5.2 Overall Risk Management Process

The suggested overall approach to risk management subdivides the process into three steps, each of which are detailed in the following sections (sections 6.2 – 6.4). This adapts the approach described in CO2QUALSTORE Guidelines (DNV, 2010a) with the requirements of the CCS Directive to provide the following framework for risk management in geological storage:

- Risk identification and assessment: Identify and characterise risks relating to potential leakage from the storage complex, other significant environmental or health risks and associated uncertainties; The identification and assessment of risks should involve hazard identification, and the assessment of potential impacts for each identified hazard[15] (i.e. Exposure and Effects assessments as required in CCS Directive[16]);

- Risk ranking: Rank and characterise the potential significance of each risk; rank in one of the following categories: Insignificant/significant;

- Risk management measures: Identify and assess risk management measures, including monitoring activities, preventive and corrective measures that may be implemented, or planned as contingency measures, in order to reduce risks or associated uncertainties, and assess the resulting risk/uncertainty reduction and risk ranking;

The first part of the process is to identify, assess and characterise potential risks for the storage complex. The second step is to rank and categorise the identified risks based on a standard matrix of probability and severity of outcome (impacts). The next step is to describe and evaluate preventive and corrective measures that can be used to manage the risks (DNV, 2010a).

For every risk identified, the aim is to reduce both the risk and the uncertainty to acceptable levels as foreseen in the CCS Directive (Figure 3). There are limitations and gaps in current knowledge in this area, but the overall approach is to identify and mitigate any significant risks. The CA should recognize that operators must undertake site-specific approaches in their risk assessment and management.

In practice, this is a matter of identifying the options for reducing the risk and uncertainty, their costs and their consequences for risk and uncertainty reduction. As more experience with geological storage and risk assessment is gained, it is expected operators would be able to systematically accept or exclude identified storage complex options and thereby identify sites that offer no significant life-cycle risks while excluding others with a significant life-cycle risks.

[15] A hazard is considered here as a feature, event or process that can cause leakage of CO_2 from the storage complex or other significant environmental or health risk.

[16] Annex 1

This approach will need to meet the requirements for risk assessment in Annex I of the CCS Directive which includes risk characterisation based on hazard characterisation, exposure and effects assessments.

It should be recognized that while the framework discussed here is based on a modified version of the CO2QUALSTORE guideline, operators could use their own risk management process, as long as they can demonstrate to the CA that it meets the requirements of the CCS Directive, as discussed above.

5.2.1 Risk Identification and Assessment

Identifying and assessing the potential risks is the first major step in the risk management process. The scope of activities required by the operator can be based on the guidelines proposed in the CO2QUALSTORE Report (DNV, 2010a), which forms the basis for this section, while meeting the requirements for Risk Assessment in Annex I of the CCSD.

An important requirement is to identify all significant risks of leakage or hazards that may prevent complete and permanent containment. These should be site specific, but should also take into consideration generic risks/hazards for different options and leakage pathways (as described in sections 4 and 5), which can be used as checklists by the CAs.

This exercise must evaluate environmental and human health risk and must address the hazard, exposure, and effects assessments that are required by the CCS Directive (see GD2). The storage complex location and local characteristics must be taken into account, giving due consideration to issues such as local population density, the nature of the biosphere, atmospheric dispersal and whether the site is onshore or offshore. The composition of the CO_2 stream should also be factored in (see Chapter 3 of GD2 for more discussion).

For a particular stage of the life cycle, the starting point would be to revisit any risk assessment or risk characterisation from any earlier phase of the life cycle. Next, risks should be assessed, in light of the new data and analysis results obtained through the project activities. Additional risks that were not previously identified should also be considered if the new data reveals new risks or uncertainties.

This process should start with a review of the geological framework, modelling, the numerical simulations, monitoring results and any other relevant data, and include consideration of the following questions:

- Does the available geological data and data resolution provide a sufficiently good basis for the geological model that gives an adequately correct and detailed representation of the storage site and its overburden?
- Has/have the geological model(s) been built and populated with appropriate lithological parameters with respect to the decisions to be made?

- Is the capacity estimated consistent with maximum allowed reservoir pressure levels?
- Have all possible existing or potential future leakage pathways been identified?
- What is the potential magnitude of leakage events for identified leakage pathways (flux rates)?
- Have the critical parameters affecting containment and leakage (e.g., maximum reservoir pressure, maximum injection rate, sensitivity to various assumptions in the simulation model, etc.) been duly considered?
- Have the most relevant secondary effects of the storage project that may have adverse impact on human health or the environment been considered, including effects of displaced formation fluids and release of heavy metals or other substances with the potential to contaminate vulnerable drinking water zones?
- Are there any other factors which could pose a hazard to human health or the environment (e.g., physical structures associated with the project)?

