ROAD P18-4 MONITORING PLAN

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OVERVIEW

- The ROAD project
- The P18 gas field
- The monitoring plan
  - Site characterisation
- The corrective measures plan
- Towards a stable situation
- Concluding remarks
THE ROAD PROJECT

- Rotterdam Opslag en Afvang Demonstratie – Rotterdam capture and storage demonstration
- E.ON Benelux, Electrabel & TAQA Energy, integrated CCS chain, 250 MW, post-combustion,
- Onshore capture, transport and off-shore, storage of ~1.1Mt of CO₂/year
P18-4 is a gas reservoir in clastic Triassic rocks at over 3 km depth, just offshore the Dutch coast.

One of three (four) compartments, faults of various generations.
Monitoring and Corrective measures plans are part of the an EU storage permit.

For ROAD the monitoring plan needs to comply with:
- Provisions in the EU CCS directive and implementation thereof in the Dutch Mining Act
- Requirements of the EU Emissions Trading System (EU ETS)
- Specific requirements to ROAD as a demonstration project

Under the EU Storage Directive a monitoring plan has to provide details about monitoring like:
- Parameters to be monitored
- Monitoring technology employed and justification for technology choice
- Monitoring locations and spatial sampling rationale
- Frequency of application and temporal sampling rationale
Comply with EU Storage Directive:
- Compare actual and modelled behaviour of CO\textsubscript{2} and brine
- Detection of significant irregularities
- Detection of CO\textsubscript{2} migration
- Detection of CO\textsubscript{2} leakage
- Detection of significant negative effects for environment, drinking water, nearby residents, the biosphere
- Evaluation of effectiveness of corrective measures
- Prove safety and integrity of the storage complex, including the assessment of complete and permanent storage
P18-4 MONITORING APPROACH – RISK BASED

- Risk-based monitoring plan
  - Ensures safety and integrity storage complex
  - Necessary information for transfer responsibility to government
  - Additional learning with respect to large-scale CCS
  - Prove effectiveness of corrective measures
  - Balance between efficiency and costs

- Consistency between:
  - Monitoring plan
  - Corrective measures plan
  - Other plans & assessments…
P18-4 – SITE CHARACTERISATION

- Geological modelling
- Dynamic flow modelling
- Geomechanical modelling
- Geochemical modelling
- Well investigations
- Migration studies
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P18-4 - SITE CHARACTERISATION

- Focus on reservoir integrity and behaviour
- Important unknown: sealing capacity of fault P18-4/P15-9

Lower Volpriehausen P15
Phi: 5% k: 0.1 mD

Hardegse P18
Phi: 12% k: 200 mD
P18-4 - SITE CHARACTERISATION

- The extensive site characterisation could not bring forward any show stoppers.

- It was concluded that the P18-4 reservoir is suitable for CO$_2$ storage.

- Some key factors:
  - Knowledge obtained during exploration and production indicates the a reservoir with a tight seal
  - The produced & under pressured reservoir will be brought back close to its original stable (hydrostatic) pressure
  - The reservoir held natural gas for millions of years, indirectly proving the quality of the storage site
P18-4 MONITORING PLAN

Designed to:

- verify CO\textsubscript{2} containment and reservoir integrity during operation
- to demonstrate long-term stability after the operational phase

This is achieved by:

- Measuring the absence of any leakage through direct detection methods (e.g. at the wells)
- Verifying indirectly that the CO\textsubscript{2} is behaving as expected through reservoir pressures

The current monitoring plan includes therefore collection of data such as:

- Pressure, composition, flow and temperature monitoring
- Well integrity monitoring (repeated) logging, measuring annuli pressures and checking of annuli fluids
- Time-lapse seismic surveys (contingency monitoring), in case of irregularities
- Monitoring of shallow overburden, to indicate absence of migration to the seabed
# P18-4 Monitoring Plan

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre-inj.</th>
<th>Injection</th>
<th>Post-inj.</th>
<th>Post-aban.</th>
<th>Post-transfer</th>
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<tbody>
<tr>
<td>Injection rate (flow meter)</td>
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<td>Well head p, T (pressure device, DTS)</td>
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<td>CO₂ composition (gas samples)</td>
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<tr>
<td>p, T reservoir (downhole device, DTS)</td>
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<tr>
<td>Stabilised p, T in reservoir (+ well shut-in)</td>
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<tr>
<td>Well integrity (logging)</td>
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<tr>
<td>Plug integrity (p test, inspection, fluid sample)</td>
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<tr>
<td>Sea-bed pock marks (echo sounding)</td>
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<tr>
<td>Pressure in adjacent reservoir (pressure device)</td>
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<tr>
<td>Seismic survey (overburden, sideburden)</td>
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<tr>
<td>Gas analysis at pock marks (gas samples)</td>
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</tbody>
</table>

