MUSTANG

A MUltiple Space and Time scale Approach for the quaNtification of deep saline formations for CO2 storaGe

Project Number:227286

Work-Package: *WP09*

WP Title
Certification

Deliverable *D091*
Scoping of the performance and risk assessment

May 2010

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Executive summary

CO_2 geological storage is one of the most promising solutions to mitigate CO_2 emissions to the atmosphere, and to minimize the impact of greenhouse gas effects. Nevertheless, some key challenges relating to capacity, injectivity and confinement need to be overcome in order to validate the performance of the storage system during its lifecycle (from a few years to several hundred years). In the case of the failure of a CO_2 storage operation, the environment, investments, and human health & safety may be at risk. It is therefore important to use risk management methods to ensure that these projects will meet their objectives, as highlighted in the EU directive regarding CO_2 geological storage.

The aims of risk management process are:

- To identify and evaluate all the risks that could impact project objectives, and
- To establish treatment and monitoring actions or plans to reduce the impact of risks and ensure project performance.

This document defines the guidelines of risk management process. It describes the seven parts of this process:

- Establishment of the context
- Risk identification
- Risk estimation
- Risk evaluation
- Risk treatment
- Communication and consultation, and
- Monitoring and review

Keywords	Risk management, establishment of the context, identification, estimation, evaluation, treatment, communication, monitoring, risk analysis, risk assessment, severity grid, probability grid, consequence grid, risk matrix.

Table of content

List of figures

List of tables

1 Introduction

1.1 Context

CO_2 geological storage is one of the most promising solutions to mitigate CO_2 emissions to the atmosphere, and minimize the impact of greenhouse gas effects. Nevertheless, some key challenges relating to capacity, injectivity, and containment need to be addressed in order to validate the performance of the storage system during its lifecycle (from some years to hundreds of years). In the case of the failure of a CO_2 storage operation, the environment, financial aspects, and human health & safety may be at risk. It is therefore important to use risk management methods to ensure that these projects will meet their objectives (each project will define its own objectives), as highlighted in the EU directive regarding CO_2 geological storage.

Risk management must be viewed as essential for CO_2 storage projects as its main principles are:

- To contribute to the achievement of **project objectives** (regarding, for example, health and safety, environment, investments) and the **improvement of project performance**.

- To support **decision making** for risk treatment and definition of any MVA (monitoring - verification - accounting) program: prioritise actions and justify the choices.

- To provide the authorities with proof of regulation compliance in the project.

- To provide **consistent, comparable and reliable results** of risk evaluation as a result of a transparent and structured methodology.

Risks must be considered in terms of their potential impacts on the achievement of project objectives and therefore be managed to lower these impacts. The risk management process includes:

- Identifying and evaluating all the risks that could impact project objectives, and
- Establishing treatment and monitoring actions or plans to reduce the impact of risks and ensure project performance.

The reference process for risk management presented in this document is derived from the international standard version ISO/FDIS 31000 coming from the International Organisation for Standardisation. The following figure presents the main steps of the risk management process.

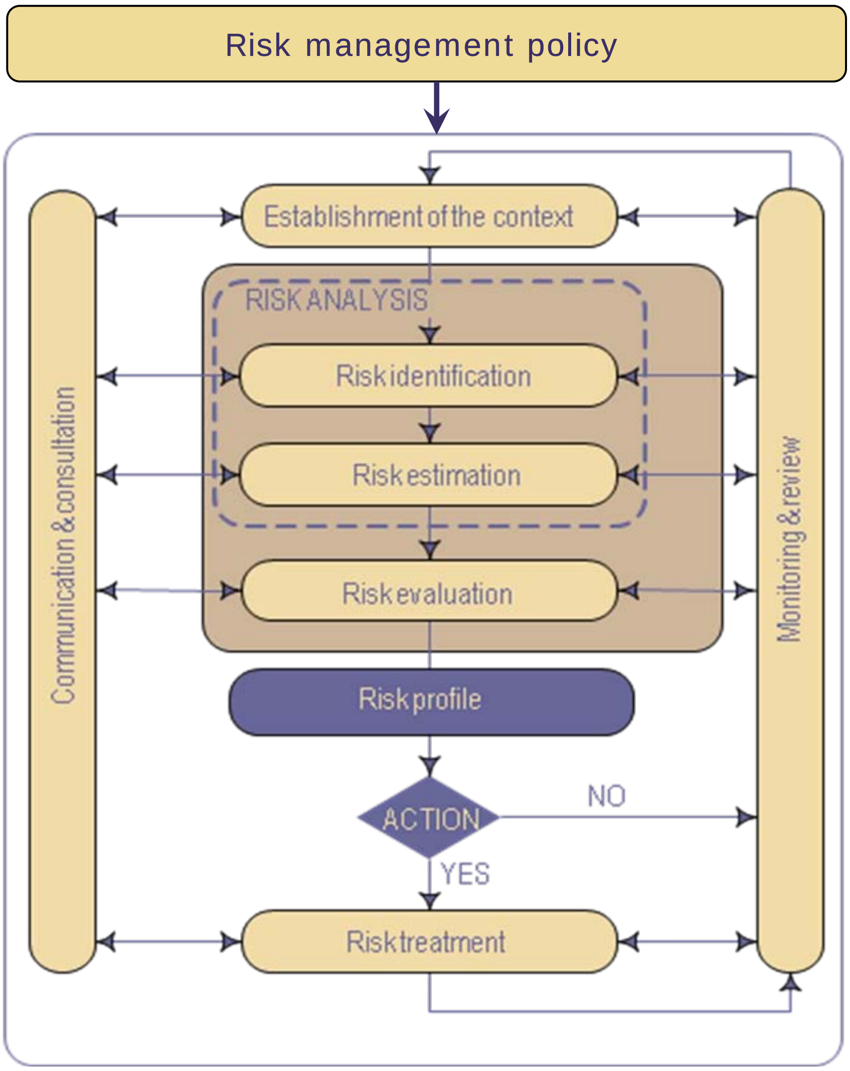

Figure 1 : Risk management process according to ISO/FDIS 31000

1.2 Objectives of the document

This document defines **guidelines** to be followed in applying a risk management approach. The different **steps of the risk management process** are described and some **tools** and **key questions** are outlined to facilitate the process.

Roles and responsibilities in managing the risks of the CO_2 project are also presented.

This Deliverable presents methodological aspects of the Risk Management process. Applications to Heletz site will be described in Deliverable D094.

