SECURe
Subsurface Evaluation of CCS and Unconventional Risks

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GOOD PRACTICE AND RISK MITIGATION FACTSHEET #4

Carbon capture and storage:

Induced/triggered seismicity or aseismic earth movement associated with CO_2 injection

SECURe employed the Bow Tie risk assessment approach, which identifies a series of barriers that prevent a principal hazard ("top event") from occurring. This factsheet outlines recommendations, which address a single top event that can occur if control of a hazard is lost: induced/triggered seismicity or aseismic earth movement associated with carbon dioxide (CO_2) injection. It should be read in conjunction with the Participatory Monitoring Factsheet, which provides overall guidance on project construction.

The issue

Although unlikely, the potential for induced or triggered seismicity and aseismic earth movements must be fully assessed in most CO_2 storage projects. Such processes could result in nuisance seismicity, damage to buildings and local infrastructure, or triggered seismic events. These may require CO_2 injection to cease, with consequent economic impacts and long-term environmental impacts. For such a hazard to occur requires an increase in pore pressure above site-specific thresholds, which may lead to microseismicity. If critically pre-stressed faults are present, seismic events may be triggered.

A range of site engineering assessments, operational strategies and monitoring provides effective barriers to prevent seismicity. These barriers, and preventive and remedial actions, are discussed in detail in SECURe report BGS-01-R-12.

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For more information about the project, contact info@securegeoenergy.eu

Risk mitigation recommendations

Monitoring approach

- **A closed loop of seismic monitoring.** We consider (near) real-time data assimilation and model updating as crucial for a robust estimation and update of seismic risks during injection operations D2.6.

Establish baseline environmental conditions

- It is fundamental to **establish the baseline level of natural seismicity through a baseline monitoring campaign before the onset of subsurface activities** in the area of operation. It is important to obtain continuous or repeated observations of a situation to detect changes that may occur over time (D3.2, D4.2). During operations, a local network should be deployed for monitoring and mitigation purposes (D4.2). If a Traffic Light System is used as a mitigation tool, it is important that the monitoring network has a detection level below the acceptable level of microseismicty as determined by the regulators. The available information related to seismicity and tectonic activities should be collected and analysed: in situ stress regime in combination with the geomechanical modelling to assess the maximum (CO_2) injection pressure limits. In cases where a baseline has not been obtained pre-operation, an undisturbed baseline can be measured in similar geology under a similar tectonic regime and compared to the seismicity measured at the active operation site.
    - Determine the acceptable level of microseismicity in the location of interest. This decision rests on both scientific knowledge (e.g. understanding of local risk, local geological conditions, presence of faults, subsurface stress regime, shallow geological conditions) and regulatory and societal considerations (e.g. site safety, avoidance of public nuisance, optimising operational parameters).
    - Perform a site survey to establish the signal-to-noise conditions and calculate the required network density and configuration to obtain the desired detection level. The detection level is key to be able to mitigate before the acceptable level of microseismicity is exceeded (D4.2).
    - Decide the level of network redundancy in the event of one or more seismograph stations failing. It is also important to decide the level of network maintenance and data analysis.
- Microseismic activity near a production site can act as a state-of-health indicator for the subsurface, where a rising level of microseismic activity can be a sign of stress perturbations or pore pressure changes. It is important to emphasise that seismic monitoring cannot serve as the sole monitoring technology. It should be part of a larger monitoring plan encompassing other geophysical, geological and geochemical technologies.

Risk mitigation recommendations (cont.)

Use of models

- Seismicity forecasts depend on a large number of input parameters, most of which are poorly constrained before the start of the operations (e.g. details on the specifics of the network used for seismic monitoring, observed background seismicity, total fault area and seismicity recorded during the injection operations)(D2.6).
- Rate-and-state seismicity theory, to assess changes in seismicity rates based on Coulomb stressing rates rather than on Coulomb stress changes, should be considered to forecast evolution of seismicity. This is in terms of frequency-magnitude distribution of events associated with injection of fluids in a reservoir (as described in D2.6). **High stressing injection rates and seismicity rates in seismic management strategies should be considered.** They may be associated with the "passage" of the thermal front (e.g. due to injection of cold CO_2) through fault planes and will affect seismic risks.
- We recommend incorporating statistical modelling in corrective measure plans, relying on observations. However, large uncertainties and complex causal relations need to be taken into account (D2.6).
- **The use of predictive model frameworks** (validated against observed data) **can optimise injection strategies** to allow maximisation of injection volumes and minimised induced seismicity (D5.6). Additionally, injection operations and mitigation measures for induced seismicity greatly benefit from optimisation of spatio-temporal injection strategies as **seismic risks can be reduced under continuing injection operations.**

