Risk assessment

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Agenda

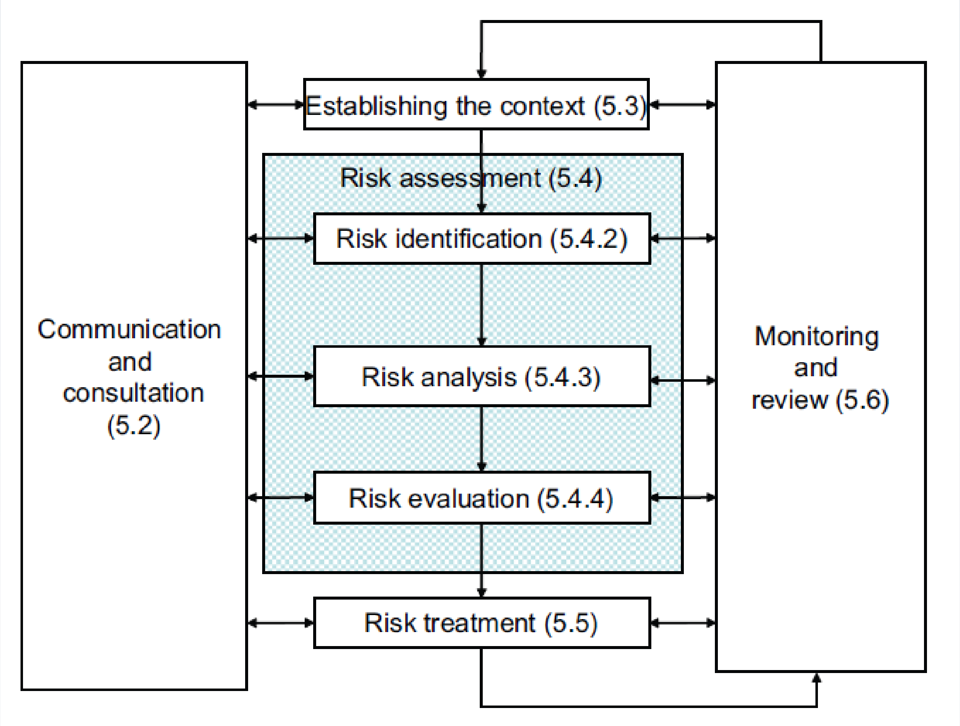
1. Overview of SOW for the Risk Assessment activity in the REPP-CO2 project
2. Area of interest
3. Risk identification process (completed)
4. Risk analysis process (completed)
5. Risk evaluation process (ongoing)

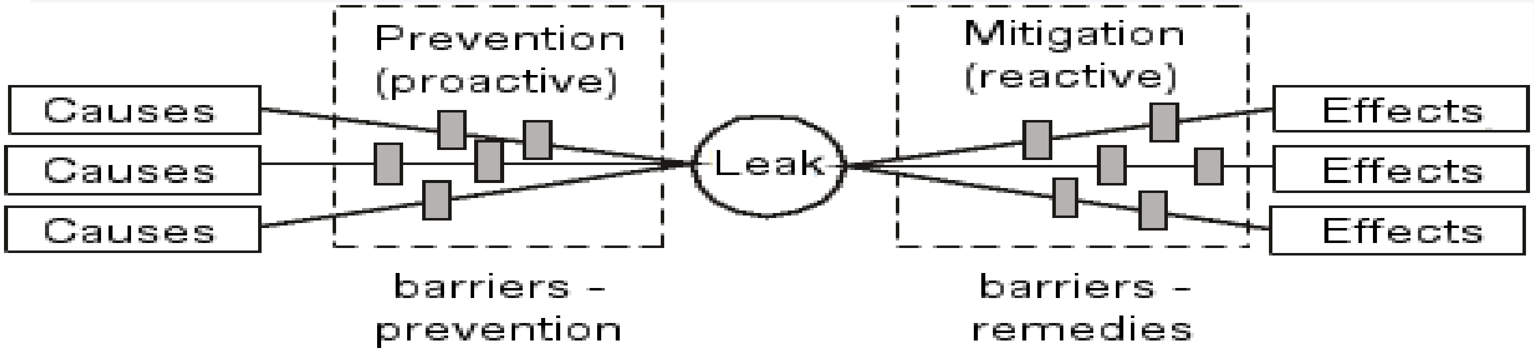
A4 Risk Assessment - SOW

Main objective: Assess the risk of carbon dioxide leakages from the storage system situated in the LBr-1 gas and oil reservoir (for the post-capture phase – transport-related risks assessed as separate sub-activity, but not presented here)