1.3 Structure and content of the report

Table 1 : Structure and content of the report

N°	Titre	Description
/	Executive summary	Summary of major information and results included in the risk management process
1	Introduction	Description of the context, the objective and the content of the report
2	Risk management policy	Description of the project objectives, the roles and responsibilities of the project team in managing risks
3	Communication and consultation	Description of the communication and consultation within risk management process
4	Establishment of the context	Description of internal and external context, risk management context and definition of the risk criteria (probability, severity and risk level)
5	Risk identification	Description of the process of identification of the risks, definition of some methodologies (FMEA, faults and events trees…)
6	Risk estimation	Description of the process of quantification of the risks (estimation of probability, severity and risk level for each risk)
7	Risk evaluation	Description of process of comparing risk level to risk criteria, and prioritisation of the risk
8	Risk treatment	Description of the process of identifying treatment options for the unacceptable risks, and establishing a risk treatment plan
9	Risk monitoring, review and reporting	Description of the goal of the step, reference period and process

2 Risk management policy

2.1 Aims and content of the risk management policy

According to the reference process for risk management described by the international standard version ISO/FDIS 31000, the risk management policy should:

- Clarify the project objectives and commitment for risk management
- Specify the link between the risk management policy and the project objectives, and rationale for managing risk
- Specify the processes, methods and tools to be used for managing the risk
- Identify the roles and responsibilities in the project team for managing risks

- Describe the way in which risk management performance will be measured and reported
- Establish the project commitment to the periodic review and verification of the risk management policy

Management and communication will ensure that this policy is understood, implemented and maintained at all levels of the organization.

Some of the elements which may be specified in the risk management policy are described in more detail in the following paragraphs:

- The reference period
- The area of application of the policy
- The general risk management process
- The roles and responsibilities of the project team in managing risk, and
- The reporting and measurement performance of the risk management

2.2 Reference period

The reference period depends on the whole duration of the CO_2 project and its context (for example, system elements and interactors which will be described in the different sections below). It is established according to the implementation of the project strategy.

The reference period of a project is usually divided into three parts: the pre-operational phase, the operational phase and the post-operational phase, as presented in Figure 2.

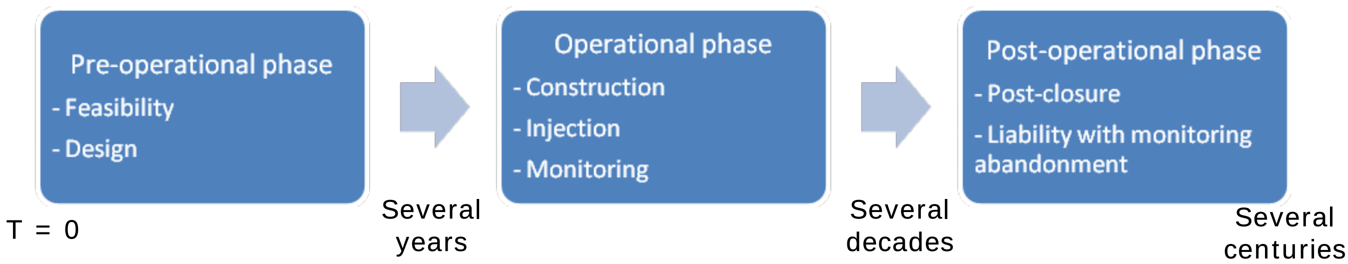

Figure 2 : Illustration of the reference period

2.3 Field of application

The field of application has to define the main concern of the risk management policy. It will simplify its application on the project by defining the **main stakes** (interests or issues in the operation), **responsibilities** and **rules** that have to be taken into account.

The field of application of the risk management policy could also define **the type of risks to be considered** in the risk management process. The MUSTANG project focuses on subsurface technical risks and their potential technical consequences on the CO_2 project as well as on internal and external stakeholders. The Risk Management process could also be applied to the organisational aspects of projects.

Different risk families can be identified within the risk management process, for example risks regarding storage activities, injection strategy, and human health and safety.

It should be noted that the definition of the field of application can evolve during the project.

2.4 Risk management process

Risk management is the process which aims at identifying all the potential risks relating to the CO_2 project, organizing them in order to define which ones are critical and outlining actions that may be taken to lower these risks. It consists of a series of steps presented in Figure 1 and described in more details in the following paragraphs.

The different steps of the risk management process are the following:

- Communication and consultation (see section 3)
- Establishment of the context (see section 4)
- Risk assessment
    - Risk identification (see section 5)
    - Risk estimation (see section 6)
    - Risk evaluation (see section 7)
- Risk treatment (see section 8)
- Risk monitoring and review (see section 9)

2.5 Roles and responsibilities in the CO_2 project

An organisational chart of the project team must define the hierarchy among the members of the team and the relationship between them. Figure 3 presents an example of such a chart, and the following paragraphs describe the roles and responsibilities of the team members.

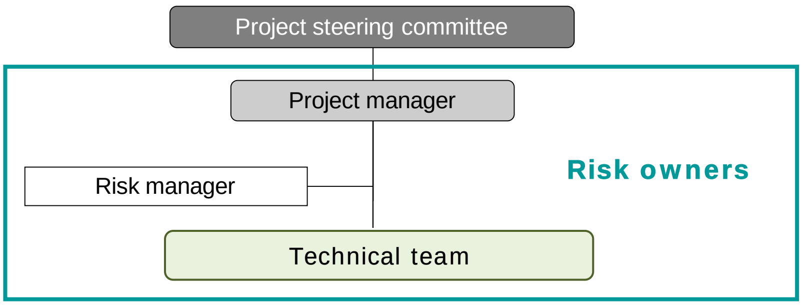

Figure 3 : Example of an organisational chart required for the risk management within a project

- Project steering committee

The roles and responsibilities of the project steering committee are to ensure that the risk management policy is integrated, understood, applied and documented. It must agree and mandate changes to the policy which may be proposed by the project team and mandate the project manager to apply the risk management policy. The committee must also verify and confirm the risk perimeters that have to be managed within the CO_2 project by the project manager, as defined project team.

- Project manager

The roles and responsibilities of the project manager are to apply the risk management policy within the CO_2 project according to the definition drawn up by the project team and to report and communicate a complete overview of the risks and the risk perimeters to the project steering committee. He/she delegates the application of the risk management process to the risk manager, approves risk treatment plans and risk management reports elaborated by the risk manager and reports unmanageable risks to the project steering committee. The project manager is also in charge of communication with the authorities but can delegate this task to communication or legal services.

- Risk manager

The roles and responsibilities of the risk manager are to assist the project manager in all risk-related tasks and to ensure that the risk management process is properly implemented within the CO_2 project. He/she must provide a detailed view of all risks to the project manager and support the risk owners in identifying, estimating, evaluating and compiling risks and recommending risk treatment actions. Finally, the risk manager collects relevant information regarding risks, formulates the risk assessment report and assists in monitoring progress on risk treatment plans.

- Technical Team

The roles and responsibilities of the technical team are to notify the hierarchy or the risk manager each time they identify a new risk. The technical team is completely involved in the risk management process and is strongly encouraged to supply proper risk descriptions and their assessment. The technical team is also encouraged to submit proposals for treatments of risks related to their particular area of knowledge.

