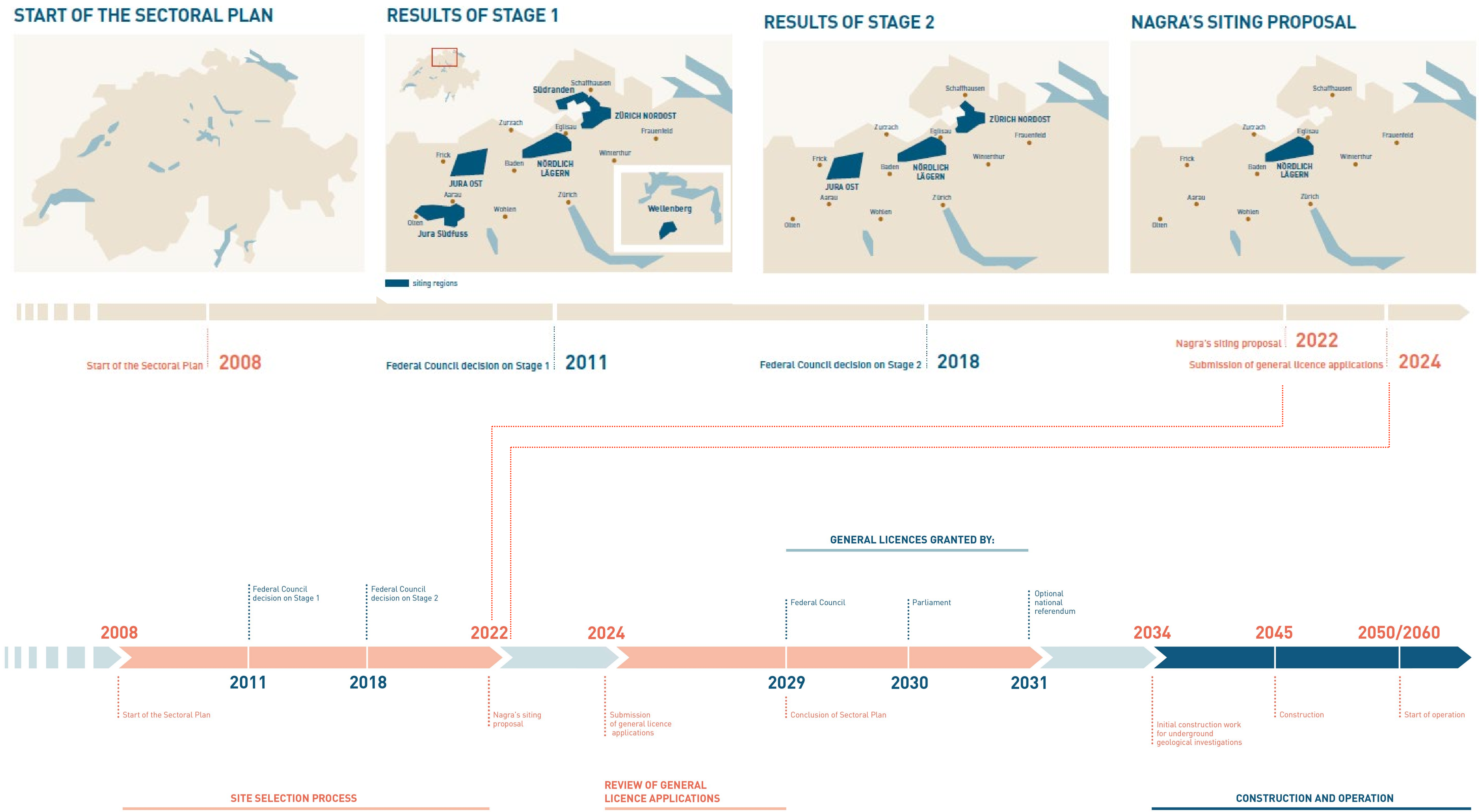
NAGRA'S SAFETY CASE - SHAPED AND SUPPORTED BY DECADES OF RD&D

Prague, 26. November 2025

Olivier Leupin

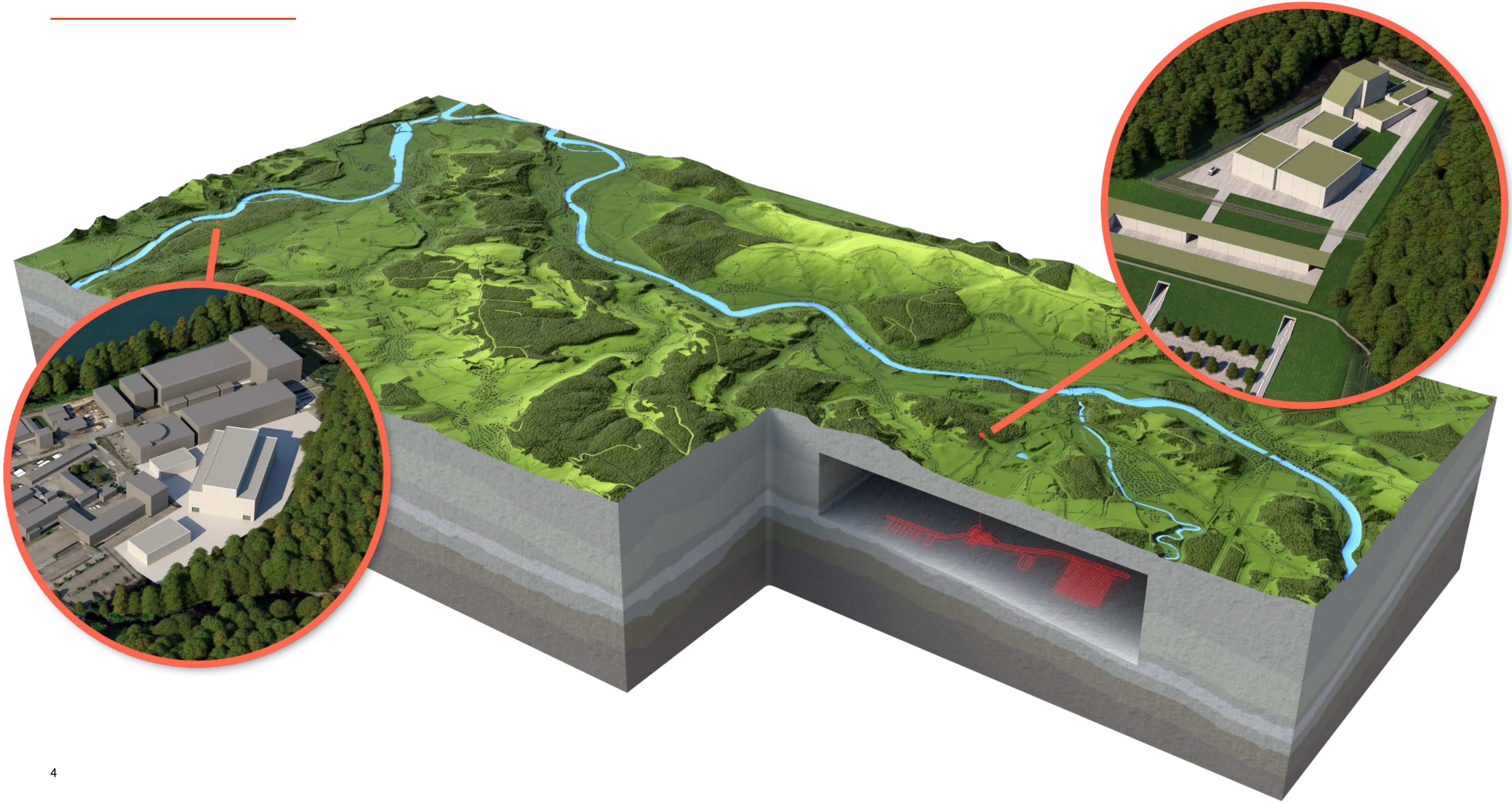
nagra.



START OF THE SECTORAL PLAN
RESULTS OF STAGE 1
RESULTS OF STAGE 2
NAGRA'S SITING PROPOSAL
Schaffhausen
Südranden
ZÜRICH NORDOST
Frauenfeld
Zurzach
Eglisau
Frick
Baden
NÖRDLICH LÄGERN
Winterthur
JURA OST
Aarau
Wohlen
Zürich
Olten
Jura Südfuss
Wellenberg
siting regions
Start of the Sectoral Plan 2008
Federal Council decision on Stage 1 2011
Federal Council decision on Stage 2 2018
Nagra's siting proposal 2022
Submission of general licence applications 2024
GENERAL LICENCES GRANTED BY:
Federal Council
decision on Stage 1
Federal Council
decision on Stage 2
Federal Council
Parliament
Optional
national
referendum
2008
2011
2018
2022
2024
2029
2030
2031
2034
2045
2050/2060
Start of the Sectoral Plan
Nagra's siting
proposal
Submission
of general licence
applications
Conclusion of Sectoral Plan
Initial construction work
for underground
geological investigations
Construction
Start of operation
SITE SELECTION PROCESS
REVIEW OF GENERAL
LICENCE APPLICATIONS
CONSTRUCTION AND OPERATION

