Visit of Mont Terri rock laboratory
Swiss Association of Energy Geoscientists SASEG
22 June 2015

www.mont-terri.ch
swisstopo
<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:30</td>
<td>Arrival at the Mont Terri visitor’s centre, near railway station of St-Ursanne, Coffee &amp; Croissants</td>
</tr>
</tbody>
</table>
| 10:00  | Welcome  
- The Mont Terri Rock Laboratory: Worldclass research facility in the Opalinus Clay  
- Discussion                                      |
| 10:45  | Transfer from the visitor’s centre to rock lab by 3 minibusses  
Froidevaux, Reiser, Fridez                         |
| 11:00  | Visit of the Mont Terri rock laboratory (3 groups with 3 guides and 3 safety persons)  
Paul Bossart  
David Jaeggi  
André Lambert                                         |
| 12:00  | Transfer from the rock laboratory to St-Ursanne, Restaurant de la Couronne by 3 minibusses  
Froidevaux, Reiser, Fridez                           |
| 12:15  | Lunch at Restaurant de la Couronne  
SASEG                                               |
| 14:10  | Guided tour: St-Ursanne medieval city and monastery  
German and English Guides                           |
| 15:40  | Return to Baden, arrival Baden around 17:10  
SASEG                                               |
Location of Mont Terri rock laboratory
The Mont Terri Underground Rock Laboratory

Security Gallery

Motorway tunnel

2011
2012
2004
2003
1998
1996
Who is doing what?

**How?** Mont Terri rock laboratory

- **Operation:** swisstopo
- **Owner:** Canton Jura
- **Research:** 16 Partners

**Where?** Sectorial plan

- **Lead:** Federal Office of Energy
- **Proposition:** Nagra
- **Verification:** ENSI & KNS, referendum
Organisation, legal base

Convention 2009

Supervision
RCJ U
Commission de suivi

Operation
Swisstopo
Swiss Geological Survey

Research
ANDRA BGR CHEVRON CRIEPI
US DOE ENRESA ENSI FANC GRS
IRSN JAEA NAGRA NWMO
OBAYASHI SCK•CEN SWISSTOPO

Agreement 2001

Steering Committee
(1 Delegate per Partner)
Experiment Programme

Principal Investigator PI
(1 PI for each experiment)

President
Experts
Yearly authorization

Director
Project Manager
Engineer
Site Manager
Scientific Collaborator
Technician
Accounting, Web
Visitor’s Coordinator
Safety Person, Supervisor
# The Partners of the Mont Terri Consortium

<table>
<thead>
<tr>
<th>Logo</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="swisstopo" /></td>
<td>Swiss Geological Survey (Lead)</td>
</tr>
<tr>
<td><img src="image" alt="NAGRA" /></td>
<td>National Cooperative for the Disposal of Radioactive Waste</td>
</tr>
<tr>
<td><img src="image" alt="ENSI" /></td>
<td>Swiss Federal Nuclear Safety Inspectorate</td>
</tr>
<tr>
<td><img src="image" alt="ANDRA" /></td>
<td>Agence Nationale pour la Gestion des Déchets Radioactifs</td>
</tr>
<tr>
<td><img src="image" alt="IRSN" /></td>
<td>Institut de Protection et de Sûreté Nucléaire</td>
</tr>
<tr>
<td><img src="image" alt="BGR" /></td>
<td>Federal Institute for Geosciences and Natural Resources</td>
</tr>
<tr>
<td><img src="image" alt="GRS" /></td>
<td>Gesellschaft für Reaktorsicherheit und Strahlenschutz</td>
</tr>
<tr>
<td><img src="image" alt="ENRESA" /></td>
<td>Empresa Nacional de Residuos Radiactivos, S.A.</td>
</tr>
<tr>
<td><img src="image" alt="SCK•CEN" /></td>
<td>Studiecentrum voor Kernenergie, Mol</td>
</tr>
<tr>
<td><img src="image" alt="JAEA" /></td>
<td>Japan Nuclear Cycle Development Institute</td>
</tr>
<tr>
<td><img src="image" alt="OBAYASHI" /></td>
<td>Obayashi Corporation</td>
</tr>
<tr>
<td><img src="image" alt="CRIEPI" /></td>
<td>Central Research Institute of Electric Power Industry</td>
</tr>
<tr>
<td><img src="image" alt="NWMO" /></td>
<td>Nuclear Waste Management Organisation, Toronto</td>
</tr>
<tr>
<td><img src="image" alt="Chevron" /></td>
<td>Chevron Energy Technology Company, Houston</td>
</tr>
<tr>
<td><img src="image" alt="U.S. DOE" /></td>
<td>Department of Energy, Washington DC</td>
</tr>
</tbody>
</table>
### Sharing of knowledge …..

