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Drafting a monitoring plan for the ROAD project under the EU CCS Directive

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Abstract

The Rotterdam Capture and Storage Demonstration Project (ROAD) is an integrated CCS project in the Netherlands that has recently completed the storage permitting process. Development of the monitoring and contingency plans is a key component of this process. Our paper discusses the development of the monitoring and contingency plans, The project is technically relatively simple in comparison to other CO_2 storage projects, with a single well penetrating the reservoir and minimum equipment installed on the platform offshore. In spite of this, a most thorough approach to monitoring will be adopted. As new techniques and equipment are developed, these will be included whenever judged appropriate and in addition, provided that these techniques do not add to the complexity associated with operating an offshore, unmanned installation that will be producing hydrocarbons continuously throughout much of the project timeline. Overall, the ROAD traffic light approach promotes transparency and provides the flexibility to adjust the monitoring plan based on data and modelling results becoming available as the project progresses. The philosophy relies on consistency of the monitoring plan and contingency plans with the risk management and closure plans as well as on regular communication with the Competent Authority and stakeholders at every stage of the project.

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Keywords: CO_2 storage; storage permit; EU CCS Directive; monitoring plan; corrective measures plan.

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1. Introduction

The ROAD project is an integrated CCS chain project. The project was initiated by Dutch energy producers E.ON Benelux and Electrabel (GdF Suez Group). The target of the project is to capture 1.1 Mt of CO_2 per year from flue gases originating from a new coal-fired power plant near Rotterdam in the Netherlands. The captured CO_2 will be transported through a pipeline to an off-shore platform, where the CO_2 will be injected into a pressure depleted natural gas field (P18-4). The gas reservoir is situated at a depth of approximately 3500 m. The reservoir rocks are clastic sandstones, overlain by a seal that is composed of siltstones, claystones, evaporites, and duotones [1]. The permitting process for the ROAD project is described in [2]. A preliminary risk management, monitoring, and contingency plan had to be submitted as part of the storage license application [3]. A brief overview of the storage aspect of the ROAD project can be found in this volume [4].

The project is technically relatively simple in comparison to other CO_2 storage projects, with a single well penetrating the reservoir and minimum equipment installed on the platform offshore. In spite of this, a most thorough approach to monitoring will be adopted. As new techniques and equipment are developed these will be included whenever judged appropriate and in addition, provided that these techniques do not add to the complexity associated with operating an offshore, unmanned installation that will be producing hydrocarbons continuously throughout much of the project timeline. An updated version of the monitoring plan will be submitted before injection begins. The monitoring and contingency plans are parts of a set of related plans that are part of the storage permit [3, 5]. A location specific risk assessment is the main input for the corrective measures and closure plans. The development of the monitoring plan is also based on a location specific risk analysis and has strong links with the corrective measures plan. Figure 1 illustrates the links and the consistency between the plans.

Throughout the process of developing the documents for the storage permit application, there has been frequent contact with the competent authorities. This has helped to develop, on the side of the operator, as well as on that of the authorities, the understanding of the risks associated with storing CO_2 in P18-4. Moreover, the frequent meetings helped both parties to understand how to, and to what depth of detail, address all issues covered in the EU Storage Directive. The application for storing CO_2 in P18-4 was the first to be undertaken in The Netherlands, and the frequent contacts during the permit application preparation period helped shape the process for both operator and authority and provided clarification for elements of the Directive that are left open-ended [2, 7].

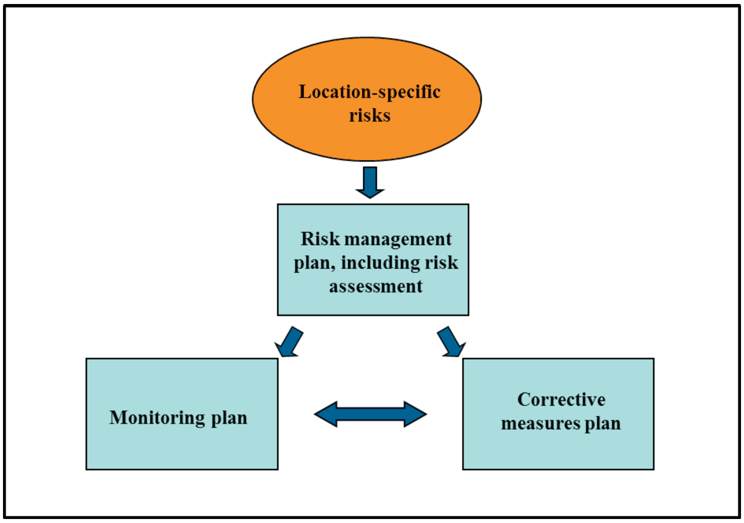

Fig. 1. Consistency between risk management, monitoring an corrective measures plans.

