Gericco: a risk management knowledge base
Thomas Le Guénan
Introduction

> Risk management according to ISO 31000

In CO2 geological storage, more emphasis is needed in the risk treatment part
Risk treatment in the European directive

> A “corrective measure” plan must be submitted as part of the permit application
  • ‘corrective measures’ means any measures taken to correct significant irregularities or to close leakages in order to prevent or stop the release of CO2 from the storage complex;

> Description of measures “to prevent significant irregularities” is expected too

> Environmental liability directive (2004-35-CE)
  • In case of imminent threat of environmental damage: preventive actions
  • In case of environmental damage: remedial actions

> In addition to the requirement of the EIA directive where the general objective is to control the expected impact on the environment

> That is a lot of different risk treatment measures to manage
Corrective measure plans

> The corrective measure plan in the CCS directive guidelines

<table>
<thead>
<tr>
<th>Risk the measure is related to</th>
<th>Irregularity this measure is related to</th>
<th>Corrective measure</th>
<th>No. of corrective measure</th>
<th>Monitoring method(s)</th>
<th>No. of monitoring method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comment: Please state the risk(s) as identified in the risk assessment</td>
<td>Comment: Please state the threshold values or qualitative conditions which will trigger this corrective measure</td>
<td></td>
<td></td>
<td>Comment: Please state name and number of the monitoring method(s) used to monitor the effectiveness of the corrective measure, as stated in Table 1</td>
<td></td>
</tr>
<tr>
<td>Measure A</td>
<td>No. 1</td>
<td>Method D</td>
<td>No. 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measure B</td>
<td>No. 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

> With the upcoming NER300 funding of several large-scale demonstration plant, people will actually need to fill this table

> We see a large discrepancy between the amount of work required to do this and the amount of related literature that has been published
Previous work

> Existing work in the field of mitigation measures: IPCC 2005 is still the most cited reference

Table 5.7. Remediation options for geological CO$_2$ storage projects (after Benson and Happe, 2005).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Remediation options</th>
</tr>
</thead>
</table>
| Leakage up faults, fractures and spill points | • Lower injection pressure by injecting at a lower rate or through more wells (Buschbach and Bond, 1974);  
• Lower reservoir pressure by removing water or other fluids from the storage structure;  
• Intersect the leakage with extraction wells in the vicinity of the leak;  
• Create a hydraulic barrier by increasing the reservoir pressure upstream of the leak;  
• Lower the reservoir pressure by creating a pathway to access new compartments in the storage reservoir;  
• Stop injection to stabilize the project;  
• Stop injection, produce the CO$_2$ from the storage reservoir and reinject it back into a more suitable storage structure. |

A simple table is not satisfying: we need more information and more “completeness”
The BGS / IEAGHG Monitoring tool

The monitoring tool on IEAGHG website is more than a monitoring technique list:
3D surface seismic

Overview

3D surface seismic is a sophisticated deep echo-sounding technique utilizing multiple seismic sources and receivers to produce full volumetric images of subsurface structure in both reservoir and overburden. A key application of surface seismic for monitoring purposes is in time-lapse (4D) mode, in which a number of repeat surveys are acquired, enabling changes in fluid distribution to be mapped through time.

Full Description

3D surface seismic is a sophisticated deep echo-sounding technique utilizing multiple seismic sources and receivers to produce full volumetric images of subsurface structure in both reservoir and overburden. Under favourable circumstances these can offer spatial resolution down to a few metres or less. It offers the most effective general-purpose means of imaging CO₂ in the subsurface and can be acquired both on land and at sea. However, it is generally cheaper and easier to acquire offshore and the results are often superior.

Offshore seismic vessel with multiple streamer array and an illustrative seismic cube. The seismic cube is part of the 3D seismic dataset from Sleipner. Its front left hand corner intersects the CO₂ plume, imaged as a number of bright sub-horizontal reflections (Courtesy of Veritas, Statoil and the SACS/CO₂-store projects).

