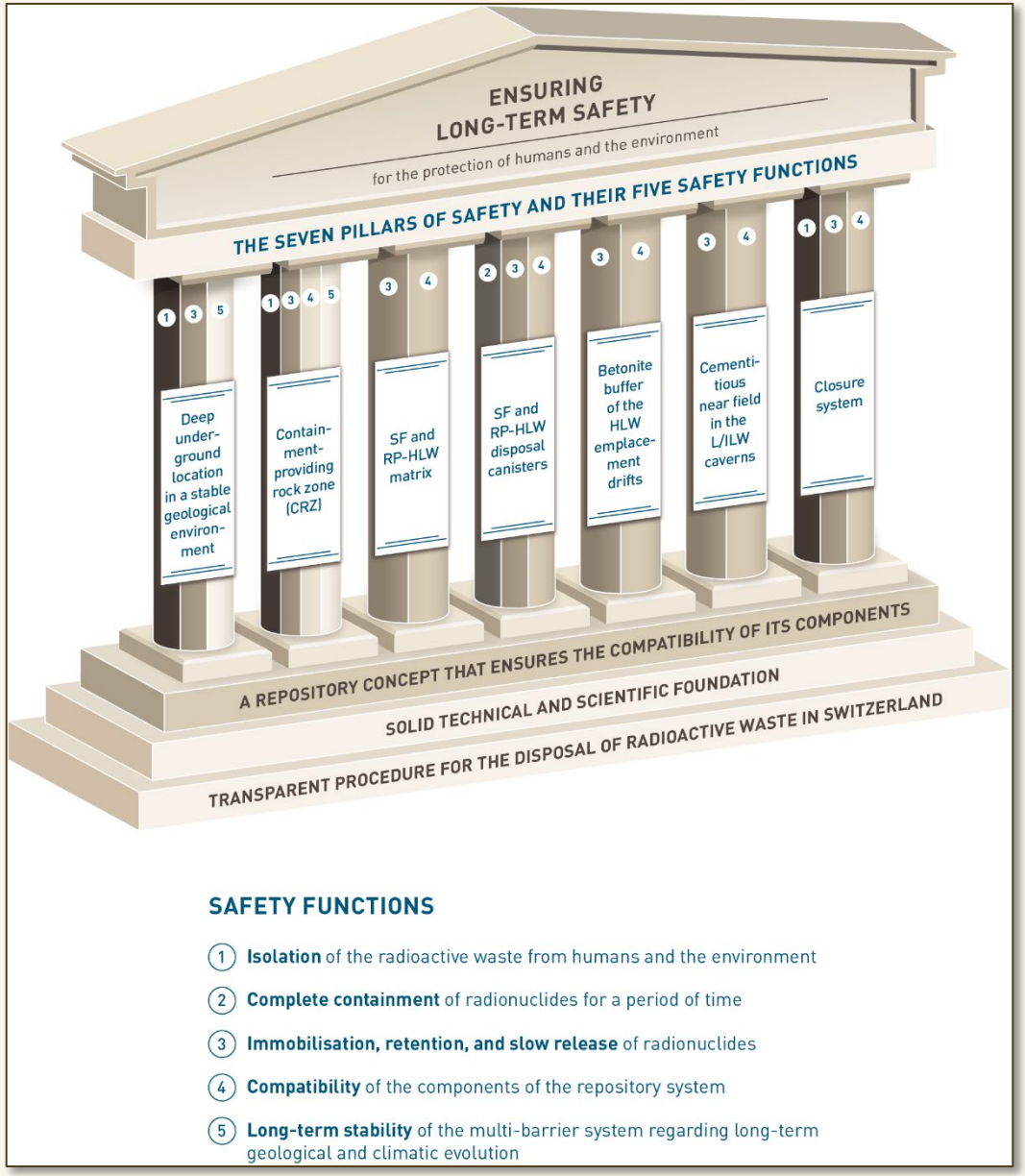
Safety architecture / "Statics" of the safety concept

- **Deep geological repository for SF/HLW and L/ILW**

→ Founded on a well-established waste disposal programme *(periodically updated)* and a robust scientific basis *(incl. periodically updated RD&D programme, waste inventory, site investigation programme)*

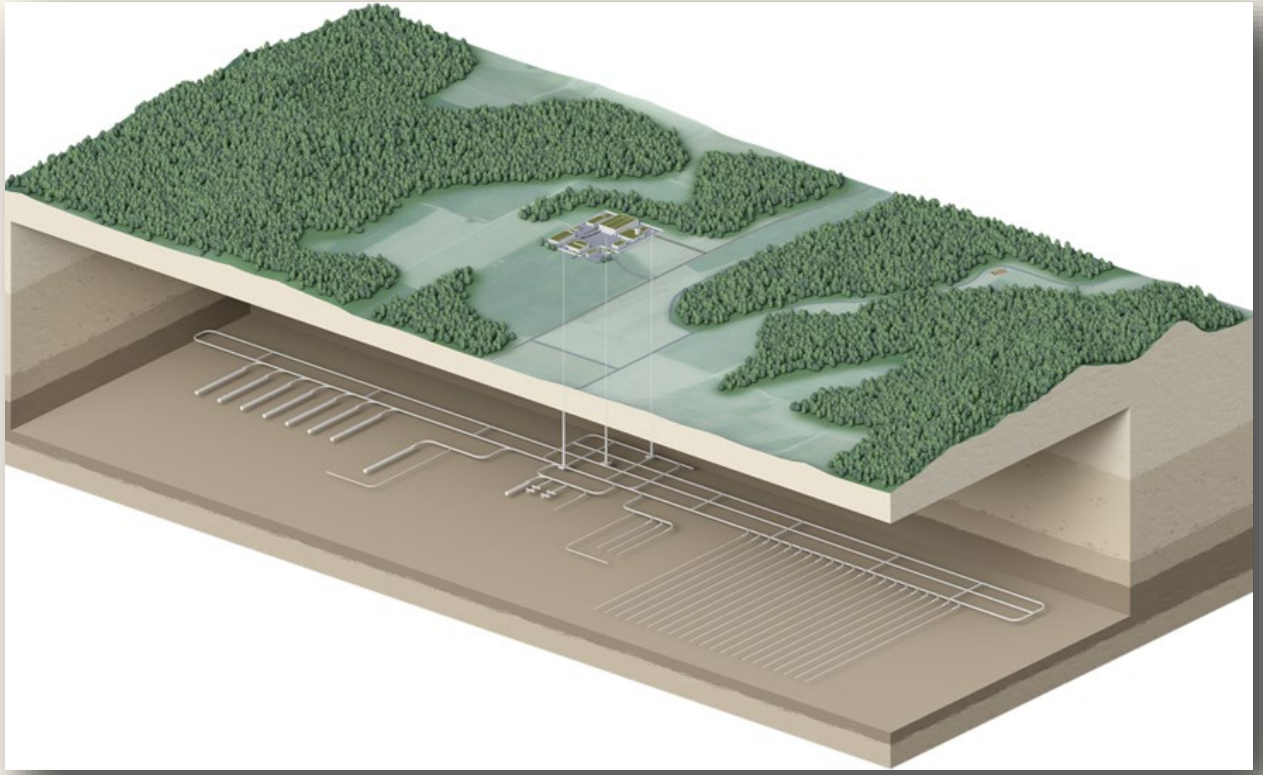
→ Pursuing a multibarrier concept, built on seven pillars of safety
(addressing redundancy, diversity)

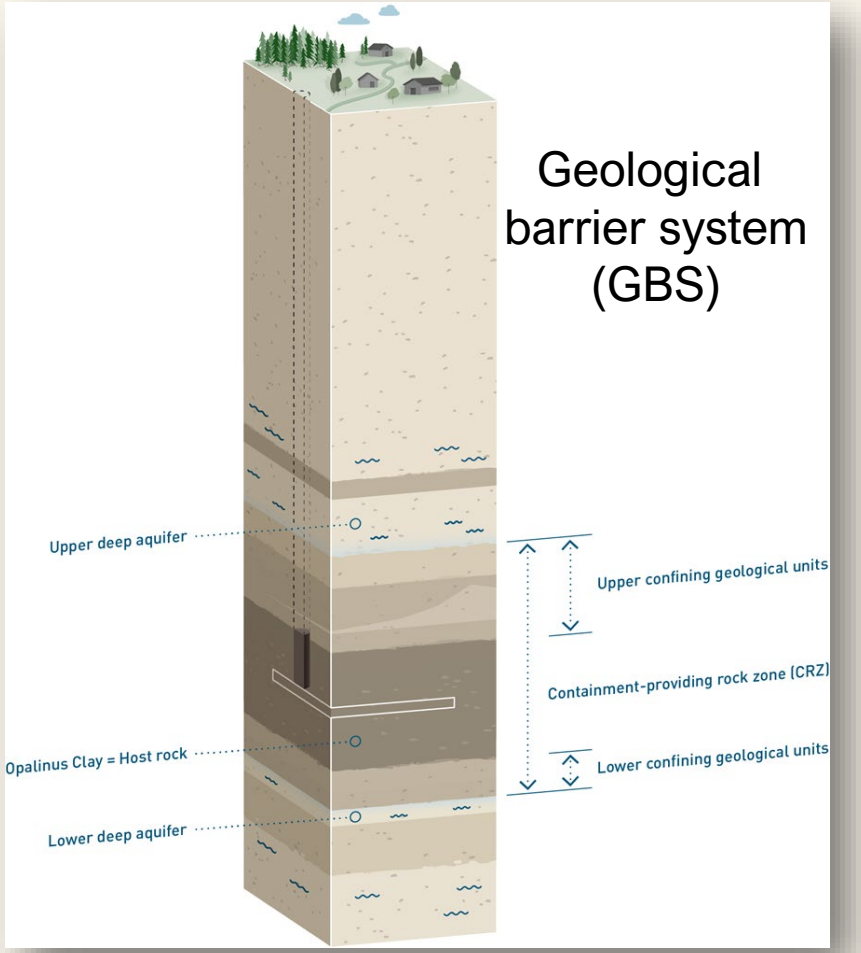
→ Complying with regulatory safety principles and and post closure safety requirements
(incl. barrier specific safety functions)