This paper is organized as follows. We will first give a summary of the monitoring approach with a focus on the various considerations that follow from the site characterization and risk assessment. We will then discuss how the monitoring plan is structured and give a description of the different categories of monitoring and the monitoring requirements for the different project phases. Following our review of the monitoring plan, we will describe the main components of the corrective measures plan, emphasizing the links and consistency with the monitoring plan.

2. Site specific aspects of the adopted monitoring approach

The adopted monitoring approach for CO_2 storage in the depleted gas field P18-4, one of three separate reservoirs (P18-2, P18-4 and P18-6) drilled from the P18-A platform, builds on the results of the site characterization and the risk assessment [1, 3, 5]. The three reservoirs have been classified as suitable for CO_2 storage, providing a stable long-term permanent containment within the bounds of each storage reservoir. This conclusion is essentially based on several key factors. First of all, natural gas has been contained in these reservoirs for millions of years, proving the quality of the seal. Second, the knowledge of the reservoirs obtained during exploration and production of the fields proves that the reservoir behaves as expected for a reservoir with a tight seal. Third, the low pressure in the reservoir after production will be brought back to the most stable situation of (not more than) hydrostatic pressure upon completing the CO_2 injection.

The monitoring system proposed is designed to verify CO_2 containment and storage reservoir integrity especially while the storage facility is operating. This is achieved by measuring the absence of any leakage through direct detection methods (for example at the wells), and by verifying indirectly that the CO_2 is behaving as expected in the reservoir. The latter will be based on static and dynamic modeling and updating thereof, corroborated by monitoring data (such as temperature and pressure measurements in the well). Therefore, the monitoring system design includes the collection of data such as representative storage pressures and annuli pressures, injected volumes and gas qualities, well integrity measurements and sea bottom measurements.

2.1. Pressure and temperature monitoring

The main component of the monitoring system that will be used to detect deviations in expected behaviour, indicating potential migration out of the reservoir consists of pressure (and temperature) monitoring. After proper history matching, any deviations from the expected pressure trend (P/z curve) during and after the operational phase are a strong indicator for migration out of the storage complex. Stabilized closed-in wellhead pressures will be measured regularly for the injection. These pressures will be converted to subsurface pressures for the control of the storage behaviour. Downhole pressure tests are envisaged to verify the storage pressures and to verify the conversion of the wellhead pressures to downhole pressures.

2.2. Time-lapse seismic surveys: contingency monitoring

Only in case irregularities are observed in the pressure behavior and when migration in the overburden is suspected, is additional time-lapse seismic monitoring proposed to detect potential migration pathways or shallow gas accumulations. The threshold value of seismically detectable accumulations of CO_2 is in the order of tens of kilotonnes, at least under the likely condition that CO_2 accumulates as a concentrated gas pocket in shallower aquifers. The shallower the CO_2 accumulates, the better the chances of picking up the signal.

2.3. Well integrity monitoring

The key tools for monitoring well integrity consist of (repeated) logging, measuring annuli pressures and regularly checking the annuli fluids for the presence of natural gas or CO_2. Prior to CO_2 injection, a rigorous assessment of the current state of the existing wells is carried out. If necessary, a work-over will be carried out. Before abandonment, wells will be suspended for a certain period to verify the quality of the plugs at cap-rock level by gas tests, monitoring the annuli pressures and sampling the fluids above the plug for the presence of CO_2.

2.4. Monitoring of shallow overburden

Finally, shallow monitoring, to prove the absence of migration to the seabed, in the form of multi-beam echo sounding can be considered, for identifying pockmarks or bubbles. Furthermore sampling fluids in the soil at the sea bottom can be used to verify the absence of traces of migrating CO_2. The locations of the sampling will essentially be chosen near the well positions, but additional locations can be selected based on the multi-beam echo sounding results.

3. Structure of the monitoring plan

The starting points for the development of the monitoring plan (Hans, 2011) were the EC CCS directive, the EU-ETS directive, and specific requirements pertaining to ROAD as a demonstration project. The objectives of the monitoring are in line with what is described in the EU guidance documentation. The plan emphasizes the interrelation of risk assessment and management, corrective measures plan, and monitoring plan. Besides meeting the legal requirements, the development of the monitoring plan has been based on a balancing of efficiency and cost.

3.1. Traffic light model

The measurement programme is based on a so-called traffic light model. This means that expected values for the measured values (from the monitoring system) are determined based on expectations that have been derived from the modelling (models are based on the current state of knowledge of the storage system). The models of the storage system may be adjusted as the project proceeds. As long as the values for an operational parameter are within its predicted range, the parameter is in the “green zone’ and operations can proceed according to planning.

