Framework for Storage Risks and Risk Assessment in Geological Storage

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Outline

1. Storage Risk Management Framework
2. Storage Risks
3. Injection Well Risks

Context

- **Widespread acceptance that geological storage will be safe and effective is an essential goal**

- **By all stakeholders:**
  - Public /Communities
  - NGOs
  - Industry
  - Government/Regulators

EU CCS Directive (2009) is the framework for Regulatory Requirements in European countries

- Article 1

  The purpose of **environmentally safe** geological storage of CO_2 is **permanent containment** of CO_2 in such a way **as to prevent** and, where this is not possible, eliminate as far **as possible negative effects and any risk to the environment and human health.**

- A geological formation shall only be selected as a storage site, if under the proposed conditions of use there is **no significant risk of leakage**, and if no significant environmental or health risks exist.

- Annex I details Site Characterisation & Risk Assessment requirements

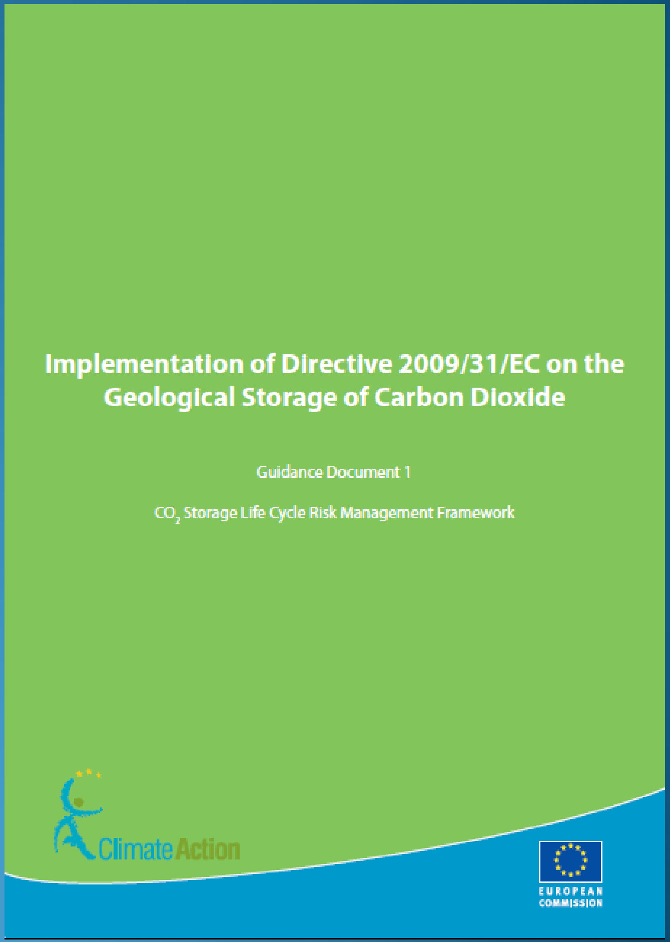
EU CCS Directive Guidance Document 1

CO_2 Storage Life Cycle Risk Management Framework

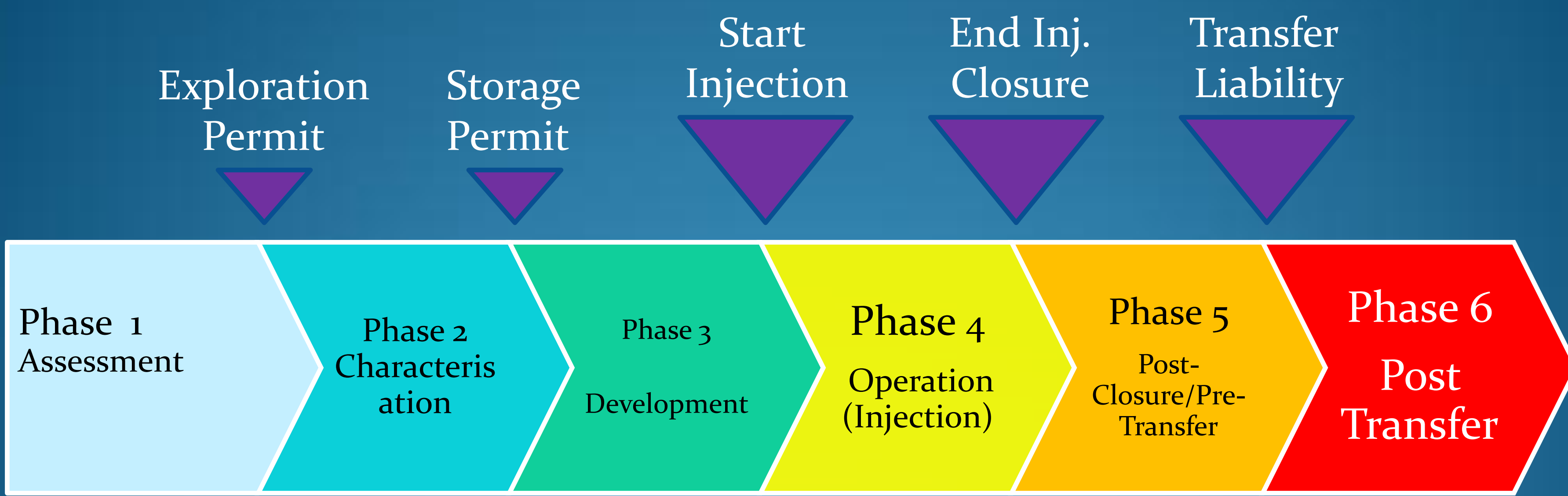
- Focused on storage security /integrity and risks related to leakage
  - distinct from but overlapping Project Risk Management , Safety processes or Environmental Impact Assessment