The risk identification and assessment should integrate the detailed hazard characterisation, exposure and effects assessments, which are described further below.

Hazard Characterisation

Hazard characterisation shall be undertaken by characterising the potential for leakage from the storage complex, as established through characterisation of the storage complex, dynamic modelling and security characterisation as detailed in GD2. This shall include consideration of, inter alia:

- potential leakage pathways;
- potential magnitude of leakage events for identified leakage pathways (flux rates);
- critical parameters affecting potential leakage (for example maximum reservoir pressure, maximum injection rate, temperature, sensitivity to various assumptions in the static geological Earth model(s));
- secondary effects of storage of CO_2, including displaced formation fluids and new substances created by the storing of CO_2;
- any other factors which could pose a hazard to human health or the environment (for example physical structures associated with the project).

The hazard characterisation shall cover the full range of potential operating conditions to test the security of the storage complex. The primary hazards of geological storage are described in Chapter 5 of GD1. These hazards include geological leakage pathways, manmade leakage pathways (i.e., wells and mining activities), and other hazards from the mobilisation of other gases and fluids by CO_2 (e.g. methane). Modelling and sensitivity analysis can be used to create scenarios for the different hazard mechanisms and determine the critical parameters that could result in potential leakage. Beyond the primary hazards, there are several secondary effects that are described further in Section 2.9 of GD2.

The hazard characterisation requires the estimation of the likely leakage rates and duration following various credible modes of containment failure (discussed further in GD2, chapter 2). A clear understanding of fluid/rock interactions, the impact of incidental substances on the CO_2 phase equilibrium behaviour (see GD2, chapter 3), as well the role of CO_2 hydrates during the migration process are important requirements.

It is also important for the operator to consider how the risks and risk profile will evolve through time throughout the lifecycle of the storage project. This should assist by depicting how different risks evolve (i.e., increasing/decreasing) over time, where in the storage complex and when in the life cycle they are most likely to occur, thereby providing quantitative risk assessment through time (Dodds et al, 2010). Where possible, quantitative profile of different risks may also be charted as a function of time.

Exposure Assessment

The Exposure assessment should be based on the characteristics of the environment and the distribution and activities of the human population above the storage complex, and the potential behaviour and fate of leaking CO_2 from potential pathways in the Risk Identification.

Effects Assessment

Effects assessment – based on the sensitivity of particular species, communities or habitats linked to potential leakage events associated with identified risks. Where relevant it shall include effects of exposure to elevated CO_2 concentrations in the biosphere (including soils, marine sediments and benthic waters (asphyxiation; hypercapnia) and reduced pH in those environments as a consequence of leaking CO_2). It shall also include an assessment of the effects of other substances that may be present in any leaking CO_2 streams (either impurities present in the injection stream or new substances formed through storage of CO_2). These effects shall be considered at a range of temporal and spatial scales, and linked to a range of different magnitudes of leakage events.

Discussion

The risk identification and assessment step should aim to increase understanding of both the likelihood and consequence of the identified hazards, risks and uncertainty elements. This step should therefore put focus on assessing if results from the data gathering process, as well as any modelling and simulation studies performed, provide an adequate basis for evaluating risks and uncertainties. This step may entail both qualitative and (semi-) quantitative evaluations of leakage, risk significance, and the associated uncertainties.

A variety of quantitative estimation methods may be applicable to risk assessment, including numerical models, analytical models and compartment models. All types may be performed in a deterministic or probabilistic manner and the underlying assumptions and boundary conditions must be thoroughly understood before using the results. Similar activities may be undertaken to assess risks, using one or more of the following illustrative analysis approaches:

- Scenario analysis: the process of analysing a range of possible future events by considering alternative outcomes. This may imply constructing a small number of models that satisfy and represent the observed characterization data to similar degree, and comparing the storage performance predicted by the distinct models.

- Reliability analysis: application of methods that aim to estimate the probability of failure of an engineered system given stochastic loads and uncertain characteristics of the engineered system.

- Sensitivity analysis: quantitative assessment of parameter sensitivity based on a formal mathematical relation between quantitatively described uncertain parameters and one or more performance functions. The emphasis with sensitivity analysis is usually to rigorously rank the relative importance of a set of uncertainties.