Main approach: Bow-tie analysis to map causes, preventive and mitigating barriers, and undesirable effects (to humans, operations and environment

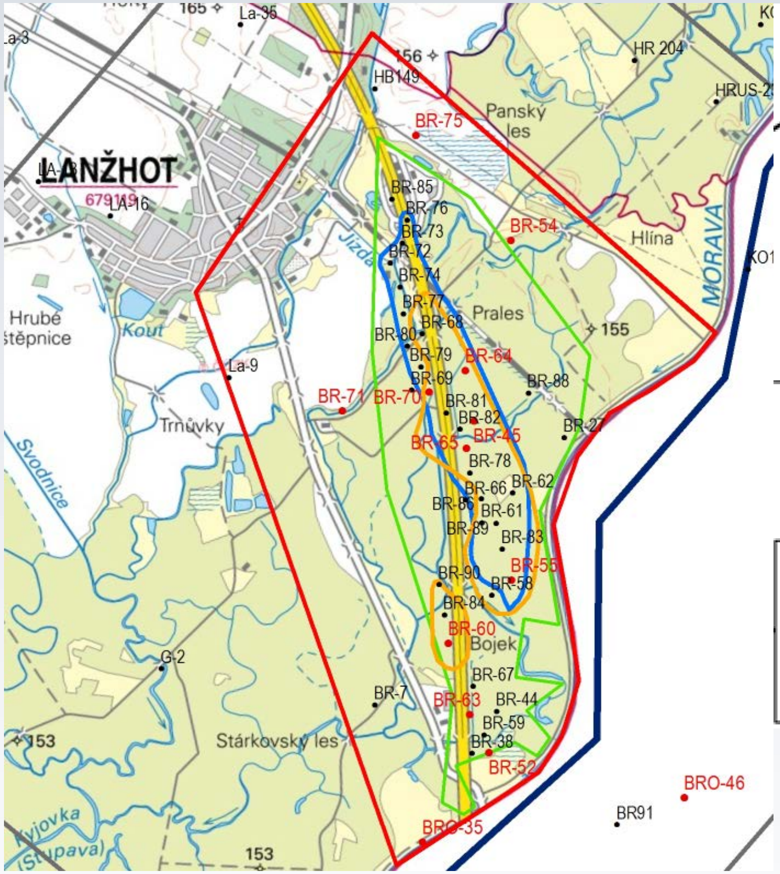
Risk assessment framework: ISO 31000:2009





Area of interest and potential consequences

- **Main concern**: 51 abandoned oil & gas wells, 22 of which were re-abandoned in recent years.
- Potential location of CO2 injection site
- Town of Lanzhot
- Morava river (drinking water supply for the towns Hodonín and Břeclav
- Area was incorporated into the system of protected areas of European significance - Natura 2000 and is included in the UNESCO Biosphere reserve
- Both motorway and railway crosses the area - the motorway D2 (part of E65) from the North to the South and a railway transit corridor from the NW to the SE. Both the motorway and the railway are lines of international importance.



Human effects
- Health degradation depending on exposure levels
- Agricultural changes
- Water contamination
- Damage to infrastructure

Environmental effects
- Damage to flora/fauna
- Changes to soil & vegetation
- Damage to animals
- Damage to ecosystems

Economic/other effects
- Economical ramifications
- Degradation of natural resources
- Other

Risk identification

Using traditional RM techniques/ tools, each of the elements in the bow-tie diagram will be mapped:

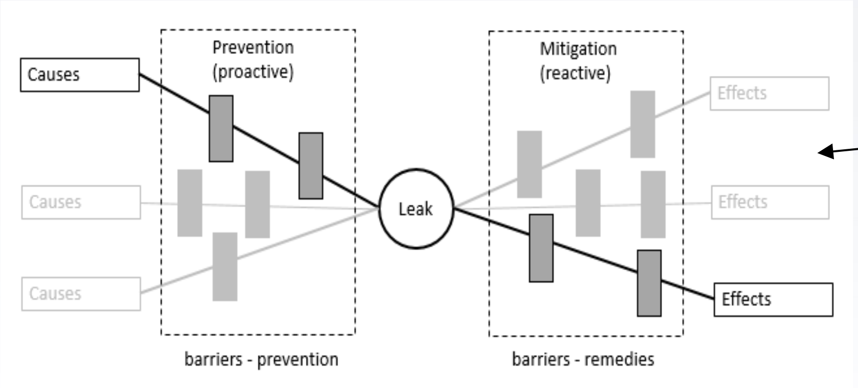
- **What are the main causes initiating a leakage?**
- **What are the preventive barriers of the system?**
- **What are the mitigating barriers of the system?**
- **What are the consequences, with respect to humans, operations and environment, of a leakage?**

Left side of bow-tie

Right side of bow-tie

Identification of leakage scenarios

Barrier analysis



Features, Events & Processes (FEP) analysis

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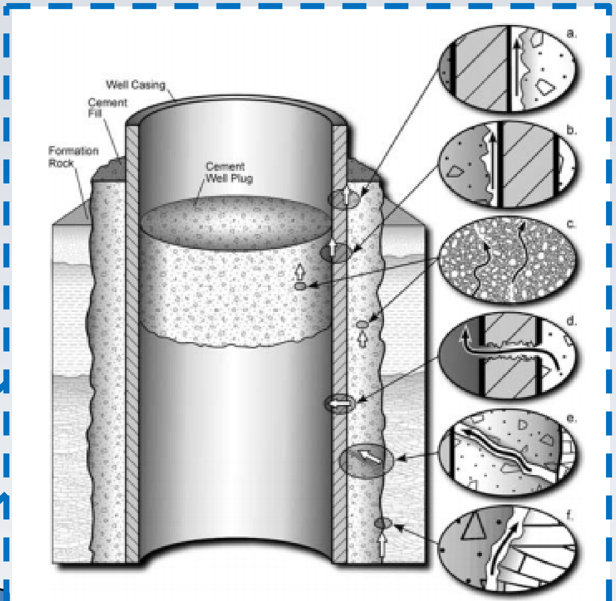
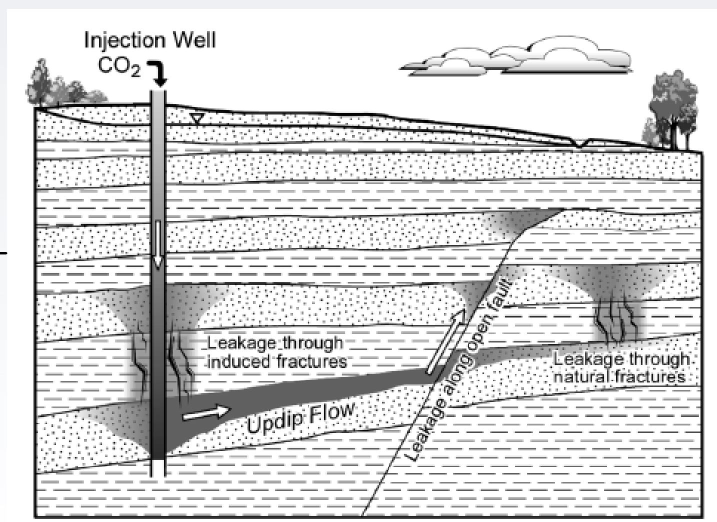
A4.1 Risk identification – Leakage causes

Leakage scenario
Leakage through wells
Leakage from an injection well to atmosphere
Blowout from an injection well during drilling
Leakage from an abandoned well to the atmosphere
Reservoir leakage
Leakage through the caprock due to gradual failure
Leakage through the caprock due to rapid, catastrophic failure
Leakage through existing faults due to increased pressure
Leakage through induced faults due to increase pressure
Leakage through spill points





