# Project *Entsorgungsnachweis*

Demonstration of disposal feasibility for SF / HLW / ILW in the Opalinus Clay of the Zürcher Weinland

## Background, Objectives & Overview

**NEA - IGSC Meeting**
**15 - 17 October 2003**

**Jürg Schneider & Piet Zuidema**

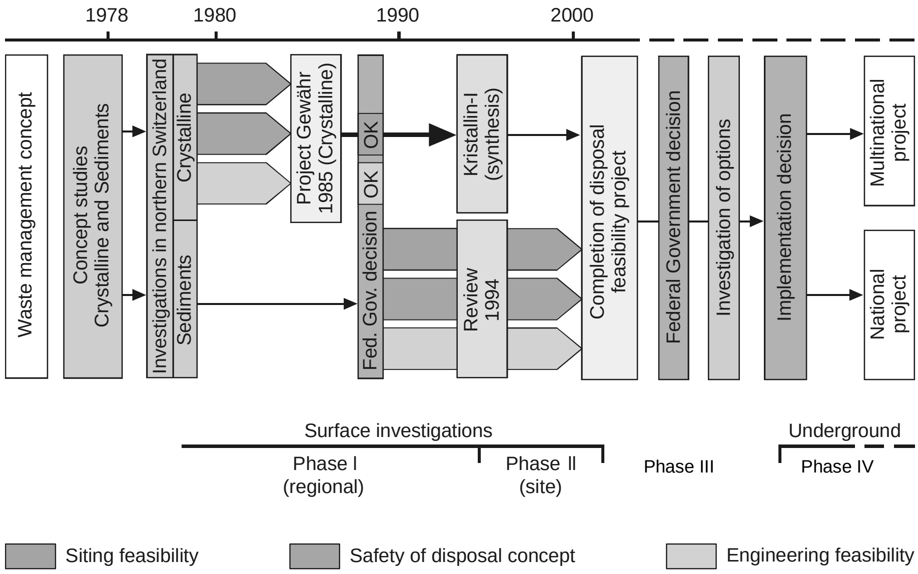


## Aims of Project *Entsorgungsnachweis*

- **Demonstration of Disposal Feasibility ➔ Extends and complements *Projekt Gewähr 1985***
  - Re-assessment of *siting feasibility* (needs also to consider *engineering feasibility & safety*)
  - The need to consider *sedimentary formations (phased selection process of preferred investigation area* ➔ Opalinus Clay in Zürcher Weinland*)*
  - p.m.: the need for a full synthesis of all information on *crystalline basement*: synthesis completed ➔ Kristallin - I[1)]
- **Preparation of Material & Input for Deciding on Future HLW Programme (approval by federal government)**
  - Assessment of the Opalinus Clay in the Zürcher Weinland by authorities
  - p.m.: Governmental working group prepares Government decision ➔ synthesis, compilation of additional information on specific aspects

[1)] Authority review completed soon; additional field work done (2-D seismics in Mettauer Tal)

## Adaptive staging in Swiss HLW programme

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## HLW programme: current situation (end Phase II)

- **Current milestone of HLW programme (*Entsorgungsnachweis*): 'Disposal Feasibility' based on localised investigations**
  - **Siting feasibility**: *'(Where) do adequate sites exist?'*
  - **Engineering feasibility**: *'Can repository be implemented as planned?'*
  - **Safety**: *'Is repository system safe for the site considered and the design envisaged?'*
- **Key issue: provide arguments for having chosen a good system for the 'way forward' & sufficient understanding to proceed (proposal to focus on the Opalinus Clay of the Zürcher Weinland)**
  - Sufficiently safe? ➔ level of **confidence**
  - Sufficiently **robust?** ➔ reliable in the face of uncertainty (and providing flexibility for changes)
  - No obviously better system? Role of **alternatives**?

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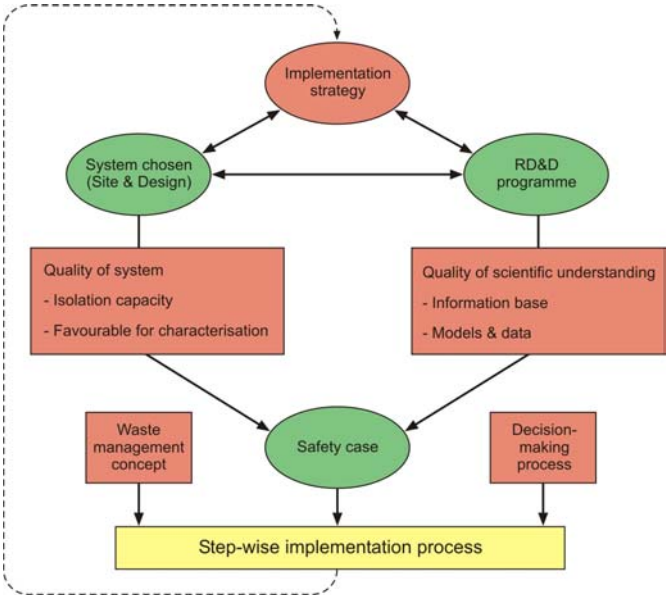
## Elements in decision-making at a given milestone




- **Implementation strategy**
  - Choice of system
  - RD+D - programme
- **Safety case: periodic assessment of strategy**
  - Quality of system
  - Quality of understanding
- **The societal element**
  - Geological disposal adequate?
  - Decision-making process (who? what? when? how?)
  - What next? flexibility left?
- **Any changes in plan?**

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14.10.03 5 NEA_IGSC_EN_Overview_141003

## Conclusions of Project *Entsorgungsnachweis*

- **The Opalinus Clay in the Zürcher Weinland and the System of Engineered Barriers ...**
  - provides high level of safety
  - is technically feasible
  - can be implemented with currently available technology
- **The results have exceeded the expectations; the data acquired are reliable & the level of understanding is good**
- **Nagra considers that ....**
  - the Opalinus Clay in the potential Siting Region of the Zürcher Weinland is promising (*Siting Feasibility*)
  - the Facility can be constructed, operated and closed as planned in that host rock / region, maintaining enough flexibility (*Engineering Feasibility*)
  - and that the Safety Case is convincing (*Safety Demonstration*)
- **Nagra therefore proposes to the Swiss Federal Government to focus future work in HLW programme on Opalinus Clay in Zürcher Weinland**
- **But: Formal siting decision still many years away**
- **And: Alternative options exist on which a watching-brief is maintained**

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## Swiss HLW Programme: Summary

**1** The *Opalinus Clay & the potential siting area Zürcher Weinland* have been **chosen from several available sediment options** (rocks, areas) **for investigation** in a step-wise procedure lasting many years with all important decisions **cleared and supported by the Swiss regulator** (and policy maker and their advisors)

**2** Due to the **excellent results** obtained in project *Entsorgungsnachweis* (investigations, synthesis), Nagra proposes to **focus future work on Opalinus Clay in the potential siting area Zürcher Weinland**.

**3** **Other options are also available** (alternative siting regions in Opalinus Clay, crystalline basement, reserve option USM) on which **a watching brief is maintained**. However, Nagra feels that it is currently **not justified to perform further extensive investigations** for these options.

**4** Project *Entsorgungsnachweis* is currently **under review** by the Swiss regulator (incl. international review under the auspices of NEA); a decision by the Swiss government on **how to proceed is expected in 2006**.