There are limitations in regard to quantitative approaches as follows:

- Research on quantification of leakage pathways and flux rates is still ongoing, and therefore these assessments are likely to be of qualitative/semi-quantitative nature, until experienced is gained. Further research studies are underway, with an aim to provide more quantitative approaches/data for such assessments.[17]

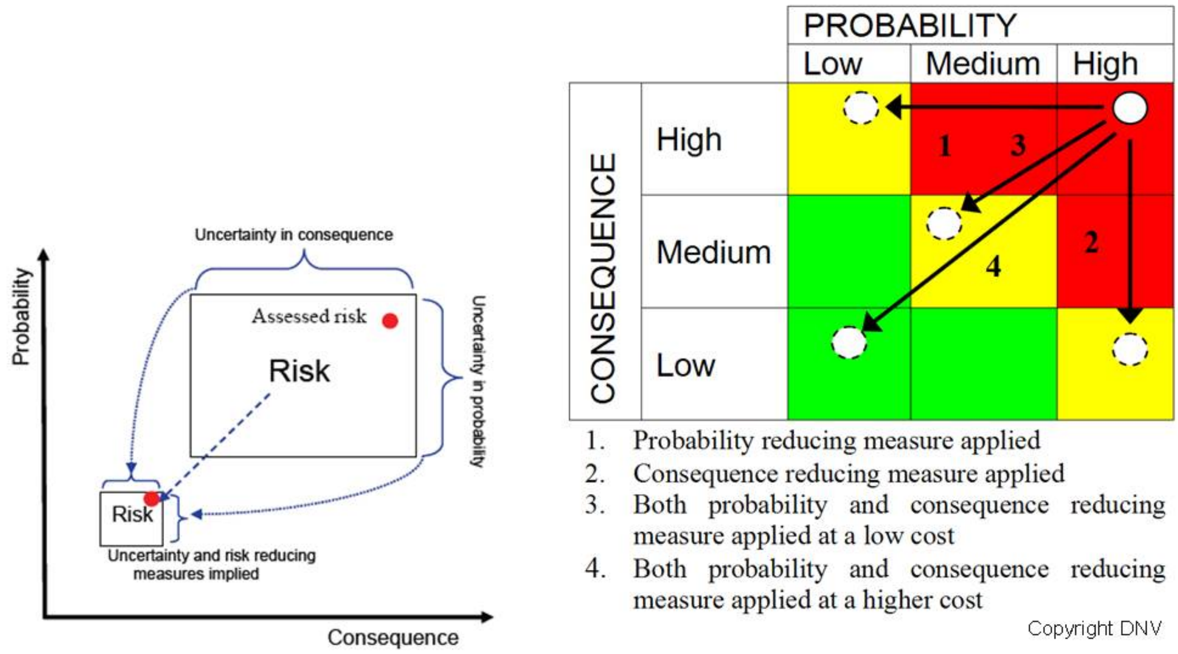
- It is recognised that current imaging technologies should be further developed to identify the existence of all relevant risks, as the scale of some risks could be less than existing surveying detection limits. Judging the likelihood and consequence of risk elements, or the associated uncertainties, both qualitatively or (semi-)quantitatively, depends in part on the reliability of the input parameters. Care should be taken that a valid body of data and experience exists for justifying the application of quantitative analysis to risk elements affecting the geological storage of CO_2.

[17] See, for example, 'IEAGHG Quantification Techniques for CO2 Leakage' study and the EU FP7 RISCS project.

5.2.2 Risk Ranking

This second step is to categorise and rank the identified risks based on a standard matrix of probability and severity of outcome (impacts).

Figure 3: Risk Management Framework (Courtesy of CO2Qualstore)



The initial ranking, based on the risk identification, may be supported by the analysis carried out in the risk assessment step. The aim is to characterize the potential significance of each risk. The probability and consequence of each risk should be assessed. The relative significance of each risk should then be characterized and prioritised, and placed in one of the following two risk categories:

1. Insignificant risks: risks that are broadly regarded as not posing a significant danger to human health or environment;

2. Significant risks, risks that must be reduced to insignificant through implementation of risk reducing measures in order to gain project approval, or to meet anticipated conditions for site closure.

Note that the result of the initial risk ranking represents the current risk level associated with the various hazards or threats with potential to have negative impact on human health or the environment. Thus, the risk ranking does not account for the effect of identified safeguards.

For many risks related to geological storage of CO_2 there may be significant uncertainty related to both probability and severity (degree of impact). To avoid underestimating risks, and thereby potentially create incidents with negative impact that could have been avoided, it is recommended that risks are ranked conservatively, e.g., by using the pessimistic end of the probability and severity scale to rank risks.

The aim is to be objective and avoid bias without exaggerating the risk unduly. Such risks would then be managed and effectively down-graded as more knowledge about the sites is acquired and uncertainties have been assessed and reduced.

In addition to modelling of risks and assessing potential impact of risks, defining how to rank identified risks could use a facilitated brainstorming session among a group of experts. This group should contain experts that have a detailed knowledge of the storage project, typically representatives from the operator, as well as experts that have no particular stakes in the associated CCS project. It might also include other stakeholders, such as representatives from the public or the local authorities that are not viewed as experts on CCS, but may evaluate certain risks differently to the operator or people with extensive knowledge about geologic storage of CO_2. Such a group exercise could reduce biases in risk assessment, focus on seeking out the weak points for each site and evaluate how these weak points could be properly tested and evaluated.