<table>
<thead>
<tr>
<th>Abbr.</th>
<th>Title of experiment</th>
<th>Phase 1 &amp; 2</th>
<th>Phase 3</th>
<th>Phase 4</th>
<th>Phase 5</th>
<th>Phase 6</th>
<th>Phase 7</th>
<th>Phase 8</th>
<th>Phase 9</th>
<th>Phase 10</th>
<th>Phase 11</th>
<th>Phase 12</th>
<th>Phase 13</th>
<th>Phase 14</th>
<th>Phase 15</th>
<th>Phase 16</th>
<th>Phase 17</th>
<th>Phase 18</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>96/97</td>
<td>97/98</td>
<td>98/99</td>
<td>99/00</td>
<td>00/01</td>
<td>01/02</td>
<td>02/03</td>
<td>03/04</td>
<td>04/05</td>
<td>05/06</td>
<td>06/07</td>
<td>07/08</td>
<td>08/09</td>
<td>09/10</td>
<td>10/11</td>
<td>11/12</td>
<td>12/13</td>
</tr>
<tr>
<td>FM-D</td>
<td>Evaporation logging</td>
<td>AJ AJ J</td>
<td>J</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>T</td>
<td>T</td>
<td>HT</td>
<td>HT</td>
<td>HT</td>
<td>HT</td>
<td>HT</td>
<td>HT</td>
<td>HT</td>
<td>HT</td>
</tr>
<tr>
<td>FP</td>
<td>Fracture propagation</td>
<td>AE AE AE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GD</td>
<td>Analysis of geochemical data</td>
<td></td>
<td></td>
<td></td>
<td>AEIN</td>
<td>ABEIJN</td>
<td>ABEIJN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GM</td>
<td>Geochemical modelling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GM-A*</td>
<td>Geophysical monitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP</td>
<td>Hydraulic and gas permeability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP-A</td>
<td>Hydraulic and gas permeability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP-B</td>
<td>Gas and water coupled processes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GR</td>
<td>Ground penetration radar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS</td>
<td>Gasfrac self-sealing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HA</td>
<td>Hydrogeologic analyses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HE</td>
<td>Heater experiment</td>
<td>AE AE AE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HE-B*</td>
<td>Heater experiment</td>
<td>BEGN BEGN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HE-C</td>
<td>Heater experiment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HE-D</td>
<td>THM behaviour of host rock (heater)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HE-E*</td>
<td>In-situ heater test in VE microtunnel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HE-S</td>
<td>Heater shaft maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HG-A</td>
<td>Gas path through host rock+along</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HG-B</td>
<td>In situ gas permeability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HG-C</td>
<td>Long-term gas migration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HG-D</td>
<td>Reactive gas transport in OPA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HM</td>
<td>Lab tests on HM coupled behaviour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HT</td>
<td>Hydrogen transfer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td>Iron corrosion in clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC-A</td>
<td>Iron corrosion of bentonite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS-A</td>
<td>In-situ stress (over/undercoring)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS-B</td>
<td>In-situ stress (borehole slotter)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS-C</td>
<td>In-situ stress (hydraulic fracturing)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS-D</td>
<td>In-situ stress (overcoring)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LP</td>
<td>Long-term monitoring pore pressures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT</td>
<td>Laboratory (temperature) testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT-A</td>
<td>Properties analyses labtesting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MA</td>
<td>Microbial activity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MB</td>
<td>Mine-by test Gallery 08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD</td>
<td>Cosmic myon density tomography</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Key

| A | ANDRA |
| B | BGR |
| D | U.S. DOE |
| C | CRIEPI |
| E | ENRESA |
| F | FOWG |
| G | GRS |
| H | ENSI (HSK) |
| I | IRSN |
| J | JAEA |
| N | NAGRA |
| W | NWMO |
| O | Obayashi |
| S | SCK•CEN |
| T | swisstopo |
| V | Chevron |
... and costs

1.1.1996 - 30.6.2015

73.5 Mio. CHF

20% remain in Canton of Jura
Paleo-Geography 175 My ago

Mont Terri

IAEA-Sandia Workshop
Mont Terri rock laboratory

Potential deep geological disposal sites
Tectonic evolution of Mont Terri anticline

From Caer et al., in prep
Balanced profile along Mont Terri tunnel

From Caer et al., in prep
Geological & tectonic map of rock laboratory
Why clay for deep geological disposal?