SUBMISSION OF THE GENERAL LICENSE APPLICATION 19TH NOVEMBER 2024

THE PROVISIONAL PROJECT AT NÖRDLICH LÄGERN

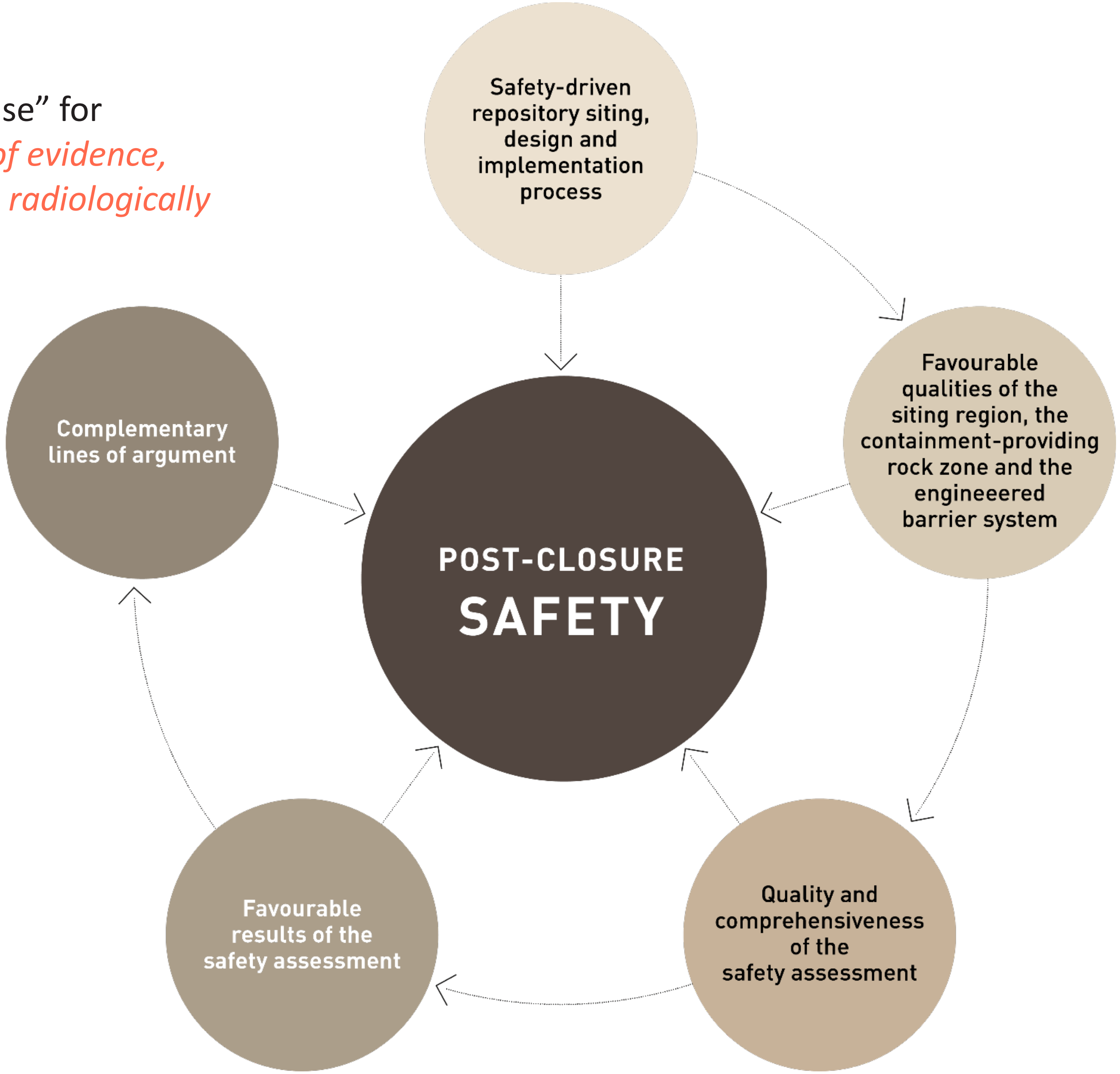


SAFETY CASE

nagra.

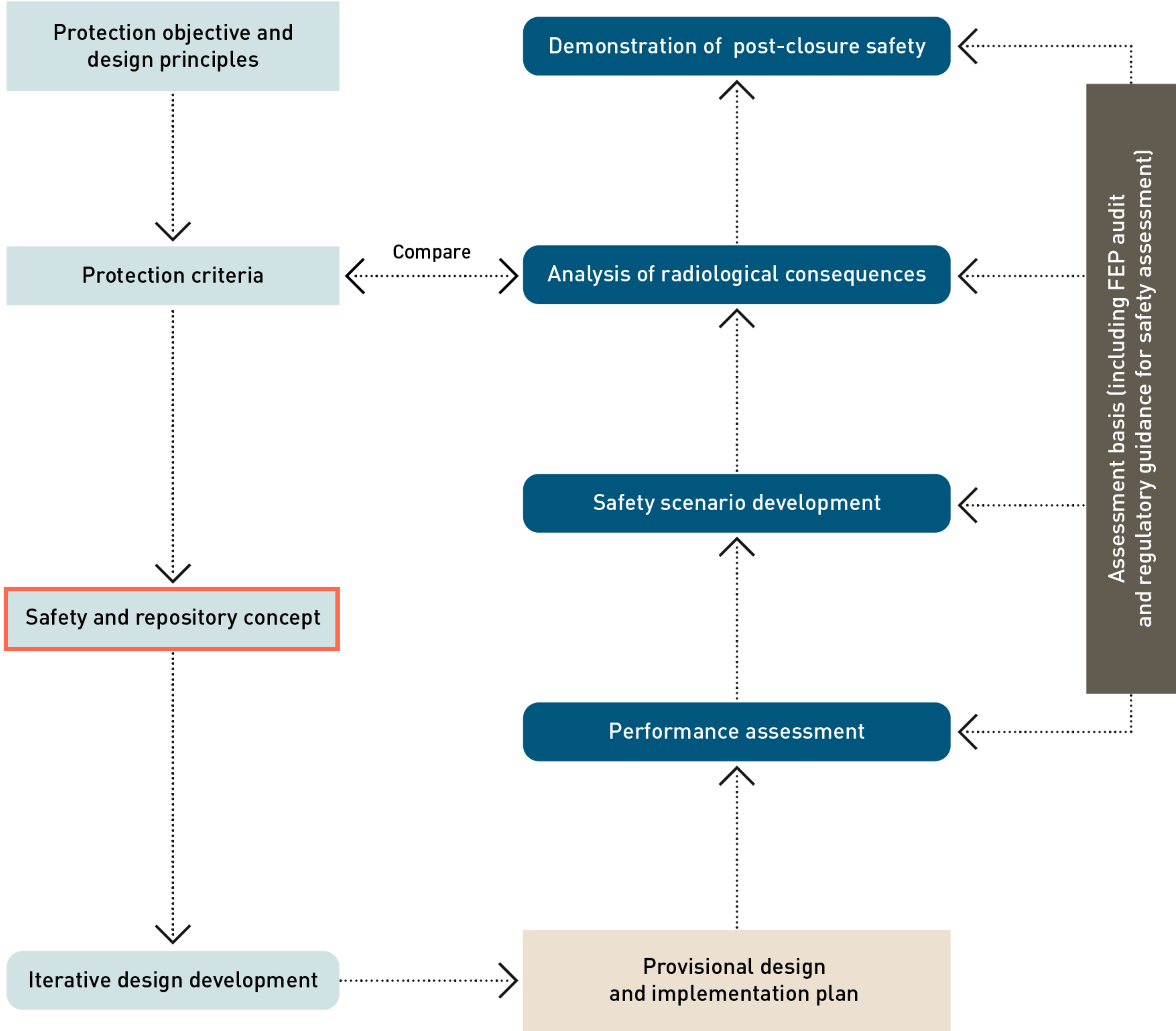
DEMONSTRATION OF SAFETY

In its 2014 brochure, NEA defines the “long-term safety case” for geological disposal of radioactive waste as *“the synthesis of evidence, analyses and arguments to affirm that a repository will be radiologically safe without human intervention after repository closure.”*



THE WORKFLOW

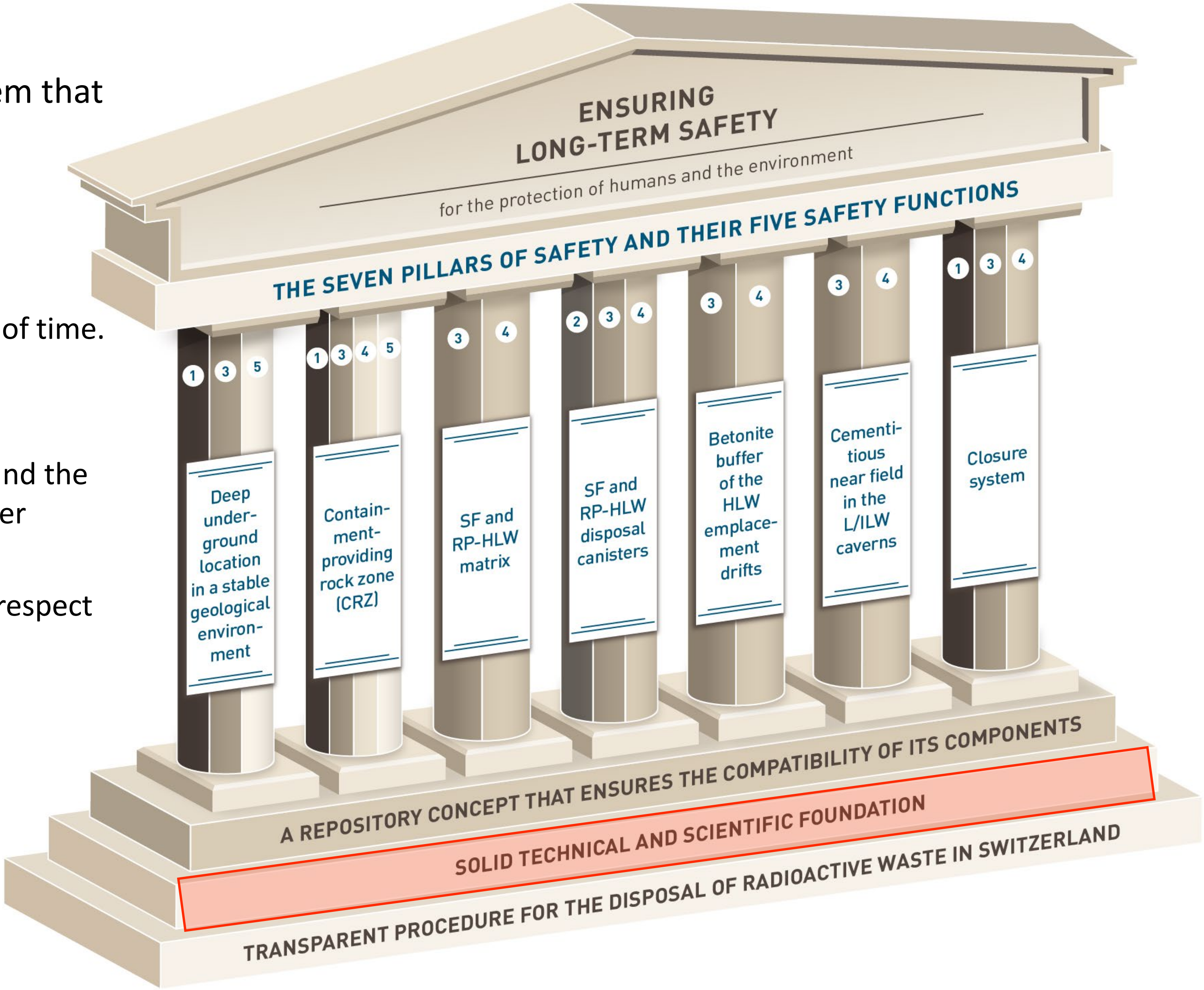
The safety case workflow explains how requirements can be related to a provisional design that can be then assessed.



