Risk assessment of a CO2 storage site and risk-driven decision process

Laurent Jammes, Jean Desroches, Natalia Quisel (SCHLUMBERGER)
NQuisel@slb.com, jammes1@slb.com
Bruno Gérard (OXAND)
bruno.gerard@oxand.com

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Outline

• Background: CO2 storage site life
• Why, What and How
• A risk driven decision process
• Concluding remarks
CO2 Storage Workflow

Pre-Operation Phase
- ~ 1-2 years
  - Site Selection
  - Site Characterization (SCP)
  - Field Design

Operation Phase
- ~ 10-50 years
  - Site Construction
  - Site Preparation
  - Injection
  - Monitoring (M&V)
    - Operation
    - Verification

Post-Injection Phase
- ~ 100+ years
  - Site Retirement Programme (SRP)
  - Environmental

Performance & Risk Management System (PRSM)
Communication and Public Acceptance
Why? Safety control

Concerns:
- Certification and permitting process
- Cost-effective risk treatment

Particular focus on:
- Sealing integrity with time
- Risk mitigation planning

<table>
<thead>
<tr>
<th>Time</th>
<th>Pre-Operation Phase</th>
<th>Operation Phase</th>
<th>Post-Injection Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>~ 1-2 year</td>
<td>Certification at start</td>
<td>~ 10-50 years</td>
<td>Transfer of Liabilities ~ 100-1000 years</td>
</tr>
</tbody>
</table>
What? Risk-driven decision process

Goal: containment
Risk: leakage (well, reservoir)

Storage system
- Uncertainties
- Material degradation

Performance Assessment of storage system
(assess the risk of insufficient containment)

Selection of action for best risk mitigation (best cost/benefit)

Decision Support
Decision
How? Risk Assessment Workflow

- Exhaustive inventory of features and potential hazards
- Identify, quantify failure mechanisms
- Construction, quantification of leakage scenarios
- Risk ranking and performance evaluation
- Risk-based decision support

Exhaustive inventory of features and potential hazards

Knowledge Data & Models Uncertainties

(from Damen et al, 2003)

C/B = 20

B = 10
System components
Well Integrity Characterization

Identify, quantify failure mechanisms

**Sonic**
- Low Attenuation
- High Attenuation

**Ultrasonic**
- Cement Bond
- Cement / Corrosion

**Multi-finger Caliper**
- Corrosion

**Electromagnetic**
- Corrosion
Well Integrity changes with time

Response of wells to injection/production operation

- Micro-annulus
- Fractures in the cement sheath
Modeling Degradation and CO$_2$ Transport

Cement behavior
- Cement leaching
- Physico-mechanical coupling
- Initial state

Steel behavior
- Steel corrosion
- Steel stability

Cap rock and Reservoir
- Transport phenomena (advection + diffusion)
- Gas migration
- Porosity, capillary pressure

Identify, quantify failure mechanisms
For each failure scenario:

- Abandonment Plug 1
- Production casing
- Cement annulus 1
- Fluid 1
- Second Casing
- Aquifer
- Reservoir with CO2
- Surface
- Abandonment Plug 2

Construction, quantification of leakage scenarios

Estimation of Leakage Rates

Estimation of Leakage Rates
# Multi-Risk Integration

## Consequence Grid

<table>
<thead>
<tr>
<th>Level</th>
<th>Stakes</th>
<th>Financial</th>
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<tbody>
<tr>
<td>1: Minor</td>
<td>&gt; 500 M$</td>
<td>&lt; 1 day</td>
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<tr>
<td>2: Low</td>
<td></td>
<td></td>
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<tr>
<td>3: Serious</td>
<td>1 - 5 M$</td>
<td>&gt; 2 days</td>
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<tr>
<td>4: Major</td>
<td></td>
<td></td>
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<tr>
<td>5: Critical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6: Extreme</td>
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</tbody>
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<tr>
<th></th>
<th>A Injection stops</th>
<th>B Government</th>
<th>C SAFETY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>People</td>
<td>Pollution</td>
<td>Environment</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
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<td>2</td>
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- **F Financial**
  - 1 - 5 M$:
    - 1 poisoned person
  - > 500 M$:
    - Temporary exceeding of regulation threshold (> 0.038% CO₂ in volume)
  - < 1 day:
    - 5% < market share lost

- **A Injection stops**
  - > 2 days

- **B Government**
  - People
  - Pollution
  - Environment

- **C SAFETY**
  - 1 poisoned person
  - Temporary exceeding of regulation threshold (> 0.038% CO₂ in volume)
  - 5% < market share lost
Risk Mapping as a decision support

Objectives:
- Rank failure scenarios
- Eliminate critical scenarios
- Choose solutions for best risk mitigation

Number of failure scenarios:
- Scenario A: 8, 10, 12
- Scenario B: 5, 2

Criticity:
- Minor
- Weak
- Middle
- High
- Critical
Action Selection – A Guide to Decision

Solution 1: Monitoring
Cost: 200

Solution 2: Thicken plug Squeeze
Cost: 600

Solution 3: Change plug position Improve cement Surface monitoring
Cost: 300

C/B = 20
C/B = 12
C/B = 10
Decision – Well Construction Technologies

- Optimum positioning of wells to minimize exposure to CO$_2$
  - Horizontal wells to maximize injection rate
- No formation damage while drilling
- Injection Well Completion
  - CO$_2$-Resistant cement
  - Casing & Completion metallurgy / protection
Decision – Well Abandonment / Work over

Plug design
Material
Placement
Monitoring

Squeeze Jobs
Placement of a special material to seal long and thin discontinuities

CO2-Resistant Materials
Decision – Well Integrity Monitoring

- Rock
- Cement
- Casing

- Rock
- Cement
- Casing

- Channeling
- Debonding steel/cement interface
- Corrosion

The 3D UCI images depict severe exterior corrosion in the outside of the casing wall.

The hole in the casing shown above is clearly visible in the amplitude image in the UCI log.
Summary

• **Decision** methodology for action selection based on risk assessment for risk mitigation

• **Knowledge and best practices**: expertise to provide fit for purpose solutions

• **Integrated approach**: could play a key contribution to establishing standards for CO₂ storage containment