SWISS PA/SA WORKFLOW FOR LA – *ITERATIVE DESIGN DEVELOPMENT*

Design and implementation plan of the multi-barrier system of the HLW and L/ILW repository





SWISS PA/SA WORKFLOW FOR LA – *ITERATIVE DESIGN DEVELOPMENT*

Performance Assessment in the context of the Safety Case for License Application (Haberstal site)

- **Assessments tailored to the design&implementation plan**

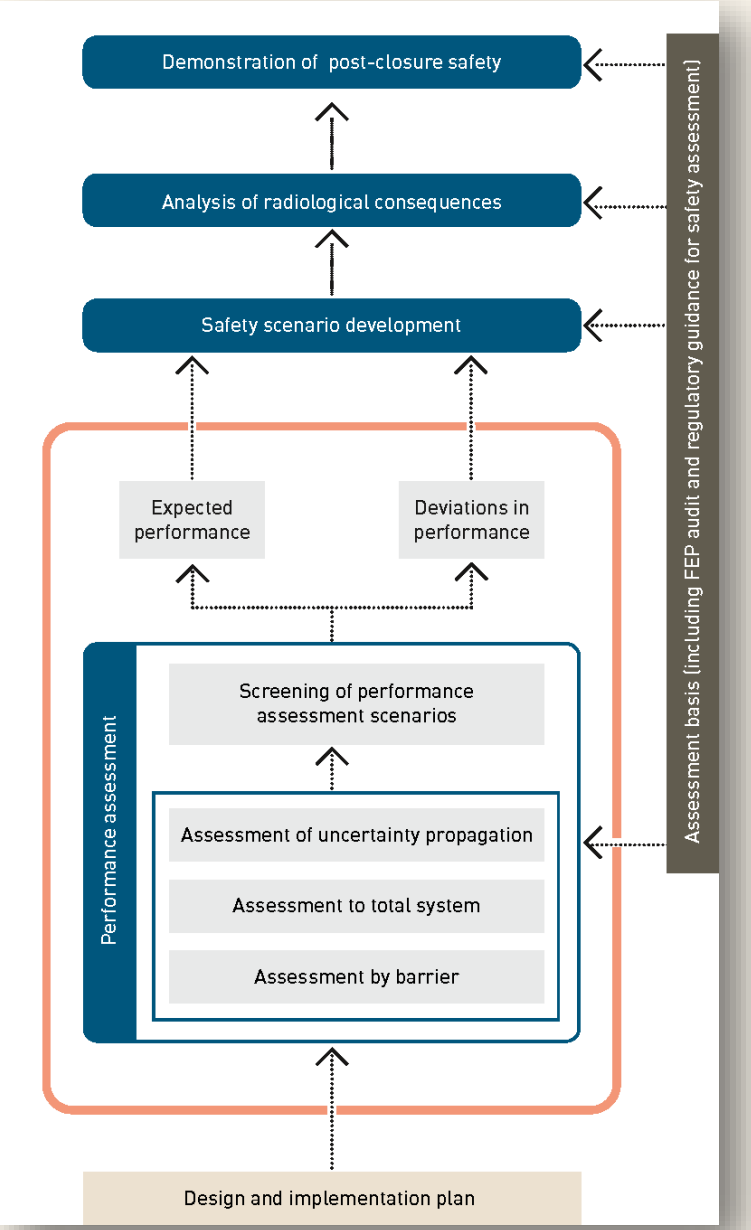
  → Assessments by barrier

  → Assessment of total system performance

  → Uncertainty quantification

  → Traceable scenario screening / classification of safety relevant scenarios

  (a) Expected repository performance
  (b) Deviations from expected performance



SWISS PA/SA WORKFLOW FOR LA - *A TRANSPARENT AND TRACEABLE WORKFLOW*

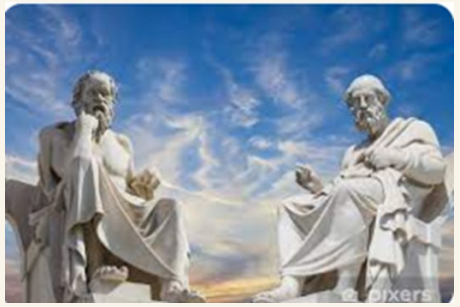
Methodology - Implementation of the guiding principles in PA

q.e.d

→ A “dialectic” method of discourse (confidence building requires discourse!)

→ ”Proof by induction” (ensures auditability!)

→ The robustness of a claim is strengthened by seeking multiple lines of arguments



SWISS PA/SA WORKFLOW FOR LA - *A TRANSPARENT AND TRACEABLE WORKFLOW*

Claims, arguments and evidence – short intro

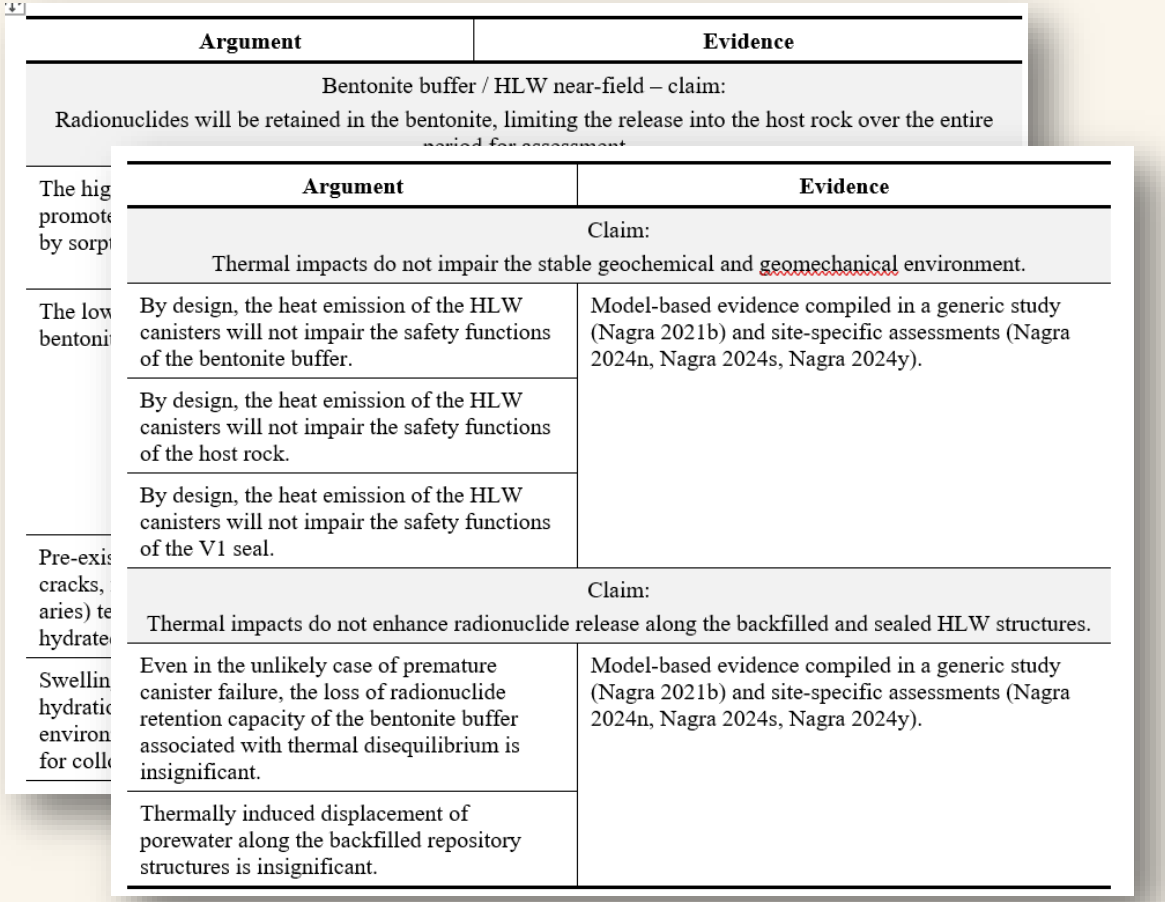
A book-keeping exercise *(collect arguments&evidence)*

- **Performance by barrier / example "HLW nearfield"**

  → *Compile multiple lines of arguments / evidence that support the assigned safety functions*

- **Total system performance / focus on interactions**

  → *heat flow*
  → *gas transport*
  → *transport of dissolved / volatile radionuclides along the backfilled repository structures*



Argument	Evidence
Bentonite buffer / HLW near-field – claim: Radionuclides will be retained in the bentonite, limiting the release into the host rock over the entire period for assessment	
The hig promote by sorpt	
The low bentoni	
Pre-exis cracks, aries) te hydrate	
Swellin hydratic environ for coll	

Argument	Evidence
Claim: Thermal impacts do not impair the stable geochemical and geomechanical environment.	
By design, the heat emission of the HLW canisters will not impair the safety functions of the bentonite buffer.	Model-based evidence compiled in a generic study (Nagra 2021b) and site-specific assessments (Nagra 2024n, Nagra 2024s, Nagra 2024y).
By design, the heat emission of the HLW canisters will not impair the safety functions of the host rock.	
By design, the heat emission of the HLW canisters will not impair the safety functions of the V1 seal.	
Claim: Thermal impacts do not enhance radionuclide release along the backfilled and sealed HLW structures.	
Even in the unlikely case of premature canister failure, the loss of radionuclide retention capacity of the bentonite buffer associated with thermal disequilibrium is insignificant.	Model-based evidence compiled in a generic study (Nagra 2021b) and site-specific assessments (Nagra 2024n, Nagra 2024s, Nagra 2024y).
Thermally induced displacement of porewater along the backfilled repository structures is insignificant.	