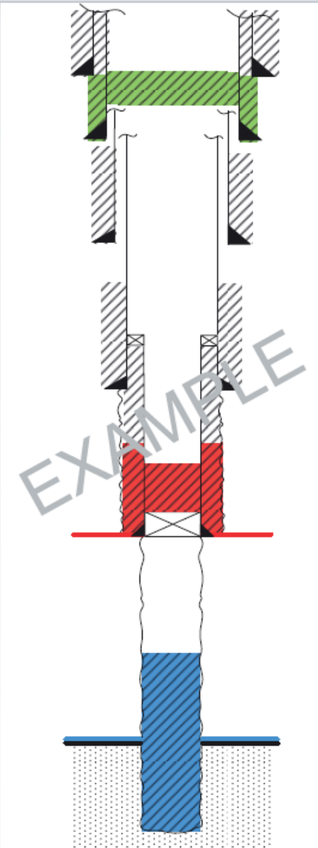
Geomechanical causes
- Local pressure increase near fault
- Pervasive pressure changes throughout reservoir
- Pressure depletion
- Reservoir expansion
- Fracture treatments
- Waterflooding
- Cementing/WO
- Too high injection pressure
- High near-well stresses
- Nigh near-well permeability zones

Geochemical causes
- Corrosion-related causes
- Cement degradation-related causes

Operation-related causes
- Improper cement job
- Improper completion
- Improper abandonment

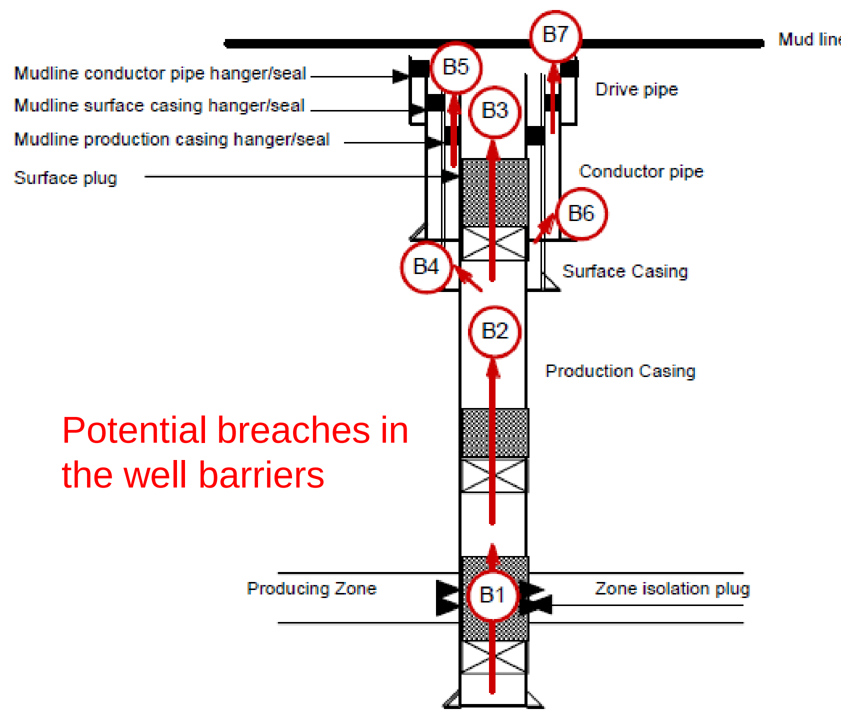
Equipment-related causes
- Design-related causes
- Fabrication/installation-related causes
- Failure related to operation/maintenance
- Failure related to management