- Risk owners

The risk owners could be members of the technical team or the risk manager. They are responsible for risks associated with their respective area of knowledge, and work closely with the risk manager in identifying, estimating, evaluating and proposing risk treatment actions. The risk owners must collect, report and register risks, propose risk treatment and implement treatment measures if needed. They are responsible for managing risks linked to their work processes (delegated by the project manager) and for monitoring risk evolution related to their scope of work. They must also notify the manager(s) or the risk manager of any risk.

2.6 Reporting and measuring the risk management performance

The objectives of reporting and measuring the risk management performance are to ensure **operational implementation** of the risk management process, to ensure that **risk exposure** is known and controlled, and to establish **performance measures** in order to periodically assess progress and deviation from the risk management policy. This process also allows to **periodically review** whether the risk management framework and policy are still appropriate and effective given the internal and external context (in case of any modification to the context) and allows to **report on the risk management progress**.

2.6.1 Performance measures

The performance measures or indicators are used to evaluate the impact of the risk management process itself on the overall performance of the project. The aim is mainly to ensure that the Risk Management process has a positive impact on the project (decrease of risk levels or increase of risk level control). These measures or indicators have to be reviewed at least once a year during the project performance review to show the evolution of the risks in the project. Risks can evolve because new data are available, new risks are identified, an effective implementation of mitigation actions is performed, etc. These performance measures should be included in the risk reports.

The following 2 **performance measures** (or key performance indicators) are identified:

- The evolution of risk profiles over time:
  A risk profile is a representation of the risks identified in the project and ranked in risk matrix (cf. section 6).

- The impact of the action plan on the risk profile:
  This action plan defines risk treatment actions to be implemented regarding risks which have been identified as critical (above the acceptability level). This action plan aims at mitigating the risks; the risk level after treatment is called risk residual.

2.6.2 Reporting pathway

The reporting pathway aims at defining the rules of the project team in the reporting process. Each member of the team needs to be involved in the report.

Some examples of reporting and informing pathways are given below:

- The project manager has to periodically report to the project steering committee.

- The risk manager has to collect information among the subsystem leaders; he can consult the team members regarding risk treatment and has to inform the project manager on risks in a periodical report, even if no change has been noticed.

- The subsystem leaders have to inform the risk manager about risks.

The **periodicity of the reporting process must be defined in the risk management policy in terms of the** situations that may require follow up.

3 Risk communication and consultation

Communication and consultation are essential components **for each step of the risk management process**. Communication and consultation aims at identifying who should be involved in the assessment of risk (including identification, analysis and evaluation) and should engage those who will be involved in the treatment, monitoring and review of risks (see section 4.1.2).

It is therefore necessary to develop a communication plan for both internal and external stakeholders at the initial stage of the process. This plan should address issues relating to the risk management process.

Effective **internal and external communication** is important to ensure that those responsible for implementing risk management and those with vested interests understand the basis on which decisions are made and why particular actions are required.

Since stakeholders can have a significant impact on the decisions made, it is important that stakeholders are clearly identified and informed throughout the risk management process. Their **perceptions of risk** have to be clearly explained and documented to ensure that it is shared and understood by all persons involved in the risk management process.

Communication about risk helps the project team establish its attitude towards risk.

The essential elements of a **communication and consultation plan** include:

- The objectives of the communication plan
- The participants who need to be included, for example:
  - Stakeholder groups and individuals
  - Specialists or experts
  - Communication team
- The perspectives of the participants that need to be taken into consideration
- The communication methods to be used
- The evaluation process to be used

To develop good practices in communication, a procedure should be established to define information exchange in the project team. Reporting pathways established in section 2.6 are the starting point. Then, different communication methods can be chosen such as newsletters, forum, workshops, databases, tools for reporting the risks (Excel sheet, dedicated software like SIMEO^{TM}-ERM, Word document …).

The periodicity of the communication varies with the function of information type; it must be defined by the project team in the risk management policy.

4 Establishment of the context

4.1 Objectives of context establishment

The definition of the context of the project supports the risk assessment process, as it defines the perimeter of the risk management and the elements to consider in the process.

The context of the risk management process will vary according to the needs of the project. It can involve, but is <u>not limited to</u>:

- Defining the **scope**, as well as the extent of the risk management activities to be carried out, including specific inclusions and exclusions
- Defining the **activity**, process, function associated to the project in terms of **time and location** as well as their **goals and objectives**
- Defining the **way performance** is evaluated in the risk management
- Identifying and specifying the **decision process** (who, when, for which purpose, what...)

The definition of the context of a project must include the elements listed below, which are described in more details in the following paragraphs:

- The **scope** of the project: environment of the project, storage properties, etc.;
- The **internal and external entities** involved in risk management;
- The **risk criteria** to evaluate the significance of the risk.

It's also important to point out that good quality information is essential in the risk assessment process. The data collection step is one of the most important steps in the Risk Management process, and must be started early in the process.

4.1.1 Scope of the study

The first step to define the scope of the risk assessment is the identification of the system to consider, and definition of the subsystems composing the system.

It is also necessary to define the type of risks that will be considered. These risks must be included in the different risk families defined previously in the field of application of the risk management policy (see section 2.3).

4.1.1.1 Define the system

To define the scope of the CO_2 project, all the elements and interactors of the project must be defined. Figure 4 and the following paragraphs (section 4.1.1.2 and section 4.1.1.3) describe what these elements and interactors could be. Here, we focus only on technical aspects.
Note that the elements and the interactors depend on the system or subsystem considered.

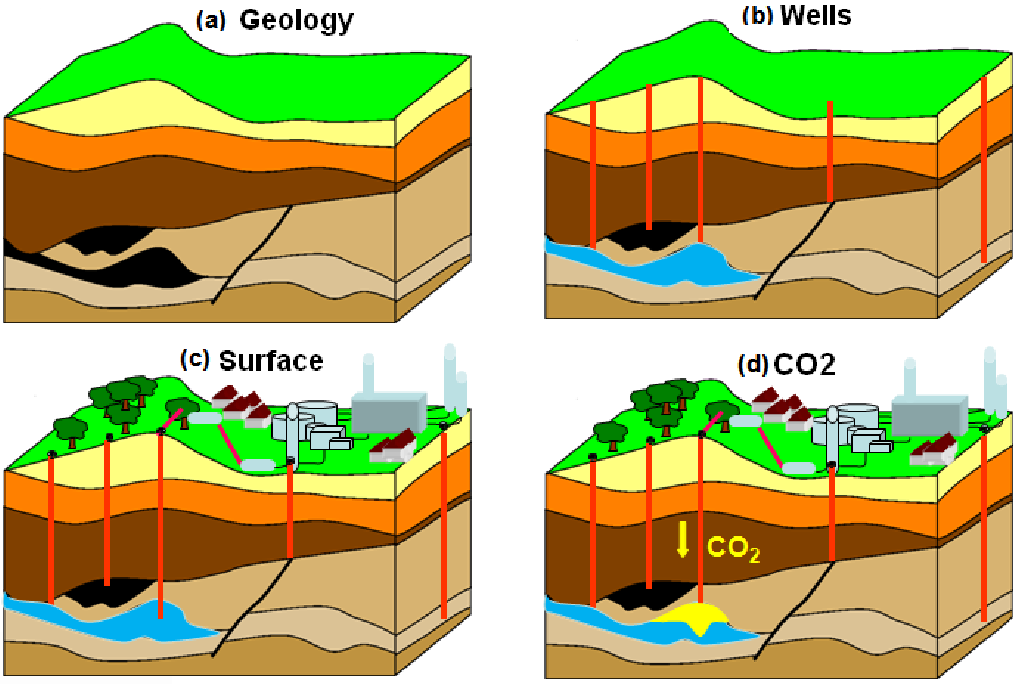

Figure 4 : Example of pattern of the elements and interactors in a CO_2 storage project