- 3 Step Approach:
  1. Risk identification and assessment
  2. Risk ranking
  3. Risk management measures

- Iterative approach throughout lifecycle



CCS/Storage Lifecycle



How Long?

Pre-injection
3-15 Years

Injection
5-50 Years

P-C./Pre-T
~20 Years

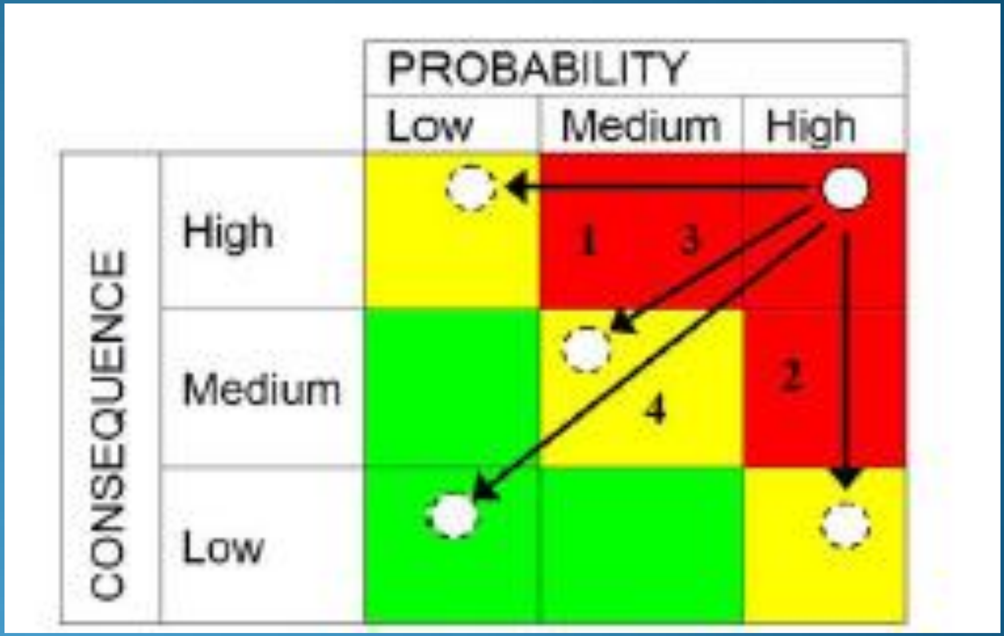
?100's
Years

Based on EC Guidance Document 1 (2010)

Risk identification and assessment:

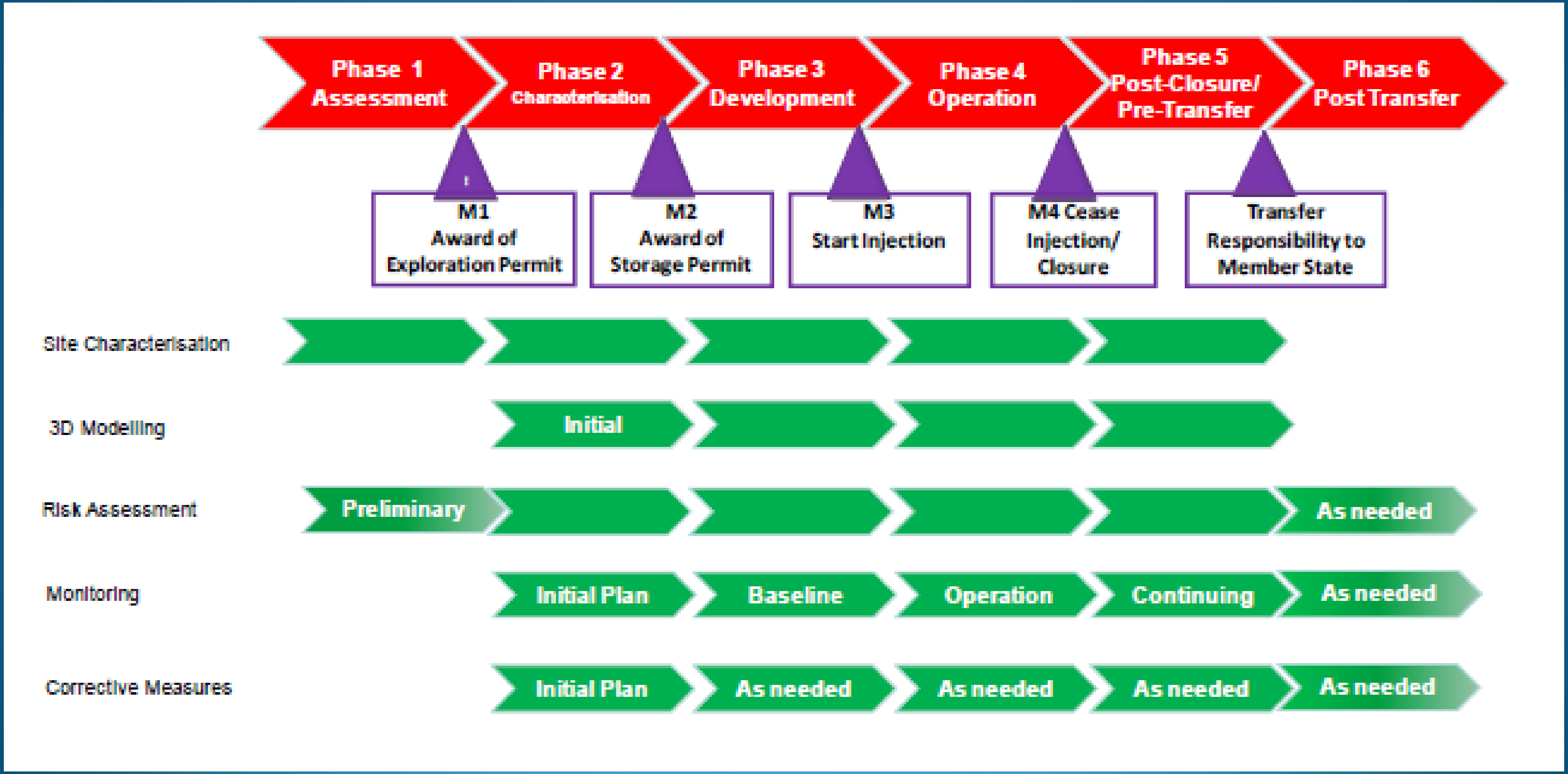
- Risk = Probability x Consequence or Impact

1. Risk identification
   - Hazard identification
     - Leakage Pathways
     - Likelihood of Leak
     - Amount, Flux, Duration
     - Critical parameters
     - Secondary effects
   - Exposure assessment
   - Effects Assessment
2. Risk Ranking, e.g Matrix
3. Risk Management Measures
   - Impact on Risk



Ref: EC Guidance Document 1 (2010)
Originally from CO2QUALSTORE Report, DNV, 2009

Storage Risk Management is Ongoing, iterative and site specific



Ref: EC Guidance Document 1 (2010)

Storage Risks

Local Risks

- Public/Workforce Safety
- Environmental impacts
- Impacts to water, oil, gas or other resources, Assets
- Ground displacement/induced seismicity