**Monitoring type**

- Regular – mandatory
- Regular – required (prelim. estimate)
- Optional – contingency
MONITORING PHILOSOPHY – TRAFFIC LIGHT

Measured values have to match values predicted by models

- **Green**
  - Monitoring data fall within expected range
  - Monitoring frequency gradually decreased

- **Yellow**
  - Deviations in monitoring data – no corrective measures yet
  - Explain deviation & update models
  - Possibly additional measurements

- **Red**
  - Data outside pre-defined bandwidth
  - Take corrective measures
  - Scale up intensity of monitoring

Data bandwidths defined prior to start of injection
**P18-4 CORRECTIVE MEASURES PLAN**

The corrective measures plan defines the actions, measures or activities taken to correct significant irregularities and is like the monitoring plan, site specific.

- Communication with stake holders and reporting to authorities
- Additional monitoring like:
  - Monitoring in neighbouring wells
  - Seismic survey (e.g. when migration out of reservoir suggested by monitoring data)
- Adjust injection (pressure, rate)
- Large-scale intervention
  - In case of well damage
  - In case of problems on platform (venting procedures)
P18-4 LARGE SCALE INTERVENTION

In case of leakage into neighbouring gas field P15-9:

- Cease injection at P18-4, in case neighbouring gas field qualifies for CCS, continuation of injection after successful request for storage licence

- Well work overs
- Termination of injection
- Venting activities

Lower Volpriehausen P15
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Hardegsen P18
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P18-4 EVENTS VS. CORRECTIVE MEASURES

<table>
<thead>
<tr>
<th>Event</th>
<th>Corrective measure</th>
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<tbody>
<tr>
<td><strong>CO\textsubscript{2} outside complex</strong></td>
<td></td>
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<tr>
<td>To overburden</td>
<td>Additional well monitoring; repair cement job</td>
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<tr>
<td>From well to biosphere</td>
<td>Additional well monitoring; repair cement job</td>
</tr>
<tr>
<td>From reservoir to biosphere</td>
<td>Additional monitoring; cease injection</td>
</tr>
<tr>
<td>To adjacent gas field</td>
<td>Monitoring adjacent field; fix wells in adjacent field</td>
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<tr>
<td><strong>Induced seismic activity</strong></td>
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<tr>
<td>Re-activated fault(s)</td>
<td>Additional monitoring; cease injection</td>
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<tr>
<td><strong>Failure / Damage</strong></td>
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<tr>
<td>Well damage</td>
<td>Repair well</td>
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<tr>
<td>Cap rock, reservoir damage</td>
<td>Additional monitoring; cease injection</td>
</tr>
<tr>
<td><strong>Monitoring</strong></td>
<td></td>
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<tr>
<td>Technical failure monitoring system</td>
<td>Cease injection; adjust monitoring</td>
</tr>
<tr>
<td>Conceptual failure monitoring system</td>
<td>Cease injection; adjust monitoring</td>
</tr>
<tr>
<td><strong>Entire system behaves differently</strong></td>
<td></td>
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<tr>
<td>Limited injection rate capacity</td>
<td>Adjust p, T; adjust monitoring</td>
</tr>
<tr>
<td>Unpredicted behaviour in well or reservoir</td>
<td>Cease injection; adjust p, T; adjust monitoring</td>
</tr>
</tbody>
</table>
TOWARDS A STABLE SITUATION

- Prediction of post injection pressures
- Indicate well integrity
- Assure complete/permanent storage of CO₂

According to regulations, we need:
- All available data to suggest complete and permanent storage
- Show that for a certain period since end of injection
  - E.g. 20 years, that storage is complete and permanent, but may be shorter if Competent Authorities are convinced
- Plug and abandone wells, removed injection facilities, etc.
CONCLUDING REMARKS

ROAD monitoring and corrective measures plans addresses the requirements of the EU CCS directive in a relatively simple and straightforward approach.

Compact monitoring plan is mainly possible due to the site being a depleted gas field:
- Large body of knowledge and experience available
- Proven seal, limited monitoring effort needed to verify containment

Traffic light model to describe site conformance – flexible and adjustable when new data and models become available.

Final version of monitoring plan after detailed site design completed.
THANK YOU FOR YOUR ATTENTION

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Take a look:
TIME.TNO.NL