4.1.1.2 System elements

For a CO_2 storage project, the system elements could be included in two main groups: the **geology** which defines the underground layers around the project injection well(s) (cap rocks, reservoirs, overburden, aquifers...) and the **wells** which include all the wells in the area (injection wells, Oil&Gas producer wells, water disposal wells, monitoring wells...).

- Geology (Figure 4, (a))

Geology could be divided into different sub-systems such as cap-rocks, CO_2 storage reservoir, faults, etc. For these sub-systems, information needs to be collected to describe them. For example:

- Stratigraphic data (locations, depths, directions, dip...)
- Petro-physical characteristics (permeabilities, porosities, heterogeneities, ...)
- Hydraulic data (connections between reservoirs, water displacement...)

- Wells and Injection strategy (Figure 4, (b))

Wells and injection strategy are the other part of the system elements of the project. To describe these elements certain information should be collected such as:

- Number and characteristics of the wells
- Well integrity data (schemes, drilling reports...) from workovers, monitoring data...

4.1.1.3 System interactors

The system interactors interact with the system and can have an effect on the system behaviour. For a CO_2 project the system interactors can be split in three main interactors: the **surface**, the **geology** and the **injected fluid** (the **CO_2** and any additional substances like water, or impurities).

- Surface and associated interactors (Figure 4, (c))

If focussing on the storage part of a CCS project, the surface is involved in the project description as an interactor with the global system as it can be impacted if CO_2 leaks to surface. The description of the surface includes: surface facilities; human activities and near environment.

For example, the following data could be collected to define the interaction between the surface and the project:

- CO_2 transport (pipelines...) and injection facilities components (compressors...)
- Other facilities in the vicinity of the site
- Population areas around the site; workers density

- Geology and associated interactors (Figure 4, (a))

The geology and its components can be integrated in the interactors of the system as they can impact the system's components over time, in particular formation fluids and the geological formations (mechanical, chemical attack …).

The data collection made to define geology as an element will be also used for the definition of the geology as an interactor, for example:

- Mechanical characteristics
- Hydraulic data

Note: In the description of the system, geology is involved as a component which has some functions but also as an interactor as it is part of the global system regarding CO_2 storage and as it can interact with the system itself. Formation fluids pressure or formation deformation can impact some of the system elements like wells and impact their integrity.

- CO_2 (Figure 4, (d))

The injected gas, CO_2, is one of the main interactors in the studied system. It needs to be clearly defined by collecting data, for example:

- CO_2 properties (temperature, pressure, impurities, water content…)
- CO_2 plume extent (transport, diffusion, fluids interactions, overpressure...)
- Modelling results available on CO_2 migration and behaviour (deterministic and/or probabilistic simulations, assumptions considered to perform these simulations…)

4.1.1.4 Outcome: functional analysis of the system

The risk management process hinges on a functional description of the subsurface described in terms of:

- **Components or subsystems** that form/make up the geology and the wells that make up the system;
- **Functions** or roles to be met by the system and its subsystems.
- **Interactors**: external entities which interact with the system components.

An example of a functional model is shown in Figure 5; it constitutes the basis of the functional analysis leading to the risk identification. The functions identified in Figure 5, are the following:

- ***F1***: To ensure CO_2 injectivity
- ***F2***: To ensure CO_2 storage capacity
- ***F3***: To resist geological formations deformation
- ***F4***: To resist the formation fluids pressure
- ***F5***: To resist the CO_2 pressure
- ***F6***: To ensure a hydrostatic pressure level in the geological system

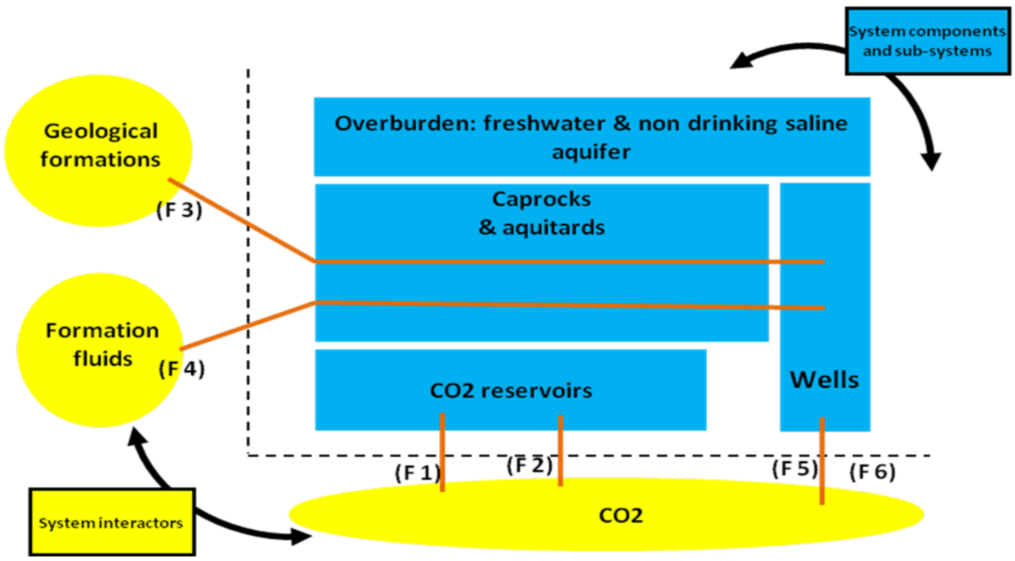

Figure 5: Example of functional representation (copyright OXAND)

4.1.2 Internal & external entities

The second step for **establishing the context** is to define the internal and external entities of the CO_2 project. The relationship between the CO_2 project and its environment (internal and external) must be taken into account for identifying and assessing risks.

The identification and definition of internal and external entities will support the identification of **stakeholders**. To ensure that no stakeholders are forgotten, both internal and external contexts are defined and linked to the subsystems by means on a functional analysis based on a systemic approach.