A key application of surface seismic methods for monitoring purposes is in time-lapse (4D) mode, in which a number of repeat surveys are acquired, enabling changes in fluid distribution to be mapped through time. This has been used successfully in the oil industry to image fluid changes in hydrocarbon reservoirs for a number of years.
The BGS / IEAGHG Monitoring tool

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Case Studies

Sleipner

The CO2 plume at Sleipner (Arts et al., 2004; Chadwick et al., 2005) is being monitored by time-lapse 4D seismic methods. Time-lapse 3D (4D) seismic data were acquired in 1995, 2001, and 2002, with respectively, 2.05, 4.26, and 4.97 million tonnes of CO2 in the reservoir. The CO2 plume is imaged as a number of bright sub-horizontal reflections, growing with time. The reflections are interpreted as arising from thin (< 0.6 m thick) layers of CO2 trapped beneath thin intra-reservoir mudstones and the reservoir caprock. The plume is roughly 300 m high and elliptical in plan, with a major axis increasing from about 1560 m in 1995 to about 2000 m in 2001. The plume is underlain by a prominent velocity pushdown (a downward relative displacement of reflectors) caused by the seismic waves travelling much more slowly through CO2-saturated rock than through the virgin aquifer.

Summary diagram showing the Sleipner injection operation and the 4D seismic monitoring results (not to scale: water depth is ~80 m, reservoir depth is ~600 m) (Datasets courtesy of EAGE/CO2STORE).

The CO2 plume at Sleipner (Arts et al., 2004; Chadwick et al., 2005) is being monitored by time-lapse 4D seismic methods. Time-lapse 3D (4D) seismic data were acquired in 1995, 2001, and 2002, with respectively, 2.05, 4.26, and 4.97 million tonnes of CO2 in the reservoir. The CO2 plume is imaged as a number of bright sub-horizontal reflections, growing with time. The reflections are interpreted as arising from thin (< 0.6 m thick) layers of CO2 trapped beneath thin intra-reservoir mudstones and the reservoir caprock. The plume is roughly 300 m high and elliptical in plan, with a major axis increasing from about 1560 m in 1995 to about 2000 m in 2001. The plume is underlain by a prominent velocity pushdown (a downward relative displacement of reflectors) caused by the seismic waves travelling much more slowly through CO2-saturated rock than through the virgin aquifer.
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Bibliography/References/Links


The BGS / IEAGHG Monitoring tool

> **Knowledge base**
  - List of techniques
  - Description and references
  - Elements of costs and applicability

> **Decision Support Tool**
  - Ranking of techniques according to the scenario

> **Communication Tool**
  - Really easy and convenient to give the link when asked about monitoring techniques

GERICO initial ambition was to be an equivalent tool for risk treatment measures
Conception of the knowledge base

- Risk mitigation measures are ordered according to causes and consequences of a top event (~ decision support)
- Starting point: the 11 generic central events identified by the ANR funded project CRISCO2 were modified and developed into bow-tie trees by internal BRGM experts meeting
- Initial approach: representation of an initial deviation from a base case scenario

> The bow-tie tree allows the identification of various risk treatment measures in a risk-related way
Evolution of the central events

> The 11 old central events
1. Leakage via an operational well
2. Local over-pressurisation around the injection well
3. Regional over-pressurisation
4. Expected lateral extent exceeded
5. Leakage due to sealing deficiency of the cap rock
6. Leakage via existing faults
7. Leakage via an abandoned well
8. Accumulation in a secondary reservoir in the near surface following unexpected vertical migration
9. Vertical flow modified due to pressure changes
10. Future well
11. Earthquake-induced fracturing

> The 11 new central events
1. Leakage via well in operation
2. Mechanical disruption around the injection well
3. Mechanical disruption at the storage complex scale
4. Exceedence of the expected lateral extent
5. Leakage due to sealing deficiency of the caprock
6. Leakage via
7. Leakage via an abandoned well
8. Secondary accumulation
9. Flow modifications
10. Disruption by a future activity
11. Earthquake-induced fracturing
Exemple of a developed (generic) event

