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GERICO: A database for CO_2 geological storage risk management

Thomas Le Guénan[a]*, Jean-Charles Manceau[a], Olivier Bouc[a], Jérémy Rohmer[a], Alexandra Ledoux[a]

[a]*BRGM, 3 avenue Claude Guillemin BP36009, 45060 Orléans Cedex 2, France*

Abstract

Before the full implementation of CO_2 capture and storage, a demonstration of its safety is needed through the implementation of reliable risk management methods. One important aspect of risk management is the development of mitigation measures that prevent any risk to the environment or human health. This paper presents a database that includes a set of risk mitigation measures, their description and main properties, and references. They are organised in connection with a detailed approach of risk events developed into bow-tie diagrams by BRGM. The goal of the database is to help the setting up of corrective measure plans that will be mandatory for all projects under the European directive on CO_2 storage.

Keywords: CO_2 geological storage; risk management; mitigation measures; safety; database

1. Introduction

CO_2 capture and storage (CCS) is seen as a promising technology to achieve large reductions in atmospheric greenhouse gas emissions. The demonstration of the safety of the storage stage is needed before the full implementation of this technique: one important aspect is to study and to take an inventory on possible risk mitigation measures. In particular, the European directive on CCS requires that an operator submits a corrective measure plan in order to obtain the necessary storage permit. The application for the storage permit must also contain a description of measures to prevent potential "significant irregularities" [1]. Consequently, operators willing to prepare a permit application for a future storage project and authorities that will have to review these applications need to know potential risk mitigation measures for all risks identified for geological storage of CO_2.

A first overview of potential mitigation measures was given by Benson & Hepple [2], and was largely taken up by the IPCC special report [3]. Other references on this subject include the publications by IEA-GHG [4] and Perry [5]. Even though these references are very useful for giving an overview of different measures, they only provide a general list with little or no description of the measures. Moreover, these measures are presented according to a precise purpose but are not integrated in a full risk scenario management strategy. The simple inventory of potential measures thus leads to two main gaps: first, the precise identification of what are the best options for mitigating a

* Corresponding author. Tel.: +33-2-38-64-38-53; fax: +33-2-38-64-35-94.
E-mail address: t.leguenan@brgm.fr.

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specific scenario is difficult; second, when an operator can set-up several different measures for the same final purpose, he needs more specific knowledge on each option so he can make the best decision. We thus developed a database, entitled GERICO, containing risk management measures for CO_2 geological storage, with the goal of bridging those two main gaps. In particular, the first gap was tackled by developing, for a variety of risk events, bow-tie diagrams combined with safety barriers. The second gap was tackled by developing each measure into individual sheets with descriptions and useful parameters.

2. Methodology for the conception of the risk management database

2.1. Terminology

As briefly mentioned above, our global approach is based on bow-tie diagrams (figure 2). These tools are widely used in industrial and technological risk management and represent graphically the *risk sequences* (or *scenarios*) that might lead to *undesirable effects* (or *impacts*). Structurally speaking, these diagrams are centered on a *major risk event* (or *top event*); its possible *causes* are given upstream of the diagram as well as the possible *consequences* downstream. Major risk events, causes and consequences are all represented as boxes that we name *episodes* and the combination between these different episodes constitutes a risk scenario. This tree-like representation allows the positioning of *safety barriers* (or *measures*) before an episode to prevent it, or after an episode to eliminate and lower the consequences [6].

2.2. Application of bow-tie diagrams to the CO_2 storage case

The development of the diagrams was based on a generic list of 11 main risk events modified from an existing list described in [7]. These constitute the top risk events, which represent the potential deviations from the expected behaviour of the storage complex and were identified based on a series of expert judgement workshops.

1. Leakage via an operational well
2. Mechanical disruption nearby the injection well
3. Mechanical disruption at the storage complex scale
4. Expected lateral extent exceeded
5. Leakage due to sealing deficiency of the caprock
6. Leakage via existing faults
7. Leakage via an abandoned well
8. Accumulation in a secondary reservoir
9. Flow modifications
10. Disruption by a later activity
11. Disruption by a natural earthquake.

Risks must be managed during all stages of a storage project i.e. during the planning stage, during the operational stage and after the transfer of responsibility. As our goal was to identify for each major risk event all possible “levers” for risk mitigation, we had to include the time-scale component in the diagrams; we then decided to develop for each event one diagram per phase:

- A diagram for the planning phase: causes are here potential evolutions of the storage site for given settings and injection scenarios. Associated measures can be taken by operators before the start of the operations in order to lower the initial level of risk.
- A diagram for the operational phase: we consider that the normal evolution scenario is known. This diagram is then only focused on the differences with this scenario: the sequences describe the alternative evolution scenarios and the causes are either under the responsibility of the operator or due to external events.
- A diagram for the long term phase (after transfer of responsibility) similar to the previous one but focused on the long terms risks; please note that in this paper the two former diagrams will be presented, the long term trees being still under development.