**5** A formal **siting decision** is not expected within the next few years (General licence).

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14.10.03 7 NEA_IGSC_EN_Overview_141003

## Making of the Safety Case

- Making of the Safety Case has to ensure proper integration of science & engineering ➔ both topics discussed in combination

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## The Safety Case - Definition

The safety case is the **set of arguments and analyses** used to justify the conclusion that a specific repository system will be **safe**. It includes, in particular, a presentation of evidence that all relevant **regulatory safety criteria can be met**.

It includes also a **series of documents** that describe the **system design** and **safety functions**, **illustrate the performance**, **present the evidence** that supports the arguments and analyses, and that discuss the significance of any **uncertainties or open questions** in the context of **decision making for further repository development**.



## Focus of the Safety Case

- **'Siting / Disposal Feasibility': importance to focus assessment on issues that could put safety of project into question**
  - **Completeness**: no important issue overlooked ➔ extensive phenomenological evaluation & broad spectrum of cases
  - **Sufficient safety** (vs exact level of safety) ➔ bounding & simplified assessments may be acceptable for (some of) the cases; deterministic analyses complemented by probabilistic calculations
  - **Robustness** ➔ insensitivity to residual **uncertainties** and/or reserves of safety exist
- **Importance of discussing key properties of system** *('make quality of system visible')*
  - Understanding
  - Uncertainties: importance of explorability & predictability of system
  - Diversity of phenomena contributing to safety
  - Independent evidence for the operation of key phenomena

## The Safety Case - Lines of argument

1 **Safety case is well-focused** & adequate for current stage
2 Strength of **geological disposal** as waste management option
3 **Safety and robustness** of the chosen disposal system
4 Reduced likelihood / consequences of **human intrusion**
5 Strength of the **stepwise repository implementation** process
6 **Good scientific understanding** of the system & its evolution
7 Adequacy of **methodology and models, codes and data**
8 Multiple **arguments for safety**
   – The demonstration of safety / **compliance with regulations**
   – The use of **alternative safety and performance indicators**
   – The existence of **reserve FEPs**
   – The **absence** of issues that could **compromise safety**

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## Safety Case: approach chosen

- **Define meaning of a 'good system' and a 'good analysis'**
  – Disposal principles
  – Assessment principles
- **Define method for processing information (➔ integration of team) and to address 'compliance' with above goals**
  – Scientific understanding as starting point (***science***)
  – Organisation, abstraction & assessment of information with explicit consideration of uncertainty (***safety assessment***)
  – Balanced & unbiased treatment of information (***bias audit***)
  – Allow for iterations & provide feed-back (***management***)
- **Conduct analysis according to method defined**
- **Documentation: the need to divide documentation into several reports** *(keep it manageable for the reader)*
  – Transparency ➔ arguments are clear & understandable
  – Traceability & retrievability of information ➔results reproducible

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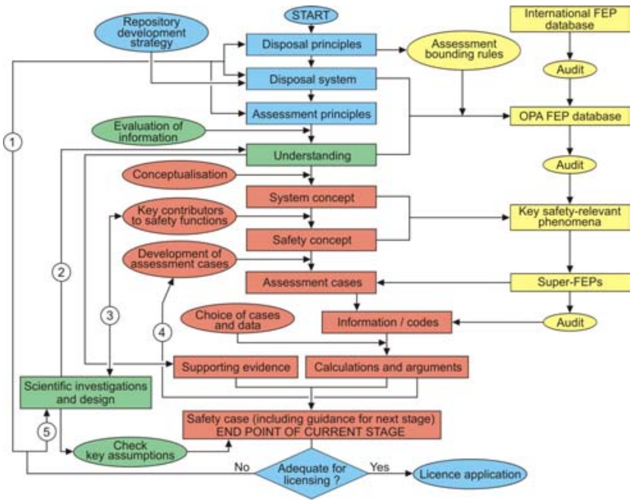
## Structured & clearly defined flow of information




- Understanding: **System Concept**
- What is important: **Safety Concept**
- Uncertainties & their potential effects: **Assessment Cases**
- Perform **Analyses**
- **Compilation** of analyses and arguments
- Address possibility for **Bias**
- **Conclusions**

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14.10.03 13 NEA_IGSC_EN_Overview_141003

## The need for different functions to develop the safety case

| | Management | Science and technology | Safety assessment | Bias audit |
|---|---|---|---|---|
| **Management** | Overall management of project | Keep work of groups focused on project goals; maintain overview of role/requirements of different groups; be responsive and accessible | | |
| **Science and technology** | Keep management informed (incl. any problem areas that need resources focussed on them) | Develop and evaluate scientific basis for safety assessment | Provide safety assessment team with understanding required to develop system concept and tools for analysis; revisit key assumptions | Provide bias audit team with comprehensive view of system understanding (including limitations) |
| **Safety assessment** | (as above) | Ensure that science and technology is aware of activities and information requirements of safety assessment team | Formulate and analyse safety assessment cases; assess "independent evidence"; compile safety case | Provide bias audit team with description of cases and concepts and tools used to analyse them |
| **Bias audit** | (as above) | Ensure that the scientific basis for safety assessment is adequately documented | Ensure that appropriate use is made by safety assessment of available scientific understanding | Ensure that the scientific basis for safety assessment is complete, adequately documented and exploited in safety assessment |

### The importance of the team

- **Management**: provide guidance, ensure interaction, iteration, feed-back
- **Science**: provide sound understanding
- **Safety assessment**: organise, analyse, compile arguments
- **Bias audit**: ensure that biases are acknowledged, avoid inadvertent biases

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14.10.03 14 NEA_IGSC_EN_Overview_141003

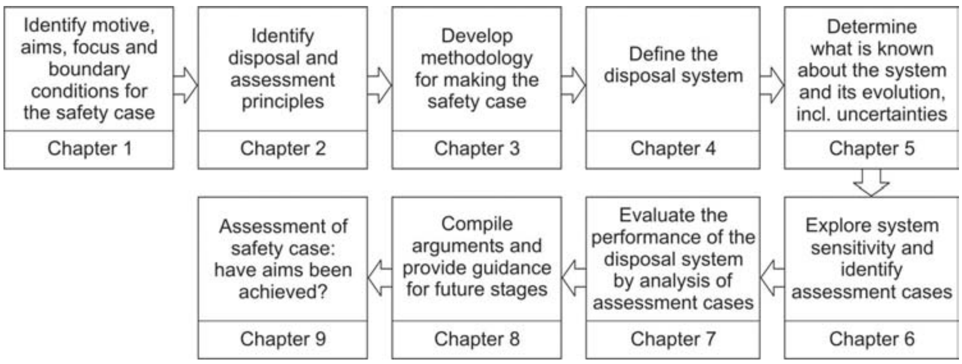
## Documentation

- **Safety Report (*transparency*)**
  - overview: background, methodology, status of science & technology
  - results (key arguments, insight, quantitative assessment cases)
  - conclusions
- **Models, codes & data (*traceability & bias audit*)**
  - provides details for quantitative assessment cases
  - description & qualification of codes used
  - complete compilation of all data used in assessment cases
- **FEP - management (*completeness in all steps & bias audit*)**
  - complete set of information?
  - information integrated?
  - codes adequate?
- **Reference reports (*detailed justification of concepts & data*)**



## The Safety Case - Flowchart for its development

## The Safety Report



## Safety Assessment

**The means to produce a Safety Case: Safety Assessment**

- **Safety Assessment is a process and includes**
  - Development of system understanding ➔ scientific analysis
  - Evaluation of safety ➔ synthesis
  - Interaction with and guidance of other disciplines (avoid unsuitable projects!)
- **Safety Assessment serves as a platform for**
  - Processing & integrating all information
  - Interaction between the different disciplines involved
  - Setting priorities and defining adequate levels of accuracy
- **Safety Assessment evaluates & documents current understanding**
  - Understanding & conceptualisation ➔ confidence in results
  - Evaluation of safety ➔ compliance
  - Feedback