Global Risks

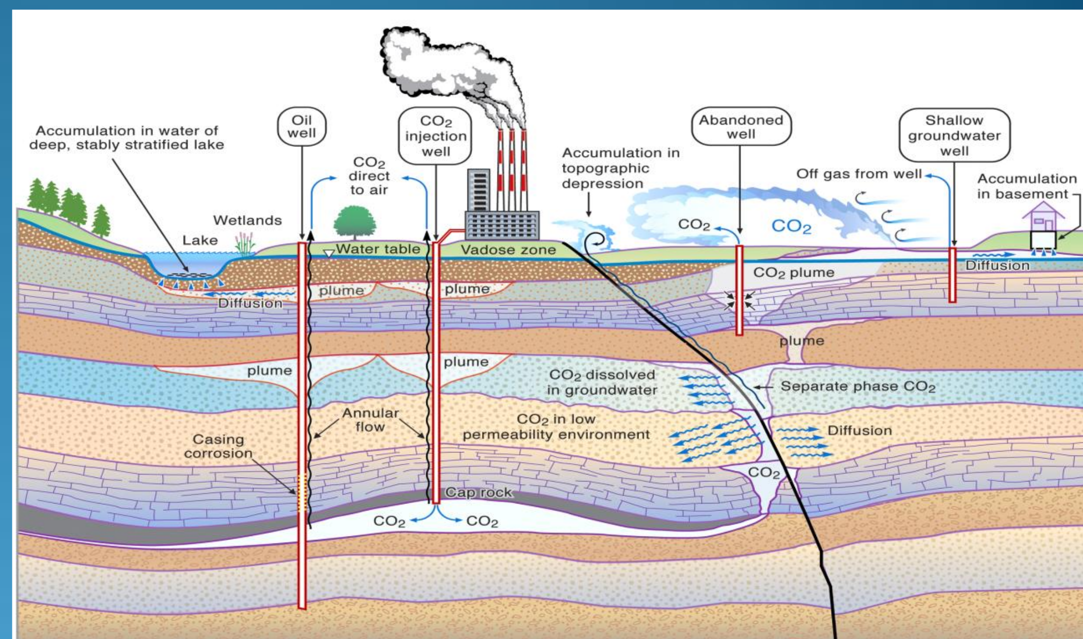
- Release of CO_2 from Storage to Atmosphere
- Storage may not be effective CO_2 mitigation

Controls

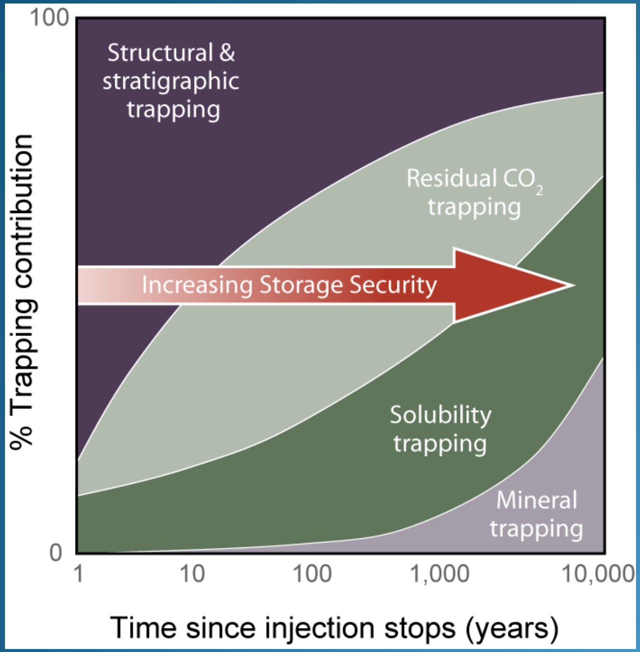
- Movement ,trapping and behaviour of CO_2 in the storage complex
- Leakage of CO_2 to shallow formations/biosphere
- Leakage pathways & mechanisms at the site
- Site characteristics (location, population density, etc)
- Exposure/Effects of CO_2 (toxicity, concentration, duration)