In concrete terms, each event was linked with causes episodes and consequences episodes, eventually identifying impacts on vulnerable elements as the ultimate consequence. Links between the main risk events were also created.

The notion of compartment was introduced in the diagrams for added precision: the main compartment is the so-called zone of influence. We define the zone of influence as the expected zone in which the sources of hazards (e.g. free gaseous CO_2, pressure) can have an influence. For instance, if the free gaseous CO_2 is the source of hazards, the area of influence will be the expected extension of the plume. Conversely, outside the zone of influence can be an overlying zone, including the confining layer, or inside the storage formation but further from the injection(s) well(s). The episodes were placed either inside the zone of influence, outside the zone of influence or in transition between the zones.

The diagrams were checked for comprehensiveness through an audit against a generic list of FEPs [8] (Features, Events, Processes).

2.3. Identification and development of mitigation measures

For each episode created in the different diagrams, we attempted to find measures that could be applied before the episode, in order to avoid it, or after the episode, to eliminate or lower its consequences. For the planning phase only measures before the episodes were needed. For each measure identified, a description sheet was then created and filled. We did not take in consideration as safety barriers the action of the natural barriers of the system (e.g. the caprock), as they are included in the expected behaviour.

2.4. *Creation of the database*

The last step was to integrate all the previous work in one database. We used MS ACCESS©.

2.5. Remediation measures

Remediation measures are the measures to be taken when environmental damage or hazardous phenomena due to the storage operations occurs. Such damage could in turn impact human health. The goal of these measures is to rehabilitate or restore the impaired natural resources in the baseline state. As such, their presence in a risk management database is worthwhile. Those measures are linked to the nature of the impact but not to the origin of the hazard and therefore, they are not directly linked with the main risk events. A separate work on those measures was hence undertaken.

The first step of this work was to identify all different impacts that CO_2 geological storage activities could create on the environment, and then to identify potential measures able to eliminate or mitigate those impacts. This work was carried out with analogy to the field of contaminated sites, based on BRGM experience ([9]). As for now, those measures are not yet implemented in the database and their development is still going on. The impacts and the associated remediation measures are listed in association with several conceptual models.

3. Results

3.1. The GERICO database

As an example, we use the event n°7: Leakage via an abandoned well. The diagram created for the planning phase is shown on figure 1, and the diagram created for the operational phase is shown on figure 2.

In these diagrams, an arrow linking two episodes should be read “can possibly induce”.

We see that this event can originate either from the storage zone, if a leakage pathway has not been detected by the operator prior to the operations or outside the storage zone, if CO_2 has migrated in an unexpected manner.

The potential hazards that apply to the central event (i.e. “top event”) are outlined underneath. Here, the hazard can be a leak of either CO_2 and associated impurities or of brine. Mechanical energy is also a potential hazard for some other events.

Some mitigation measures identified for this diagram are listed in table 1.

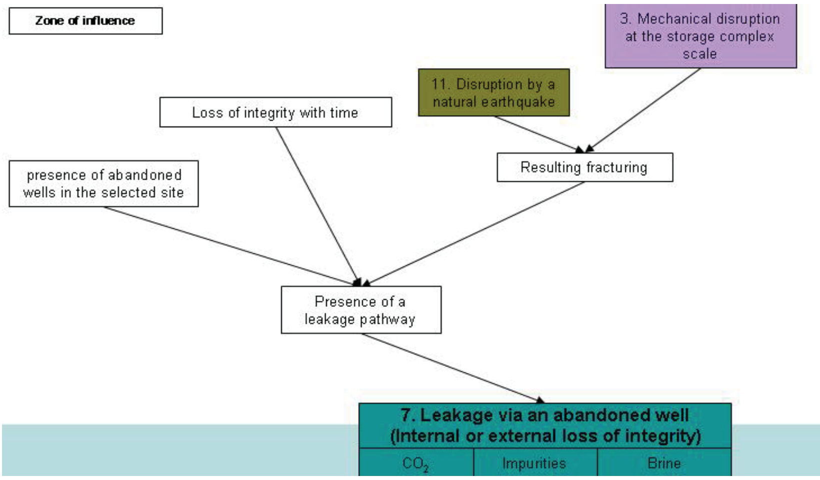

Figure 1: Planning phase diagram for event n°7: “Leakage via an abandoned well”. Only the upper part of the diagram is shown, as consequences are similar to the operational phase diagram.