Particular attention is required to risks with high impact (consequence) including those with low probability. An expert group can assist in assessing the relative importance in such circumstances. High impact events require additional analysis in terms of risk management and mitigating actions.

5.2.3 Risk Management Measures

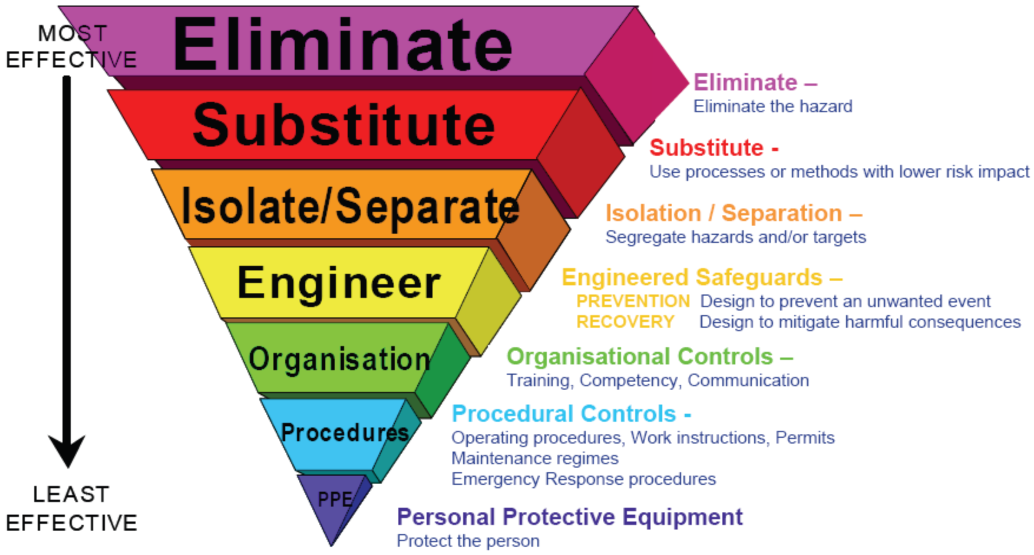
The objective of this step is to identify mitigating actions and safeguards, including monitoring, preventive and corrective measures, and other types of action, that can be used to reduce the risks and/or uncertainty for the identified risks. Contingency measures would be identified for implementation or planning at different stages of the life cycle.

Safeguards are expected to avoid the risks from developing into irregularities or leakage, or mitigate their effects. Safeguards may be preventive or corrective. Preventive safeguards can be implemented prior to the event in order to reduce the probability of an incident occurring or reduce the impact associated with an incident if it occurs. Corrective measures are safeguards that are implemented to correct significant irregularities or leakages in order to prevent or stop the release of CO_2 from the storage complex. Safeguards can be natural (inherent), engineered, or operational (procedural). These may include the consideration and use of multiple storage sites and/or storage targets within the same storage complex.

This step should evaluate what monitoring methods, preventive or corrective measures exist as options for each of the identified risks. These should be integrated with monitoring and corrective measures activities, which are essential safeguards (discussed further in Chapter 4 and 5 of GD2).

For each safeguard an assessment of the risk reduction effect of the alternative safeguards for the associated risk should be evaluated which may be either qualitative or quantitative. If the effect of the safeguard is uncertain, the uncertainty should be accounted for conservatively. The impact of the measure on the risk assessment should be assessed and can be illustrated using charts similar to Figure 3.

Figure 4: Potential Hierarchy of Control to help compare alternative safeguards for risk reduction



Source: CO2QUALSTORE 2010

Figure 4 shows a hierarchy of different types of safeguards which reflects the hierarchy of risk control mechanisms that may be applied. The top three elements of the Hierarchy of Control (i.e., Eliminate, Substitute, and Separate) bring with them “inherent safety”. It follows that these three elements of risk reduction are the most important for CCS projects, and they must be considered early.

The evaluation of more than one storage option ensures that site with poor life-cycle containment can be characterised and “eliminated” through appropriate risk assessment and a preferred site with demonstrably secure capacity can be selected. The residual risk features within that preferred site can then be isolated by physical separation (e.g. distance of injection wells from susceptible faults and below cap-rock).

CCS demonstration projects have shown that defining the lower elements of the Hierarchy of Control - is not yet “business as usual”. There is significantly more effort required to achieve robustness in these areas. Different types of safeguards will be relevant at different stages in the project life cycle. These include potential safeguards that may be incorporated in site characterisation, CO_2 composition, monitoring and corrective measures (as described in GD2).