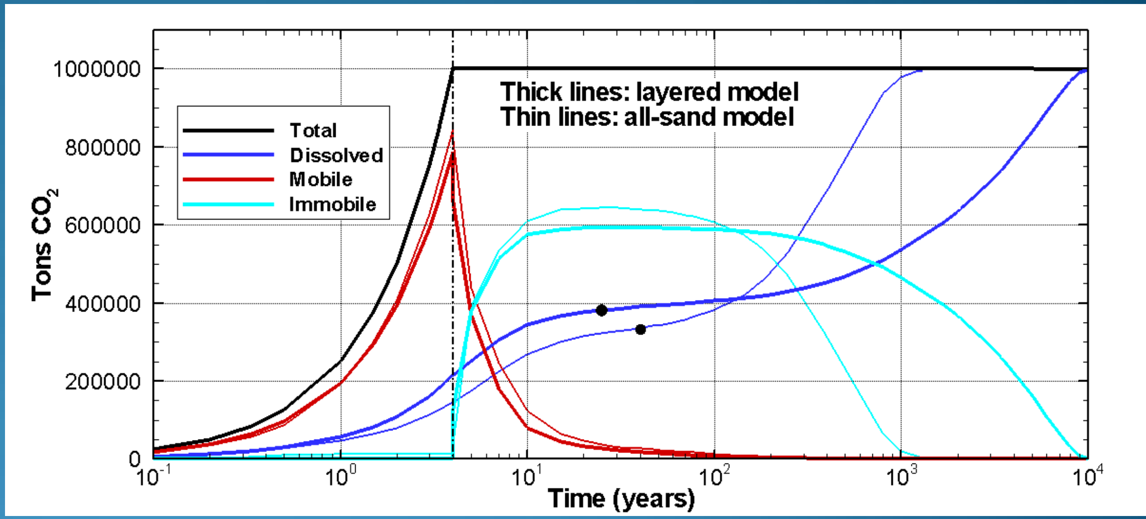
Main Leakage Pathways and Leakage mechanisms well understood

- Geological
  - Faults and Fractures
  - Seal or Caprock
  - Spill from Trap
- Wells
  - Abandoned wells
  - Injection operations
- Other Manmade
  - Mines, caverns



Trapping mechanisms lead to immobilisation of injected CO_2 on different timescales





Time evolution of the CO_2 mass distribution, for a sand/shale layered model and for an all- sand model. The black dots show the times at which the plumes are effectively immobilized.

Ref: IPCC Special Report on CCS, 2005

*Ref: NETL, 2010-
from US West Coast Regional Partnership*

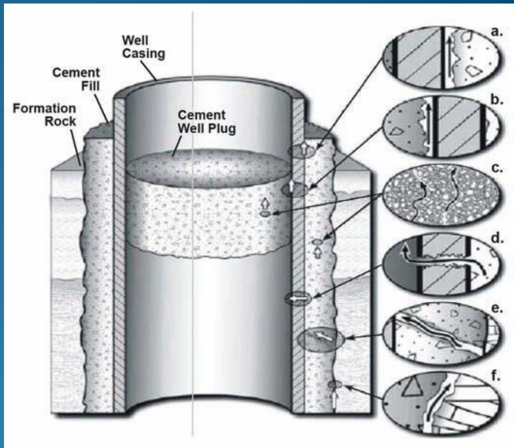
Well Leakage Risk Scenarios

Abandoned Wells

- Operations, Post Closure and Post-Transfer Phases
- Pre-existing wells (all types)
- Injection wells - once abandoned
- Leakage due to degradation of cement and well materials
- Pathways between/through cements, casings, well materials and formation

Injection Wells (Operational)

- Operations Phase only - not Post-closure
- Pathway through injection well tubing and/or behind production casing – potentially open
- Potential for uncontrolled release to surface or well blow out of CO_2 in worse case scenario



Potential leakage pathways along an existing abandoned well: between cement and casing (Paths a and b), through the cement (c), through the casing (d), through fractures (e), and between cement and formation (f) (Celia et al., 2004).

Analogue Data for Injection Well Leakage: Oil & Gas Release/Blowout Datasets

- Oil & Gas Industry Dataset (OGP 2010)
  - >36,000 wells
  - 50+Years
  - North Sea Standard (including Gulf of Mexico)
- 3 Categories of Release/Flow from Well (or between formations)
  - Blowouts: after all the pre-defined technical barriers have failed
  - Well release: flow was stopped by use of the barrier system that was available on the well at the time of the incident
  - Shallow gas releases: where shallow gas zone has been penetrated before the Blowout Preventer (BOP) has been installed

Analogue Data for Injection Well Leakage: Oil & Gas Blowout Frequencies

Oil and Gas Blowout Frequency	Average Frequency		
	Blowout	**Well Release**	**Unit**
Development Drilling Deep Normal wells	6.0×10^{-5}	4.9×10^{-4}	Per drilled well
Completions	9.7×10^{-5}	3.9×10^{-4}	Per Operation
Wirelining	6.5×10^{-6}	1.1×10^{-5}	Per Operation
Workovers	1.8×10^{-4}	5.8×10^{-4}	Per Operation
Gas Injection Wells	1.8×10^{-5}	2.0×10^{-5}	Per Well Year

Ref OGP 2010

Excludes : Exploration Drilling, High Pressure, High Temperature , Production and Water Injection well categories

Oil and Gas Blowout Duration

Calculation of expected blowout duration for a hypothetical conventional oil/gas well drilled in 337 metres of water in the Norwegian Sea using state-of-the-art technology and modern procedures.