4.1.2.1 Internal entities

Internal context is the internal environment in which the project seeks support to achieve its objectives, including project management, risk management, QHSE, IT, human resources. Internal context is anything within the project that can influence the way in which a project will be managed, and therefore that could lead to risk.

The understanding of the internal context can include, for example:

- The capabilities, understood in terms of **resources** and **knowledge** (e.g. time, people, processes, systems and technologies)
- **Information systems**, **information flows**, and **decision making processes** (both formal and informal)
- Internal **stakeholders**
- **Standards** and **reference models** adopted within the project

4.1.2.2 External (strategic) entities

External context is the external environment in which the project seeks support to achieve its objectives.

The external context can include, but is not limited to:

- The **cultural, political**, **legal**, **regulatory**, **financial**, **technological, economic**, **natural and competitive environment**, whether international, national, regional or local
- **Key drivers** and **trends** having impact on the objectives of the project

4.1.3 Objectives of the project

The definition of objectives is one of the important steps of the establishment of the project context. The project team needs to identify the activities, the media and the organisations which can be affected by any risk.

Examples of objectives for a CO_2 storage project (non-exhaustive list):

- Technical aspects: capability to transport and to safely store CO_2
- Health and safety aspects: ensure that the technical staff or the local population will not be endangered by any of the activities related to the CO_2 project
- Public outreach/confidence aspects: demonstrate to the public its ability to lead such a project and the benefits of such project to reach public confidence
- Financial aspects: achieving the CO_2 project within the agreed budget
- Compliance with authorities' requirements

4.1.4 Key performance indicators: risk criteria

This step uses the project **objectives** to identify **key performance indicators** that will be used to estimate, evaluate and treat risks.

In this step, the **risk criteria** will be defined and used to evaluate the importance of risk. The criteria must reflect the project values and objectives. ***The criteria should continually be reviewed***.

Risk criteria could be defined according to expert opinions, interviews with stakeholders and actors, or by brainstorming with the project team.

This good practice establishes that risk criteria are identified and defined before the risk assessment, i.e. during the establishment of the context, and are impartial and not influenced by the risk identification. Nevertheless, during the risk assessment, especially during risk estimation and evaluation, the criteria can be adjusted.

4.1.4.1 Probability grid

The definition of the probability grid is defined with the knowledge of the project team and eventually with expert opinions.

When possible, a quantitative estimation has to be used (example: probability of CO_2 leakage, probability of mechanical failure, etc.). Then, this quantitative estimation is converted to a probability level on the basis of the probability grid used for the project; an example of such a grid is presented in Table 1.

Table 1 : Example of probability grid

Description	Probability over CO_2 storage period[1]	Level
Unlikely: very rare.	< 0.001 %	A
Possible: can be observed, feared.	[0.001 % ; 0.1 %]	B
Likely: already observed, will probably occur.	[0.1 % ; 10 %]	C
Very likely: expected to occur (almost certain).	> 10 %	D

[1] Provided as an example

4.1.4.2 Severity grid

The severity levels indicate the magnitude of the impact if a failure occurs. The definition of the severity grid is also defined with the knowledge of the project team and with expert opinions. It is the preliminary step of the consequence grid elaboration. Table 2 is an example of a severity grid with 4 levels.

Table 2 : Example of severity grid

Description	Level
Minor	1
Medium	2
High	3
Very high	4

4.1.4.3 Consequence grid

The consequence grid provides a description of the different **severity levels for each project objective identified**. The objectives are expressed in using performance indicators to illustrate the different level of impact (severity levels).

This grid is the link between the project objectives (section 4.1.3) impacted and resulting severity level (section 4.1.4.2). It must be developed closely with the project stakeholders, and eventually with expert opinions. When the objectives of the project and the key indicators (severity levels) are defined, each project stakeholder defines the minimum and maximum severity levels regarding each objective and then proceeds to complete the intermediate levels.

4.1.4.4 Risk matrix

The risk matrix shown in Figure 6 is also named a criticality matrix. The criticality “C” represents a mathematical relation between the severity and probability level.

Mostly, criticality is equal to the sum of the severity level and the probability level (the probability levels expressed in letters are translated into numbers, i.e. A= level 1, B= level 2, C= level 3, D= level 4...):

C (Criticality) **= S** (Severity) **+ P** (Probability)

The higher the criticality level, the higher the risk.

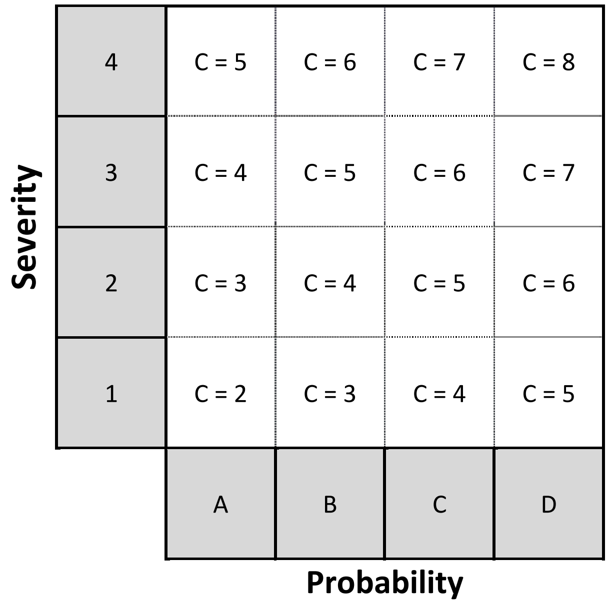

Figure 6 : Illustration of risk matrix

4.1.4.5 Level of acceptability

The level of acceptability is the level used to decide if treatment actions or monitoring actions are required. The definition of the level of acceptability depends on **each objective** identified by the project team. This level is defined according to technical, financial, legal, social and other criteria. It is defined within the project and reflects the appetence or aversion of risks by the company.

Acceptability level of risk delimits 2 zones: a zone where risks are **critical** (i.e., not acceptable) and a zone where risks are acceptable. For example, if the acceptability level is a criticality level of 6, the critical risks are those with a **criticality equals to 7 or 8**. An example of an acceptability level of risk is represented by the red line in Figure 7.

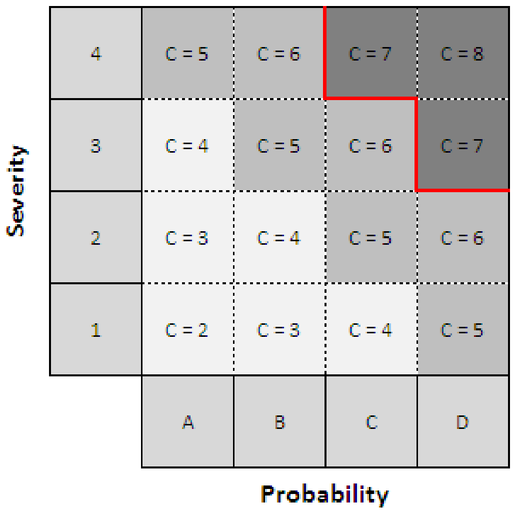

Figure 7 : Example of the level of acceptability risk equal to 6

5 Risk identification

5.1 Aim

The aim of risk identification is to develop a list of risk sources and events that might have an impact on the achievement of one or several objectives of the project (identified in the context of the project, section4.1.3).