SAFETY& REPOSITORY CONCEPT

- Safety functions are the roles of the multi-barrier system that together ensure post-closure safety.

  - S1: Isolation of radioactive waste from the surface environment.
  - S2: Complete containment of radionuclides for a period of time.
  - S3: Immobilisation, retention, and slow release of radionuclides.
  - S4: Compatibility of the multi-barrier system elements and the radioactive waste types among each other and with other materials.
  - S5: Long-term stability of the multi-barrier system with respect to long-term geological and climatic processes.



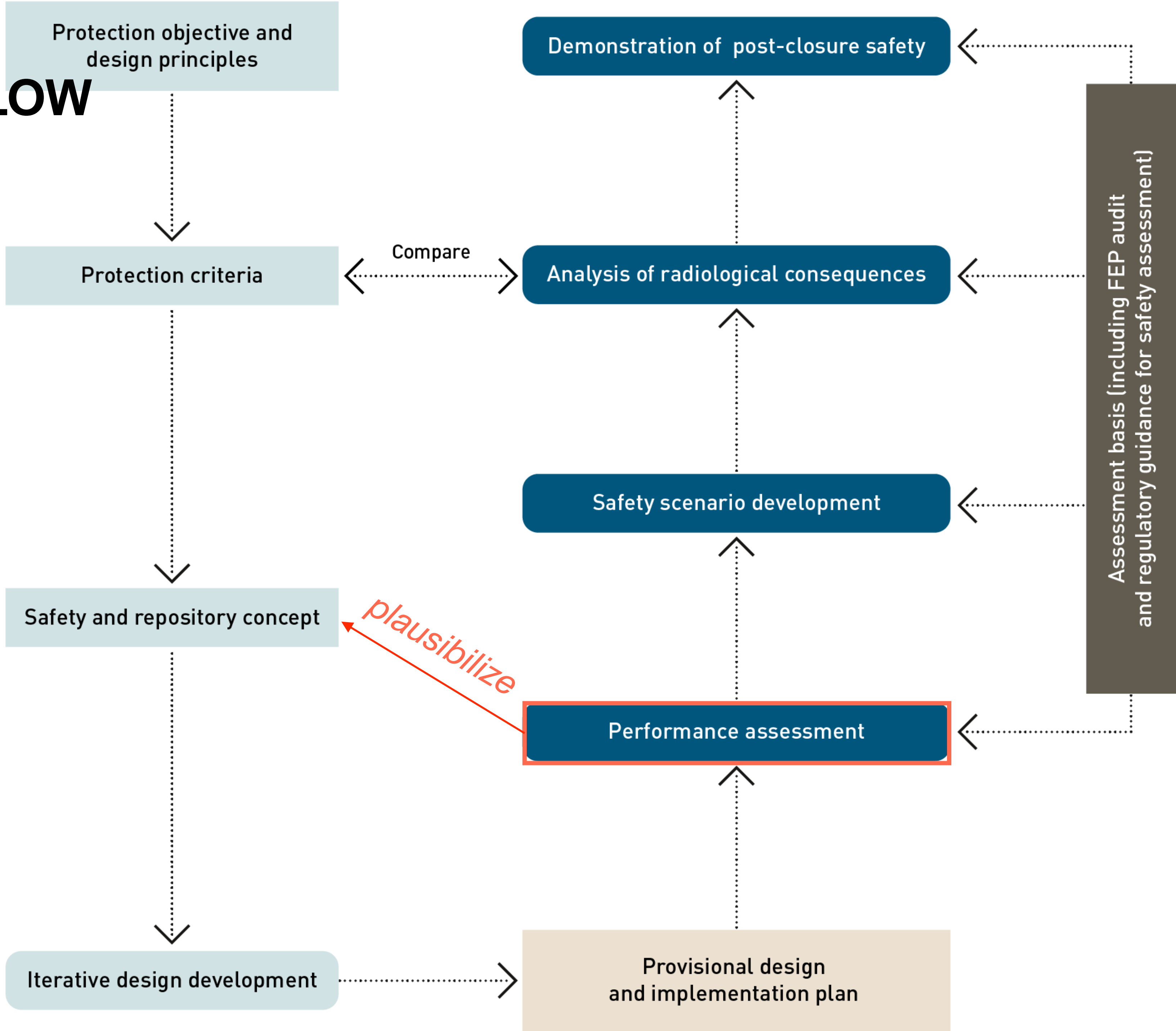
BACK TO THE WORKFLOW

Performance assessment is the first step in the general safety assessment workflow.

Performance assessment (PA) foresees 4 steps:

1. PA by barrier
2. PA by total system
3. Uncertainty quantification
4. Performance screening

For auditability of the assessment workflow claims are formulated, assigning one or more intended safety functions to each component of the multi-barrier system and to the repository system as a whole.



CLAIMS, ARGUMENTS AND EVIDENCE

Claims are related to safety functions. Claims contribute to the demonstration that the long-term safety objectives and regulatory safety criteria can be robustly met for a repository at the proposed site:

- Isolation of radioactive waste from the surface environment
- Complete containment of radionuclides for a period of time (for HLW especially)
- Immobilisation retention and slow release of radionuclides
- Compatibility of the elements of the barrier system and radioactive waste with each other and with other materials
- Long-term stability of the barrier system with respect to long-term geological and climatic processes

Claims

- Linked to safety functions

Arguments

- Adequate Design
- Favourable features / properties / conditions / evolutions

Evidence

- Empirical evidence / well-established knowledge base
- Dedicated experimental evidence
- Gained by model-supported quantitative assessments

LET'S WALK THROUGH AN EXAMPLE

Assessment object	Claim	Arguments
Host rock	Radionuclides will be retained in the CRZ; any releases result in dose rates that are below the regulatory dose limit over the entire repository lifetime	The intact Opalinus Clay represents a diffusion dominated transport barrier with sufficient vertical and lateral extent
		The Opalinus Clay is well characterizable and exhibits low spatial variability of flow / transport properties
		Sorption is an additional retardation mechanism, contributing to the efficiency of the host rock as a transport barrier
		The transmissivity of faults in OPA and clay-rich sequences of the confining units is limited such that diffusion dominated transport is maintained in the geological barrier under a wide range of conditions
		The self-sealing capacity of the Opalinus Clay ensures re-sealing of activated fractures

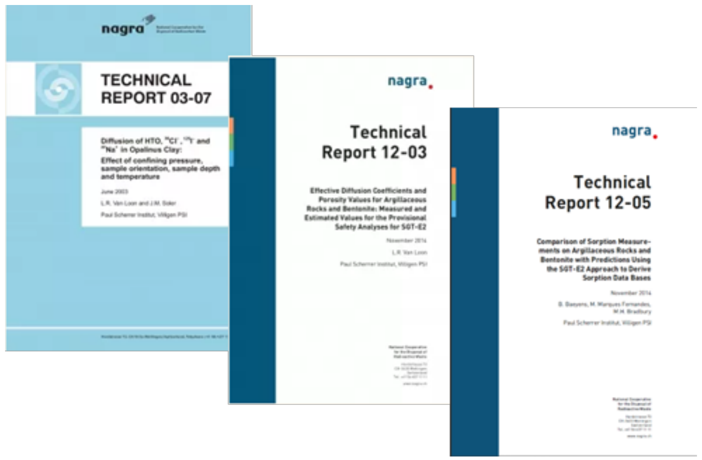
LET’S WALK THROUGH AN EXAMPLE

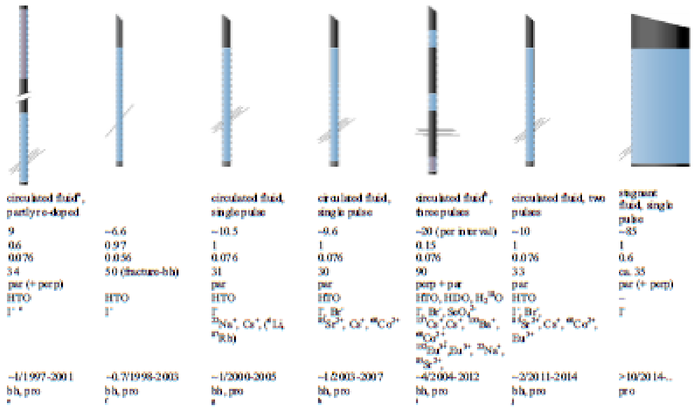
What evidence support following argument?