Risk identification – barrier analysis

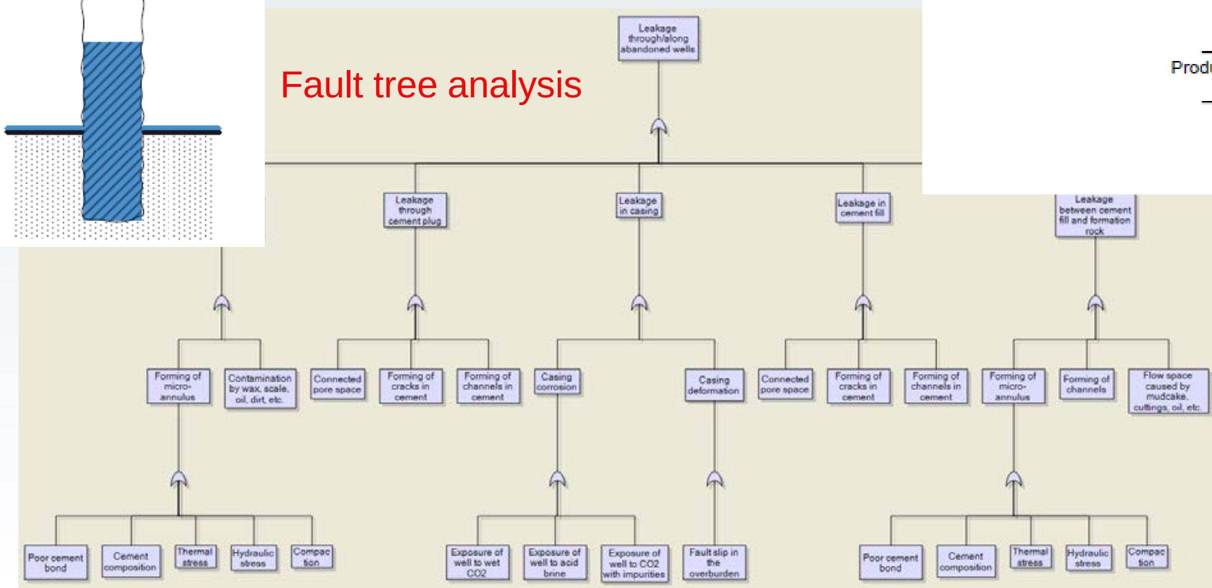


Barrier type	Well barrier elements
Primary well barrier	In-situ formation
	Cement plug
Secondary well barrier, reservoir	Formation in-situ
	Casing cement
	Casing
	Cement plug
Open hole to surface well barrier	Casing cement
	Casing
	Cement plug

Well barrier elements (NORSOK D-010)



Potential breaches in the well barriers



Fault tree analysis

Focus: What are the barrier elements of the system, and how can they fail?

Risk identification - FEP

Quintessa

Risk Assessment

Name | **5.2.2 Seal failure**

F E P

Description

Borehole linings and seals (metal and cement) will evolve with time and may degrade. The nature of the evolution, and whether it will be detrimental to seal performance, will depend on the temperature and stress conditions and natural fluid compositions in the deep reservoir and overlying rocks. This evolution may be influenced by the input of high concentrations of CO2. Any H2S present may accelerate corrosion of metal linings. Cement will react with CO2 at high partial pressures and may undergo a range of reactions in the presence of fluid with low pH and appreciable concentrations of sulphate, chloride, and magnesium ions. Seal failure will occur if liners have degraded and corroded.

Borehole seals will be designed to minimise the likelihood of failure. Monitoring will typically be undertaken to ensure performance and to mitigate any observed performance defects. The main risk therefore will typically be associated with the longer-term post-monitoring period.

		5.2	**Borehole seals and abandonment**			FEPs relevant to the closure of boreholes drilled within the system domain.	
				5.2.1	Closure and sealing for boreholes	Features related to the cessation of CO2 injection operations at a site and the sealing of injection and monitoring wells. *When a borehole is drilled to the potential storage reservoir, it creates communication with possible overlying reservoirs and with the surface. Cementing and abandonment procedures are designed to permanently plug such communication channel. At the time of well abandonment, cement plugs tens to hundreds of metres thick are placed at intervals inside the well casing.The cement plugs are commonly located across potential problem spots (e.g. perforations, casing shoes, top of liner, etc.), to minimise leaking risks. Particular attention should be paid to the quality of the original cement job behind the casing string The schedule and procedure for sealing and closure may need to be considered in the assessment.*	YES (State of sealing after abandonment will be assess – leakage risk during abandonment may not be)
				5.2.2	Seal failure	Degradation of borehole linings (metal and cement) will occur with time, depending on the natural fluid composition of the deep reservoir and the input of high concentrations of CO2. Any H2S present may accelerate corrosion of	YES