This list must be comprehensive for the sake of the project, and it has to include all the risks regardless of if their risk level is acceptable or not, and whether or not their source is under control.

Risk identification is the first step of risk analysis (Figure 1).

5.2 Description of the risk identification process

5.2.1 General methodology

A comprehensive identification based on a well-structured and systematic process is essential to ensure that all risks are considered. Different methodologies can be used to identify risk: FMEA (Failure Mode and Effects Analysis), Fault tree analysis, Event tree analysis, or FEP (Features, Events and Processes) analysis. We propose to use the F.M.E.A., a systemic approach that focuses on the function to be fulfilled by the subsystems and components. In this process, the list of risks is based on the failure modes that might prevent, degrade or delay the achievement or performance of the objectives of the CO_2 project; it uses the results of the establishment of the context detailed in Chapter 4 (Figure 1):

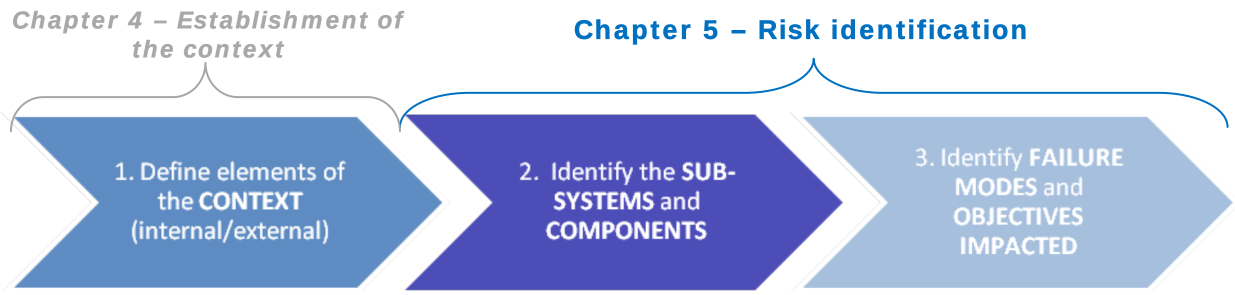

Figure 8 : Risk identification process

For each subsystem and component (outlined in section 4, Establishment of the context), the **failure modes**, their **causes** and their potential **impacts** (or consequences) on the objectives are defined.

5.2.2 Outcome

The outcome of the risk identification step is a **comprehensive list of risks** related to the project **compiled in a risk register**. This risk register is the input for the risk estimation step.

6 Risk estimation

6.1 Aims

The aim of this step is to assign to all the risks identified in the "identification" step a level of:

- Probability;
- Severity; and
- Criticality.

To establish these elements, probability, severity and consequence grids are used, which were defined previously in the establishment of the context (see section 4.1.4).

6.2 Description of the risk estimation process

6.2.1 General methodology

Risk estimation is the second step of risk analysis (Figure 1).

The input data for this step is the list of risks established by the risk identification process.

Risk estimation is the step where the risk levels are estimated. The risk level, or criticality, is a combination of (Figure 9):

- A **severity level**: the magnitude of the impact of a failure mode on the identified objectives. The definition of the different severity levels is established by defining the consequence grid (section 4.1.4.3);
- A **probability level**: the occurrence of the failure mode. The definition of the different probability levels is established by defining the probability grid (section 4.1.4.1).

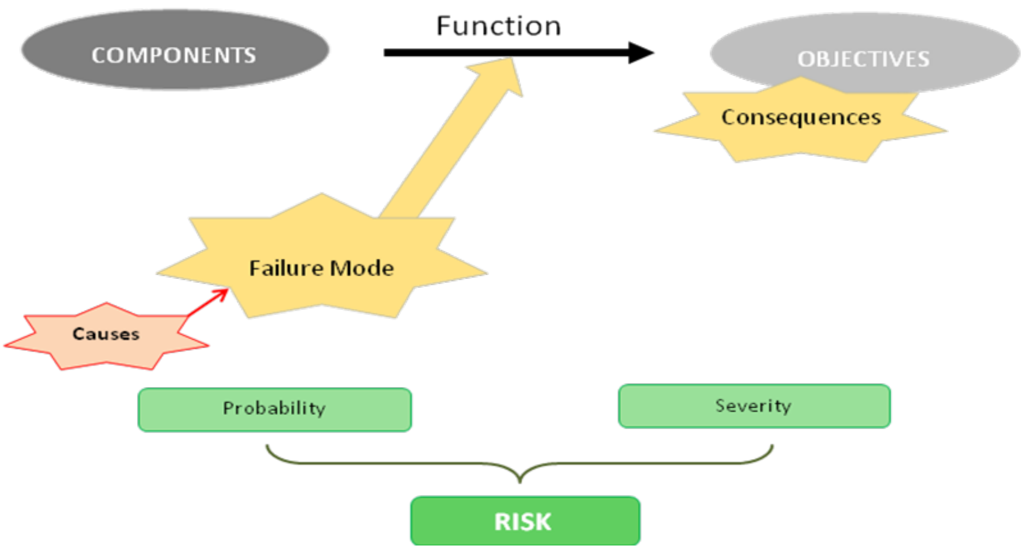

Figure 9 : Pattern of risk estimation

Probability and severity levels are defined in conjunction with the project stakeholders reflecting the project values and objectives.

Estimation can be **qualitative or** (preferentially when possible) **quantitative** depending on the type of failure mode and its impacts and on the associated performance indicators:

- **Quantitatively**, using statistical analysis, modelling and simulations;
- **Qualitatively**, on the basis of past records, experience, expert's opinions or literature review.

A failure mode can have multiple consequences and can impact various objectives, thus each risk must be estimated for every threatened objective.