The CA should ensure that practical and effective safeguard options are applied with due consideration of potential risks, so that the requirements of the CCS Directive are fully met.

5.3 Interaction between Operator and Competent Authorities

Within the proposed approach, the risk assessment, ranking and range of options for tackling the risk are identified by the operator and should form the basis for a dialogue with CAs to ensure that the legal requirements of the CCS Directive are met. To meet requirements of the CCS Directive, the proposed approach should therefore meet the pre-conditions for safe storage of CO_2 set out earlier (section 6.1). Given that the CCS Directive sets the risk reduction targets, the discussion between CAs and operator should focus on the best way to achieve these.

An example of the Risk Management process is given in the text Box 1 below (courtesy of DNV).

The nature of the interaction between the operator and the CAs in respect to the risk management will depend where in the life cycle the project is. Operators will have to interact with the CAs in the following circumstances, all of which should be linked to the risk management framework:

- Applying for an exploration permit;
- Applying for a storage permit, which includes proof of the technical competence of the potential operator, the characterisation of the storage site and storage complex with an assessment of its expected security, specifications related to CO_2 streams (total quantity to be injected and stored, composition, injection rates and pressures), description of preventive measures to prevent significant irregularities, a monitoring plan for the storage complex and the injection facilities, a corrective measures plan for leakages or significant irregularities, a provisional post closure plan, and proof of financial security or any other equivalent;
- Reviewing of storage permit and updating of monitoring plan;
- Reporting;
- Routine and non-routine inspections;
- Notifying the CA in the event of leakages or significant irregularities and implementing corrective measures and measures related to the protection of human health and the environment;
- Applying for closure of the storage site, including an updated post closure plan;
- Transferring the responsibility for all legal obligations after making a financial contribution available to the CA.

In all cases an ongoing and active dialogue between the operator and CA is recommended as the best practise to be adopted.

In addition to this interaction between operators and CAs, the MS and CAs will also interact with the Commission. According to Articles 10 and 18, MS shall inform the Commission of all draft storage permits and draft decisions of approval of the transfer of responsibility and any other material taken into consideration for the adoption of the draft storage permit or draft decision of approval of the transfer of responsibility. Within four months after receipt of the draft storage permit or draft decision, the Commission may issue a non-binding opinion on it. If the Commission decides not to issue an opinion, it shall inform the MS within one month of submission of the draft permit or the draft decision and state its reasons. The CA shall notify the final decision to the Commission, and where it departs from the Commission opinion it shall state its reasons.

Box 1: Risk Management Process Example, based on CO2QUALSTORE (DNV, 2010a)

This concrete example is described to clarify how this might apply in practise (example provided by DNV 2010a). Consider the following situation:

- Abandoned well within the permit area in an onshore storage project
- Plume set to intersect the well 10 years after injection
- Comprehensive well records exist from time of abandonment (1982)
- Well integrity considered to be good

The initial views of the regulator and the operator are as follows:

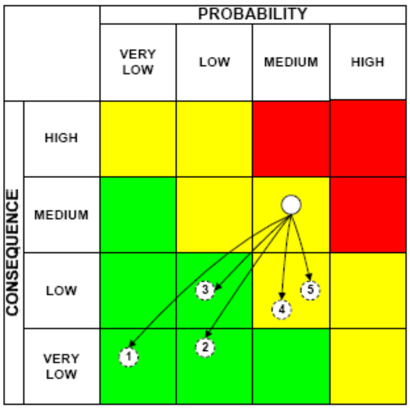
- Regulator: all abandoned wells that may come into contact with the plume must be re-abandoned.
- Operator: well will be re-abandoned if leakage occurs.

A number of options are then identified to reduce the risk, as follows:

1. Re-abandon well
2. Monitoring well for early signs of leakage – re-abandon if detected
3. Monitoring well for early signs of leakage – re-design injection strategy if detected
4. Monitoring of surface – re-abandon well if leakage
5. Monitoring surface – assess impact of leakage and redesign injection strategy. Reabandon if significant leakage

The risk reduction potential of the measures is represented in example below. A dialogue would take place between the operator and the regulator to determine which of the options should be taken in practice in order to meet the pre-conceived level of insignificant risk. Note that the result of the dialogue would normally include selection both of a monitoring strategy for this particular risk (monitoring either the well or the surface) and of a corrective measure if an adverse event occurs (redesign of injection strategy, re-abandoning of well).

Example of risk reduction options



If option 2 were taken, for instance, the performance target would be that the well is maintained secure and leak-proof; if option 5 were taken, the performance target would be that no significant leakage takes place via the well. Each of these performance targets has an associated regime of monitoring and corrective measures. Only options that satisfy the risk reduction requirements of the Directive would be eligible.

The process would be repeated for the range of risks identified, working down the ranking set out.