[1] importance of adaptive staging: iterative nature of Safety Assessment



## Conclusions

- **Safety Case is integral part of adaptive staging**
- **At each milestone the safety case needs to be focused on the decision at hand**
- **A safety case (at least in the early parts of the project) contains both qualitative and quantitative arguments**
- **Important aspects of the methodology**
  - Importance of scientific basis (*what is known? what not?*)
  - Systematic processing of information (*completeness*)
  - Assessment of *uncertainties*
  - *Bias* (acknowledged vs inadvertent bias)
  - *Feed-back* (within current phase & input for next phase)
- **Successful analysis needs integrated & dedicated team**
- **Importance of well-structured documentation**

## The Safety Case & Peer Reviews

- **Role & importance of the Safety Case**
  - Framework: adaptive staging ➔ phases & milestones (decisions)
  - Safety Case: important element for decision-making
- **Role of peer review: background, framework & impact**
  - Endpoint: government decision on how to proceed with Swiss HLW programme
  - Preparing this decision: a process with reviews, consultation, ...
  - Visibility (➔ importance) of NEA International Review expected to be very high
  - p.m.: importance of peer review in preparing the project
- **Making the Safety Case: a discussion of aims, functions and interrelation of activities**
- **Integration of science as part of making the Safety Case**
  - Broad role of safety assessment (integration of & judgement on "scientific understanding")
  - Working process adopted in making the safety case (the specific function of science, interrelation of science with other activities)
  - Importance of organisational & cultural framework (everything integrated in one unit since quite some time)

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## Stepwise approach: what, when, why & how

- **Phases delineated by different milestones / decision-points**
- **No other possibility to implement such a project (of such long duration)**
  - Nobody will take full commitment at the beginning
  - Allow for learning & involvement of stakeholders
- **Elements of stepwise approach**
  - Define boundary conditions/criteria (& process) for initial definition of project & for adapting project
  - Define aim / objective of project (e.g. *finding a solution to long-term waste management*) & organisation of project (*responsibilities, milestones, ...*)
  - Adapt project according to learning & changing boundary conditions (also with the possibility to reverse)
  - Involvement of stakeholders (when, how, ...) in adapting project

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14.10.03 21 NEA_IGSC_EN_Overview_141003

## Stepwise approach: technical & societal issues

### Phases delineated by different milestones / decision-points

- For each of the decisions the **information required** depends upon the **commitment involved** in the decision
  - How good is good enough? (➔ importance of concept of robustness[1)])
  - How to **choose the system** to achieve significant level of robustness (➔ confidence in feasibility of 'path chosen')
  - How to acquire the necessary information? (boundary conditions)

[1)] limited sensitivity towards residual uncertainty & changing boundary conditions

- In each of the decisions **the involvement of stakeholders** depends upon the importance of the decision at hand
  - What **information do the stakeholders** need?
  - How to ensure proper **interaction between stakeholders**?
  - How to get **'legitimation' to solve national problem**?

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## The early phases of the Swiss HLW programme

- **Phase I: Feasibility of final disposal**
  - assess basic feasibility
  - develop basic concept
  - investigate siting possibilities (**regional** field programme)
  - develop expertise & infrastructure (labs, URL, team, ...)
- **Phase II: Siting feasibility**
  - consider lessons learnt from Phase I
  - optimise concept (robustness)
  - assess **siting** (& safety, engineering) feasibility
- **Phase III: Investigation of options**
  - consider lessons learnt from Phase II
  - optimise (& confirm) concept (robustness, safety, cost, ...)
  - assess alternative options (including multinational solution)
  - **decide on option** to be implemented (➔ 'Decision in Principle')

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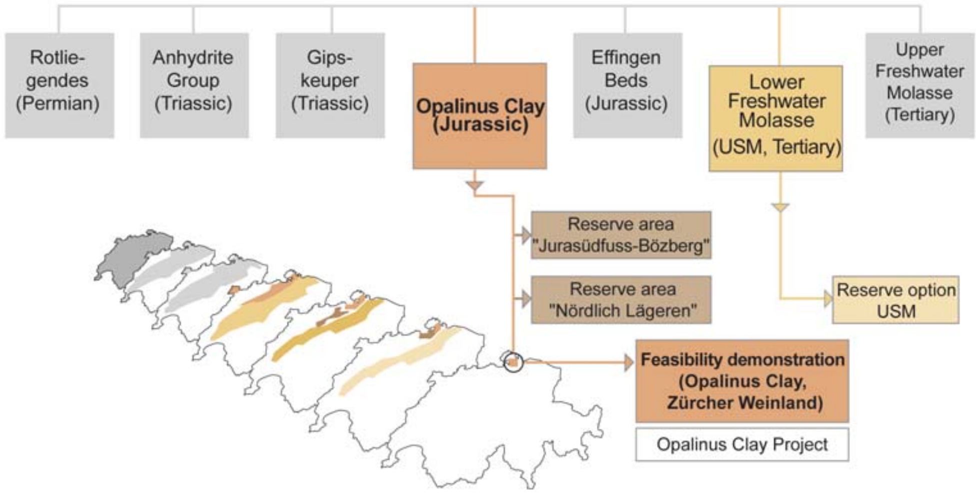
## Host rock and siting area options (sediments)

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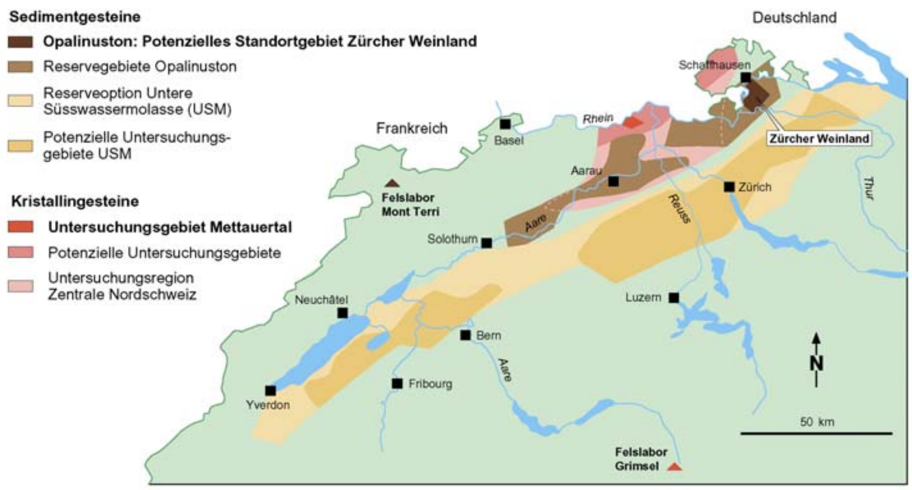
14.10.03 24 NEA_IGSC_EN_Overview_141003

