GOOD PRACTICE AND RISK MITIGATION
FACTSHEET #9

Unconventional hydrocarbons exploration:

Induced/triggered seismicity or aseismic earth movement associated with hydraulic fracturing

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 hydraulic fracturing. It should be read in conjunction with the Participatory Monitoring Factsheet, which provides overall guidance on project construction.

The issue

The potential for induced or triggered seismicity and aseismic earth movements must be fully assessed for unconventional hydrocarbons extraction (UHE) projects. Such processes could result in nuisance seismicity, damage to buildings and local infrastructure, and triggered seismic events. These may require injection to be halted, 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 post-hydraulic fracturing. If critically pre-stressed faults are present, seismic events may be triggered. A range of site engineering assessments, operational strategies and monitoring provide effective barriers to prevent seismicity. These barriers, and preventive and remedial actions, are discussed in detail in SECURe report BGS-01-R-11.

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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, which may occur over time (D3.2). 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 microseismicity as determined by the authorities:
    - 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 political considerations (e.g. site safety, avoidance of public nuisance, optimising operational parameters)(D4.2);
    - 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;
    - 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.
- 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.

Use of models

- **Rapid semi-analytical modelling to help address uncertainties**: this should be used in a closed-loop approach, where computationally intensive models are difficult to use (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 the evolution of seismicity, in terms of frequency-magnitude distribution of events associated with the injection of fluids in a reservoir (D2.6).
- Statistical modelling should be included in "traffic light systems" 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.**

Risk mitigation recommendations (cont.)

Development of technology

- Based on the results of **laboratory acoustic emission (AE) tests** in D5.2, we recommend that **some mitigation strategies for seismicity be tested at larger scale**. One could, for example, closely monitor precursors to hydraulic fracturing with downhole acoustic sensors, such as DAS cables, when the well pressure is slowly increased; this supposes that some shear deformation occurs around the borehole, due to rock heterogeneity and completion geometry (presence of cement sheath and perforations). If initial microcracking is recorded, one could simply hold the well pressure at this constant level or, alternatively, cycle it up and down from or around this value to induce fatigue and stress corrosion. Once an initial fracture is thus obtained, it is speculated that reopening and further propagation could be obtained at lower well pressure and with less acoustic energy release.
- **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 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.

Image 1: 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