For each parameter there is also a yellow zone, which indicates a deviation from the predictions, but no immediate cause for corrective measures. However, it is important to explain this deviation from the predictions. For instance, this could require the taking of additional measurements, deploying other measurement techniques, or adjustments to the models.

If a parameter deviates such that it falls within the red zone of the stoplight model, corrective measures are necessary. This could mean suspension of operations until the anomalies are understood and models are adjusted and calibrated such that the confidence in the predictions is restored.

3.2. Types of measurements

Regular measurements are measurements of primary operational parameters and measurements to verify the current models of the storage system. These measurements include regular measurements of parameters such as pressure, temperature, CO_2 density and the total amount of CO_2 injected. These parameters will be used to determine whether the injection programme is proceeding according to plan and to determine whether and to what extent anomalies occur with respect to modelled behaviour.

Apart from the regular measurements, the monitoring recognizes special measurements, which are performed to determine the baseline situation and measurements surrounding closure and transfer of the site.

Finally, there are measurements that are taken under special circumstances, such as measurements informing about the conditions arising when CO_2 injection is temporarily paused or when injection is resumed.

3.3. Categories of monitoring

The monitoring plan recognizes four aspects to be monitored: (1) the injection process, (2) the well properties, (3) the reservoir properties, and (4) the surroundings/environment. Table 1 summarizes this categorization and the corresponding parameters and issues or features to be monitored.

3.4. Monitoring plan and project phases

The monitoring requirements have been evaluated for each of the phases of the storage project separately. Pre-injection monitoring focuses on recording the baseline situation within the storage complex and its environment. The next step to be considered in the monitoring plan is the operational phase in which injection takes place. In this phase, accounting for the amounts of CO_2 injected is one of the important monitoring tasks. After injection operations have been ceased, the monitoring plan recognizes four post-injection phases. First, while the reservoir is still accessible, there will be a period of observation to verify that the reservoir is moving towards a stable end situation. Then the well will be plugged and monitoring will focus on integrity of the well, and if the quality of the seal is found to be sufficient, the well is sealed and the monitoring is continued in the post-abandonment phase.

Table 1. Categories of monitoring.

	Regular monitoring	*Monitoring related to corrective measures (extra measures in case of deviations)*	*Special circumstances (closure and transfer)*
Injection process	Amount and composition of CO_2, pressure, temperature	Composition of gas at extraction well	
Well properties	Integrity (wireline logging)		Pressure, temperature, plug testing
Reservoir properties	Pressure, temperature	Seismic survey	
Environment/surroundings		Possible traces of leakage	Seabed

Finally, after the site is transferred to the Competent Authority any developments in the reservoir will be followed periodically. However, as post-transfer monitoring is the responsibility of the Competent Authority the monitoring program does not address this phase. However, it can be expected that environmental monitoring activities will continue into this phase.

4. Corrective measures plan

The EU Guidance Document #2 [6] describes a corrective measures plan as integral part of a storage permit application. Corrective measures are defined as: "[...] actions, measures, or activities taken to correct significant irregularities or to close leakages in order to prevent or stop the release of CO_2 from the storage complex". The Corrective Measures plan for the ROAD project is part of the documentation submitted for the storage license application [5]. The development of the plan is based on three guiding principles, which define corrective measures and their place in the overall risk management strategy. The following generic principles apply to corrective measures:

- Corrective measures are risk based and site specific. The Corrective Measures plan is based on a site specific risk assessment. There is a strong link with the risk management plan, in which the site specific risk assessment is documented;
- The monitoring plan and corrective measures plan are strongly interrelated. In the monitoring plan triggers are defined to indicate a potential significant irregularity or leakage that warrants the activation of corrective measures. In addition, monitoring is required in order to assess the effectiveness of a corrective measure;
- Corrective measures will become operative in the event of leakage or significant irregularity occurring.

4.1. Structure of the corrective measures plan

The plan recognizes two categories of corrective measures: corrective measures related to the natural geological system and those related to the man-made, engineered system.

In addition, the plan has been designed to be ‘ready-to-use’ and builds on ‘early warning’ and ‘early intervention’ capabilities, as reducing the risk of further migration or additional leakage requires timely activation of corrective measures. The plan recognizes the importance of communication and sharing of information with the Competent Authorities and stakeholders in case a leakage or significant irregularity is detected or a corrective measure becomes operative.

Table 2: Corrective measures plan summary for ROAD.