## Options for HLW disposal in Switzerland

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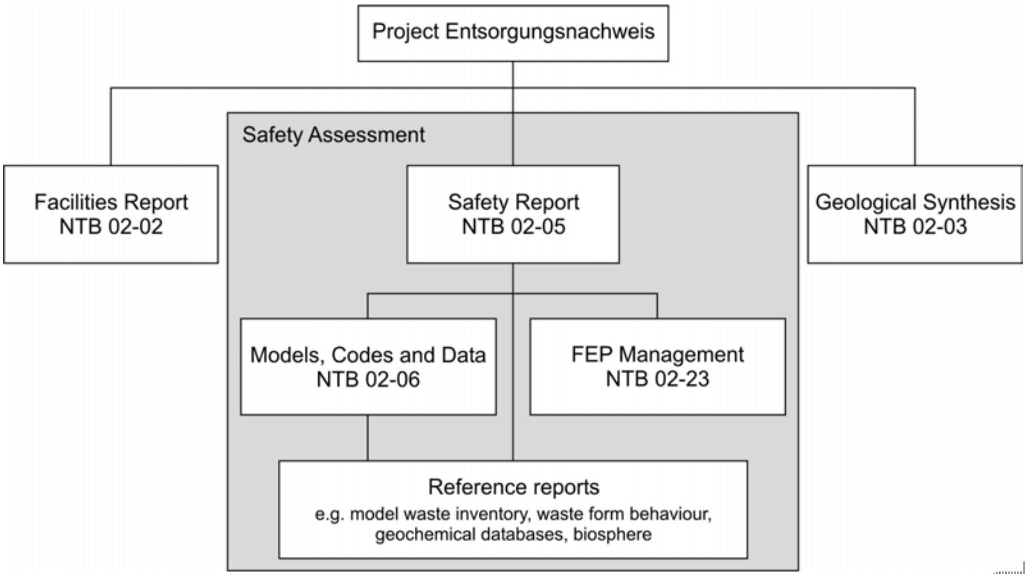
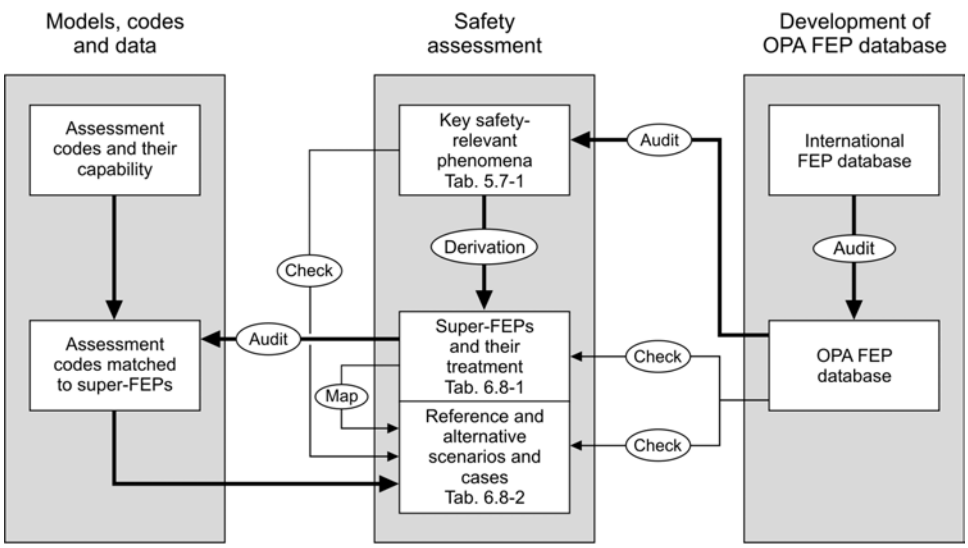
## Project *Entsorgungsnachweis*: Reporting Structure (Safety)



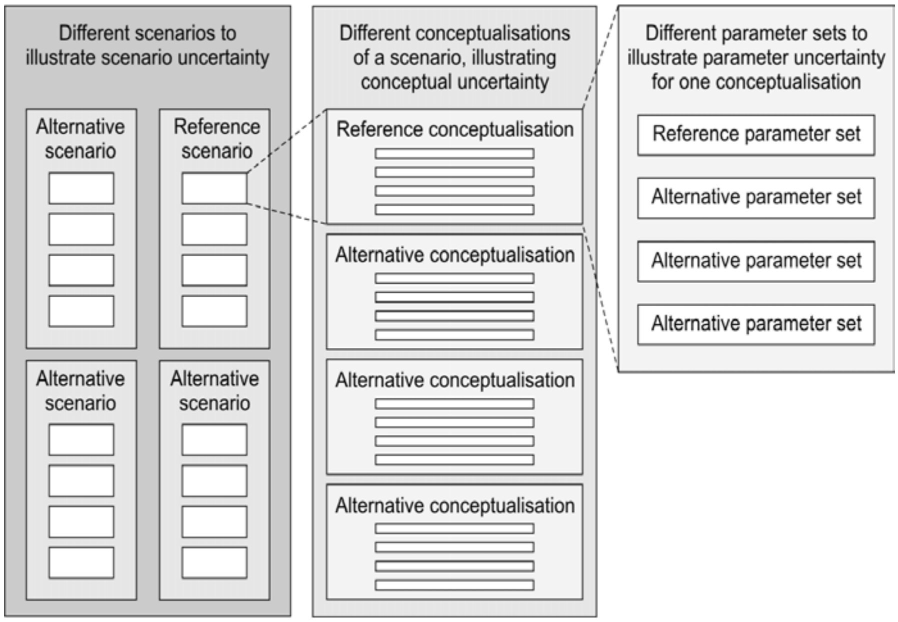

14.10.03 26 NEA_IGSC_EN_Overview_141003

## Interrelation between reports




14.10.03 27 NEA_IGSC_EN_Overview_141003

## Structure of Assessment Cases

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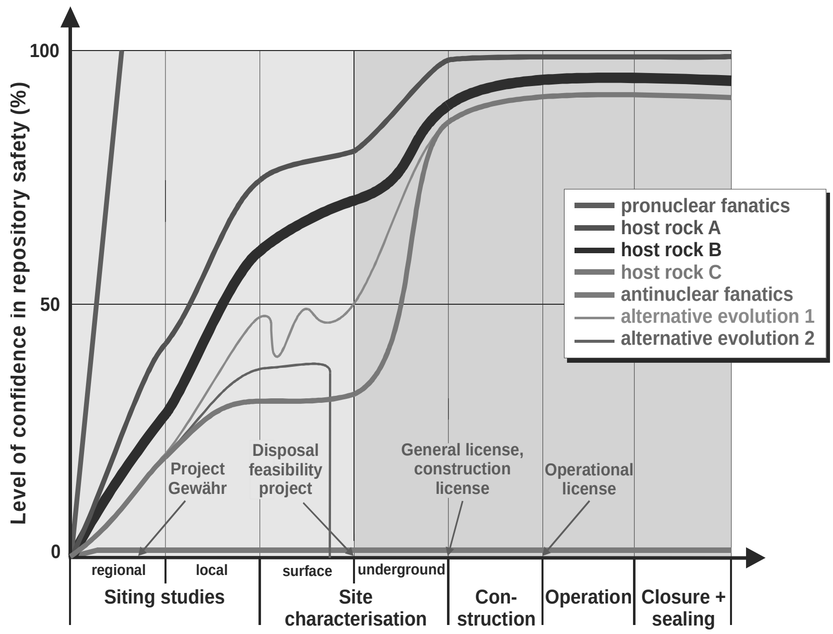
14.10.03 28 NEA_IGSC_EN_Overview_141003