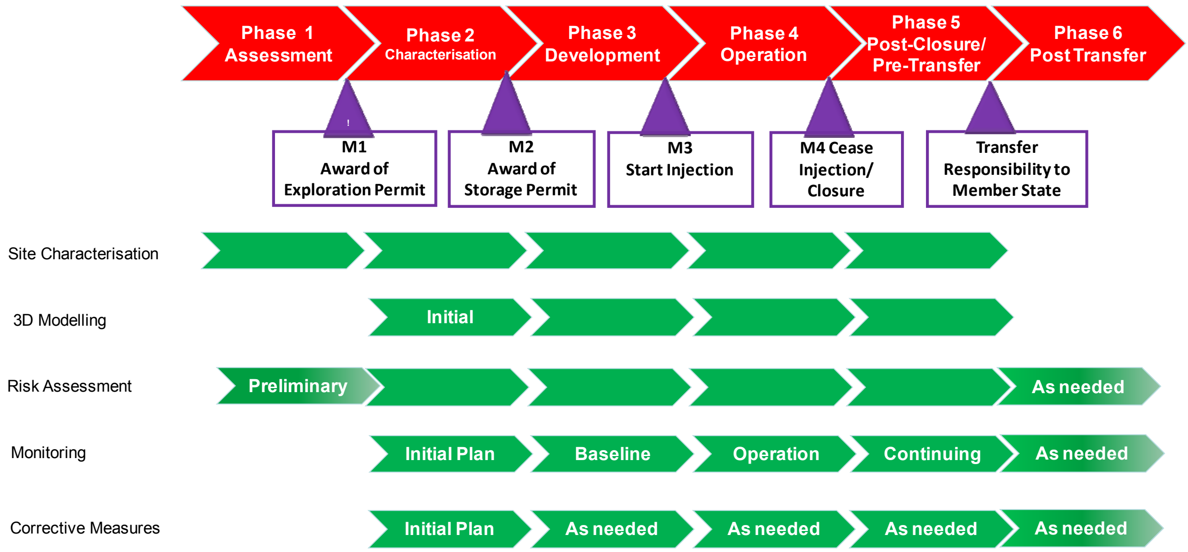
The approach is also applicable in principle to the conditions for transfer of responsibility: for instance, a range of performance targets for transfer in the above case could be elaborated (e.g. that the site had completed injection and had been monitored according to the agreed approach for a period of x years after closure and no leakage had been identified) and if the agreed target was met, the condition for transfer (in relation to that risk) would be satisfied.

5.4 Risk Management at Different Project Phases

The approach outlined above is based on identifying and assessing risks and options for tackling the risk at a given site at any phase in the project life cycle. In view of the vital importance of ensuring safe storage, the principle of risk management is relevant and applicable throughout the entire storage life cycle.

The main activities, mitigating actions and safeguards are considered for different phases below, and illustrated in Figure 5. It is important to recognise the risk identification and management process are ongoing processes through the storage life cycle, with several updates as additional data is collected about site characteristics and performance, and risk and uncertainties are better understood. The risks and uncertainty about the potential for the risk are reduced in most cases as one moves along the life cycle.

Figure 5: CO_2 Storage Life Cycle Framework - Risk Management during the Main Project Phases and Milestones



5.4.1 Phase 1: Assessment of Storage Capacity

Although there are no formal risk management requirements at this phase in the CCS Directive, initial consideration of the potential risks relating to the safety of storage should be taken account of both by the operators and the CAs in initial assessments and screening, and in identification of potential storage sites and exploration permit areas. These considerations of risks in the screening assessments may be generic or regional in nature but should give a clear idea of what further information is needed to ensure that a particular site will be suitable and safe (e.g., whether the caprock is likely to be homogenously developed across the region). These might then form the basis for the exploration permit and activities during the characterisation phase.

For operators, consideration of multiple potential storage sites may be useful in the initial assessment and screening as well as the subsequent characterisation phase. This would serve to develop a risk-diverse portfolio in order to mitigate geotechnical and other development risks. In this way, potential operators can gain a relatively high confidence that at least one site could be developed for storage. This approach is consistent in making full use of the risk mitigation potential offered by the Hierarchy of Control (see Figure 4).

5.4.2 Phase 2: Characterisation and Assessment of Storage Complex

Risk management is an essential activity during this phase in order to ensure selection of safe sites ahead of storage permitting and subsequent development.

Risk identification and assessment should be initiated at an early stage in this phase and used to determine the nature of exploration activities and evaluation work that may be required to address specific risks and uncertainties. Seismic and drilling activities can be used to reduce the uncertainties and risks relating to geological pathways. For example seismic surveys can be used to delineate the extent of caprocks and to understand the nature of faulting in a region. Wells can be drilled to confirm the suitability of different formations as caprocks and to obtain samples for detailed analysis. Engineering surveys, testing and remediation activity can be conducted to evaluate and reduce risks associated with well integrity (e.g. the status of an abandoned well that might be encountered by a CO_2 plume) and other man-made pathways.