SWISS PA/SA WORKFLOW – *THE ROLE OF MODEL-SUPPORTED EVIDENCE*

TH^2(-M) Modelling in support of performance assessment

- **Indicator-based deterministic assessments for general system understanding**

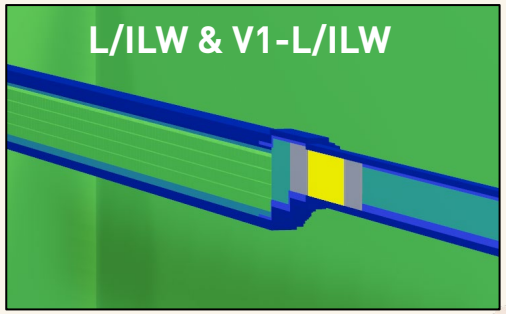
  → *barrier integrity at component / total system level*
  → *transport of dissolved / volatile radionuclides through the host rock / along the backfilled repository structures*

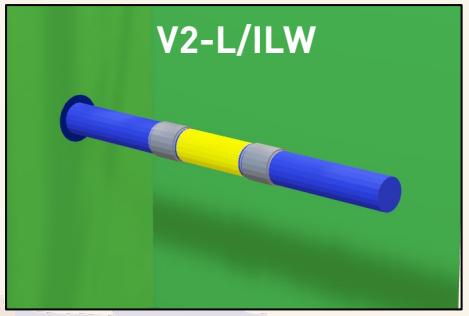
- ***Probabilistic assessments in support of scenario screening***

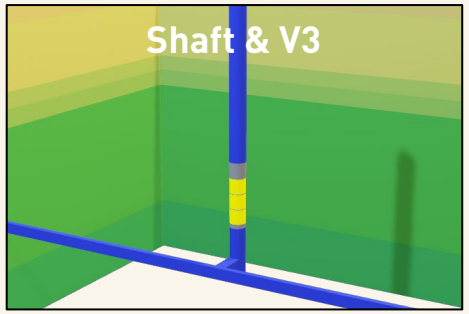
  → *expected performance of the repository as-designed*
  → *deviations from expected performance*

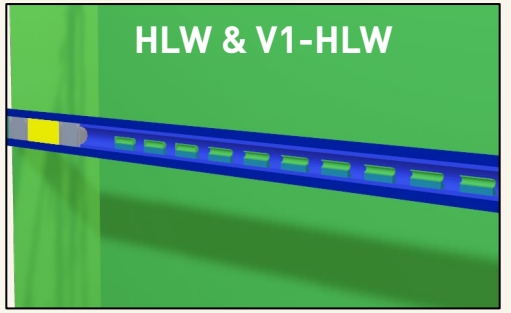
SWISS PA/SA WORKFLOW – *MODEL PORTFOLIO*

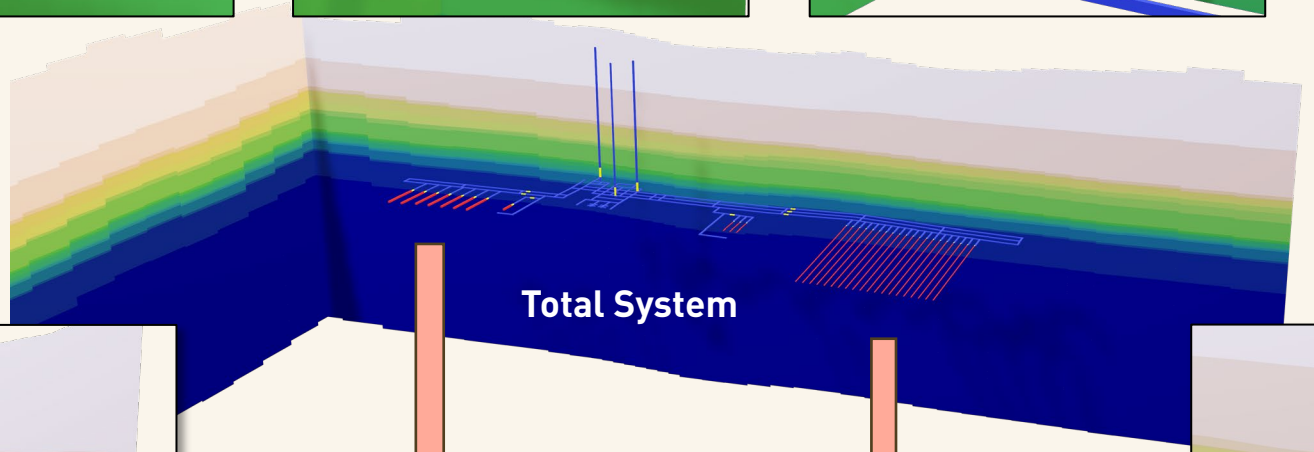
Component models

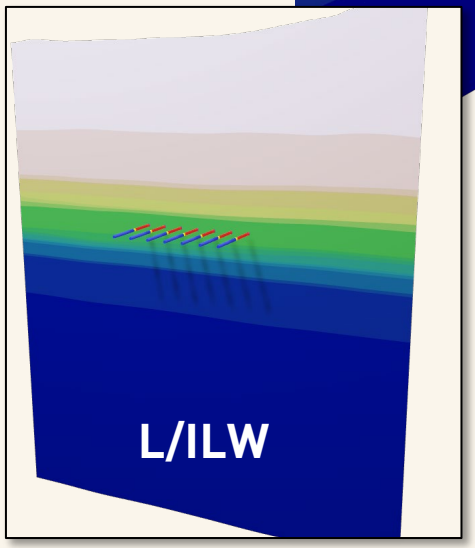


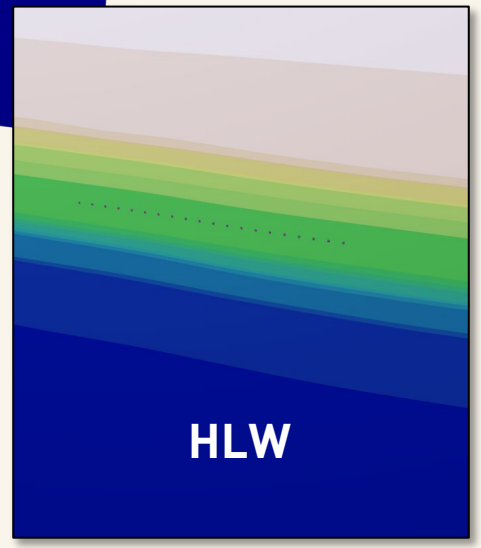






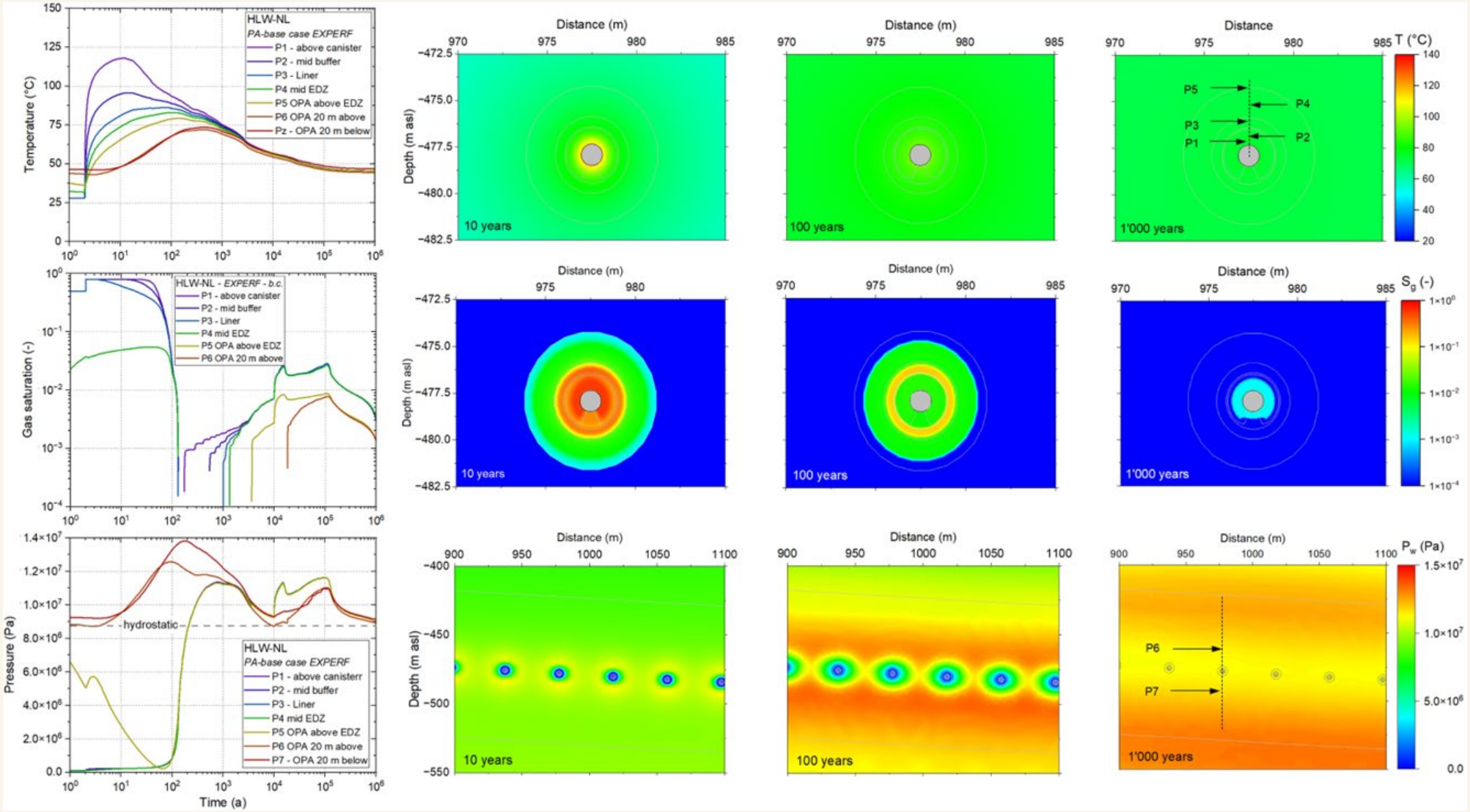






Probabilistic modelling
(for scenario screening)