## Stepwise Approach: Level of Confidence

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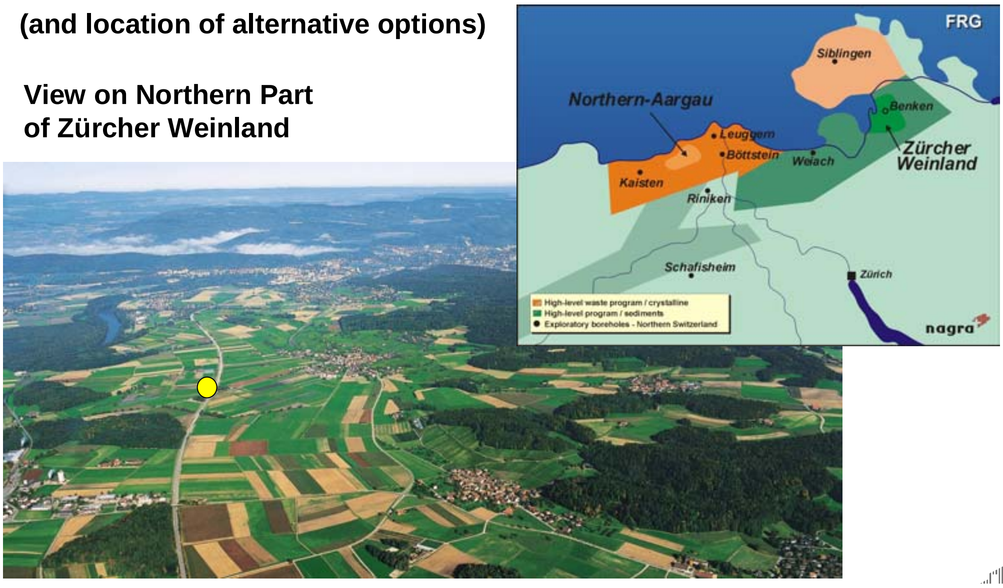
## Investigation Area Zürcher Weinland

**(and location of alternative options)**

**View on Northern Part of Zürcher Weinland**

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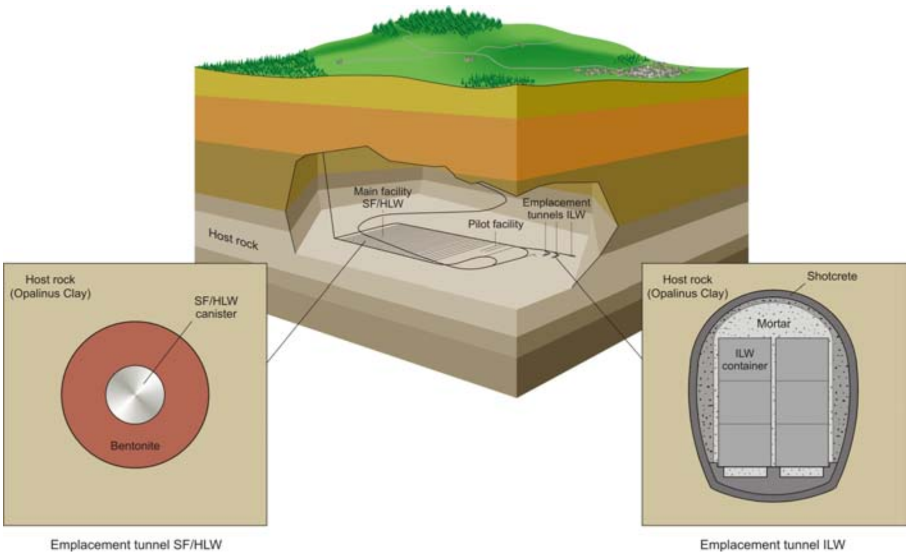
## SF/HLW/ILW - Repository in Opalinus Clay

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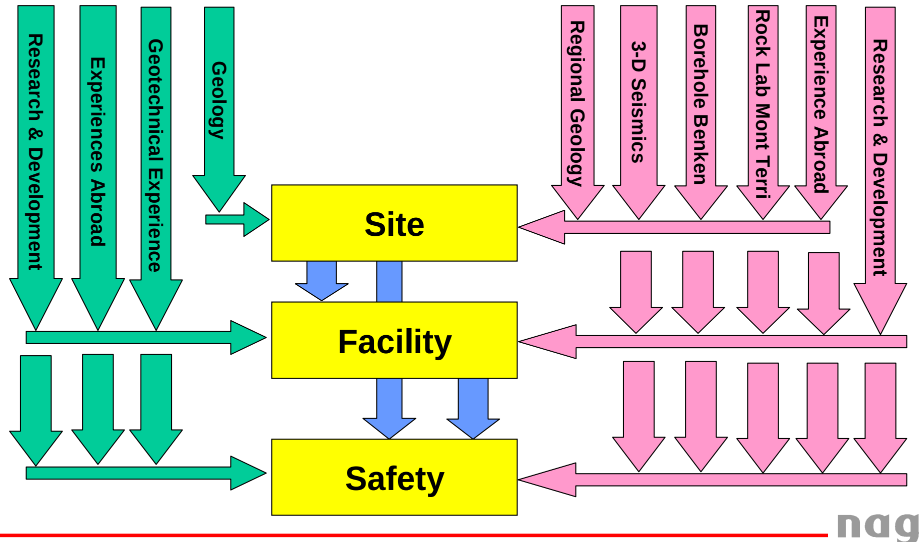
## Technical Basis and Work Performed

### Results of a 30 Year Programme

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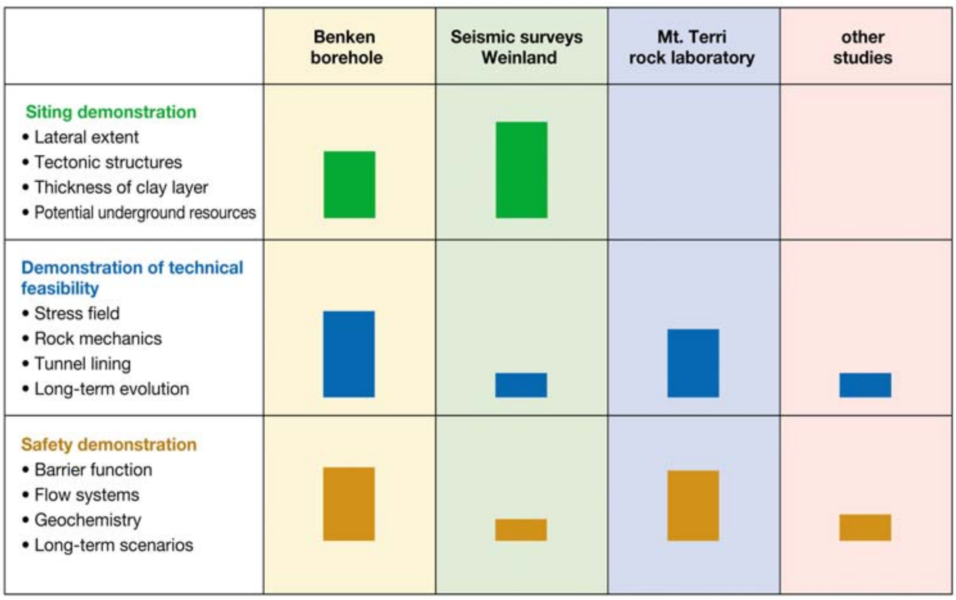
14.10.03 32 NEA_IGSC_EN_Overview_141003