Table 1: Extract of the list of mitigation measures associated with the diagram of the event n°7

Planning phase		**Operational phase**	
Episode	Mitigation measure	Episode	Mitigation Measure
Resulting fracturing	Re-abandonment	Expected lateral extent exceeded	Produce and re-inject CO_2
Presence of a leakage pathway	Re-abandonment	Accumulation in a secondary reservoir	Hydraulic Barrier
Loss of integrity with time	Use of chemical additives	Accumulation in a secondary reservoir	Produce and re-inject CO_2
Presence of abandoned wells in the selected site	Change site	Presence of a leakage pathway	Re-abandonment
Leakage of CO_2	Enhance CO_2 trapping	Presence of an unexpected leakage pathway	Re-abandonment
Leakage of brine	Pressure control strategies	Ignorance of the presence of abandoned well	Investigations for abandoned wells

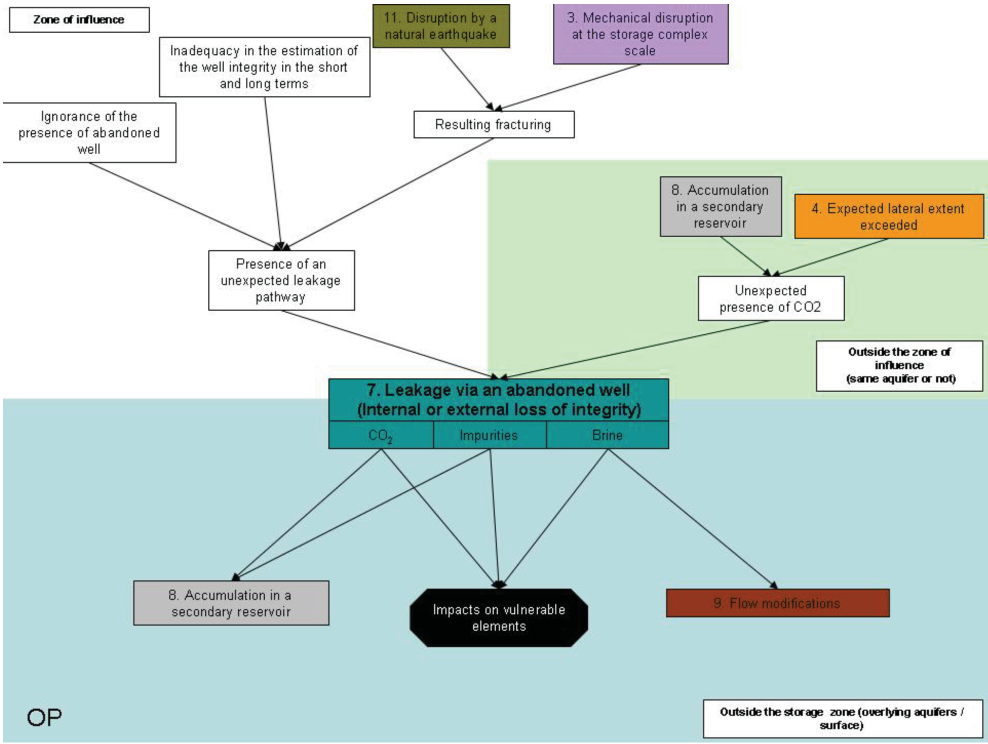

Figure 2: Operational phase diagram for event n°7: "Leakage via an abandoned well"