Duration (Days)		<0.5	0.5-2	2-5	5-14	>14
Probability	Topside (20%)	0.49	0.19	0.12	0.13	0.07
	Subsea (80%)	0.33	0.2	0.14	0.16	0.17

- 56% Chance 2 Days or Less
- 15% Chance >14Days

Ref EC 2011; Originally from Det Norske Veritas, Environmental Risk Assessment of Exploration Drilling in Nordland VI, Report No. 20/04/2010

Sheep Mountain CO_2 Field Colorado, USA

- Natural CO_2 Field
- Cretaceous Dakota Fm
- 2.5 Tcf Reserves
- Gas phase - 97% CO_2
- Shallow reservoir (TVD 875m)
- CO_2 produced for EOR in Permian Basin (West Texas)

Ref: Allis et al ,2001

1982: Blow out of Development Well 4-15-H

- Loss of control while circulating with drill string in hole
- Flow of CO_2 and solid dry ice
- Flowing at surface through fissures away from wellsite and offset well
- Underground blowout
- Initial well control methods unsuccessful
- Flowed for 17 days before well controlled and flow stopped
- Estimated flow rate of 90-200 x 10^6 scf/day
- 4,700-10,500Tonnes/day
- =>CO_2 released 80-179, 000 Tonnes

Ref: Lynch et al, SPE 1983

Analogue Implications for CO_2 Injection Well Leakage

- CO2 Leakage/blow out risk differs from Oil and Gas:
  - No CO2 in reservoir at outset prior to start of injection and storage
  - Risk confined to areas where wells penetrate CO2 plume
  - Normally dense phase CO2 in reservoir during storage
  - Phase behaviour during release will be different
- CO2 release/blow outs are a potential source of CO2 leakage during injection (ie. Lifecycle Operations Phase)
  - Mainly related to Injection, Wirelining, Workover activities
  - May be high flux
  - Usually short duration
  - in worse case this may take 2-3 months where relief well required
- Risk depends on specific conditions(e.g.reservoir ,well)
  - Plume, P/T, productivity, well design
- Risk management by by drilling practises, standards & blow out controls
  - Leakage can be stopped and well remediated

Storage Risk- issues

- Need better quantification and prediction of:
  - probability of leakage,
  - potential flux rates, duration & amount
- Improve understanding :
  - dynamic controls
  - variation of risks with time
  - dispersion models
  - marine impacts
- Integration between technical assessments and commercial and regulatory aspects, for example relating to transfer of liability and financial security.

Risk Profile through CCS Lifecycle

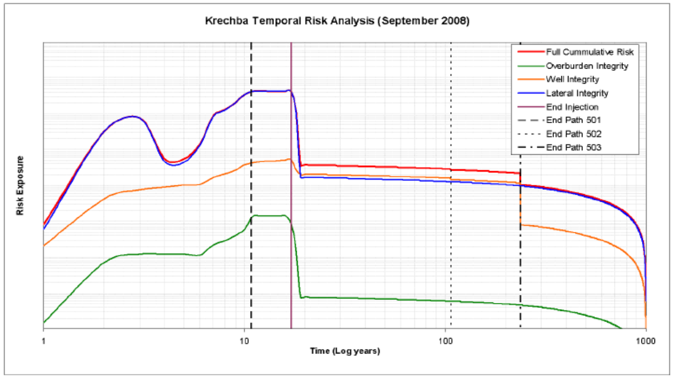


Figure 1: Full quantitative risk profile through time for the In Salah CO_2 Storage Project. Risk Exposure and Time axes are in logarithmic scale. Vertical lines represent temporal end of lateral migration paths and end of injection. The red line is the cumulative risk profile for the project. All risks associated with well leakage (orange), and migration direction & exceeding spill point risks (blue) are grouped.

Ref Dodds et al, 2010

Summary

- Ongoing Risk Management an essential activity to ensure storage will be safe
- Storage risks well understood in general terms
- Generally dealing with very low probability hazards for well characterised sites
- Further work to develop capability and case studies, particularly to improve quantification and assessment of risks through time and for wells during operational phase

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