Site characterisation in the final stage of selecting the site in sedimentary clay rock in Switzerland

Bernd Frieg
Swiss waste management concept
Sectoral Plan – 3 stages towards site selection

<table>
<thead>
<tr>
<th>Stage</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>2008 - 2011</td>
</tr>
<tr>
<td>Stage 2</td>
<td>2012 - 2018</td>
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<tr>
<td>Stage 3</td>
<td>~ 6 years</td>
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</table>
Proposed siting regions (end of SGT E2 (stage 2))
Combined repository or two single repositories: Decision steps

- With the Stage 2 available data, the disposal perimeters at each site are large enough to also accommodate both repositories (combined repository)

- For each site, variants for a HLW-repository, a LLW-repository or a combined repository are being developed

- Based on the results from the Stage 3 investigations and considering the safety and engineering feasibility criteria:
  - the preferred site for the HLW-repository will be determined first
  - in a second step it will be assessed if there is still enough volume to locate the LLW-repository at the same site
  - if yes, the site will be proposed for a combined repository

Example of variants for combined repositories (ref. Cost Study 2016)
Existing investigations (end of SGT E2 (stage 2))

Deep boreholes
Seismic surveys

Mont Terri Project

Grimsel Test Site
Geological mapping & sampling

e.g. for dating quaternary sediments
Exploration concepts (until the end of SGT E3 (stage 3))

Stage 1 2008 - 2011
Stage 2 2012 - 2018
Stage 3 ~ 6 years
Planning products

- **Site investigations strategy** (all phases and all sites update for each phase)
  - Aims per phase («identify / confirm / proof potential to construct safe repository»)
  - Investigations (desk study, airborne surveys, ground surveys, drilling, underground labs)
  - Key products and level of detail (see legal framework)

- **Site investigation concepts** (per phase and per site) → regulator
  - Geology
  - Phase specific aims
  - Breakdown of aims to individual methods

- **Survey / campaign concepts** where necessary
  - 2D, 3D-Seismics: not done (target description only)
  - shallow drilling: not done (target description only)
  - deep drilling: planning report including
    - breakdown of aims to drilling sites
    - Scenarios for different outcomes

- **Drilling applications** (invasive investigations require licensing): catalog of investigations and drill paths / site → licensing authority

- **Drill site work programs** (for authorisation by regulator): selected methods / investigations per section → regulator
## Key features – Stage 3 investigations

<table>
<thead>
<tr>
<th>No.</th>
<th>Feature</th>
<th>Mainly applicable to</th>
<th>Investigations in Stage 3</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>HLW</td>
<td>L/ILW</td>
</tr>
<tr>
<td>M01</td>
<td>Higher fault density in parts of the disposal perimeter and shearing in the host rock due to thrusting from the Alps</td>
<td>X</td>
<td>(X)</td>
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<tr>
<td>M02</td>
<td>Zones with increased density of sub-vertical faults</td>
<td>(X)</td>
<td>(X)</td>
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<tr>
<td>M03</td>
<td>Zones with increased fault density in the vicinity of local compressive structures</td>
<td>X</td>
<td>X</td>
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<tr>
<td>M04</td>
<td>Confirmation of depth of the containment-providing rock zone</td>
<td>X</td>
<td>X</td>
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<tr>
<td>M05</td>
<td>Significance of overdeepened gullies (channels) for the erosion scenarios</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>M06</td>
<td>Thickness and quality of the upper confining units of the Opalinus Clay, particularly the lower parts of the ‘Brauner Dogger’</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>M07</td>
<td>Thickness and quality of the host rock, particularly with respect to construction engineering aspects</td>
<td>X</td>
<td>X</td>
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<tr>
<td>M08</td>
<td>Basement geology with regard to fault reactivation and conflicts of use</td>
<td>X</td>
<td>X</td>
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</table>
Current schedule and key milestones