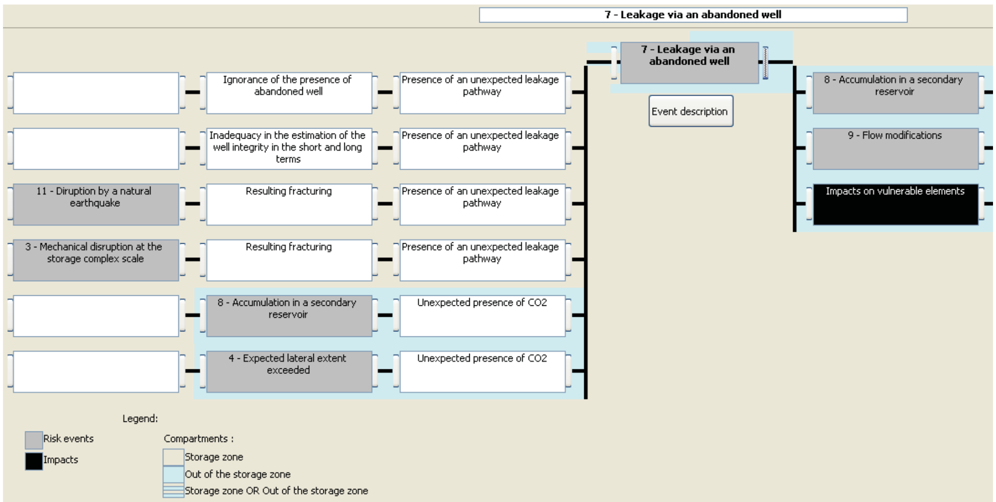

Figure 3: Implementation of the diagrams inside the GERICO database

The conceptual diagram on figure 2 is implemented inside the GERICO database as shown on figure 3. The compartments are represented using different colors and buttons represent the safety barriers associated with each episode.

An example of a mitigation measure description sheet is shown in figure 4. Each measure is characterized by a generic description, an objective in relation with the associated episode, an application phase, an indicative qualitative cost with comments, an indicative duration of deployment and implementation with comments, the maturity of the measure with identified gaps, and references. All this information is devised to facilitate the choice of the appropriate measure under a given situation.

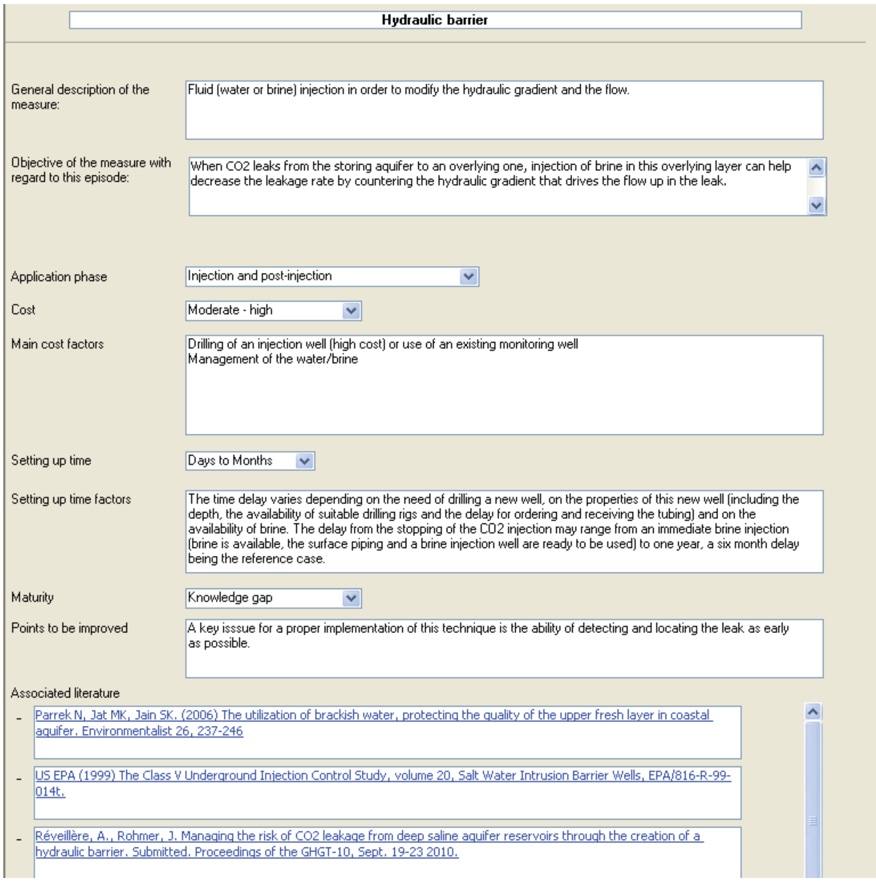

Figure 4: description sheet for the Hydraulic barrier in the GERICO database

3.2. Remediation measures

In figure 5 is represented the conceptual model for the migration of CO_2 inside an aquifer. The represented impacts are:

1. Acidification of the aquifer and mobilization of trace elements
2. Corrosion of alimentation wells following a mobilization of heavy metals

3. Pollution of groundwater extracted for consumption or other uses
4. Pollution of surface water
5. Damaging of aquatic habitats
6. Pollution of alluvial deposits
7. Direct or indirect ingestion by the population

The associated measures are:

1. Measures that control the source of the impact (*i.e.* the trace elements pollution or the acidity)
   1.1. treatment of acidity and of CO_2 (e.g. use of lime or "pump & treat" techniques)
   1.2. treatment of mobilized metals (e.g. electrokinetic extraction)
2. Measures to control the transfer of the pollution (e.g. permeable reactive barrier or physical containment of the pollutant)