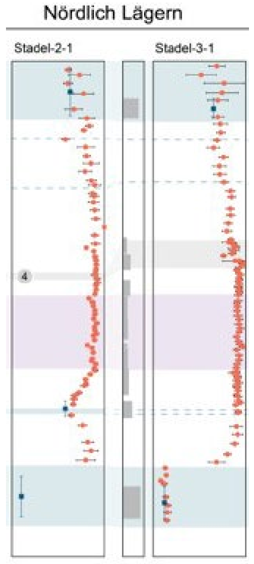
The intact Opalinus Clay represents a diffusion dominated transport barrier with sufficient vertical and lateral extent

Strategy: multiple lines of **evidence that are published** and **reviewed and** of which the results are **consistent** are needed to **support the argument**

Small Scale Lab Experiments	Medium Scale URL experiments	Large Scale natural analogies

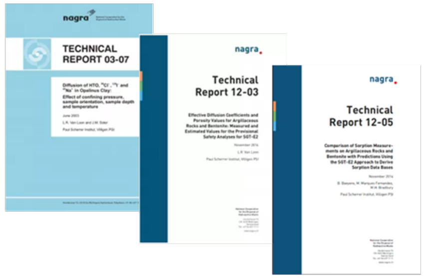
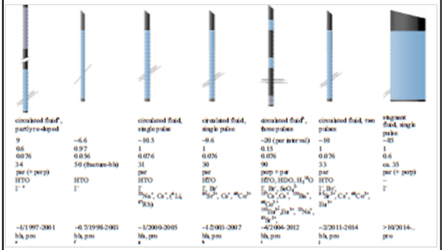
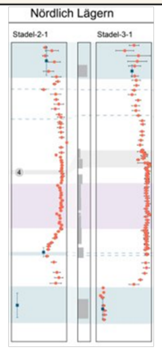


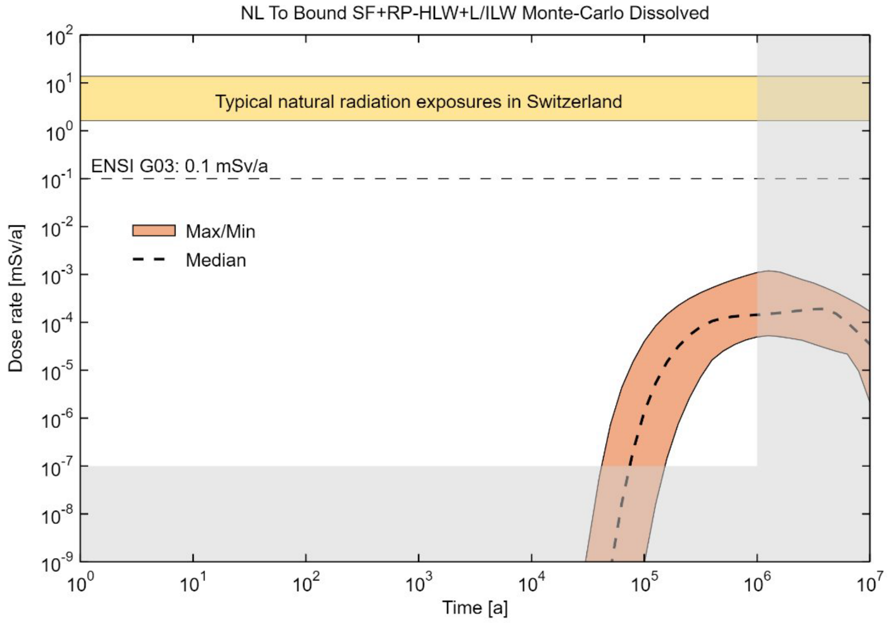




LET’S WALK THROUGH AN EXAMPLE

- Experiments can be terminated when the uncertainty they address has been reduced to a levels that is no longer relevant to safety

Small Scale Lab Experiments	Medium Scale URL experiments	Large Scale natural analogies
		



CONCLUSIONS 1

The methodology developed for the demonstration of safety in the frame of the general license application allows to connect evidence from RD&D and claims from safety.

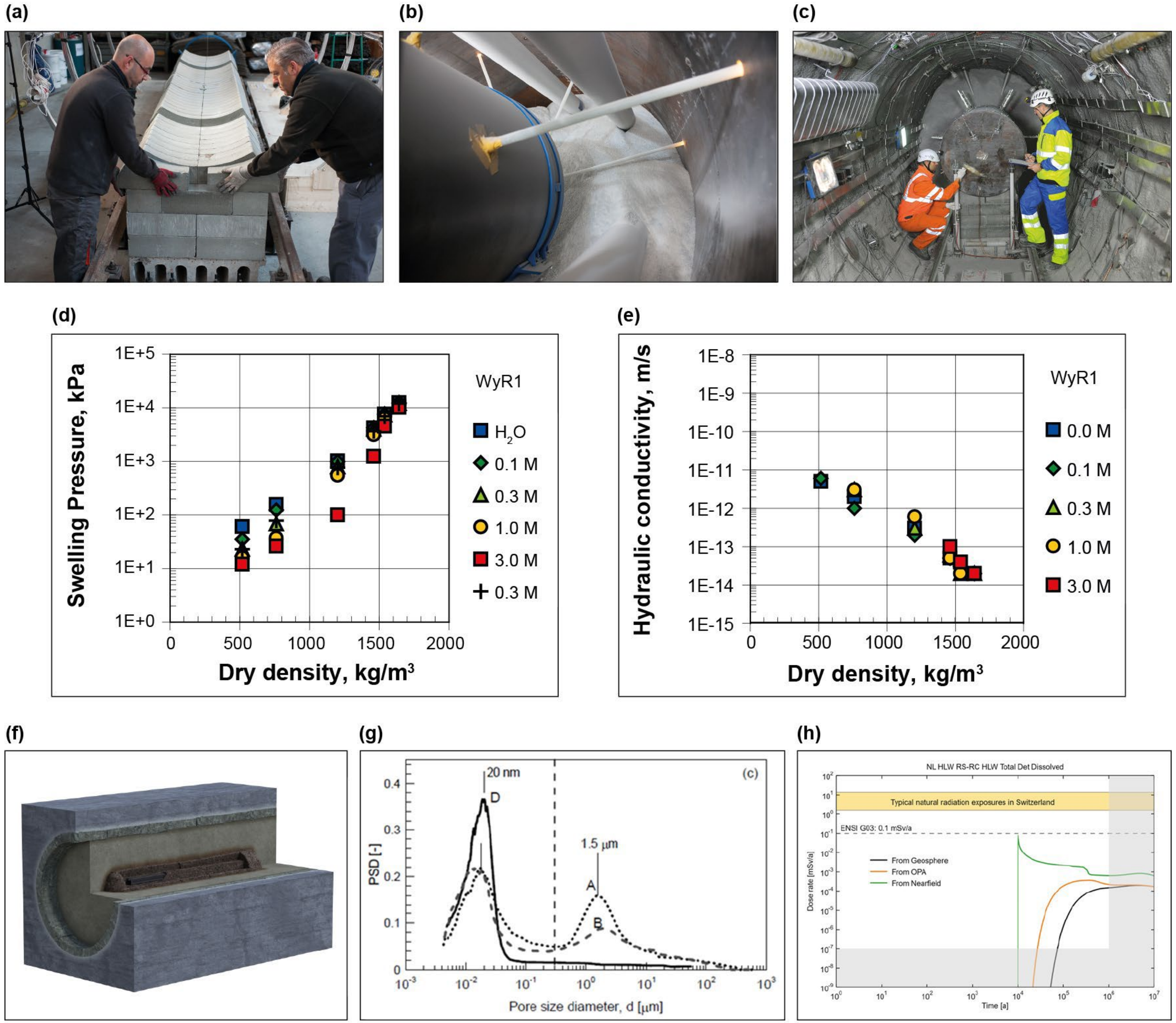
Well designed and dedicated experiments are key to performance assessment which is the first step in development of a safety case.

A logical framework relates experimental evidence with claims made for the safety case.

DEMONSTRATION OF SAFETY: SOUND SCIENTIFIC BASIS

Quality and comprehensiveness of the safety assessment

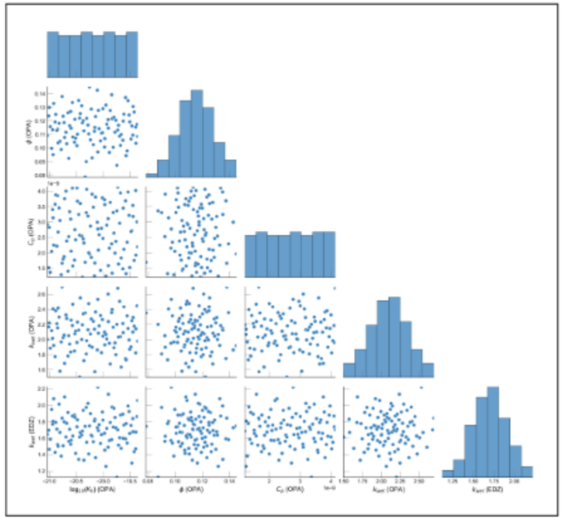
- Part of the confidence building process:
  Multiple lines of evidence



DEMONSTRATION OF SAFETY: PERFORMANCE ASSESSMENT

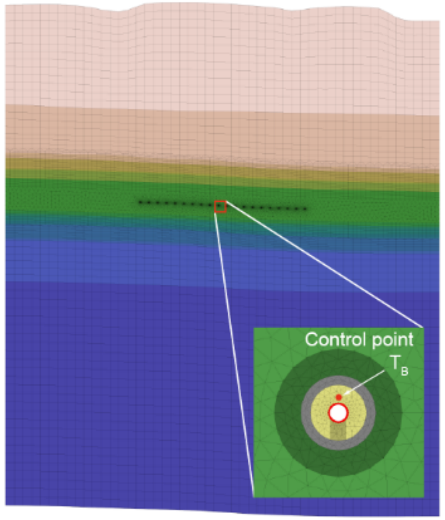
Favourable findings of the safety assessment

- How good is good enough? Indicators were used to assess the performance of the repository
- How likely is the performance according to design?