Risk assessment is required by the CCS Directive as an integral part of the site selection, site characterisation and storage permitting. This should be based on the approach described above - further guidance on this is provided in GD2. At this phase some risks identified during the site characterisation phase can be addressed by mitigating actions and safeguards as part of the plans that are prepared and submitted with the storage permit application:

- Project design and development plans (e.g. well locations, numbers, operating and injection plans); these can be used to manage risks associated with geological pathways and parameters (e.g., by limiting pressure build-up and allowable capacity); remediative activity can be included in the development plan in event of well integrity risks associated with pre-existing wells.
- Description of measures to prevent significant irregularities;
- Monitoring plan (which must be developed to address specific risks identified in the risk assessment—see Chapter 4 of GD2);
- Corrective measures plans—see Chapter 5 of GD2;
- Provisional post-closure plan—see above.

The monitoring and corrective measures plans that are prepared at this stage as well as the description of measures to prevent significant irregularities are closely related to the Risk Assessment for the project. They must be developed to take account of and address the specific risks that are identified for the storage complex.

The CA has responsibility for approval of storage permits, and making sure that sites are suitable for CO_2 storage, with appropriate operating plans. This is in effect part of the overall risk management process and a vital aspect of ensuring that suitable sites are selected.

5.4.3 Phase 3: Development

Additional information will usually become available in this stage through development drilling and any baseline monitoring activity undertaken. The logging, coring and other measurements conducted during development drilling should be used to refine the subsurface characterisation, modelling and risk assessment conducted at the time of storage permitting.

Baseline monitoring of the storage complex should be conducted and assessed to help determine whether the monitoring results during the injection phase are irregular. This is important because it is essential to have comprehensive baseline data before CO_2 injection starts.

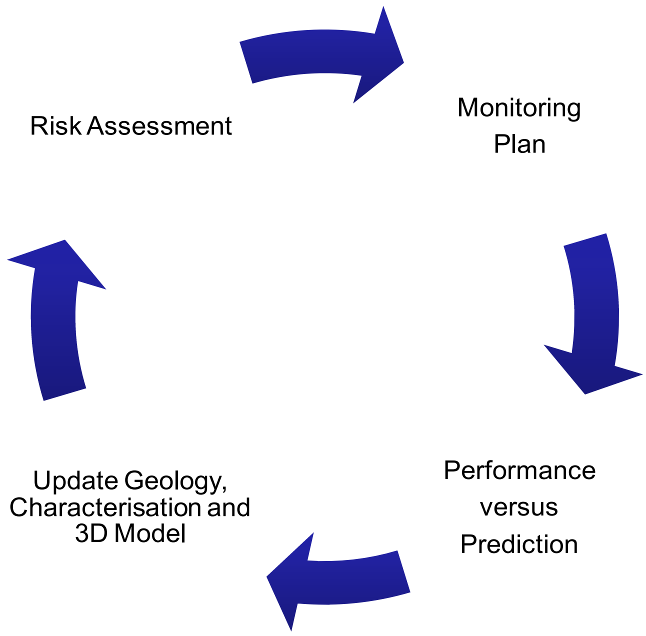
5.4.4 Phase 4: Operations

The operations phase is one of the most important periods from a risk management perspective, because large scale commercial CO_2 injection into the storage complex is initiated. This is the first phase in the life cycle when there is any actual risk of irregularities and leakage as a result of the injection project. The initial migration and movement of CO_2 may test different pathways and risks as the plume develops and expands, and pressures start to increase.

As the main phase of injection and with ongoing monitoring, there will be a continuous flow of new information and data about the project and its performance (as shown in Figure 6).

The monitoring plan and activity is an essential part of the risk management approach. The results from injection and monitoring should be used by the operator to verify, test and iterate the risk assessment, models and performance predictions on an iterative and ongoing basis. The results must also be reported to the CA in line with the CCS Directive, and the monitoring plan must be updated at least every five years (see GD2).

Figure 6: Risk Management based approach to storage project



During this phase there are a range of mitigating actions and safeguards that include:

- Operations management, procedures and practises including preventive measures;
- Monitoring activity and update of monitoring plans;
- Inspections;
- Corrective measures;
- Review of storage permit.

5.4.5 Phase 5: Post-Closure Pre-Transfer

Although CO_2 injection has stopped by this phase, the underground CO_2 plume may not have stabilised and therefore there is continued risk of irregularities and actual leakage from the storage complex.