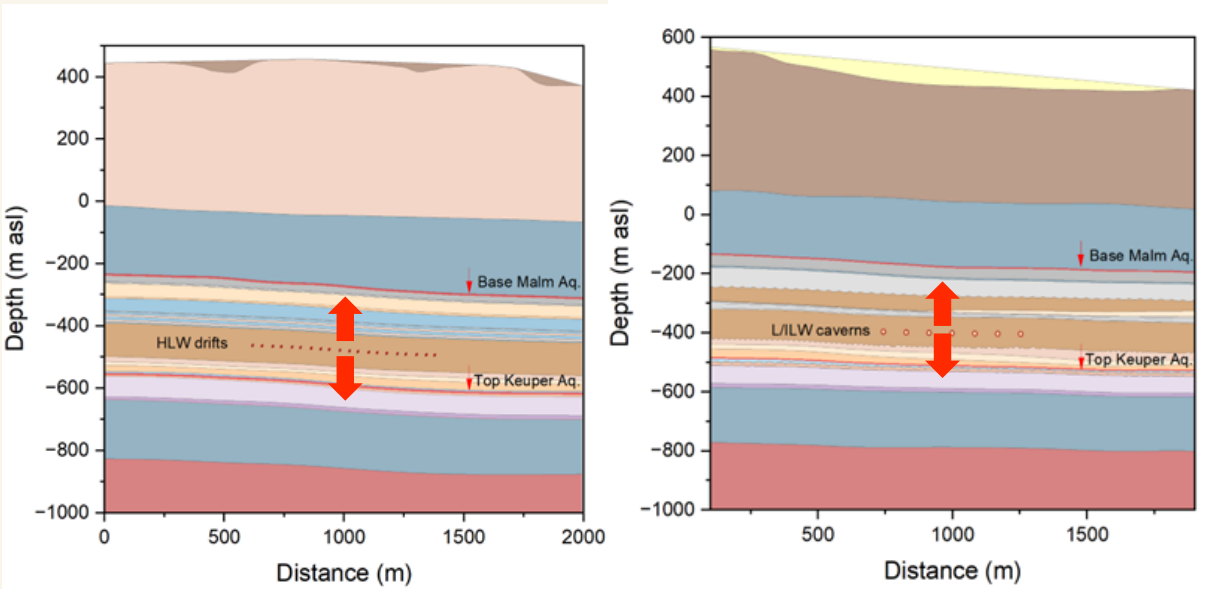
SWISS PA/SA WORKFLOW – *PERFORMANCE INDICATORS / BARRIER INTEGRITY (T, S_G, P_W)*



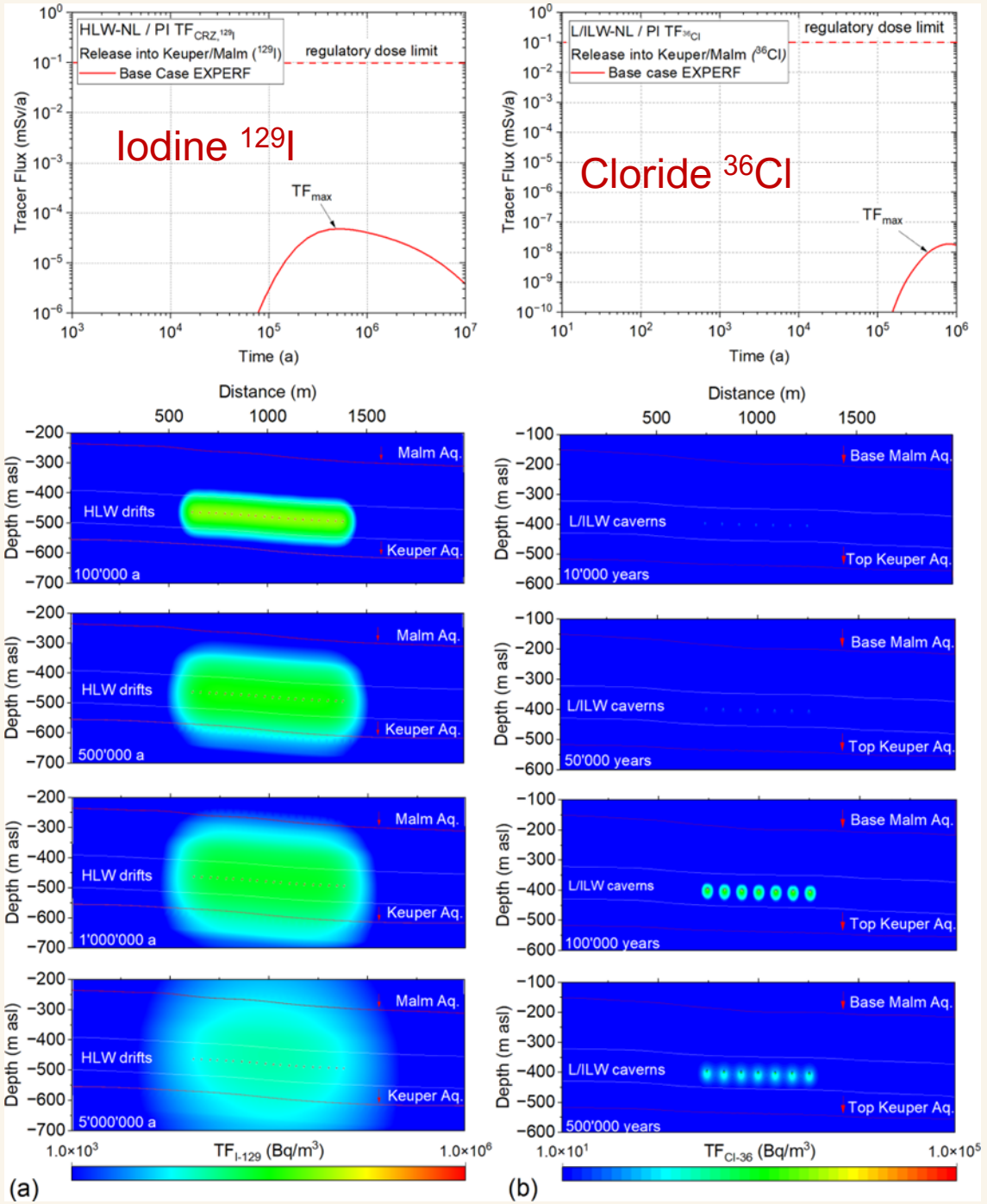
SWISS PA/SA WORKFLOW

- **Further performance indicators / transport**

→ Tracer flux through the geological barrier (HLW – ^{129}I; L/ILW – ^{36}Cl, ^{14}C)



Release from emplacement drifts /caverns

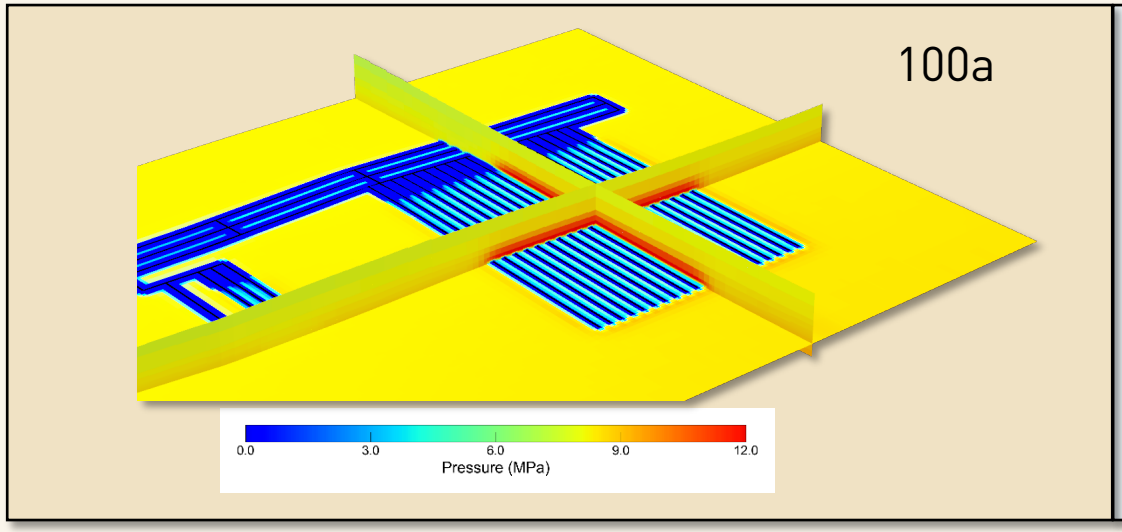


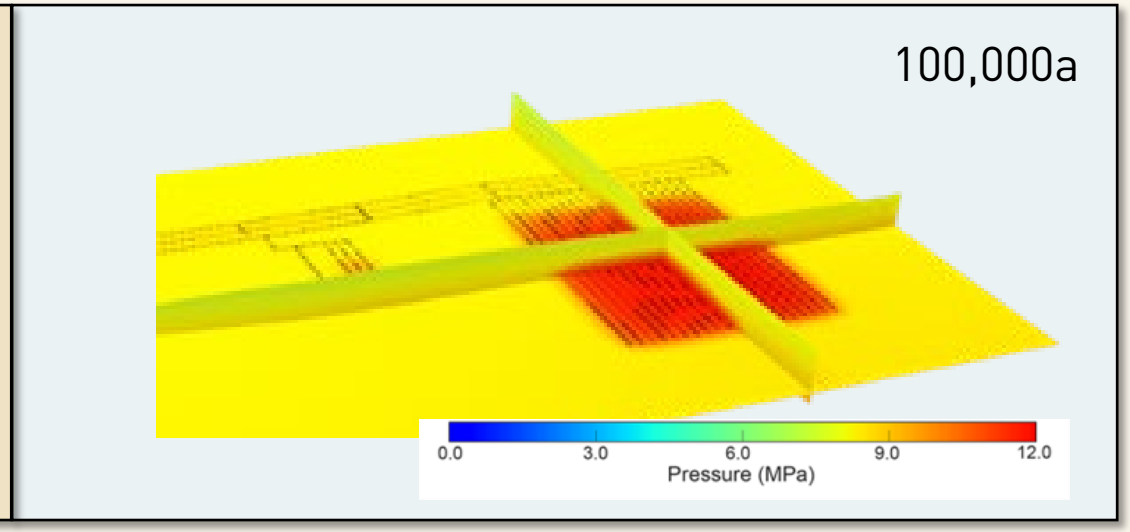
SWISS PA/SA WORKFLOW – *SAFETY RELEVANT ASPECTS*