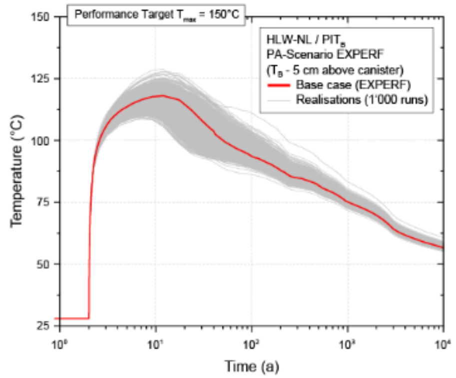
Parameter ranges representing expected performance

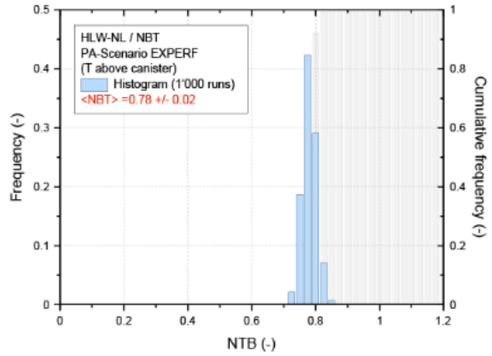
2-D simulations – HLW nearfield



100-1‘000 Monte Carlo Simulations

Performance indicator T_B

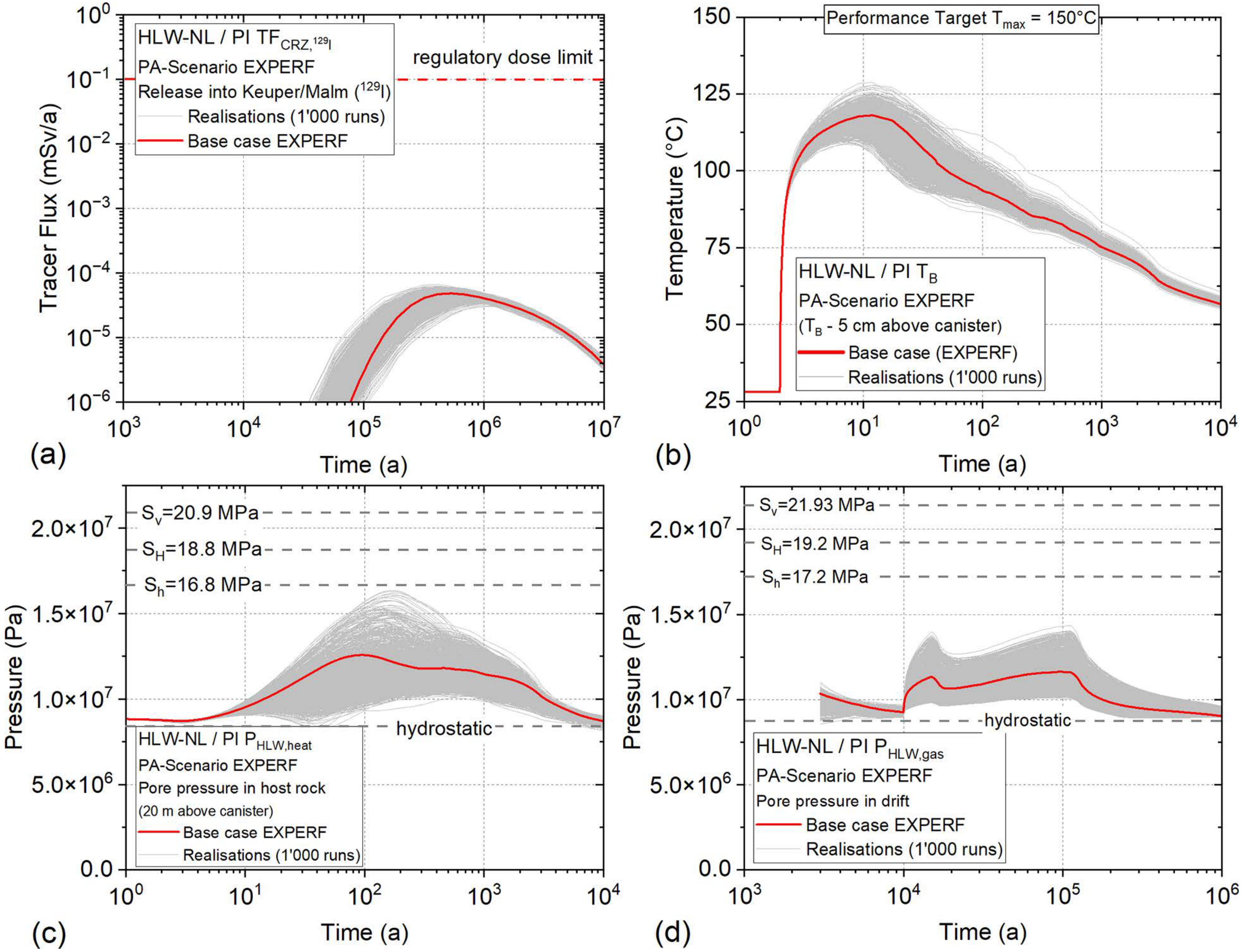




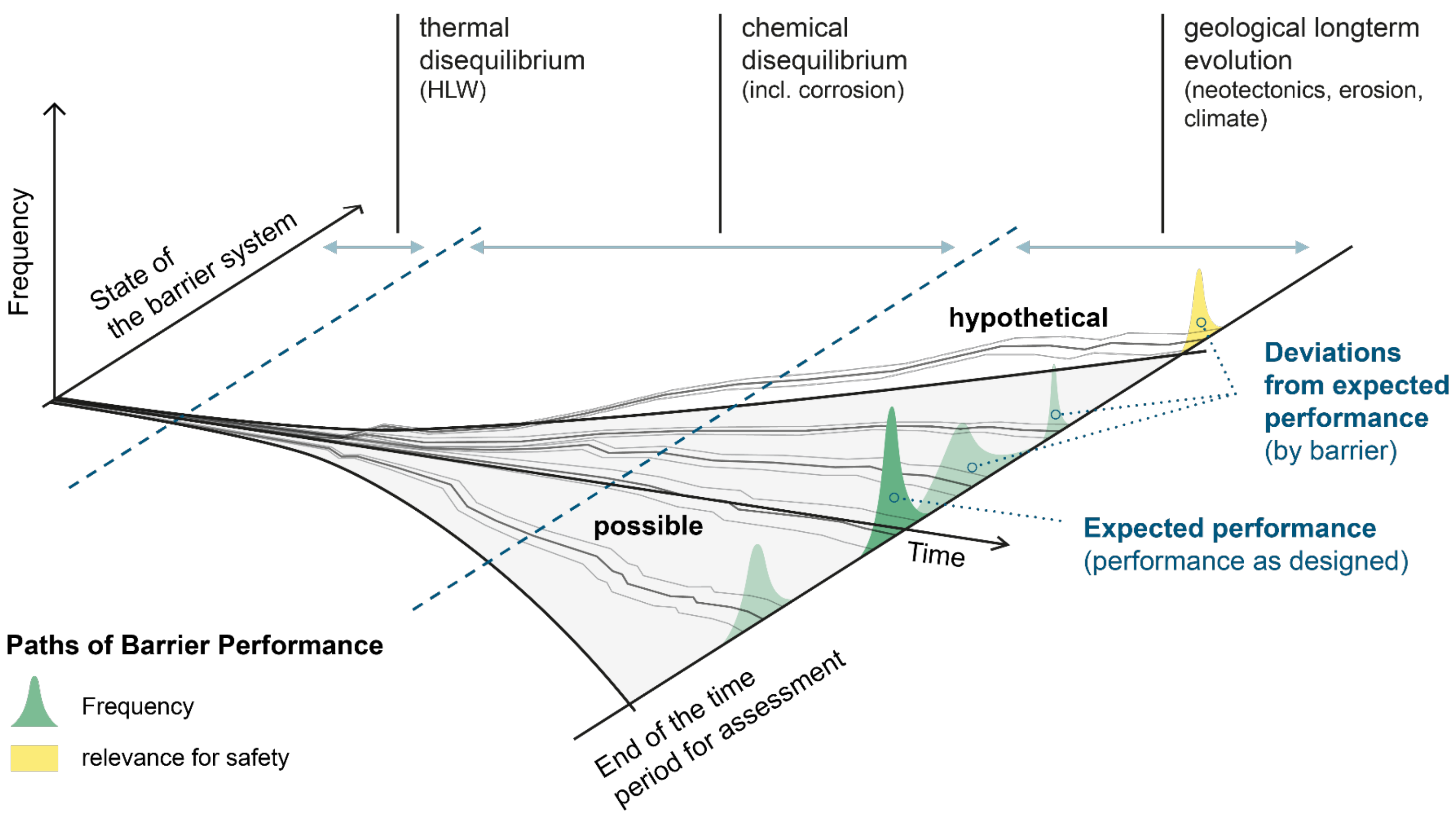
Normalised performance index NTB

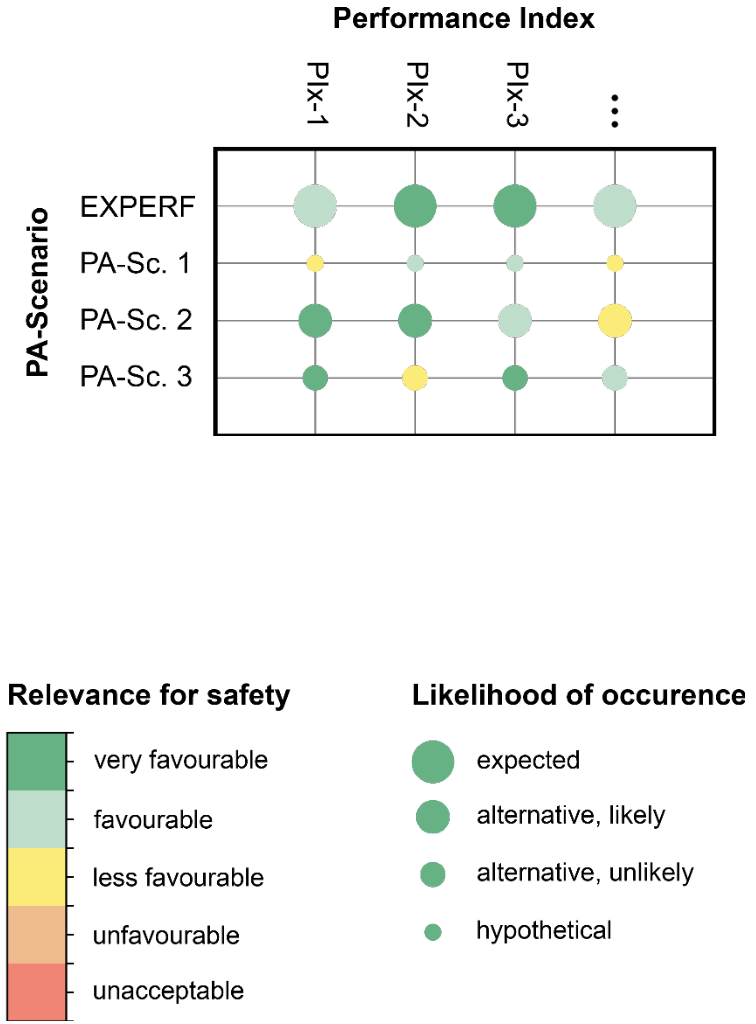
DEMONSTRATION OF SAFETY FOR EXPECTED EVOLUTION