## Project Opalinus Clay: Contribution of Different Investigations

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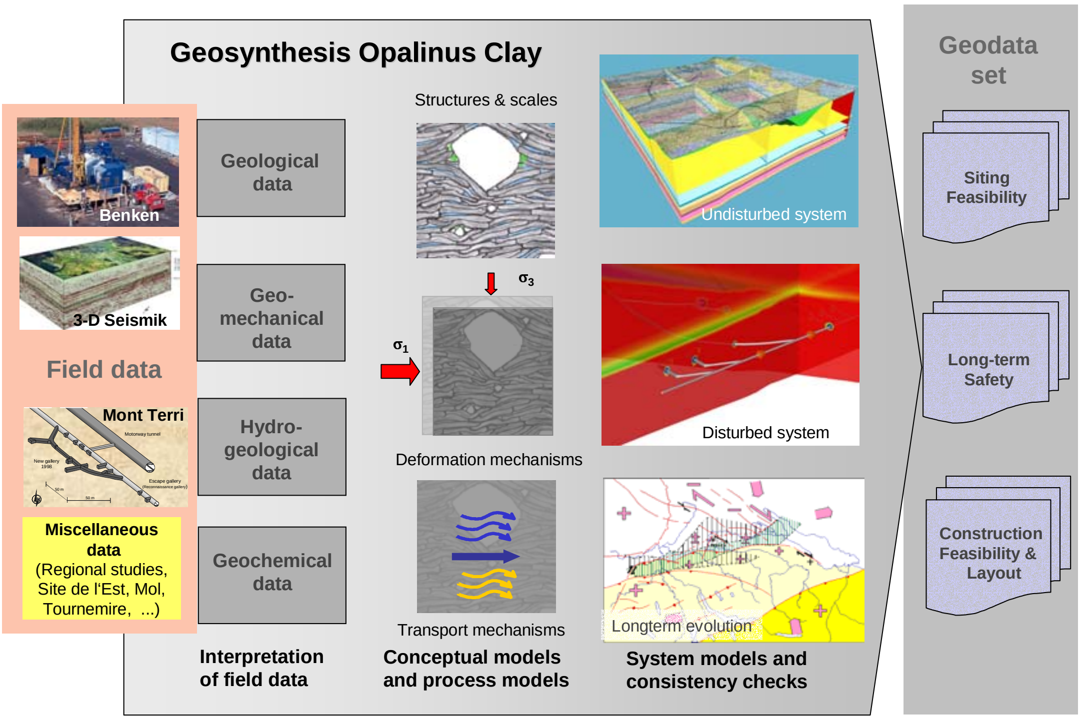
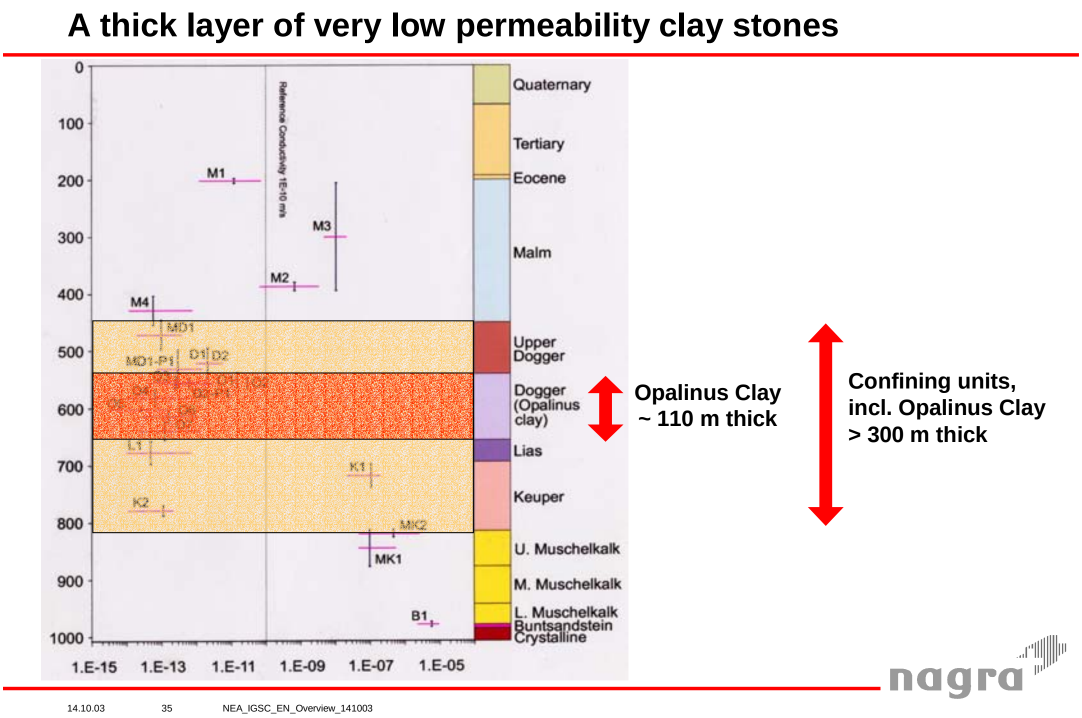
14.10.03 33 NEA_IGSC_EN_Overview_141003


Geosynthesis Opalinus Clay
Geodata set
Benken
3-D Seismik
Field data
Mont Terri
Miscellaneous data
(Regional studies, Site de l'Est, Mol, Tournemire, ...)
Geological data
Geo-mechanical data
Hydro-geological data
Geochemical data
Interpretation of field data
Structures & scales
Deformation mechanisms
Transport mechanisms
Conceptual models and process models
Undisturbed system
Disturbed system
Longterm evolution
System models and consistency checks
Siting Feasibility
Long-term Safety
Construction Feasibility & Layout


A thick layer of very low permeability clay stones
0
100
200
300
400
500
600
700
800
900
1000
1.E-15
1.E-13
1.E-11
1.E-09
1.E-07
1.E-05
M1
M2
M3
M4
MD1
MD1-P1
D1
D2
L1
K1
K2
MK1
MK2
B1
Quaternary
Tertiary
Eocene
Malm
Upper Dogger
Dogger (Opalinus clay)
Lias
Keuper
U. Muschelkalk
M. Muschelkalk
L. Muschelkalk
Buntsandstein
Crystalline
Opalinus Clay
~ 110 m thick
Confining units, incl. Opalinus Clay
> 300 m thick
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35
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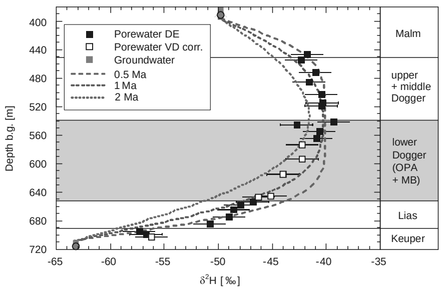
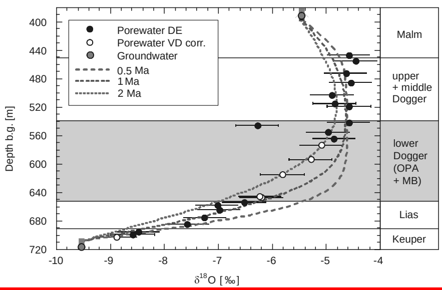
## Isotope profiles: '... a diffusion - dominated system'

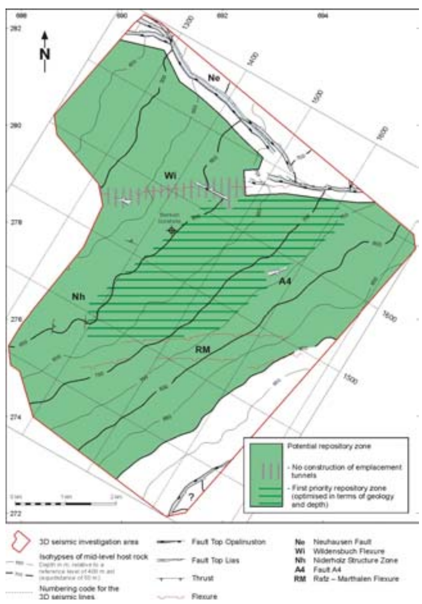



- Shape of isotope profiles: nature and rate of transport processes
- Data from potential siting area (Benken borehole)
- 2 naturally occurring isotopes: $^{2}H$, $^{18}O$
- Modelling:
  - start with uniform concentration
  - change of water composition in Malm and Keuper 1 Ma b.p.
  - best fit: diffusion only; no trace of advection
- '...in Opalinus Clay in the potential siting area, the dominating radionuclide transport process is diffusion'



## Size of potential siting area




- Investigation area (including regional fracture zone als boundary) ~ 50 km²
- undisturbed area ~ 35 km²
- undisturbed area at preferred depth ~ 22 km²
- within that area: area for repository for Project Entsorgungsnachweis[1)] ~ 8 km²
- area needed for repository ~ 2 km²

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1) optimised with respect to depth and geological situation (tectonics, permocarboniferous trough?)