- Regular re-evaluation of the well integrity
- Use of research results and previous case studies
- Inadequacy in the estimation of the well integrity in the short and long terms
- Ignorance of the presence of abandoned well
- Presence of an unexpected leakage pathway
- Expected lateral extent exceeded
- Mechanical disruption at the storage complex scale
- Disruption by a natural earthquake
- Resulting fracturing
- Accumulation in a secondary reservoir
- Impacts on vulnerable elements
- Leakage via an abandoned well (Internal or external loss of integrity)
- Producing and re-inject CO2
- Enhancement of CO2 trapping
- Hydraulic barrier
- Modify injection scheme
- Purification of CO2 stream
- Overpressure reduction
- Remediation measures
- Re-abandonment
Other diagrams were needed as risk reduction measures for the base case could not be placed.

- Presence of abandoned wells in the selected site
- Loss of integrity with time
- Resulting fracturing
- Presence of a leakage pathway
- 7. Leakage via an abandoned well (Internal or external loss of integrity)
  - CO$_2$
  - Impurities
  - Brine
- 3. Mechanical disruption at the storage complex scale
- 11. Disruption by a natural earthquake
**GERICO at the moment**

> **A knowledge base with data on the developed events and associated measures**

<table>
<thead>
<tr>
<th>Episodes</th>
<th>Fracturation induite</th>
<th>Paramètres intrinsèques au site peu favorables</th>
<th>Conception de l’injection non adaptée</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description de l’épisode</td>
<td>Création de fractures sous l’effet d’une contrainte externe. Dans un cas majorant, ces fractures peuvent devenir des conduits préférentiels pour une migration ou une fuite de CO2.</td>
<td>Les paramètres intrinsèques au site ayant le plus d’influence sur l’étendue de la bulle sont : la profondeur (condition de pression et de température), la salinité de la saumure (influence sur la dissolution), l’épaisseur du réservoir, la structure du toit du réservoir, la porosité, les perméabilités relatives du CO2 et de la saumure et son anisotropie, les hétérogénéités rencontrées lors de la migration verticale et de la migration horizontale (couches argileuses, failles, réseaux de fractures, présence de chenaux, etc.)</td>
<td>Les paramètres que contrôlent l’opérateur, ayant une influence sur l’étendue prévue du panache sont : la quantité de CO2 injecté, sa température et pression d’injection, la configuration du puits (vertical ou horizontal, et longueur perforée), le nombre de puits</td>
</tr>
</tbody>
</table>

| Bibliographie associée | Chadwick2009 - latest time-lapse seismic data from Sleipner yield new insights into CO2 plume development; Eiken2011 - Lessons Learned from 14 years of CCS operations; Durucan2011 - CO2 plume extension; SPE-134891-MS-P | BRGM RP-56963-FR_Modélisation scénarios de risque.pdf |
GERICO at the moment

> An Access interface for internal data management
The “happy accidents”

> Its scope is broader than initially intended
  • The key is the description of the measure, and the references: it could be a place where best practices, guidelines could be mentioned
  • Exemples: evaluation of well integrity, investigation of potential unknown abandoned well, etc.

> When complete, it will give a quick snapshot of the « state of the art » and could help in defining future research topics
Work in progress

> The structure of the base has been defined

> Need more work on the content (references)

> Integration of remediation techniques by expanding the « impact » black boxes

> Once a 1.0 version is completed, the base should go online ASAP
  • In French and in English

> We need to think of a mean to make it as « user friendly » as possible

> A way to make external contribution (and peer-review) possible would be a great feature too
The it-would-be-so-great-to-have-but-we-are-really-busy-right-now Fantasy

> A link between this risk management knowledge base and monitoring techniques would be great

> Possibly using the existing BGS/IEAGHG monitoring tool?
Conclusions

> Instead of a simple list of all mitigation measures, GERICO provides measures associated with particular generic risk events

> With description fields and references for each measures, it is a knowledge base useful for operators and authorities preparing risk management plans

> It will be a promotion / communication tool for mitigation techniques in the CO2 storage field
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