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<tbody>
<tr>
<td>Stage 2</td>
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<tr>
<td></td>
<td>Collaboration with the regions</td>
<td>Identification of the location of surface facilities</td>
<td>Nagra submits at least 2 proposals for each type of repository</td>
<td>Review, consultation and Federal Council decision on Stage 2</td>
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<tr>
<td>Stage 3</td>
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</tr>
<tr>
<td></td>
<td>3D seismic campaign for Stage 3</td>
<td>Drilling permit application for Stage 3</td>
<td>Review of drilling permit applications / Decision UVEK / DETEC</td>
<td></td>
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<td></td>
<td>Drilling campaigns</td>
<td>Continued collaboration with the regions</td>
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<td></td>
<td></td>
<td></td>
<td>Site selection in preparation for general licence</td>
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<tr>
<td></td>
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<td></td>
<td>Continued collaboration with the regions</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>General licence application</td>
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</tbody>
</table>
Geological investigations in Stage 3

3D-Seismic
- Geological model
- Available volume → Spatial extent

Deep boreholes
- Rock properties
- Seismic calibration
- Available volume → Vertical extent

Quaternary investigations
- Basis for derivation of future erosion scenarios
## 3D-seismic campaign 2015 - 2017

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Jura Ost</th>
<th>Zürich Nordost</th>
<th>Nörlich Lägern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area [km²]</td>
<td>92.6</td>
<td>18.3</td>
<td>91.6</td>
</tr>
<tr>
<td>Land owners contacted</td>
<td>1'624</td>
<td>565</td>
<td>1'810</td>
</tr>
<tr>
<td>Land owners giving their permission</td>
<td>1'609 (99%)</td>
<td>548 (97%)</td>
<td>1'750 (97%)</td>
</tr>
<tr>
<td>Communities</td>
<td>27</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Measurement days</td>
<td>97</td>
<td>17</td>
<td>77</td>
</tr>
<tr>
<td>Person days</td>
<td>12'730</td>
<td>2'400</td>
<td>13'500</td>
</tr>
<tr>
<td>Kilometers driven</td>
<td>410'000</td>
<td>100'000</td>
<td>600'000</td>
</tr>
<tr>
<td>Shot points (vibration vehicles/explosives)</td>
<td>16'315 / 3'409</td>
<td>3'319 / 407</td>
<td>14'937 / 2'392</td>
</tr>
<tr>
<td>Measurements points</td>
<td>25'742</td>
<td>5'109</td>
<td>20'258</td>
</tr>
</tbody>
</table>
Quaternary investigations

- **Field investigations**
  - Drilling into *quaternary* deposits to investigate erosion processes (dating sediments)
  - *First drilling started in March 2018,* permit applications for 3 additional drillings undergone public consultation and in the licensing stage by DETEC
Longterm erosion and uplift rates from fluvial terraces

- Fluvial terraces: archives for reconstruction of base level evolution
- Periods of consideration:
  - Past approx. 2 mio yrs
  - Future approx. 1 mio yrs

Mammal remains dated to 1.8 – 2.5 Ma (Bolliger et al. 1996)

Total fluvial erosion
- last 2 mio yrs 210 m
- last 1 mio yrs 130 m
- last 0.4 mio yrs 30 m

Average erosion rates
- last 2 mio yrs 0.11 m/a
- last 1 mio yrs 0.13 m/a
- last 0.4 mio yrs 0.08 m/a
What is the probability of a critical erosion volume at site X and at time Y?

- Fluvial erosion
- Glacial erosion (→ significant overdeepenings)
- Climate scenarios

Bayesian analysis (stochastic)
Site investigation concepts – underlying strategy

- **3D-Seismics**: include tectonic context
- **Deep drilling**: go for the boring geology (proof suitability) avoid complexities
- **Drilling applications**: 2 years for a license (plus planning / negotiations and optional legal procedures); 3D-seismics: 1 year preparation (no license required) 1 year processing and interpretation; in-sequence work: 4 years min. to locate drill sites
  - → locate drill sites based on 2D-results (on lines)
  - → use approximate locations to distribute targets, built in soft links (avoid to be cornered)
- **Effort vs. flexibility? Flexibility!** 6 – 8 drilling applications / site with 3-4 directions each. **Invest** in preparation work and negotiations (licensing authority, regulator, cantons, communities, land owners) → **React quickly** to investigation results and availability of drilling licenses
Deep borehole investigations