## Geosynthesis Opalinus Clay: Key Findings

- **Simplicity** - predictable structural, hydrogeological and geochemical properties over a scale of tens of kms
- **Stability** - region tectonically stable (next few Ma); average heat flows and in situ stresses, low rate of uplift/erosion
- **Absence of resource potential**
- **Absence of water flow** - solute transport dominated by diffusion
- **Self-sealing capacity**
- **Good (reducing) + stable geochemical properties** - preservation of EBS, low solubility limits and strong sorption
- **Engineering feasibility** - Opalinus Clay: indurated moderately overconsolidated claystone
- **Sufficiently large 'block of rock'** - thickness & lateral extent

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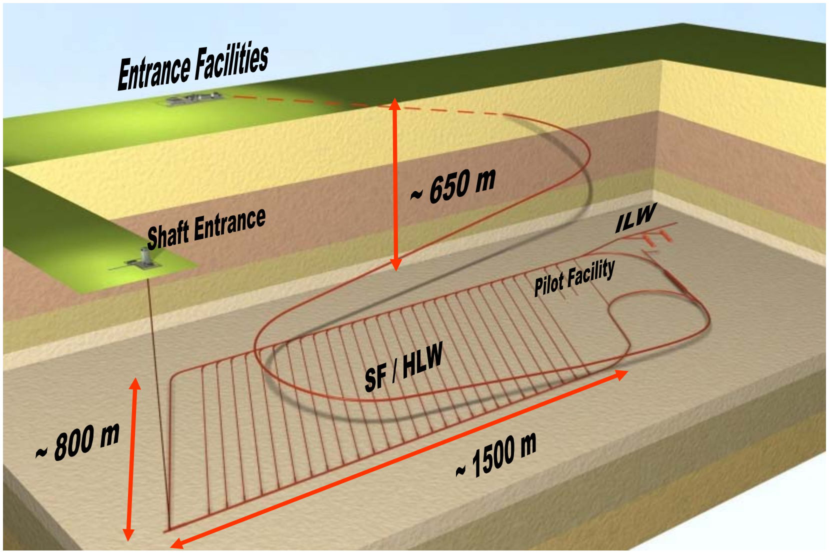
14.10.03 38 NEA_IGSC_EN_Overview_141003

## Layout for SF/HLW/ILW - Repository

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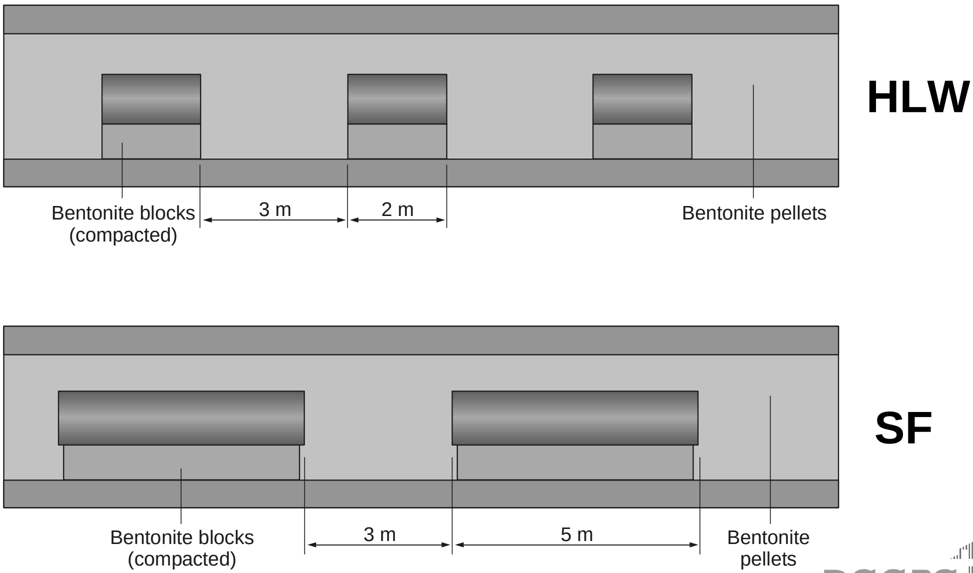
14.10.03 39 NEA_IGSC_EN_Overview_141003

## Emplacement of SF/HLW Canisters

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## Entrance Facility (approx. 300 m x 150 m)


**1 Administrationsgebäude**
**2 Betriebsgebäude**
**3 Lüftungsgebäude**
**4 Geräteschleuse**
**5 Konditionier- und Verpackungsanlage BE/HAA**
**6 Bahnzufahrt**
**7 Strassenzufahrt**
**8 Zugangstunnel, Rampe (überdeckt)**

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## Shaft Entrance (approx. 100 m x 100 m)


1 Förderturm mit Abluftöffnungen
2 Baubüro, Mannschaftsräume, Werkstatt, Trafoanlage etc.
3 Ausbruchmaterialdepot, gedeckt
4 Geräte-/Materialhalle

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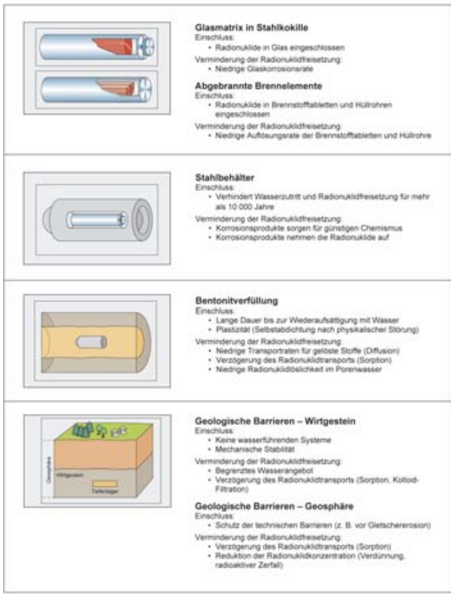
14.10.03 42 NEA_IGSC_EN_Overview_141003

## Post - Closure Safety




- **System with multiple safety barriers**
  - Waste matrix (glass, $UO_2$/MOX)
  - Container
  - Bentonite backfill
  - Opalinus Clay + other clay stones
- **Situated in stable environment**
  - large depth
  - stable geological environment
  - no resource conflicts
- **Results in:**
  - Isolation of radionuclides: Decay of nearly all nuclides
  - Release of remaining nuclides: very small (low doses)