With ongoing monitoring, there will continue to be a flow of new information and data about the project and its performance. The monitoring activity is an essential part of the risk management approach. The results from monitoring should be used by the operator to verify, test and iterate the risk assessment on an ongoing basis. This should include updates to modelling which should assess and calibrate the plume migration and migration rates, which is of particular importance for MAS storage at this phase. The results must also be reported to the CA in line with the CCS Directive.

Although the range of mitigation actions is reduced after the injection period, the mitigating actions and safeguards in this phase continue to include monitoring activity and updates of monitoring plans, as well as corrective measures and inspections.

5.4.6 Phase 6: Post-Transfer

While routine inspections by the CA will cease in this project phase, monitoring will continue, although it may be reduced to a level which allows for detection of leakages or significant irregularities. If any leakages or significant irregularities are detected, the risk assessment will need to be reviewed and monitoring will need to be intensified to assess the scale of the problem and the effectiveness of corrective measures.

6. Summary

This GD addresses the overall framework for geological storage in the CCS Directive and provides a framework for the entire life cycle of geological storage of CO_2 activities covering the phases, main activities and major regulatory milestones. It presents the high-level approach to risk assessment and management that is intended to ensure the safety and effectiveness of geological storage of CO_2.

The life cycle for any CO_2 storage project from initial assessment and characterization of a site to its transfer to the CA could be in the region of 50-70 years up to the final transfer of responsibility to the Member State/CA. The framework covers all phases in a comprehensive manner and describes the role of CAs through the life cycle, and provides guidance on the interactions with the operator at different milestones and during different phases, particularly with regard to risk management.

The scale and nature of geological storage potential for CO_2 varies by country across Europe and different options are more or less important in different countries. Major options are oil and gas fields and saline aquifers, with further potential in other storage types. CO_2 storage potential occurs in both onshore and offshore settings. The setting and type of CO_2 storage option should be taken account of in risk management.

Risk management should be used by the operator to identify, mitigate, and manage identified risks and uncertainties in order to ensure the safety of any storage through the life cycle of every CO_2 storage project. The intent of the risk assessment is for the operator to assess all potential risks for a CO_2 storage opportunity. There are a series of generic risks that need to be considered on a case by case basis. These include geological CO_2 leakage pathways, manmade CO_2 leakage pathways and a range of other risks.

The overall approach to risk management subdivides the process into three steps, each of which are detailed in the guidance. The steps are

- Risk identification and assessment: Identify and characterise risks relating to potential CO_2 leakage from the storage complex, other significant environmental or health risks and associated uncertainties; The identification and assessment of risks should involve hazard identification, and the assessment of potential impacts for each identified hazard (i.e. Exposure and Effects assessments as required in CCS Directive;

- Risk ranking: Characterise the potential significance of each risk by the probability of occurrence and consequence of the risk; the risks should then be ranked in one of the following categories: insignificant or significant;

- Risk management measures: Identify and assess risk management measures, mitigating actions and safeguards that may be implemented, or planned as contingency measures, in order to reduce risks or associated uncertainties, and assess the resulting risk/uncertainty reduction and risk ranking.

Risk management should be considered as an ongoing and iterative process throughout the CO_2 storage life cycle that aims at continual improvement of risk assessment. This will involve periodic and ongoing assessment of risks relating to containment and leakage, as well as uncertainties in the geological framework, models and performance assessments. It is also important for operators to communicate the risks to the CA and other stakeholders based on structured and publicly accepted industry methods.

Within the proposed approach, the risk assessment, ranking and range of options for tackling the risk are identified by the operator and should form the basis for a dialogue with the CA to ensure that the legal requirements of the CCS Directive are met. The nature of the interaction between the operator and the CA in respect to the risk management will depend where in the life cycle the CO_2 storage project is, what the regulatory requirements are, and whether there are specific formal approvals or milestones.

7. Acronyms

2D	Two dimensional
3D	Three dimensional
CA or CAs	Competent Authority or Competent Authorities
CCS	Carbon Dioxide Capture and Storage
CCS Directive	Directive on the Geological Storage of Carbon Dioxide (2009/31/EC)
CO_2	Carbon dioxide
DNV	Det Norske Veritas
ECBM	Enhanced Coal Bed Methane
e.g.	For example
EHR	Enhanced Hydrocarbon Recovery

EOR	Enhanced Oil Recovery
etc.	Et Cetera (Latin: And So Forth)
EU	European Union
FEED	Front End Engineering Design
FS	Financial Security
GCCSI	Global Carbon Capture and Storage Institute
GD	Guidance document
Gt	Giga tonnes
i.e.	Id est (Latin: that is)
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
m	Meter
MAS	Migration Assisted Storage
pH	Potential for hydrogen ion concentration
UCG	Underground Coal Gasification
UK	United Kingdom
US	Of the United States of America
USA	United States of America

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