Favourable findings of the safety assessment



EXPECTED, ALTERNATIVE AND HYPOTHETICAL PERFORMANCE ASSESSMENT SCENARIOS





CONCLUSIONS 2

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

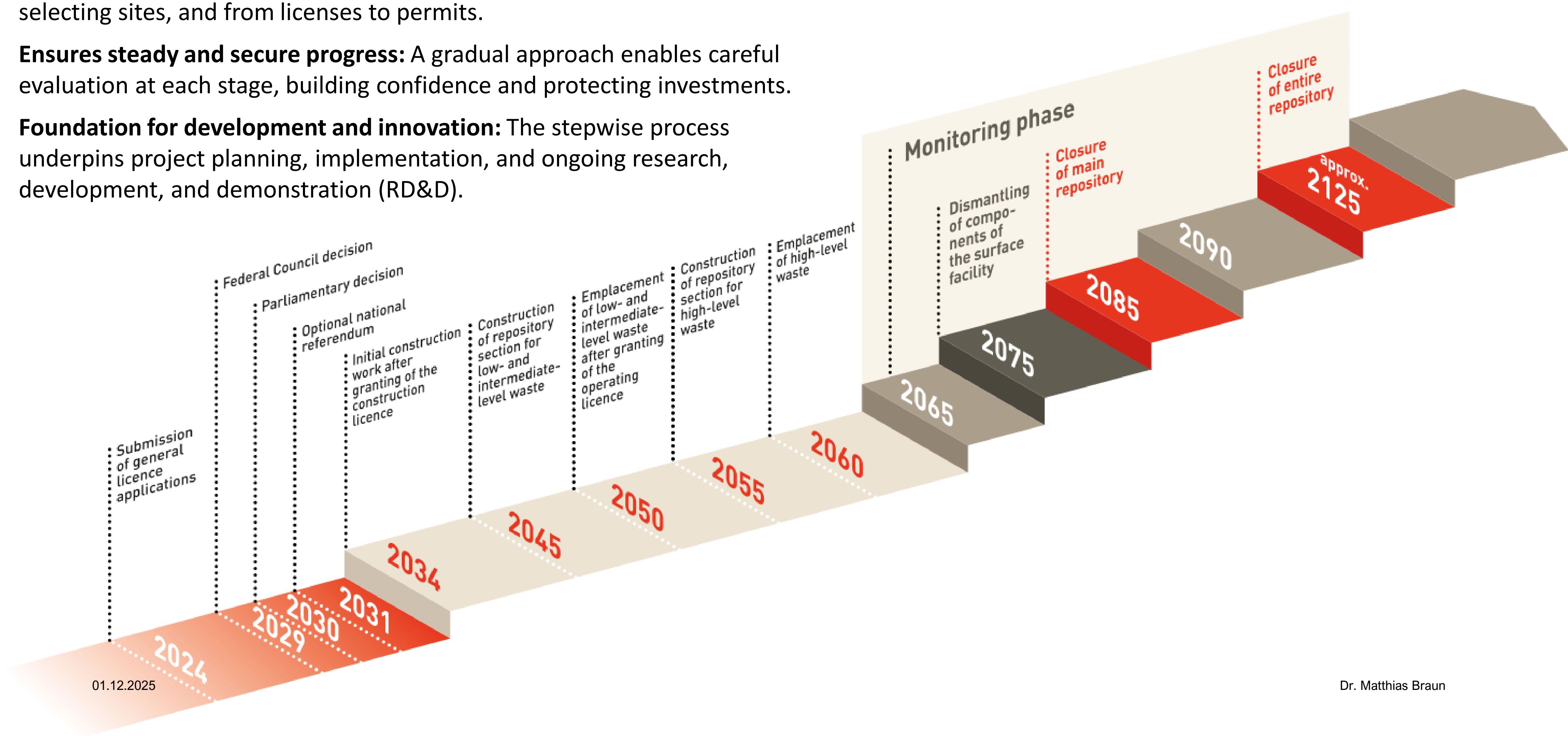
The performance assessment workflow encompasses four steps:

- Assessment of barrier performance at the component level "performance assessment by barrier"
- Assessment at the level of the entire system "total system performance"
- Uncertainty quantification focusing on parametric and conceptual uncertainties
- Performance screening (addressing scenario uncertainties), to screen the possible paths of repository performance and to identify, bundle and formulate safety scenario.

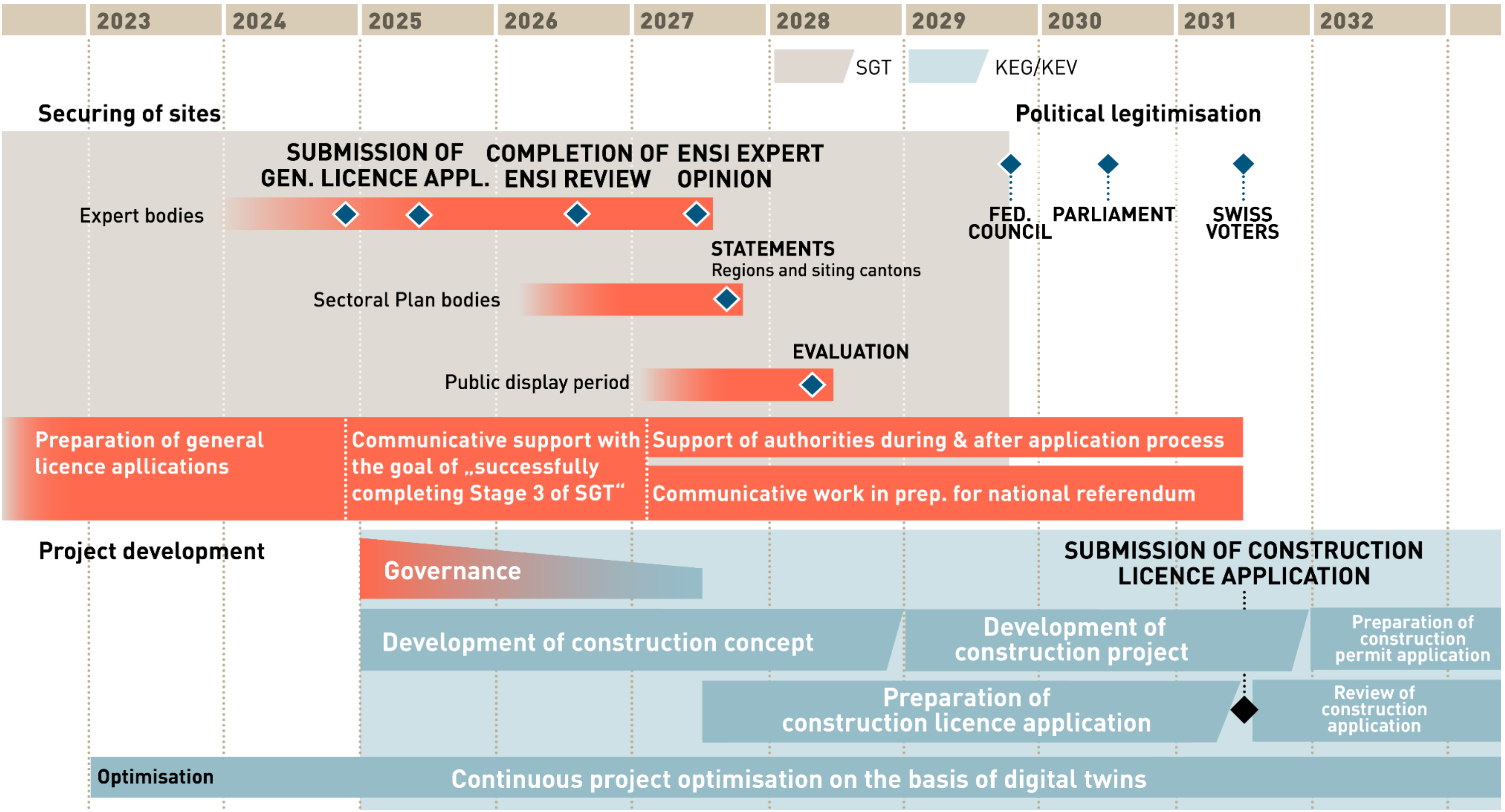
LONG-TERM PLANNING

The **stepwise approach** to realizing a geological repository:

- **Anchored in law:** Progress follows a legally mandated sequence — from conceptual studies to detailed design, from identifying siting regions to selecting sites, and from licenses to permits.
- **Ensures steady and secure progress:** A gradual approach enables careful evaluation at each stage, building confidence and protecting investments.
- **Foundation for development and innovation:** The stepwise process underpins project planning, implementation, and ongoing research, development, and demonstration (RD&D).