HLW thermally-induced effects (P_w, T)

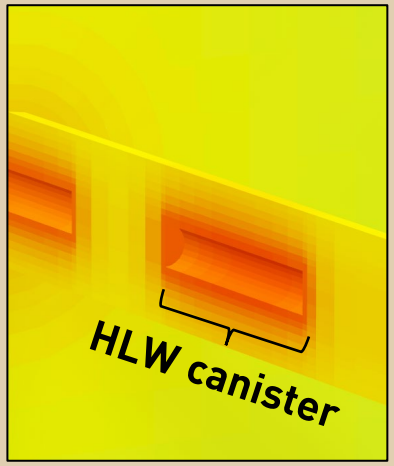
HLW gas-induced effects (P_g,S_g)

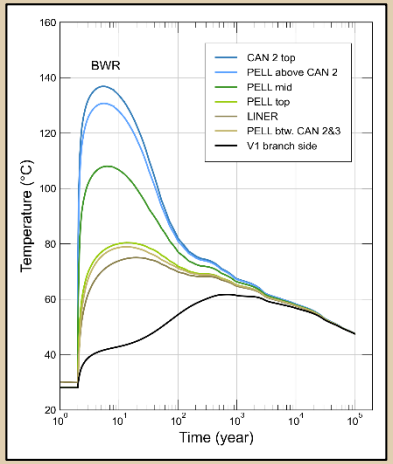
Total System

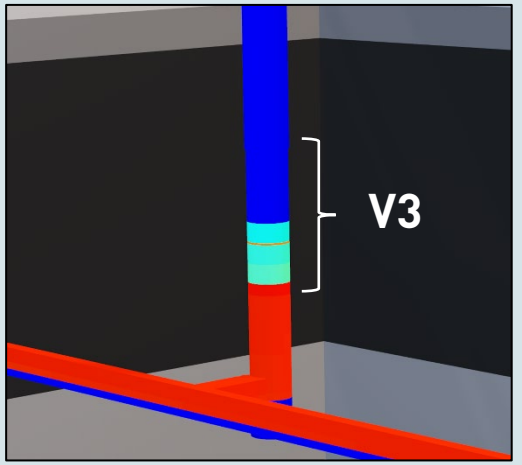


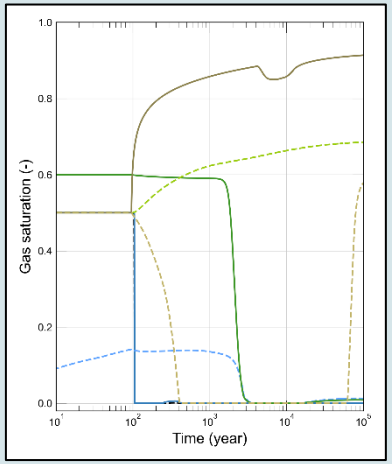


Components







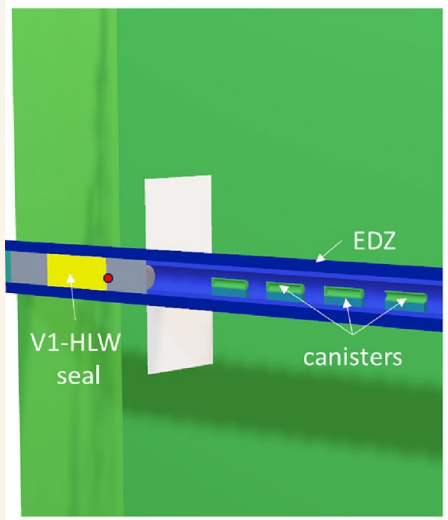


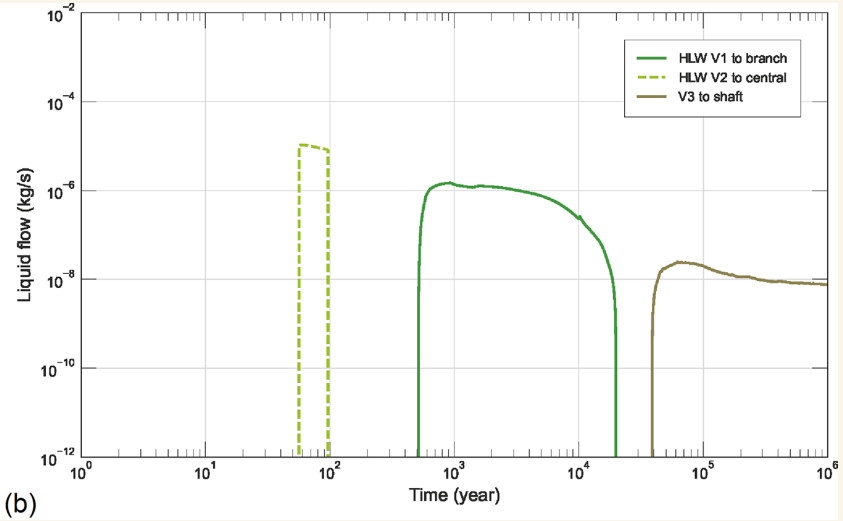
SWISS PA/SA WORKFLOW – *SAFETY RELEVANT ASPECTS*

- **Transport of dissolved / volatile radionuclides along the backfilled repository structures**

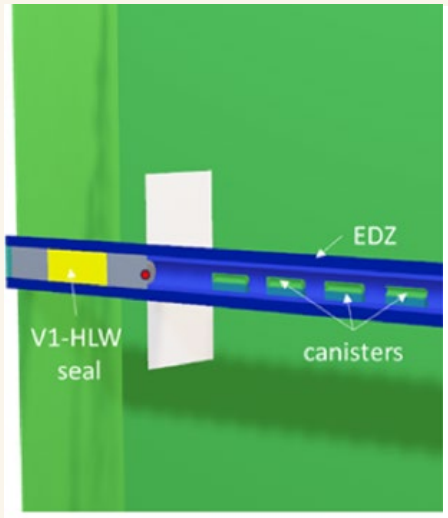
  → Focus on seal sections

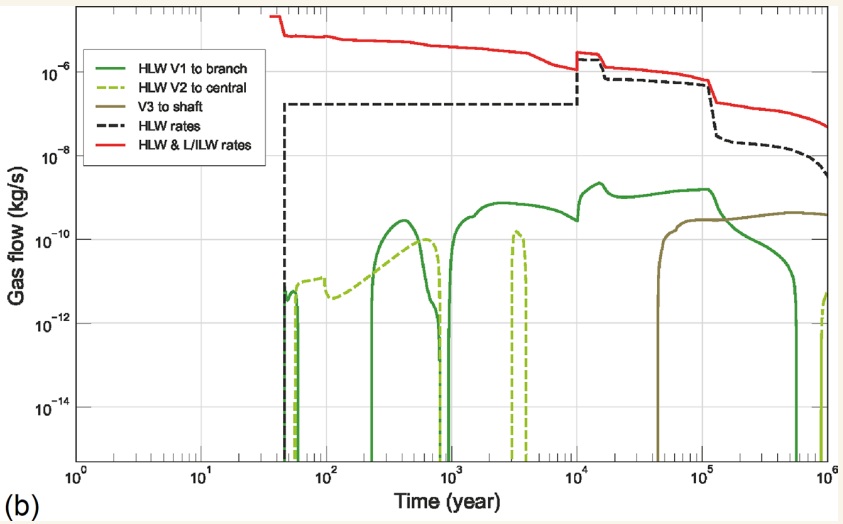
Liquid flow through seals





Gas flow through seals





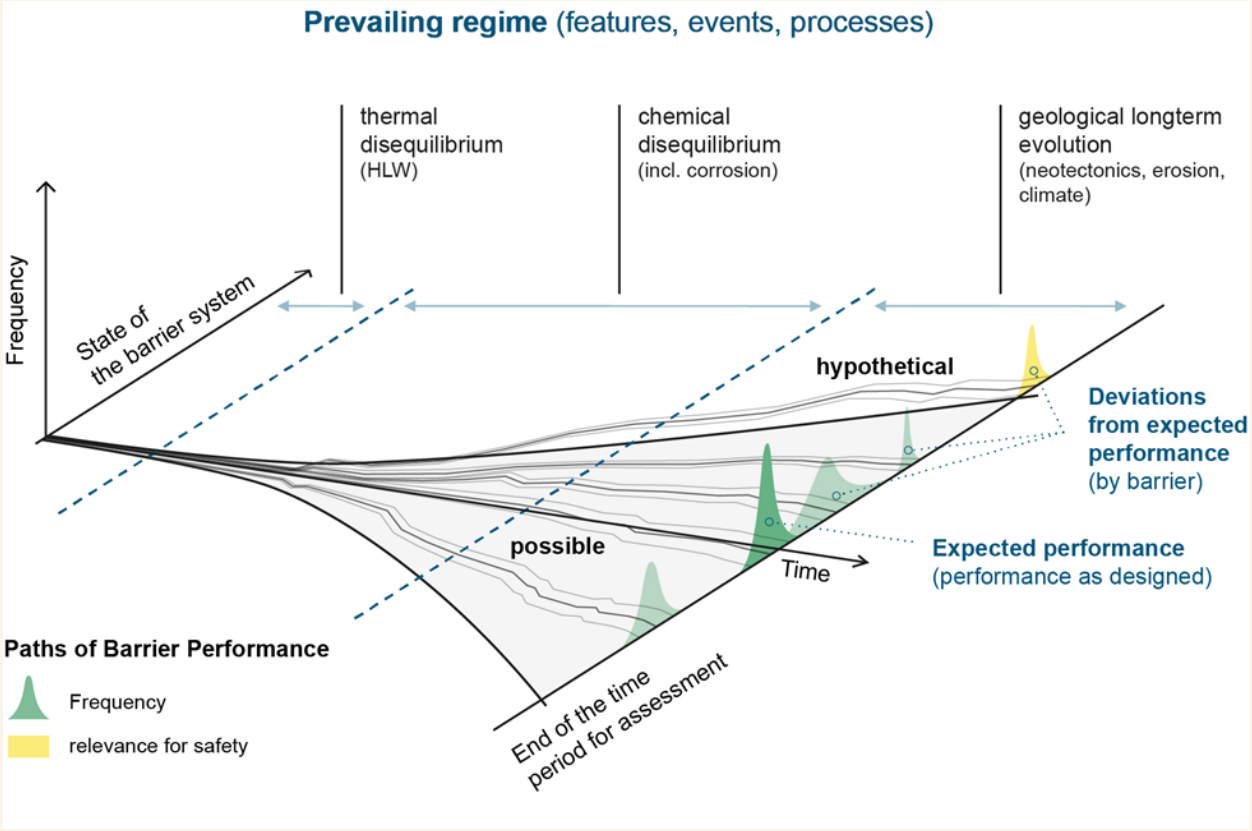
SWISS PA/SA WORKFLOW – *PROBABILISTIC ASSESSMENTS*