Contingency scenario	Consequences	Corrective measures (apart from communication and information sharing, etc.)
1. CO_2 migrates outside storage complex		
CO_2 migration from well into formations above reservoir	CO_2 outside of reservoir in the subsurface	Additional inspection well cementation Remediate well cementation
CO_2 migration from well into biosphere	CO_2 in biosphere	Additional monitoring Remediate well cementation
CO_2 migrates from reservoir into biosphere	CO_2 in biosphere	Additional monitoring Stop injection
CO_2 migrates from storage reservoir into nearby reservoir (P15-9)	CO_2 migrates through fault into P15-9	Monitoring of P15-9 Measures to arrive at safe CO_2 storage in P15-9
2. Seismic activity caused by CO_2 storage		
Re-activation of fault zones	Integrity of storage reservoir compromised	Additional monitoring Stop injection
3. Failure/damage		
Well damage	Functioning of well deteriorates	Remediate well
Degradation of reservoir/seal (due to mechanical, chemical, or temperature effects)	Integrity of subsurface is compromised	Additional monitoring Stop injection
4. Monitoring		
Failure of monitoring system	No information on injection process	Stop injection Adjust monitoring
Conceptual failure of monitoring system	No information on injection process	Stop injection Adjust monitoring
5. System performance deviates from expectations		
Limited injection performance	Less CO_2 can be stored than planned	Adjust pressure and temperature Adjust monitoring
Behaviour of CO_2 in well or reservoir deviates from expected values or models	Injection performance unpredictable	Stop injection Adjust pressure and temperature Adjust monitoring

The plan recognizes five types of measures that can be ranked according to their potential impact on the storage operations and the storage complex. The five types of corrective measures can be summarized as follows:

1. Communication. Reporting detection of a leakage or significant irregularity to the Competent Authorities and communication with stakeholders.
2. Additional monitoring. Additional monitoring may be required to further delineate and improve understanding the causes of the leakage. Also, monitoring may be needed to assess the effectiveness and potential impact of additional corrective measures. The monitoring plan describes the monitoring technologies that could be applied in support of corrective measures.
3. Adjustment of the operational parameters. As long as the well and reservoir can be accessed the following corrective measures may be applied:
    1. Stop injection (temporarily or permanently);
    2. Adjust injection pressure or temperature;
    3. Decrease maximum allowable pressure (reduce the volume of CO_2 ultimately to be stored in the reservoir).

   4. Change the composition of the CO_2 stream, in case of chemical reactions in the well, at the cap rock, or in the reservoir cause leakage or a significant irregularity.
4. Technical adjustments to the system. A contingency may require corrective measures that include a technical intervention in the storage complex. Most likely this would be remediation of well bore cementation to prevent leakage through the well.
5. Large scale intervention. In case of large deviations from what is expected or significant risk of containment loss, large scale corrective measures may be considered. Although a contingency that would require this type of measures is highly unlikely, the plan includes these measures to ensure that the plan covers all corrective measures possible. These measures are related to large deviations from expectations or in the context of a contingency taking place after closure of the reservoir. Two types of measures are considered for large scale intervention:
   1. in case of spill-over from the P18-4 reservoir into the nearby P15-9 reservoir, measures to enable storage in the P15-9 reservoir can be taken (see also [4]) (although this is not leakage since the CO_2 remains in the storage complex), and
   2. in case of large scale leakage out of the storage complex, the CO_2 could be (partly) produced back out of the reservoir again.

   In the latter case, it could be considered to store the CO_2 elsewhere, or enable controlled escape into the atmosphere, and to take measures to return the storage complex back into a stable state.

The plan is structured into three important aspects: the contingency scenario, consequences of a scenario, and the corresponding corrective measures. Table 2 summarizes the Corrective Measures plan. In addition to the summary table, the plan provides a brief technical description of the site specific corrective measures, included related operational aspects and remarks about their rational and potential technical challenges [5].

5. Discussion and conclusions

The ROAD project (actually, TAQA, as operator of the P18-4 storage site) holds the first CO_2 storage permit approved and issued under the EU CCS Directive. The monitoring and corrective measures plans presented in this paper demonstrate that *relatively simple and straightforward plans* can be sufficient in addressing all requirements set out in the EU Storage Directive.

It should be noted that the monitoring plan is compact because the storage reservoir is a depleted gas field. A large body of knowledge and experience on the field has been accumulated over the period the field was produced. The field has a proven seal and only a single well and a limited monitoring effort is needed to verify containment of the injected CO_2. The monitoring plan that is part of the permit will be replaced with a final version once detailed site design has been completed.

A traffic light model is proposed to describe site conformance. This model is flexible and allows operator and regulator to adapt the monitoring plan during the storage project operation, as monitoring data and modelling results become available.

Close and frequent contact between the operator and the competent authorities during the permit application preparation process helped shape the process on both sides: the approach and level of detail with which each of the issues raised in the EU Storage Directive was to be addressed, and clarification of elements of the Directive that were left open-ended.

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