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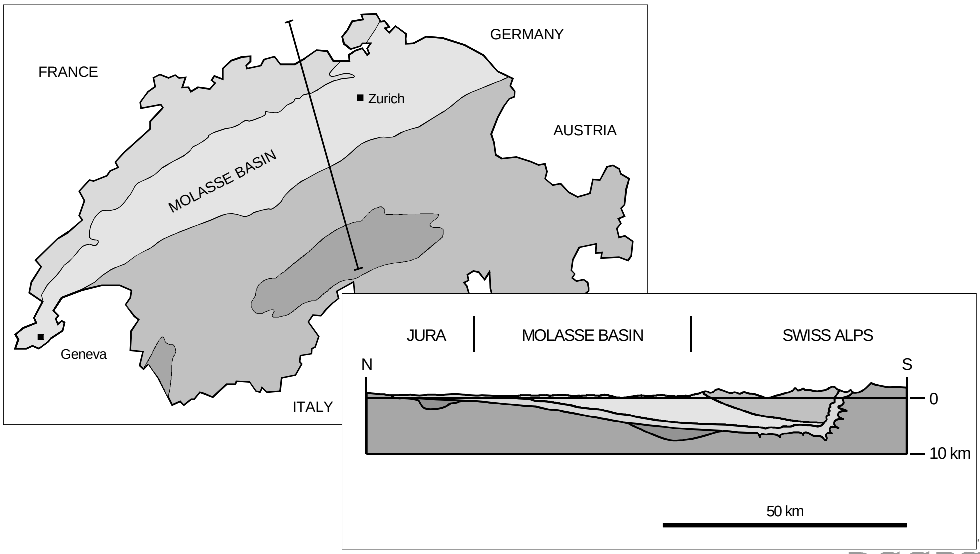
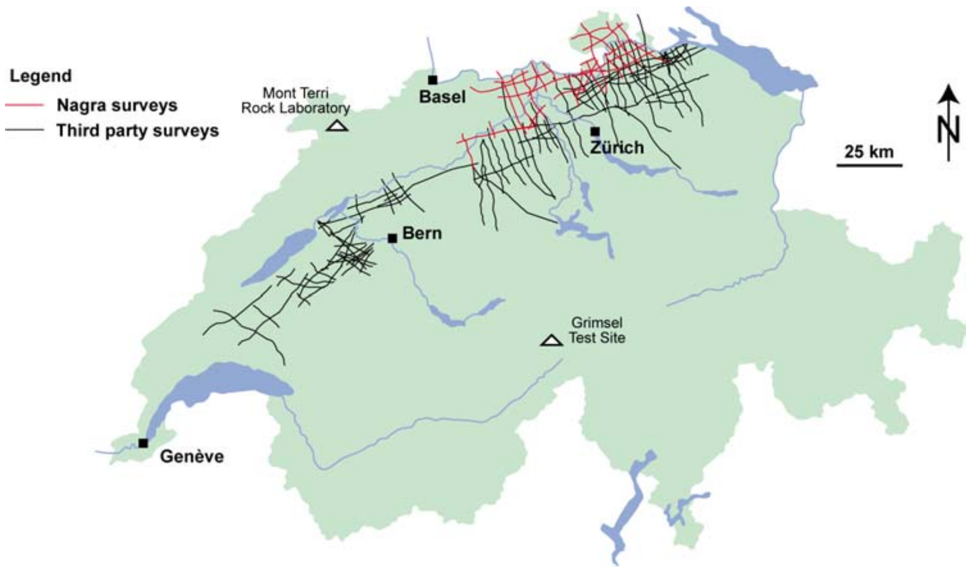
# Geological boundary conditions Switzerland

Importance of 'schweizerisches Mittelland'



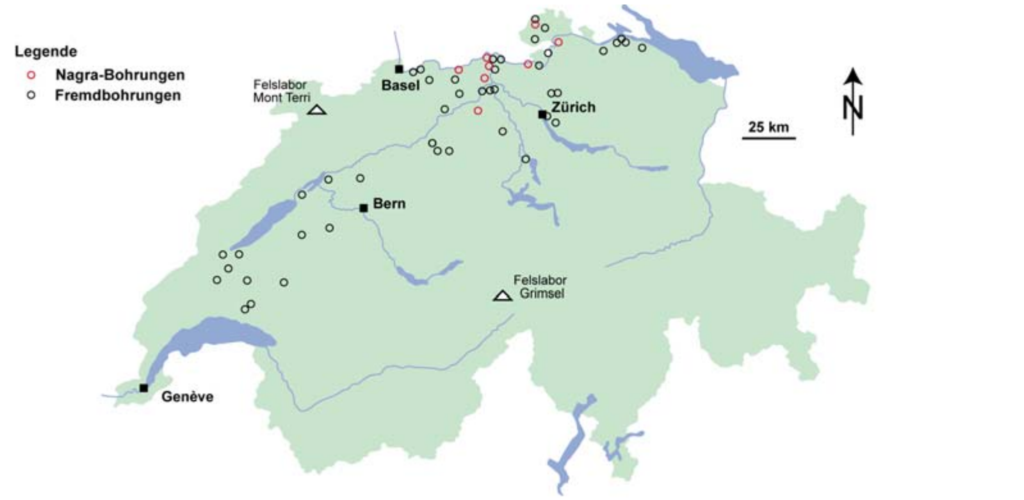

14.10.03 44 NEA_IGSC_EN_Overview_141003

# Screening of siting regions: 2D reflection seismics




14.10.03 45 NEA_IGSC_EN_Overview_141003

## Screening of siting regions: Boreholes (Selection)

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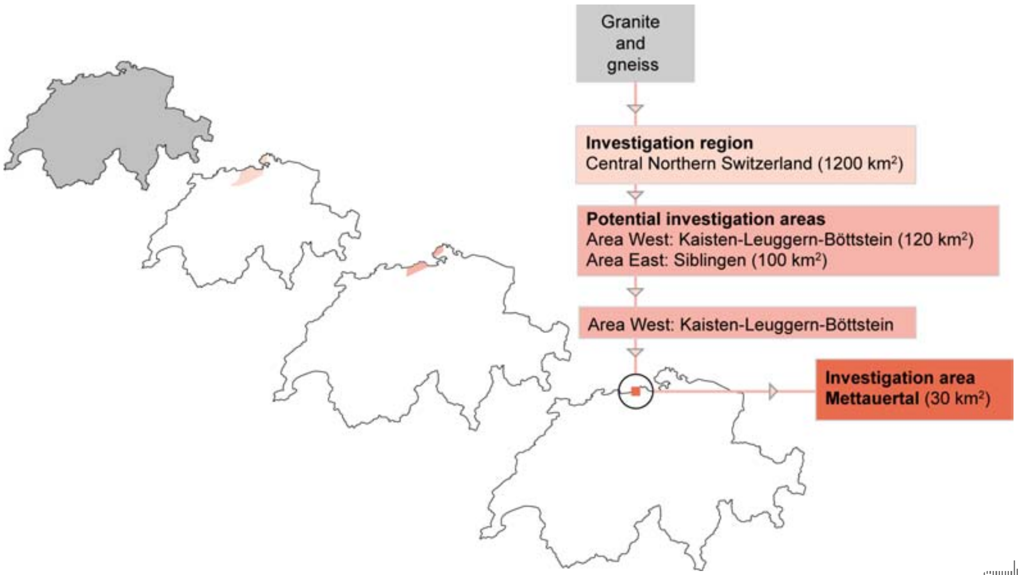
14.10.03 46 NEA_IGSC_EN_Overview_141003

## Host rock and siting area options (crystalline)

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14.10.03 47 NEA_IGSC_EN_Overview_141003