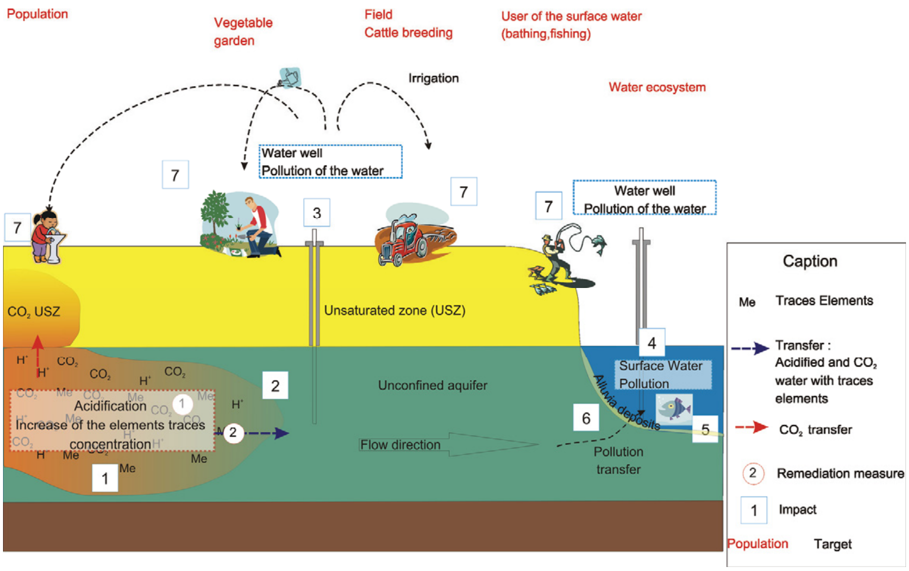

Figure 5: conceptual model for the migration of CO_2 inside an aquifer

4. Discussion and perspectives

The EU directive on CCS [1] explicitly distinguishes two kinds of risk mitigation measures:

- measures that prevent significant irregularities (whose description is required in the permit application),
- corrective measures (detailed in a plan, as explained in the introduction).

In addition, CO_2 storage activities are explicitly covered by the directive on environmental liability [10] that distinguishes two other kinds of measures:

- preventive measures (aiming at preventing an imminent threat of environmental damage);
- remedial measures (aiming at restoring, rehabilitating damaged natural resources).

In relation to our work, what we called "remediation measures" is very close to the "remedial measures". But the difference is unclear between "preventive measures" as of [10] and the mitigation measures as of [1]. We hence chose not to differentiate the measures, and all of them are called "mitigation measures" in the database. In order to keep a distinction between "preventive" and "corrective", each episode is linked with 2 buttons as it can be seen in figure 3. Each button gives a link to measures that can be taken respectively before or after the episode occurs.

Difficulties may arise when an episode is not exactly datable, as is the case with the episode "Ignorance of the presence of abandoned wells" in figure 2. Here, it is difficult to choose with which button the measure "Investigations for possible abandoned wells" should be associated. Having only one button for all measures associated with an episode would be a potential solution, if each measure has an indication on its applicability i.e. "before", "after", "both" or "N/A".

Moreover, this problem is strongly linked with the choice of the ACCESS© software, which lacks in flexibility concerning the display of the bow-tie diagrams, as it can be seen for example on figure 3. As for now, the database is still under development; our goal is to make it available on the web using for instance an ORACLE®-type database. The database would then be hosted by a server and the web display would allow for more options.

As mentioned above, the diagrams presented here do not take into account the long term behaviour of the storage complex, though risk management will still be of prime importance in the post-closure phase. We are currently working on a third kind of diagrams focused on this phase. The next step will be to initiate thoughts on potential mitigation measures, taking into account that fewer possibilities for mitigation will be available in the long term, since wells will no longer be accessible for instance.

Lastly, an integrated risk management database should take into account the monitoring system that is inextricably linked with the detection of irregularities and the associated mitigation measures. This will be investigated in future tasks.

5. Conclusion

In comparison with a simple list of all mitigation measures available, the GERICO database is particularly useful for identifying the mitigation measures only relevant to one particular risk scenario. Besides, ranking the most appropriate measures according to the situation is facilitated by the different information contained in the database. These capabilities are essential particularly for operators willing to prepare a corrective measures plan, as required by the European directive on CCS [1] or by authorities appointed to review the permit applications. In addition, when the database will be made available on the web, the GERICO will be useful for non-specialists in order to have an overview of risk mitigation measures and for CO_2 storage scientists looking for a state-of-the-art in the area.

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