Figure 10 highlights the methodology for estimating risks:

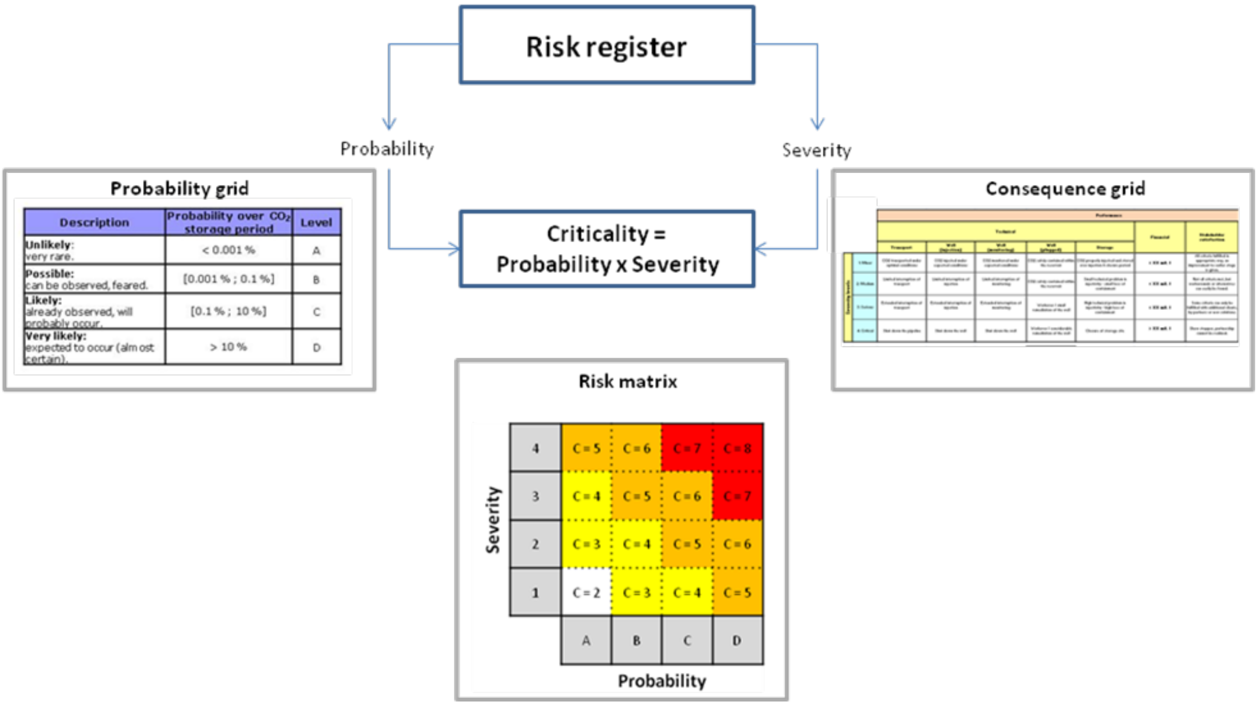

Figure 10 : Method for estimating risks

6.2.2 Outcome

The resultant outcome of the "risk estimation" step is **risk mapping** where each risk is plotted by means of its criticality value, represented by the severity level (y-axis) vs. probability level (x-axis) of a failure mode (see Figure 11).

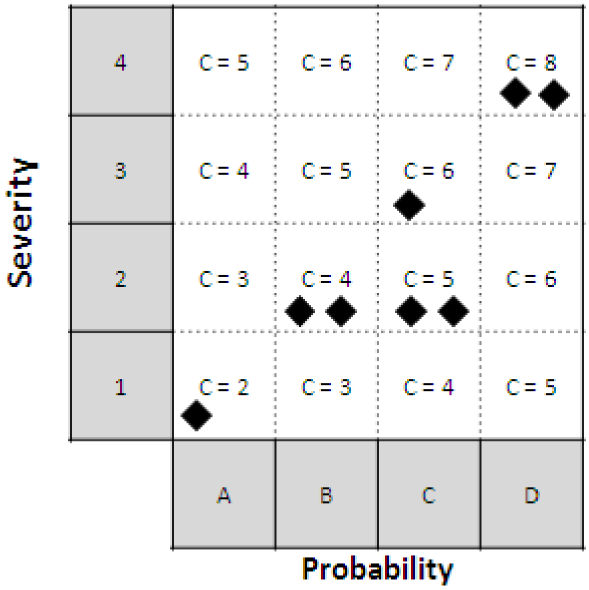

Figure 11 : Illustration of risk mapping, with 8 risks plotted

7 Risk evaluation

7.1 Aims

The purpose of **risk evaluation** is to define which risks are critical in terms of the project and hence assist in identifying the risks that need to be mitigated in order of priority. Risk evaluation involves comparing the levels of risks (criticality) identified during the risk analysis process to risk criterion (risk criterion = level of risk acceptability). The risks that should be treated are those for which the risk level for at least one of the project stakes (interests or issues in the operation) is above the acceptability level (according to the level of acceptability defined in section 4.1.4.5).

7.2 Description of risk evaluation process

7.2.1 General methodology

Risk evaluation is the third step of risk assessment. The input data for this step are the outcome of the risk analysis, i.e. the list of the risks with a level of severity, probability and criticality.

The purpose of risk evaluation, based on the outcomes of risk analysis, is to make decisions about which risks require treatment and to define priorities between treatment actions.

7.2.2 Outcomes

The final outcome of a risk evaluation is a **prioritised risk register** recommending further action. In addition, the risk evaluation yields a risk matrix in which risks are ranked: risks with the higher criticality levels should be treated with priority.

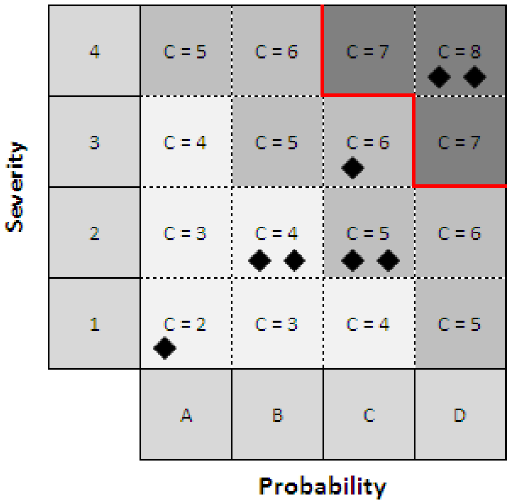

Figure 12 : Risk matrix with 2 critical risks that have to be treated

8 Risk treatment

8.1 Aims

Risk treatment aims at defining and implementing options for lowering the risk level of the risks that were considered critical at the evaluation stage so that the residual risk attained complies with the project risk criteria.

8.2 Description of risk treatment process

8.2.1 General methodology

Risk treatment defines the processes of selection and implementation of measures to modify the risk. Risk treatment is based on the outcomes of the risk evaluation which ranked the risks that have to be treated by priority.

Risk treatment involves:

(a) Identifying the range of options for treating risk:
- selecting a short list of actions among treatment options and applying those options to critical risks;

(b) Assessing the options:
- **definition** (in terms of cost, nature, and duration) of the actions

(c) Preparing and implementing risk treatment plans:
- **planning** of risk treatment options

8.2.2 Treatment options

Before a risk can be effectively treated, it is necessary to understand its cause, in order to identify and select the appropriate actions.

Possible risk treatment actions are defined by the project team during review meetings and the selection of treatment options is made by project managers or by others delegated by the project manager.