1 g of clay has a specific surface of about 100 m²

„Key-Results“

- High sorption capacity
- Very low hydraulic conductivity
- Molecular diffusion
- Self-sealing of fractures
Very low hydraulic conductivity

Matrix: $K_{\text{mean}}$: 4.6E-13 m/s

N = 93 measurements

Tectonic faults: $K_{\text{mean}}$: 7.6E-13 m/s

N = 58 measurements
Molecular diffusion

CLAYTRAC
Mazurek et al., 2007
Self-sealing of fractures

- Unloading fractures parallel to bedding
- Unloading fractures oblique to bedding

Transmissivity decreases with time

Transmissivity vs. elapsed time (after first saturation): log-log plot

- BEH-30
- BEH-32
- BEH-53
- BEH-62
- BEH-63
- BEH-64
- BEH-65
- BEH-66
- BEH-67
- BEH-68
- BEH-69
- BEH-70
- BEH-71

- Test 1
- Test 2
- Test 3
- Test 4
- Test 5
- Test 6
- Test 7/8
- Test 9
- Test 10

Transmissivity (m²/s)

$\Delta t$ (d): time since 1. saturation
Repository performance, key experiments

Disequilibrium. Thermo-Hydraulic-Mechanical-Chemical (THMC) Processes

Equilibrium

Construction  Emplacement  Backfill  Monitoring  Sealing

Oxidising conditions

Elevated temperatures
Surface of canister 130-150°C.

EDZ-self-sealing
Bentonite saturat.

Canister corrosion, formation of H₂

Canister failure

Release of radionuclides

1  10  100  1,000  10,000  100,000  1,000,000 (years)

Swiss disposal concept (Nagra)
Experiments & repository evolution

45 ongoing experiments

Experiments
- BN: Bitumen-nitrate-clay interaction
- CI: Cement-clay interaction
- CS: Near well sealing integrity for CO2 geological storage
- CS-A: Caprock integrity & CO2 leakage remediation
- CS-B: Caprock integrity & fracture remediation
- DB: Deep inclined borehole through the OPB
- DB-A: Porous characterization-Benchmarking
- DM-A: Long-term deformation measurement
- DR-A: Diffusion, retention and perturbations
- DR-B: Long-term diffusion
- EC: EDF gas dissolution by carbon isotope
- FE-B: THM part of full scale emplacement exp.
- FE-C/D: Emplacement LUCED (part of the Full-Scale Emplacement Experiment)
- FE-E: FE-C coupling isothermal Silicate Chemistry (interaction CSH-bentonite phases, Diffusion, Sorption, Competition
- FE-F: FE-C coupling isothermal Silicate Chemistry (interaction CSH-bentonite phases, Diffusion, Sorption, Competition
- FE-M: Long-term monitoring of the Full-Scale Emplacement Experiment
- FI: Fluid-mineral interactions in OPB during natural faulting and heating
- FM-D: Evaporation logging
- F5: Fault-slip hydro-mechanical characterization
- GD: Analysis of geothermal data
- G5: Hydrogeological analyses and synthesis
- HE-E: In-situ heater test in VE microstructural
- HG-A: Gas path host rock & seals
- HG-D: Reactive gas transport in Opalinus Clay
- HM: Experimental lab investig. on HM-coupled properties & behavior OPB
- HM-A: 3D numerical simulations of OPB
- HT: Hydrogen transfer
- IC: Iron corrosion of Opalinus Clay
- IC-A: Iron corrosion of iron in bentonite
- LP-A: Long-term monitoring of pore parameters
- LT-A: Properties analysis in lab tests
- MA: Microbial activity in Opalinus Clay
- MA-A: Modular platform for microbial studies
- MD: Density tomography with cosmic rays
- MH: Long-term monitoring of heaves
- MO: Preparation for technology for monitoring
- MO-A: Long-term and multi-scale monitoring using passive geophysical methods
- PS: Petrofabric and strain determination
- RA: Rock mechanics analyses
- SB-A: Borehole sealing experiment
- SM-B: High resolution seismic monitoring
- SM-C: Permanent nanoseismic monitoring
- SG: Sedimentology of Opalinus Clay
- SO-A: Polymyx of the Opalinus Clay
- VA: Investigation of spatial variability within OPB
- WS-I: Investigation of wet spots

Repository evolution

Safety relevant processes
- Canister emplacement
  - Swelling of the bentonite (SB-A)
  - Porewater pressure in NF increases (LP-A)
  - Tunnel convergence (DM-A, HM, HM-A, MH)
  - Self-sealing (CS-B)
  - Saturation of NF through pore water diffusing through liner
  - Chemical dissolution and precipitation processes

Chemical processes
- HA: Hydrogenation
- FM-D: Evaporation logging

Initial conditions

Degree of Saturation within the buffer
- 1: Construction (~1 y)
- 2: Emplacement (~10 y)
- 3: Post-closure transient (~100 y)
- 4: Post-closure equilibrium (~1'000 y)
- 5: Radionuclide transport (~10'000 y)
- 6: ~100'000 y
Construction, excavation damaged zone
Detection of EDZ fractures during mine-by test