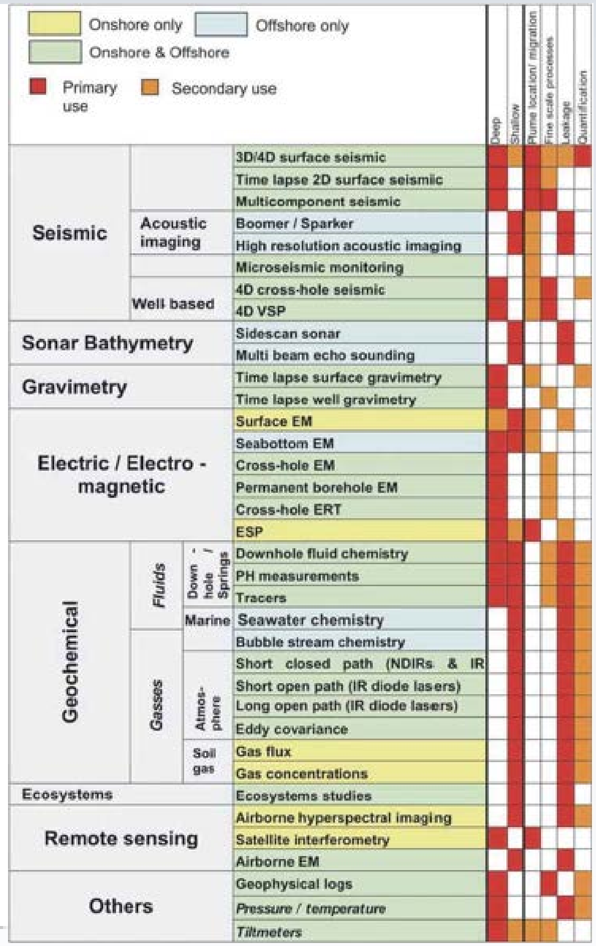
Risk identification – Mitigating barriers

Mitigation (reactive)

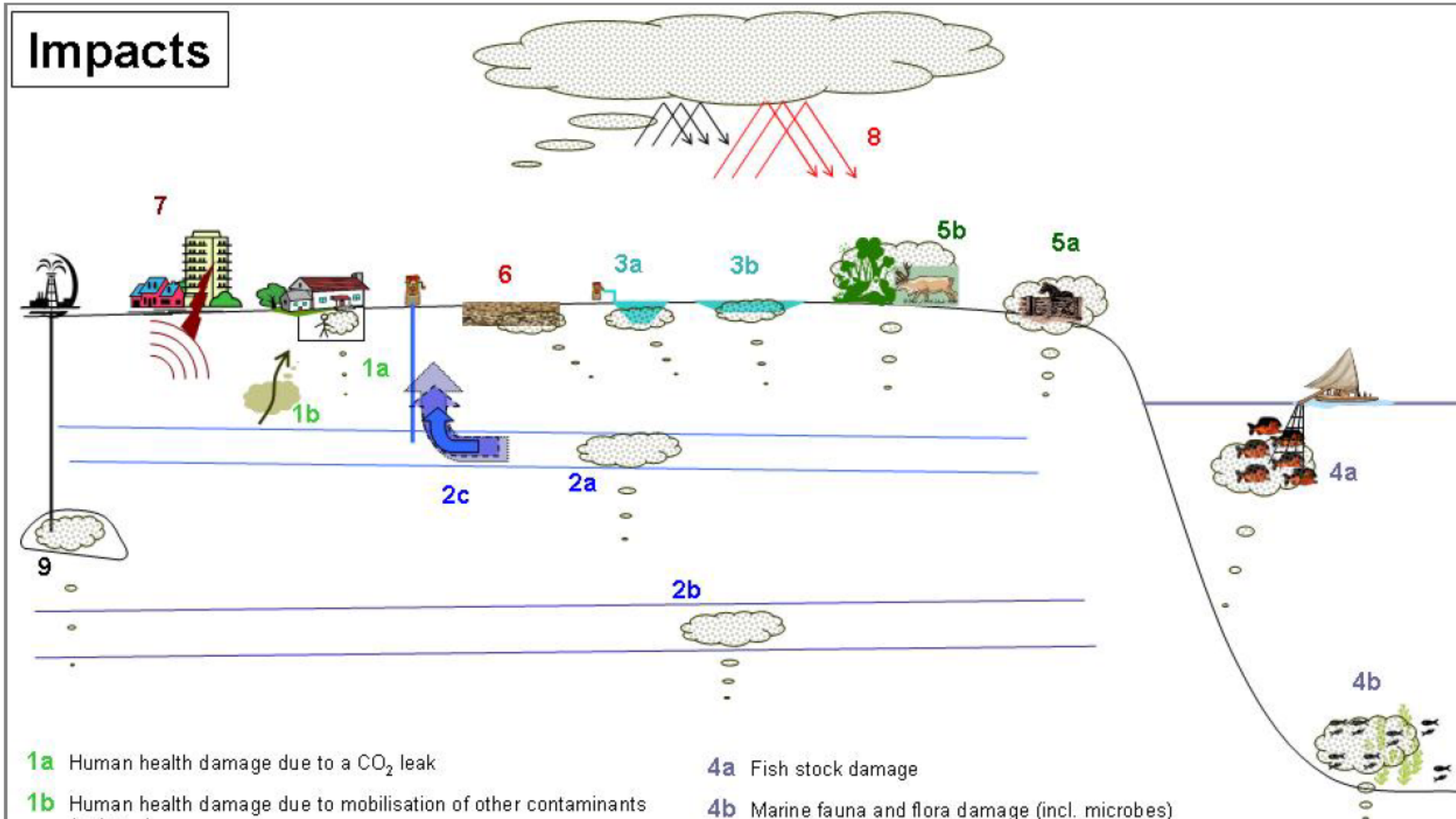
Monitoring
- Microseismic
- Gas analysis
- Sonic logging
- Wellhead P&T
- Downhole P&T
- Wireline logging