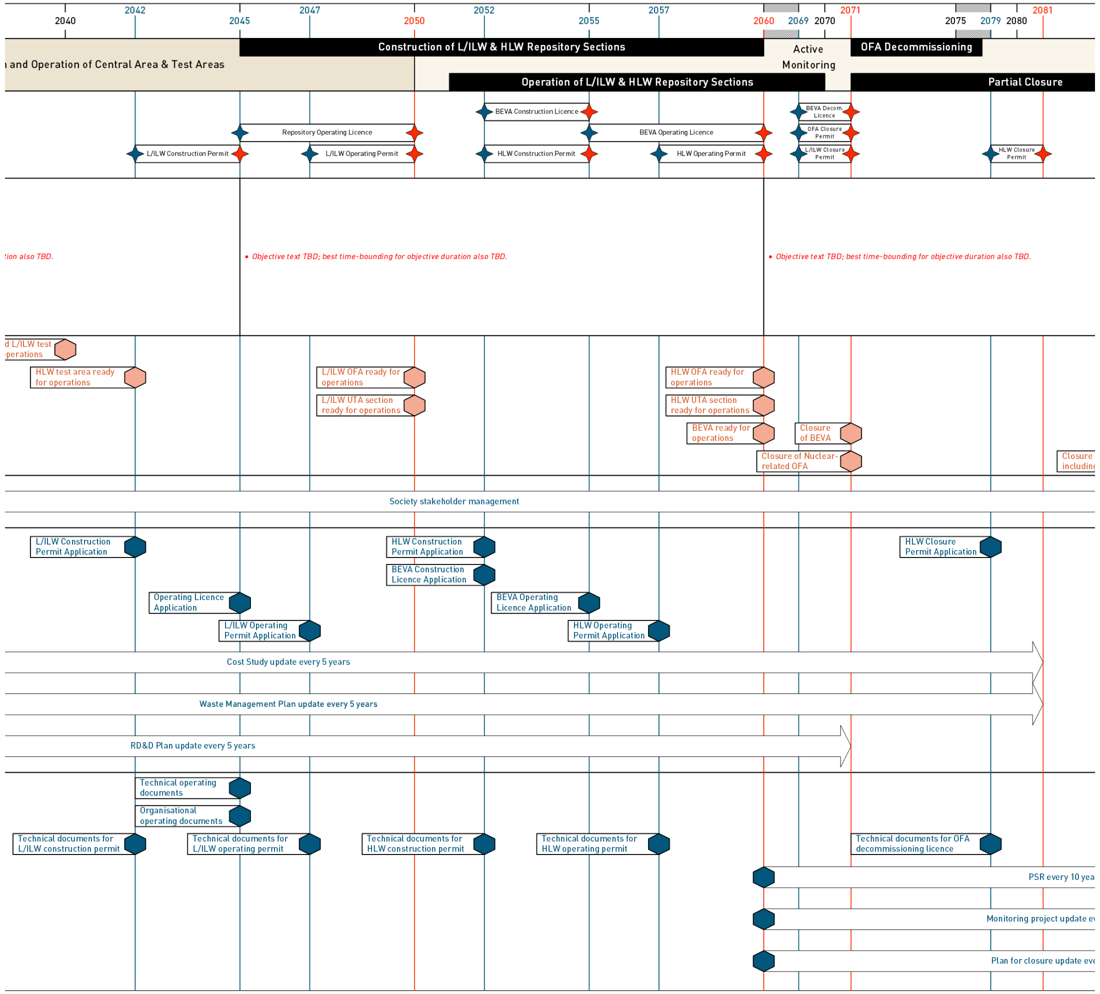
MID-TERM PLANNING



DETAILED ROAD MAPS DRIVING REPOSITORY IMPLENTATION

Roadmaps:

- capture the work required to further develop Nagra's science and engineering base
- ensure that the **technology, data and expertise** necessary for optimising the concepts **are acquired in a timely and cost-effective manner**.



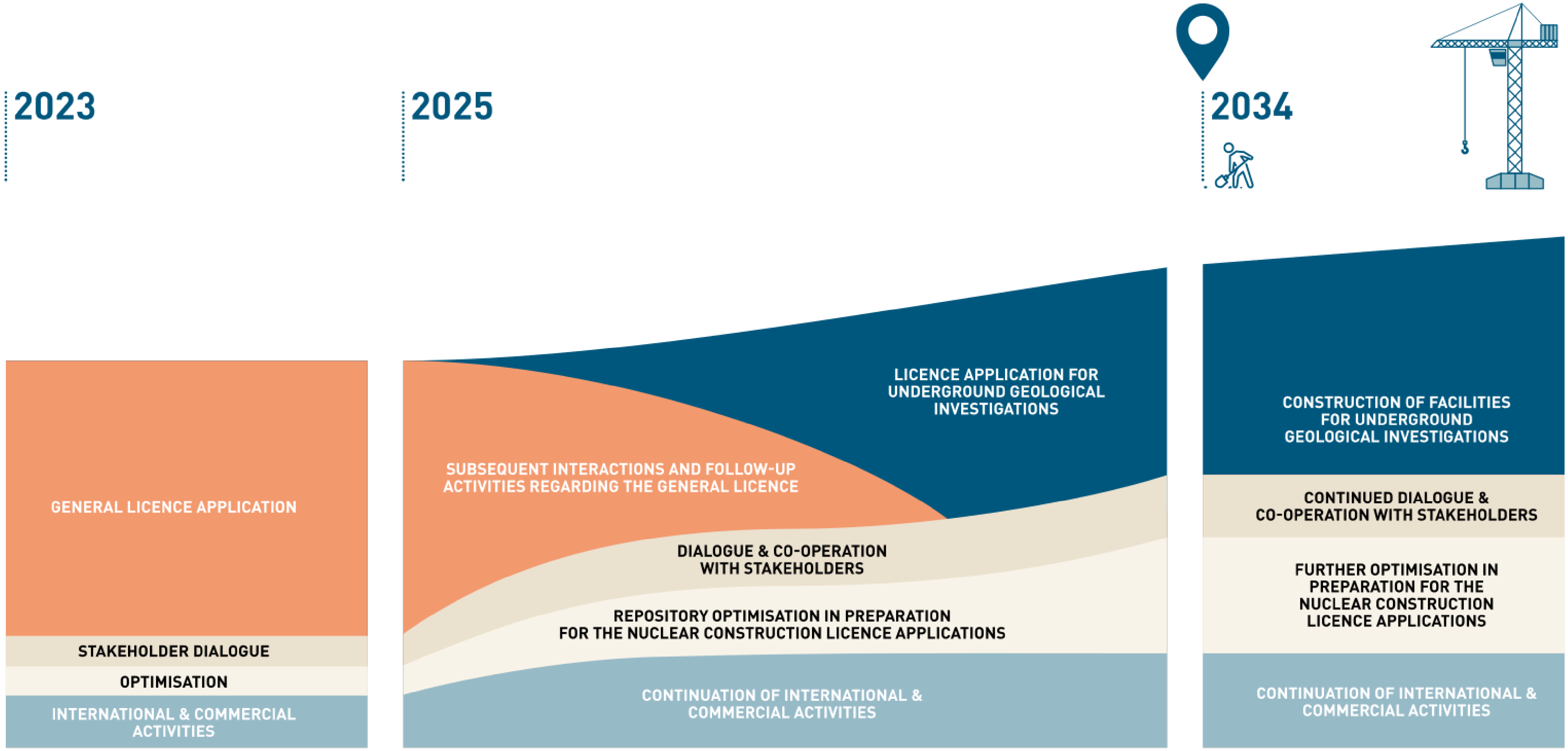
CONCLUSIONS 3

The reasons for carrying out RD&D and the drivers for identifying RD&D needs have evolved considerably.

In the early years, Nagra carried out exploratory RD&D on the basic scientific and technological options underlying the evolving geological disposal concept.

Today, RD&D focuses on contributing to the highly specific requirements arising from having an established repository conceptual design and safety case for a specific geological formation, and a specific regulatory framework.

WHEN DO WE HAVE TO KNOW WHAT AND AT WHAT DEGREE OF DETAIL?



THE CONCEPT OF TECHNOLOGY READINESS LEVEL (TRL)