- Permits from the Federal Government sequential starting **August 2018**
- Borehole site preparation in late Fall 2018
- **Start** of drilling operations at selected sites in 2019

<table>
<thead>
<tr>
<th>Location</th>
<th># boreholes</th>
<th>ENSI approval</th>
<th>Fed. Gov. approval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jura Ost</td>
<td>8</td>
<td>11/2017</td>
<td>pending</td>
</tr>
<tr>
<td>Nördlich Lägern</td>
<td>6</td>
<td>3/2018</td>
<td>1/6 (Aug. 18)</td>
</tr>
<tr>
<td>Zürich Nordost</td>
<td>8</td>
<td>1/2017</td>
<td>2/8 (Aug. 18)</td>
</tr>
</tbody>
</table>
Survey / campaign concept (drilling campaign)

- Identification of most promising areas within siting regions
- Updated and refined targets
- Discussion of drilling sequence → base for discussion with regulator
NL – SDM – Geological profiles
Deep and quaternary borehole locations
Drilling license application

- Justification of location (at the edge of most interesting regions)
- Catalog of methods: includes everything, excludes as little as possible
- → flexibility
## Drilling applications for deep boreholes

<table>
<thead>
<tr>
<th>Until Sept. 2018</th>
<th>Jura Ost (JO)</th>
<th>Nördlich Lägern (NL)</th>
<th>Zürich Nordost (ZNO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of sites handed in</td>
<td>8</td>
<td>6 (+1 until Dec. 2018)</td>
<td>8</td>
</tr>
<tr>
<td>Permits given</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

![Maps of drilling sites]( attach:image )
Investigation objectives of TBO campaign

- Assessment of spatial extent
  - Confirmation of thickness/depth/lateral extent of containment zone
  - Evaluation / Characterization of structural inventory

- Hydraulic barrier effect
  - Confirmation of hydraulic separation («Stockwerkbau»)
  - Evaluation of barrier efficiency of Upper/Lower Confining Units
  - Confirmation of barrier efficiency of host rock (ss)

- Long-term stability
  - Characterization of tectonic regime
  - Confirmation of THM Properties of host rock
  - Evaluation of conflict of use (permocarboniferous trough)

- Reliability of geological predictions
  - Evaluation of structural inventory
  - Characterization of continuity of Upper/Lower Confining Units
  - Confirmation of continuity of host rock (facial variability)

- Engineering suitability
  - Characterization of geotechnical properties of host rock and stress
Exploration boreholes – organisation, planning, tendering

- Tendering of different work packages (not general contractor):
  - Drilling company
  - Logging services
  - Hydraulic Testing
  - On-site geological investigations (multiple work packages)
  - ....

- Drilling at 2 sites in parallel
  - Management of each work package remains by Nagra
  - Detailed planning as basis for tender a requirement
  - Optimisation of the interaction of the individual teams critical (time, resources)

Borehole on-site geological investigations

Activities, flow diagram and interactions

Background colors indicate the different teams involved
Time-depth diagram (for planning/costing)
General schedule

Base data
- Nuclear power plants
  - NPP operation
  - Post-operational phase and NPP decommissioning

Waste: arising and interim storage
- L/ILW (operational and decommissioning waste)
- L/ILW (medicine, industry and research)
- Long-lived ILW (various)
- Long-lived ILW (medicine, industry and research)
- SF/HLW

HLW repository
- Site selection/general licence
- Preparation and start of underground investigations
- Continuation of underground investigations
- Nuclear construction licence
- Repository construction
- Nuclear operating licence
- Emplacement operations
- Monitoring phase
- Closure of main facility
- Closure of whole repository
- Long-term monitoring

L/ILW repository
- Site selection/general licence
- Preparation and start of underground investigations
- Continuation of underground investigations
- Nuclear construction licence
- Repository construction
- Nuclear operating licence
- Emplacement operations
- Monitoring phase
- Closure of main facility
- Closure of whole repository
- Long-term monitoring
thank you for your attention