Treatment options can include the following:

- **Avoid** the risk by deciding not to start or to stop any activity that contributes to the risk (***terminate the risk***)
- Change the nature and magnitude of probability (**prevention, monitoring**) (***lower probability of the risk***)
- Decrease the severity of a risk (**protection, curative actions**) (***lower consequence(s) of the risk***)

Other options can be chosen, such as to t**olerate** the risk by deciding to start or to stop any activity that contributes to the risk (***tolerate the risk***).

8.2.3 Assessing risk treatment options

Selection of the most appropriate treatment option involves balancing the cost of implementing each option against the expected benefits.

A **cost-benefit analysis** is required to justify if the cost of any particular method of treating a potential risk is appropriate, and, if so, possibly identify the order of priority in which individual risk treatments should be implemented. The expected benefit from treatment options (i.e. reduction of severity, probability and total risk level) and total cost of treatment option constitute part of the analysis.

The **residual level** of risk represents the new level of risks (probability, severity) assuming treatment action(s) has been successfully applied. The residual level has to be estimated with cost/benefits assessment. This residual risk level should be monitored and reviewed to control its evolution over time.

8.2.4 Preparing and implementing risk treatment plans

In implementing a risk treatment plan, a strategy is formulated using for example: proposed actions, benefit expected to be gained (i.e. residual risk), budget allocation, resource requirements to treat the risk, and planning.

8.2.5 Outcomes

The outcomes of the risk treatment are:

- A list of treatment actions associated to each risk, with actions, resources and planning: the **risk treatment plan**;
- A new **risk matrix** which takes into account the effect of the treatment actions. The risks are plotted in the risk matrix after treatment (for actions which needed to be treated), they have new severity and/or probability levels.

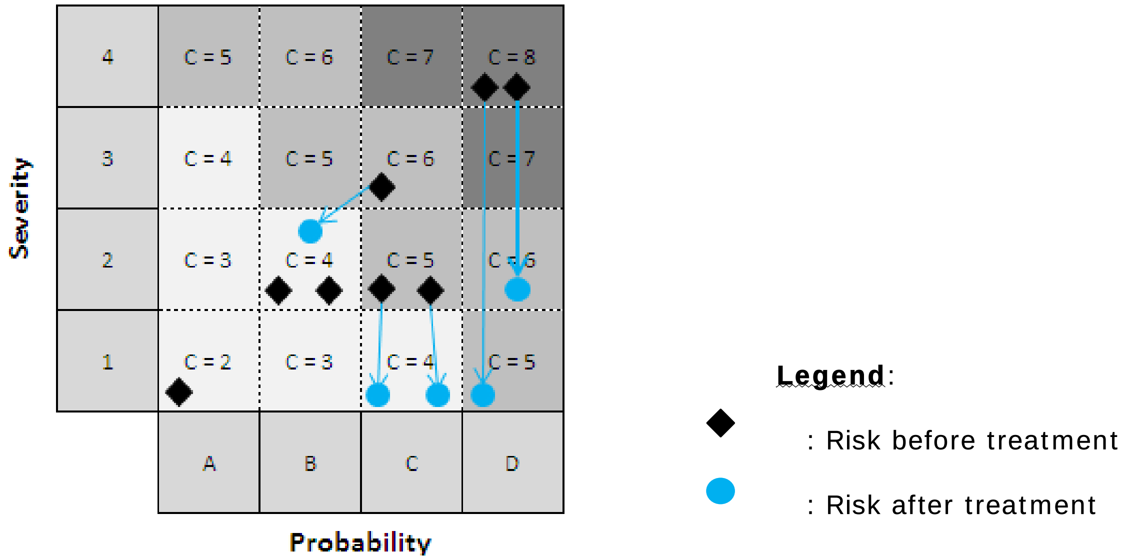

Figure 13 : Risk matrix after treatment actions

9 Risk monitoring, review and reporting

9.1 Aims

Risk monitoring allows risk evolution to be tracked over time. In an operational way, risk monitoring is focused on processes and causes of the risks. The purpose is to ensure that risk is known and controlled. Monitoring will also ensure that risk treatment actions are effective.

Monitoring, review and reporting is an essential and integral step in the risk management process, it takes place throughout the risk management process (see Figure 1).

9.2 Description of risk monitoring, review and reporting process

9.2.1 Risk monitoring

Risks need to be monitored to ensure that changing circumstances are recorded and duly reported and analysed. Monitoring actions must be continuous and need to be reinforced during particular actions or phenomena. The periodicity of risk monitoring has to be defined in the risk management policy.

Very few risks will remain static. Therefore, the ***risk management process needs to be regularly repeated*** so that identified risks are up-to-date and the new risks are captured in the process.

9.2.2 Risk review

Risk review establishes continuity and improvement of the whole risk management process. This stage helps to identify possible deviation from the objectives defined by the risk management policy. It also evaluates the benefits of the risk treatment actions implemented.

Periodical re-assessment of the risks must be performed to control risk changes and residual risk levels. After treatment actions, the risks must be re-assessed to identify if the objectives of the treatment action have been achieved.

9.2.3 Risk reporting

Risk reporting constitutes a necessary support for monitoring and reviewing risks. It relies on a functional risk management tool that provides risk reports.

Risk reporting is important to ensure an efficient communication and traceability between all persons involved in the process.

10 References

Several organizations and companies have already done a lot of work on risk assessment regarding CO_2 storage and other fields like nuclear waste. Within the MUSTANG project, these works will be integrated in the recommendations and will be used as references.

Furthermore, the following documents have been used to establish this report:

- **Standard and international guidelines**

AS/NZS 4360:2004 (2004) – Risk Management, Australian / New Zealand Standard

ISO/FDIS 31000 (2008) – Risk Management, Principles and guidelines, International Standard

ISO/IEC Guide 73 (2002) – Risk management – Vocabulary – Guidelines for use in standards, International Standard

ON Regel 49000 (2004) – Gestion du risque pour organisations et systèmes – Vocabulaire et principes de base, http://www.on-norm.at, Osterreichisches Normunginstitut, Austria.

OSPAR Convention, OSPAR Guideline for risk assessment and management of CO2 in sub-seabed geological formations, 2007-12

- **Risk assessment applied to international projects**

FutureGen Project Environmental Impact Statement, Final Risk Assessment Report, October 2007, http://www.futuregenalliance.org

IEA Greenhouse Gas R&D Programme, 4th Risk Assessment Workshop, 2009/07, July 2009, http://www.ieaghg.org

IEA Greenhouse Gas R&D Programme, 2009 A review of the international state of the art in risk assessment guidelines and proposed terminology for use in CO_2 geological storage, 2009/TR7, December 2009, http://www.ieaghg.org

IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [B. Metz, O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)], http://www.ipcc.ch

Savage, D. Maul, P. R. Benbow, S. Walke, R. C., A generic FEP database for the assessment of long-term performance and safety of the geological storage of CO2 – Quintessa, June 2004, http://www.quintessa.org/co2fepdb/PHP/frames.php