Licensing

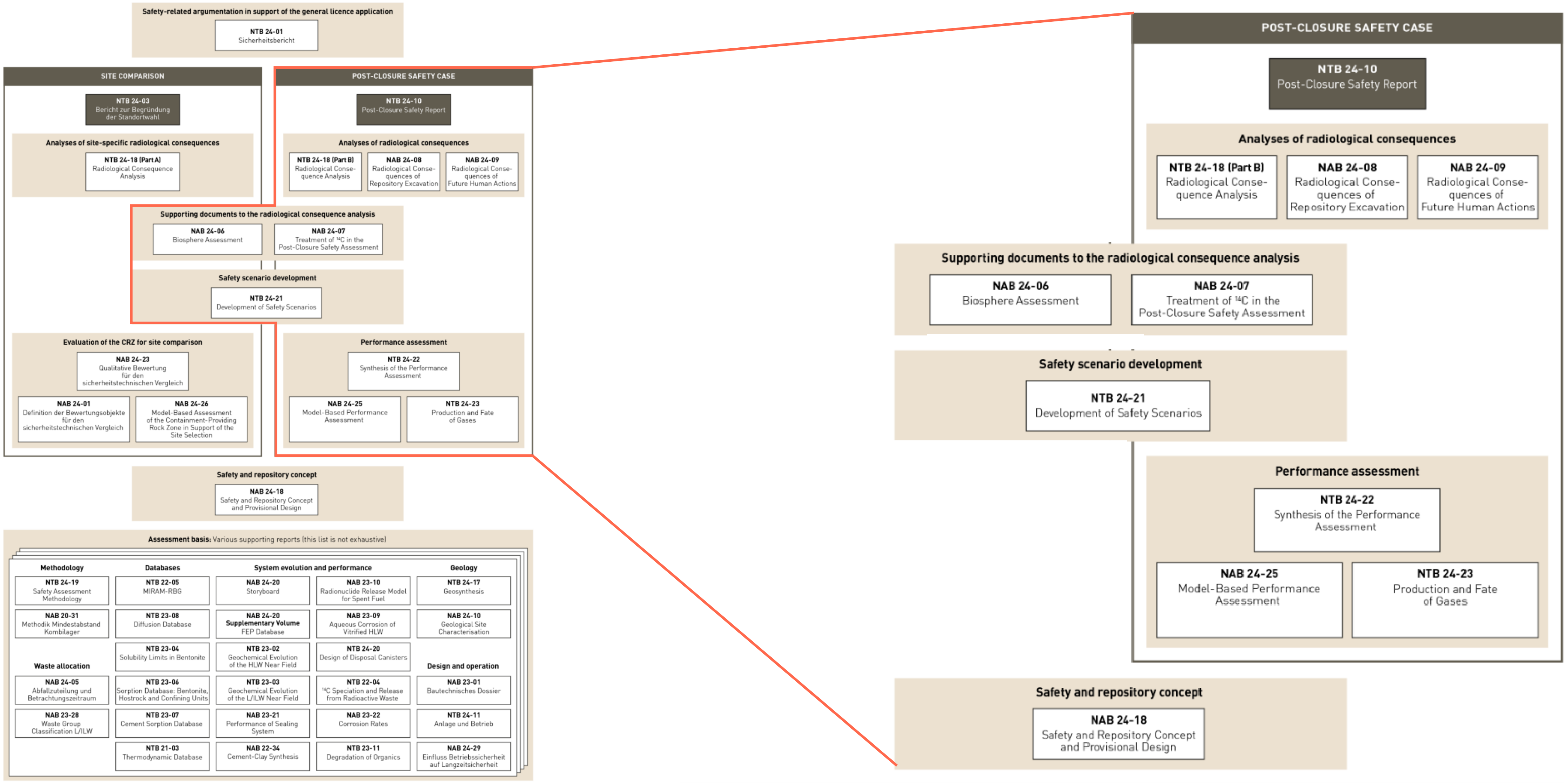
Operational Licence(s)
Repository site

Construction Licence(s)
EUU, Pilot repository at NL

General Licence
Generic rock laboratories

Deployment	9	ACTUAL SYSTEM PROVEN IN OPERATIONAL ENVIRONMENT
	8	SYSTEM COMPLETE AND QUALIFIED
	7	SYSTEM PROTOTYPE DEMONSTRATION IN OPERATIONAL ENVIRONMENT
Development	6	TECHNOLOGY DEMONSTRATED IN RELEVANT ENVIRONMENT
	5	TECHNOLOGY VALIDATED IN RELEVANT ENVIRONMENT
	4	TECHNOLOGY VALIDATED IN THE LAB
Research	3	EXPERIMENTAL PROOF OF CONCEPT
	2	TECHNOLOGY FORMULATED
	1	BASIC PRINCIPLES OBSERVED

SAFETY CASE DOCUMENTATION



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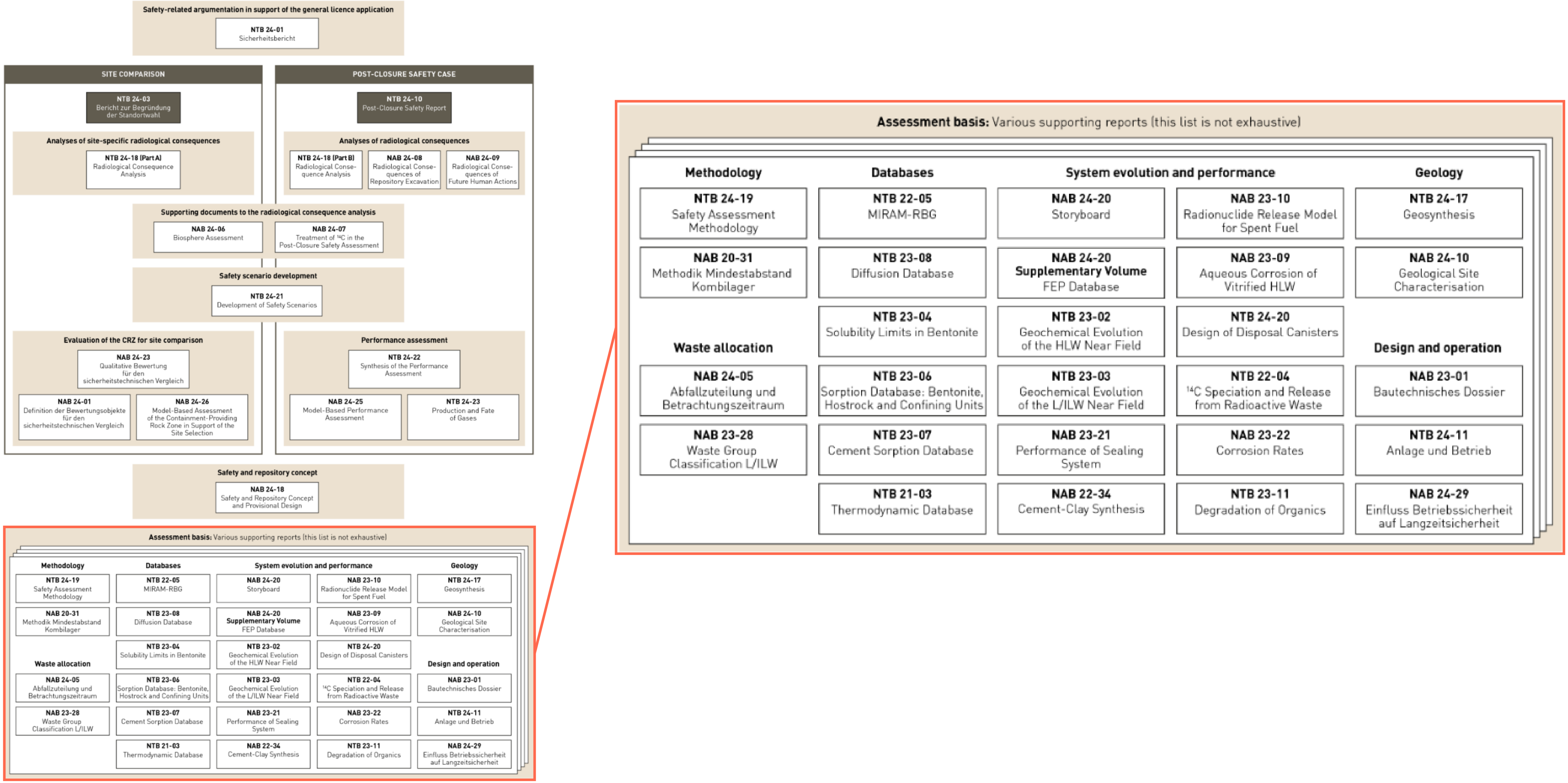

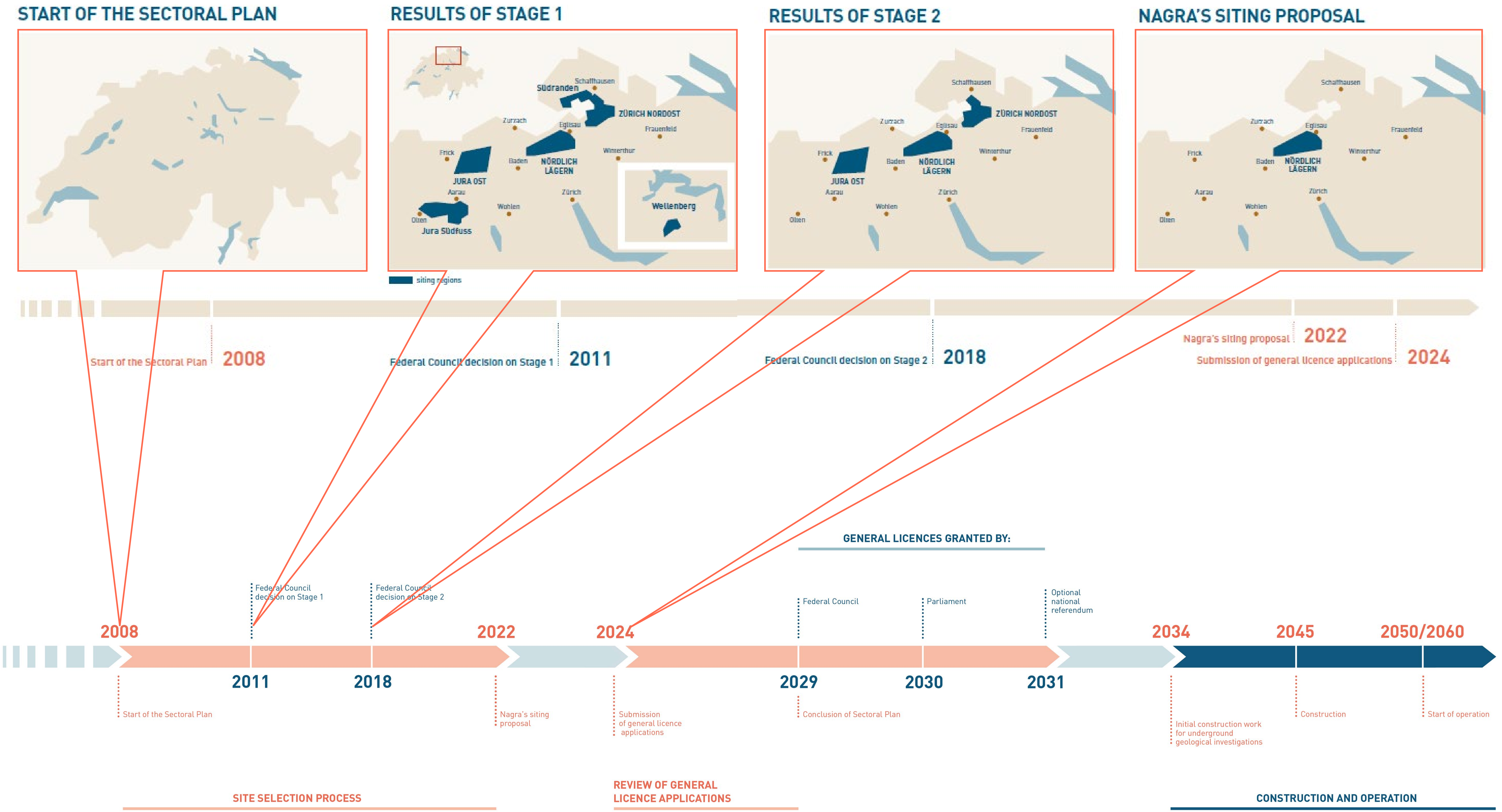
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