- **Performance screening as input for scenario development / radiological consequence analysis**

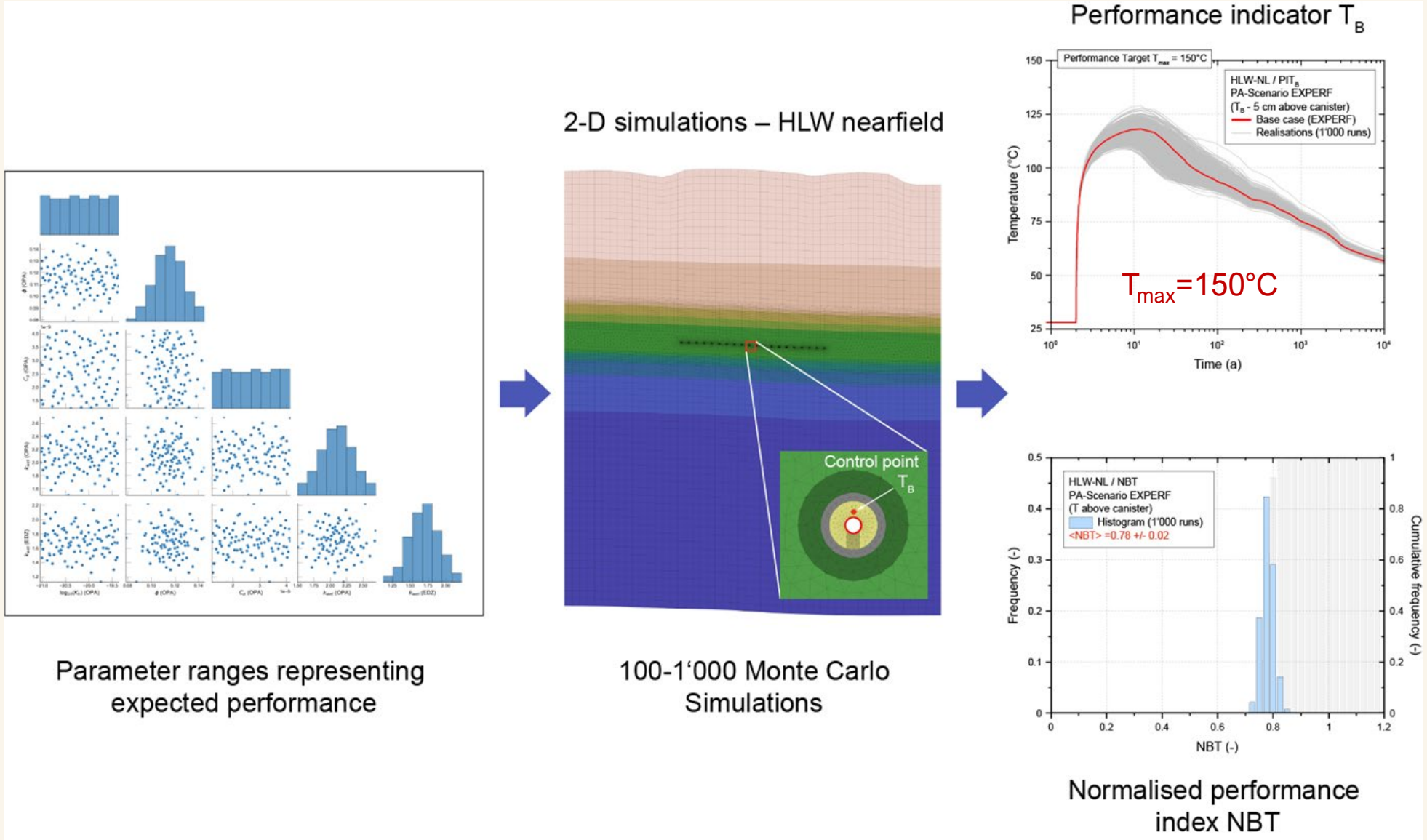
  → Probabilistic assessments
  → based on four safety relevant indicators (HLW)

- **Outputs of the screening process**

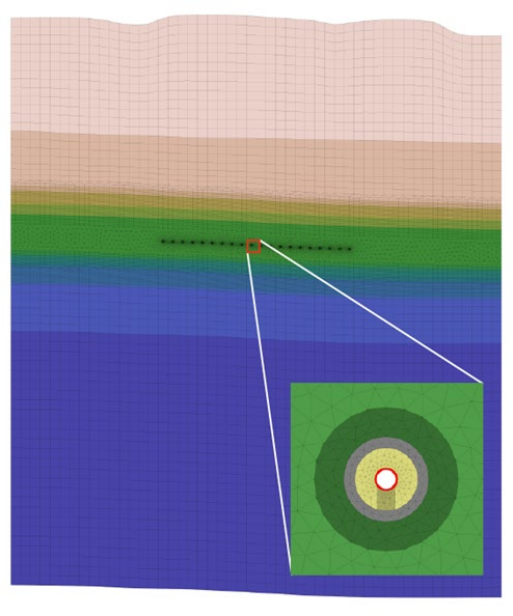
  → Relevance for safety / safety margins
  → Likelihood of occurence