Monitoring of the EDZ with active and passive geophysical methods: the EZ-G experiment

Ga04 face: 4-years old EDZ
Advancing Ga08 face: newly formed EDZ

ANDRA (GdR Forpro), swisstopo
Locations of micro-seismic events

- Simultaneous fracture formation
- Fractures bound to shaly facies
- Fault mechanisms: bedding parallel slip and extension joints

ANDRA (GdR Forpro), swisstopo

56'446 events detected
278 processed true events
- 11 July 2008 (191 events)
- 12 July 2008 (71 events)
- 13 July 2008 (16 events)

Le Gonidec et al., 2014
Emplacement: 1:1 demonstration experiment

NAGRA, ANDRA, BGR, DOE, NWMO
Iron corrosion....

Corrosion rate
0.6 – 2 µm/Jahr
nach 4.5 Jahren

No data

ANDRA, JAEA, NAGRA, NWMO
ANDRA, NAGRA, NWMO

...with formation of hydrogen

- on line $H_2$ sensor,
- on line Raman spectrometry
- gas sampling

End January 2013, a total quantity of about 0.15 moles $H_2$ has been injected

ANDRA, NAGRA, NWMO
Release of radionuclides

Diffusion and Retention Experiment

Applied tracers

- $^3$H
- $^{22}$Na
- $^{60}$Co
- $^{75}$Se
- $^{85}$Sr
- $^{133}$Ba
- $^{137}$Cs
- $^{152}$Eu

Parameters:
- Diffusion coefficients parallel and normal to bedding, $D_p$ & $D_n$
- Diffusion porosity $n_e$
- Sorption coefficient $K_d$

ANDRA, IRSN, JAEA, NAGRA, NWMO
CO$_2$ sequestration

CO$_2$ integrity experiments:

- **Borehole integrity**: are old cemented boreholes tight?
- **Fault integrity**: are tectonic faults hydraulic- and gas-tight?
- **Caprock integrity**: how does CO$_2$ migrate through undeformed caprock? What are the transport processes? Time scales?
Borehole integrity: the CS experiment

**Aim:** Measure the CO₂ flow inside and outside the casing -> *sealing changes*

**Concept:**
- Injected isotope-labelled CO₂
- Well permeability testing, sampling
- Overcoring, geochemical analyses

*CHEVRON, OBAYASHI, SWISSTOPO*
• **Result:** well permeability is pressure dependent. This pressure dependent permeability is largely reduced after CO2 injection.

• **Interpretation:** carbonation at interfaces?? Needs to be confirmed with the results of fluid composition changes and with characterization of mineralogical changes after the overcoring of the system.
Fault integrity: what are the tectonic fault elements?
slickenside in side-view shear zone of platy clay particles is only about 50 nm wide!

From Laurich et al., 2014
Fault integrity: Reactivation of main fault (FS experiment)

Objectives:

- Assess hydraulic leakage potential of tectonic fault in caprock
- Assess the risk of induced seismicity

Concept:

- Increase water pressure in different testing sections
- Monitoring of fault slip and induced seismicity
- Analyses: evolution of fault permeability, stress and strain tensors
## Fault integrity: Reactivation of main fault (FS experiment)

<table>
<thead>
<tr>
<th>Passive seismic monitoring:</th>
<th>Step-Rate Injection Method for Fracture In-Situ Properties (SIMFIP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 accelerometers and two geophones</td>
<td>Using a 3-components borehole deformation sensor</td>
</tr>
</tbody>
</table>
Pilot project Haute Sorne, GeoEnergie Suisse AG

Mont Terri rock laboratory

Haute Sorne
Planned borehole

2 surface mini-arrays

2 underground mini-arrays
Extension of rock laboratory (2018-2020)

B1 OPA, rectangular

B2 OPA + Staffelegg, rectangular

B3 OPA + Staffelegg, oblique

Construction costs  4.5-5.5 Mio CHF
Yearly maintenance costs  0.05- 0.1 Mio CHF
Conclusions

• The Mont Terri project is a scientific and technological platform for geological disposal of radwaste in argillaceous formations. And recently also experiments related to CO$_2$ storage projects have been started.

• 16 Partners from CH, EU, Japan, Canada and USA are participating under the lead of SWISSTOPO: ANDRA, BGR, CHEVRON, CRIEPI, DOE, ENRESA, ENSI, GRS, IRSN, JAEA, NAGRA, NWMO, OBAYASHI, SCK-CEN. Sharing of knowledge and costs.

• The Mont Terri rock laboratory is opened to “energy experiments” such as CO2 disposal (integrity experiments) and geothermal experiments (monitoring of seismicity during hydraulic stimulation). Extension of rock laboratory 2018-2020.
Thank you for your attention