Development of technology

- **Acoustic emission (AE) mostly arises due to reactivation of small faults** (D5.1), critically stressed and favourably oriented as the pressure plume from the injected CO_2 passes through the fault. The assumed mechanism that generates AE is an increase in pore pressure, with shear stress leading to sliding on a critically oriented fault. This is also possible to investigate in the laboratory, provided the in-situ stress state can be approximated by biaxial conditions, or where a triaxial cell with pore-pressure control is available. Examination of the energy distribution, together with triangulation to localise the origin of the emission, may be an indicator of the reactivation of sub-seismic faults.
- **Laboratory experiments**, if possible on relevant field cores, can be used **to understand the propagation of microseismicity in the subsurface**, primarily in calibration of models for the area considered (D5.2). These can shed light on the localisation of AE sources. This can correct any early interpretation of underground events leading to microseismicity occurrence and suggest corrective action, such as injection rate reduction, or even suspension of injection.

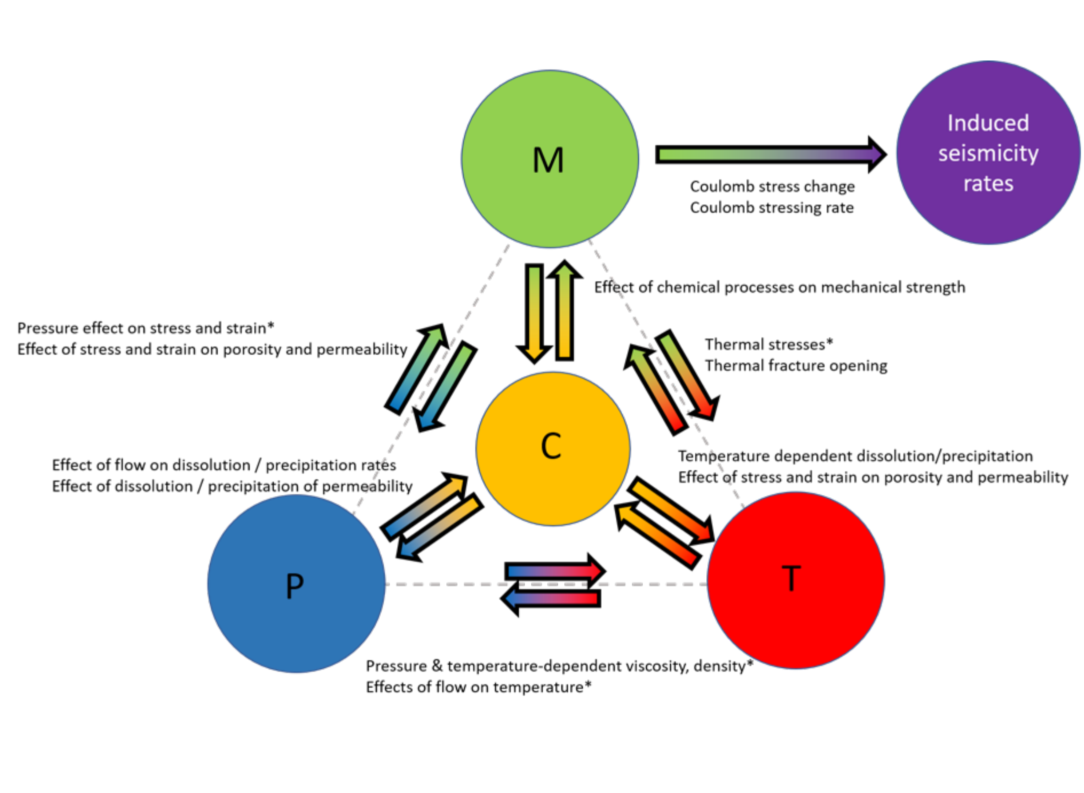

Figure 1: Schematic presentation of the interaction and coupling between processes that can play a role during fluid (e.g. CO_2, water) injection. M: mechanics, T: thermal, H: hydraulic, C: chemical processes. Processes that are expected to be dominant for injection into a depleted sandstone reservoirs have been marked with an asterisk. Though chemical processes can be part of the analysis, in the present SECURe project the interaction of chemical processes with flow and mechanics has not been taken into account.

Seismometer installation in the field to monitor for earthquakes. This is an important part of establishing natural baseline conditions and can identify impacts of human activity in the subsurface. Credit: BGS © UKRI