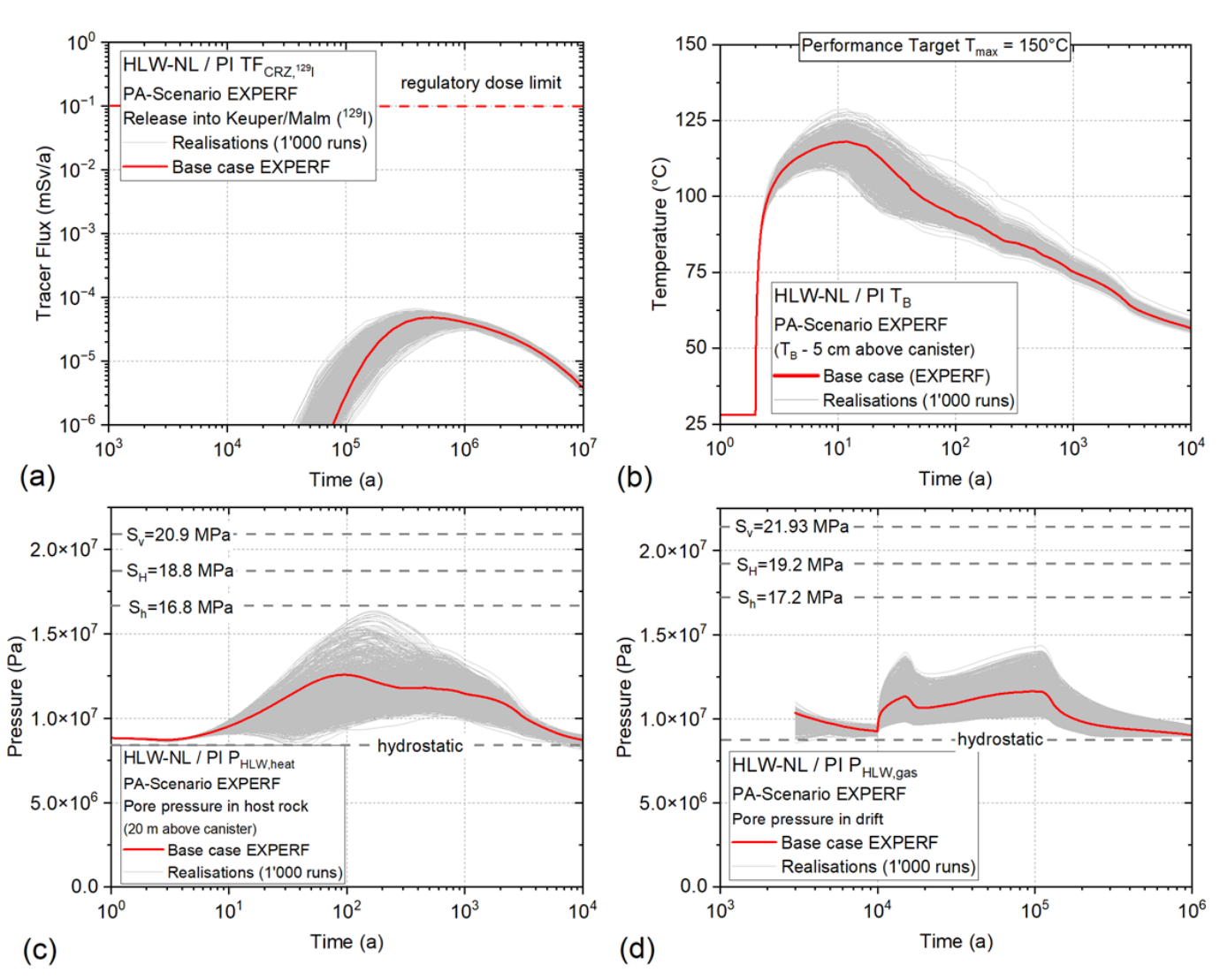
SWISS PA/SA WORKFLOW – *PROBABILISTIC ASSESSMENTS / METHODOLOGY*



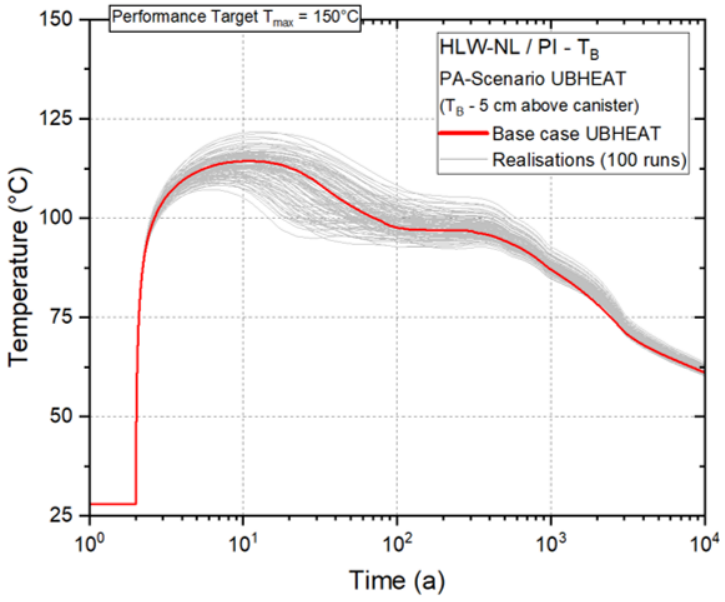
SWISS PA/SA WORKFLOW – *PROBABILISTIC ASSESSMENTS / METHODOLOGY*

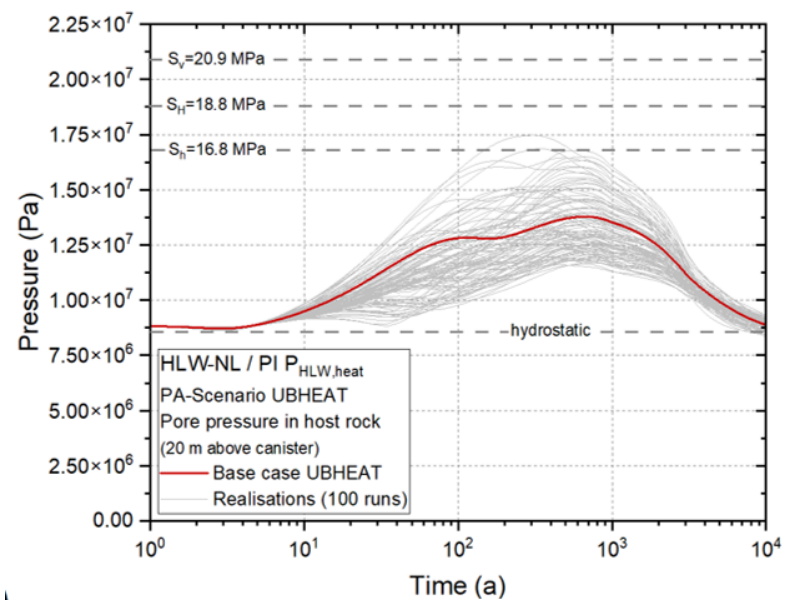


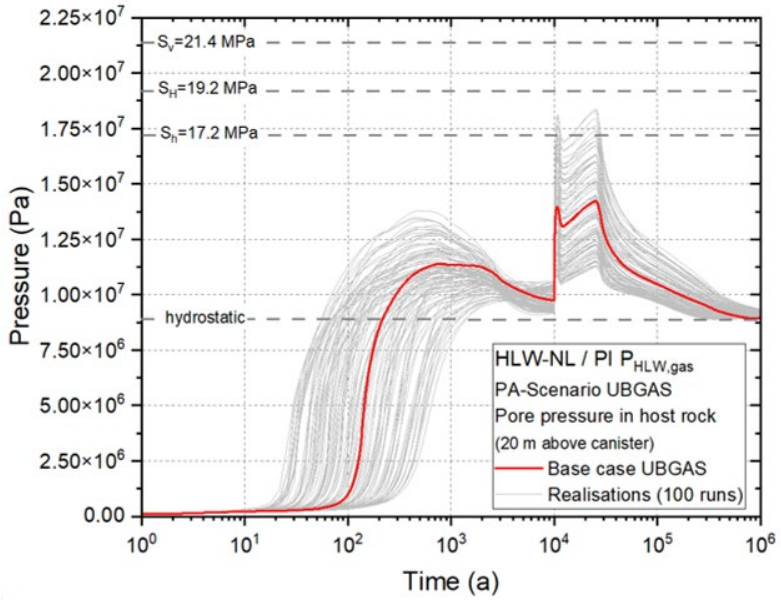
HLW: 2-D model set-up



SWISS PA/SA WORKFLOW – *SCENARIO SCREENING*







HLW near-field

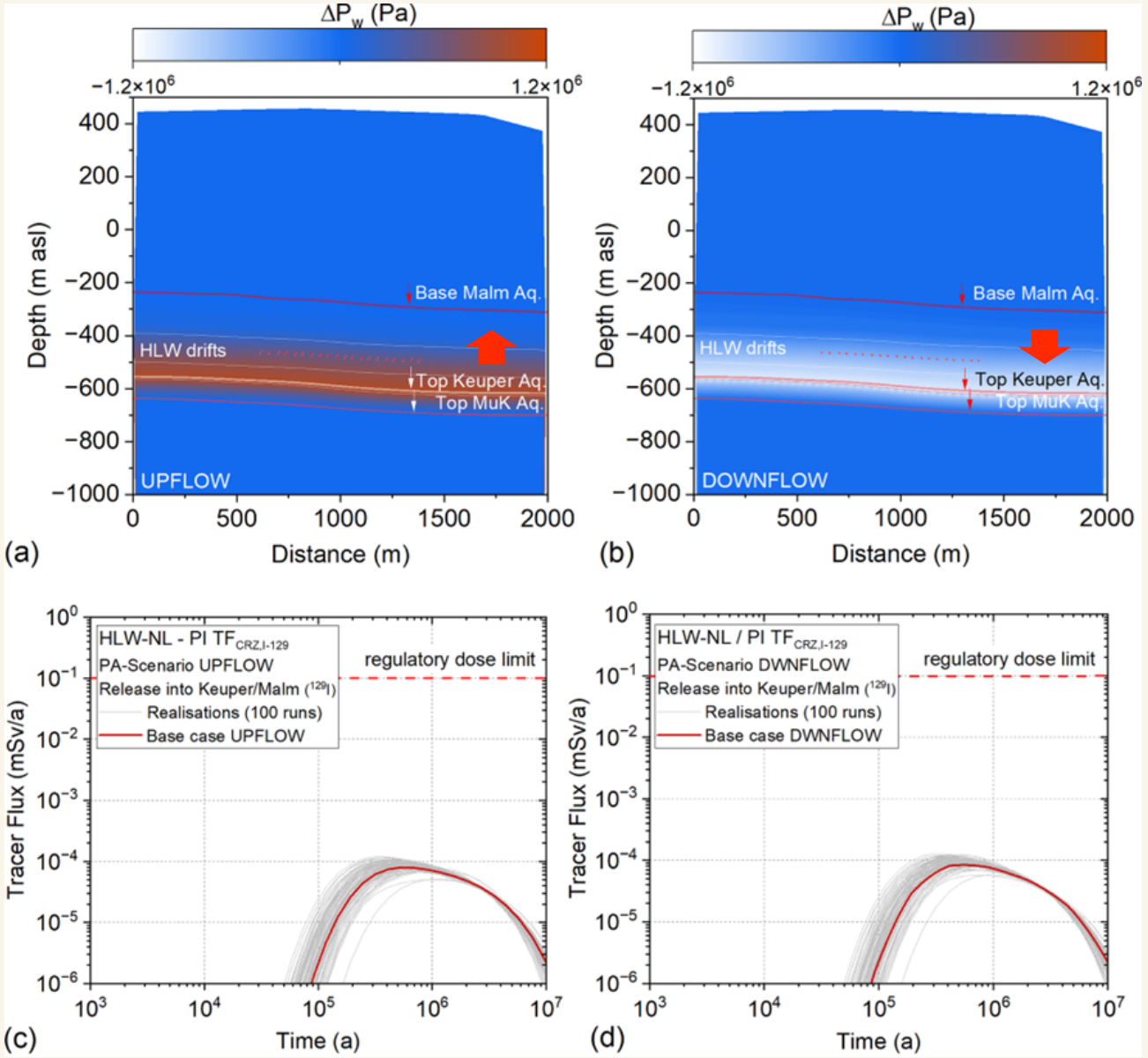
HLW far-field

PA-Sc.: Upper bound heat source term

PA-Sc.: Upper bound gas source term

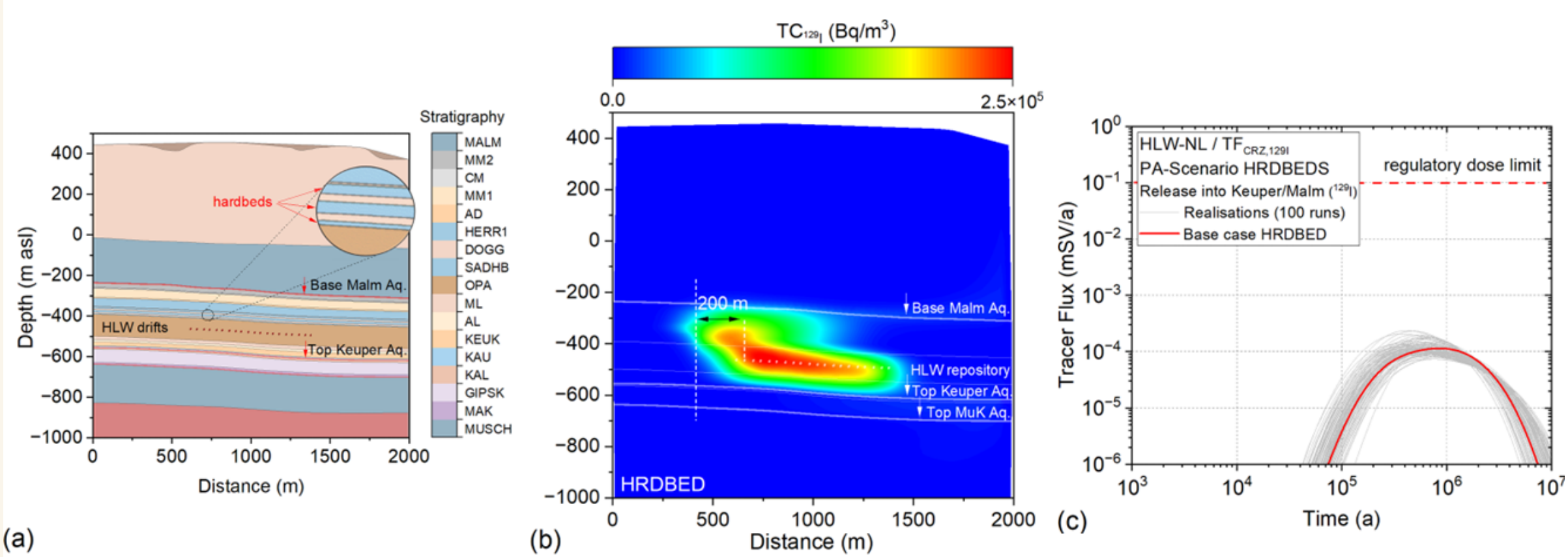
SWISS PA/SA WORKFLOW – *SCENARIO SCREENING*

PA-Sc.:
Upflow regime



PA-Sc.:
Downflow regime

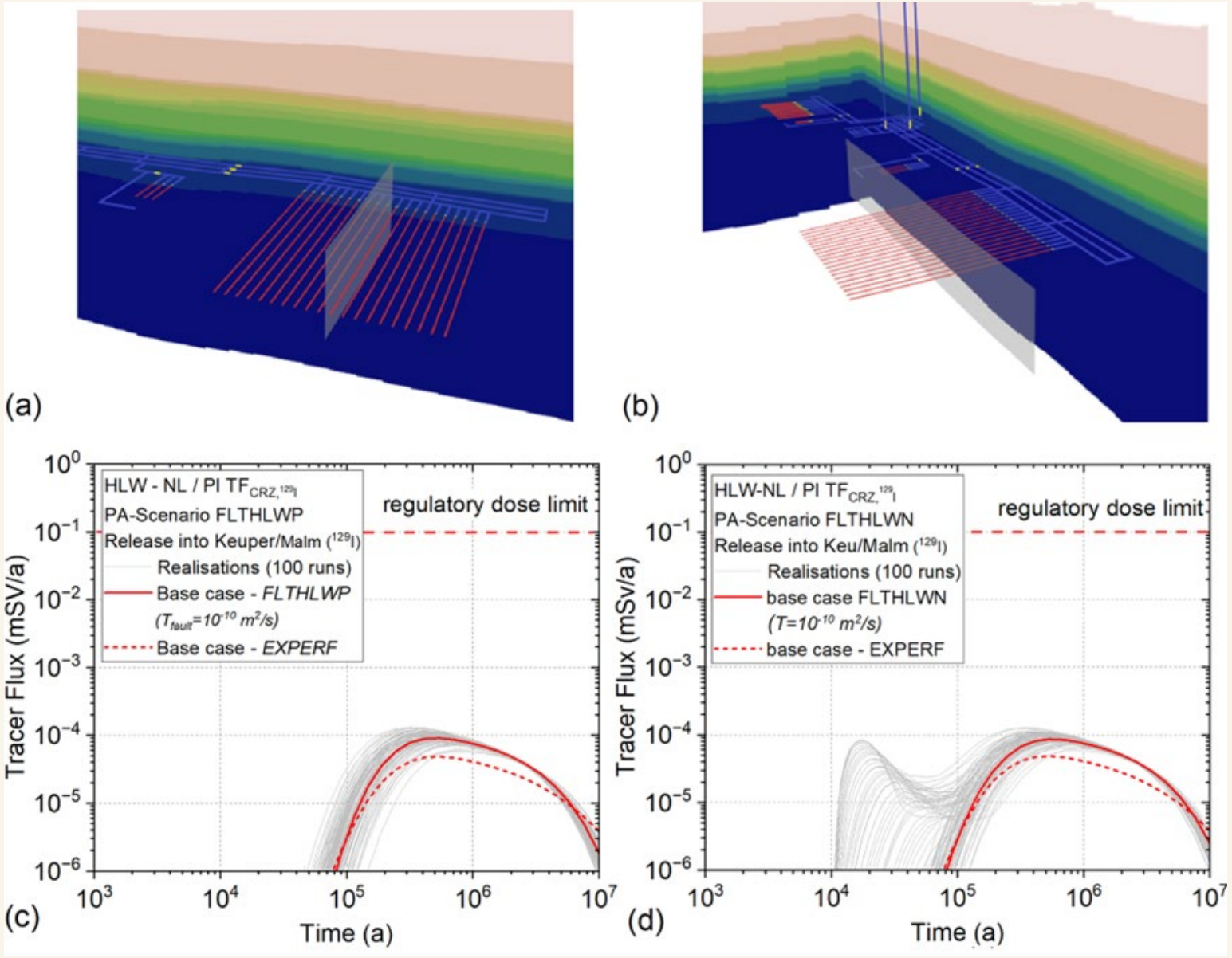
SWISS PA/SA WORKFLOW – *SCENARIO SCREENING*



PA-Sc.: High-permeability hardbeds above the host rock

SWISS PA/SA WORKFLOW – *SCENARIO SCREENING*

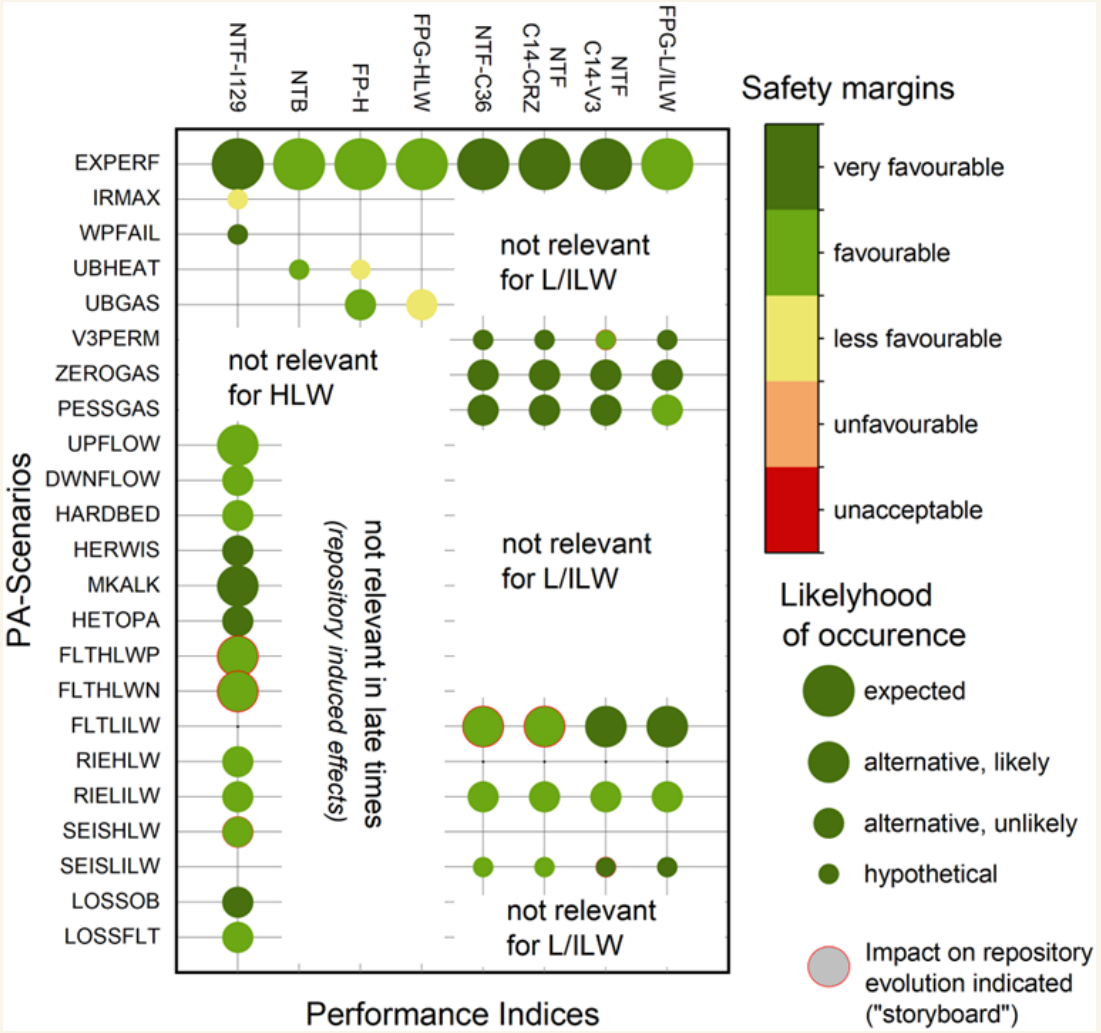
PA-Sc.:
Vertical transmissive fault through the disposal area



SWISS PA/SA WORKFLOW – *SCENARIO SCREENING / OUTCOMES*

- **Performance screening as input for scenario development / radiological consequence analysis**

  → Identify those deviations from expected performance, that are worth for a more detailed assessment of radiological consequences!



SWISS PA/SA WORKFLOW

- **Concluding remarks**

→ Performance and safety assessment is no rocket science!

→ … but QA/QC procedures sometimes resemble a Mars mission (☺)

→ Model-based sensitivity and robustness analyses constitute important lines of evidence

→ Traceable and transparent uncertainty quantification is a key for trust-building
(incl. code verification and model validation / benchmarking)