Well design
- Overthickness
- Corrosion inhibitors
- Corrosion-resistant alloys
- Well placement
- Cement properties

Operational
- Injection pressure
- Reservoir pressure
- Loss control material
- Stop injection
- Relief well
- Fault reactivation
- Shut-in
- Well kill
- Repair
- P&A
- Venting
- Pressurization



Risk identification - consequences



1a Human health damage due to a CO_2 leak

1b Human health damage due to mobilisation of other contaminants (radon...)

2a Underground potable water supply pollution

2b Modified physical-chemical quality of groundwater and consecutive impacts

2c Groundwater extraction yield reduction

3a Surface potable water supply pollution

3b Modified physical-chemical quality of surface water and consecutive impacts

4a Fish stock damage

4b Marine fauna and flora damage (incl. microbes)

5a Livestock damage

5b Terrestrial fauna and flora damage

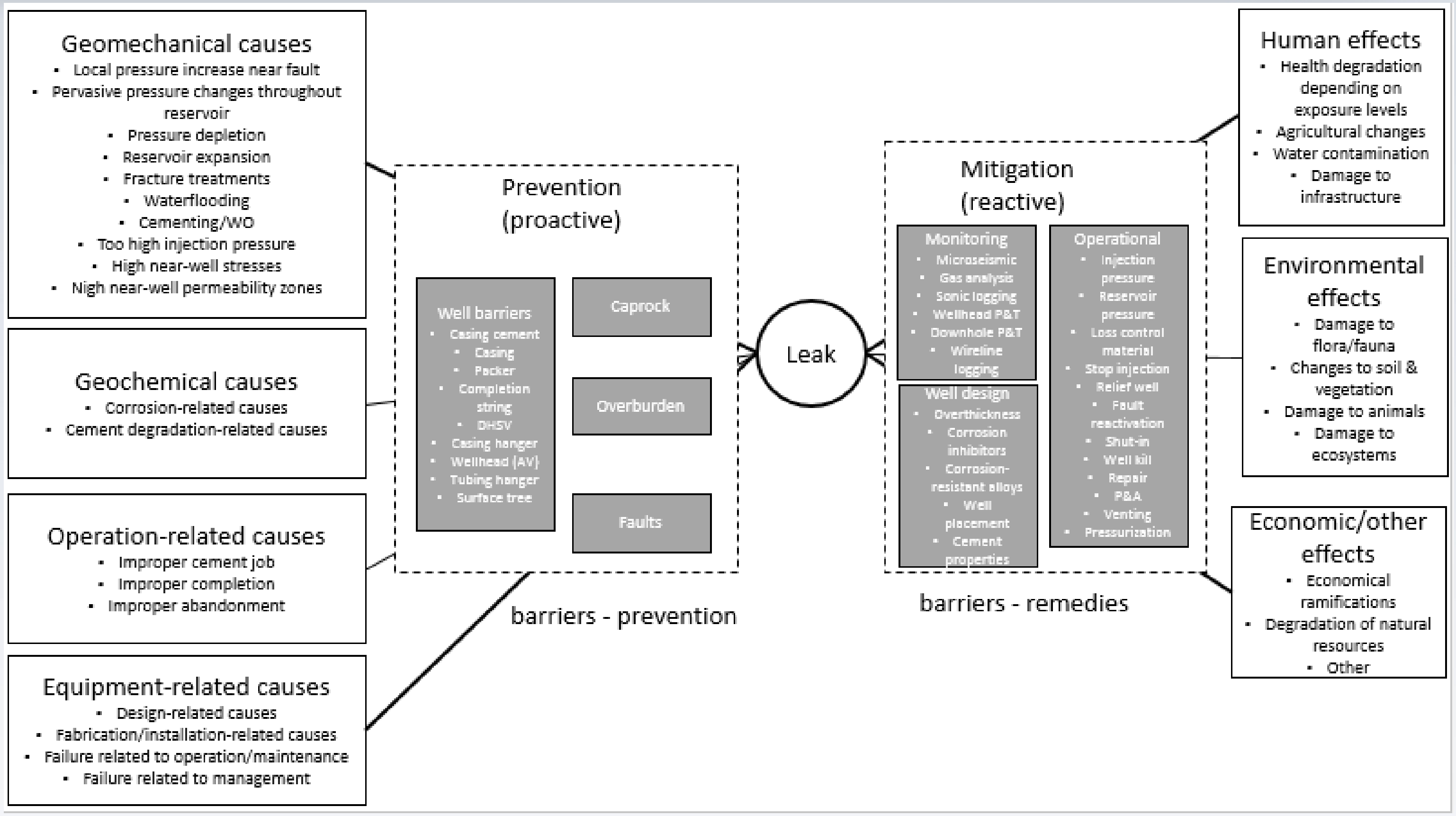
6 Pedological and microbiological impacts

7 Damage to buildings due to geotechnical motions

8 Increased greenhouse effect

9 Impact on the use of other underground resources

A4.1 Risk identification - Summary



Main approach: Bow-tie analysis to map causes, preventive and mitigating barriers, and undesirable effects (to humans, operations and environment

A4.2 Risk Analysis

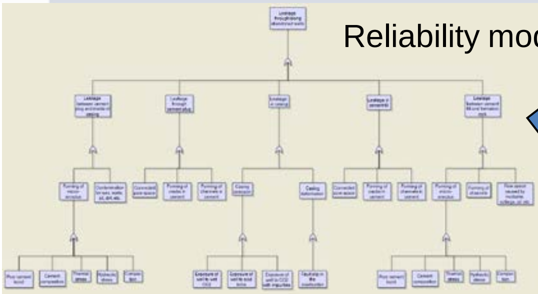
Main objective:

- Determine most important CO_2 leakage risk factors,
- Quantify probabilities of leakage scenarios and
- Quantify effects,
- Assess uncertainties

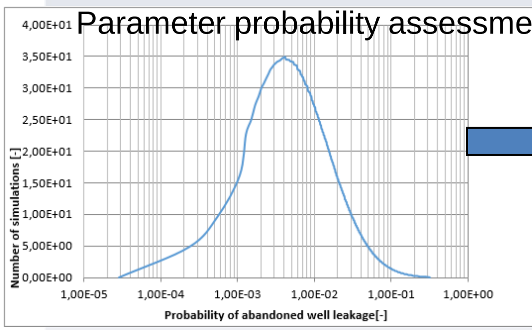
(Primary focus on leakage from abandoned wells)

Risk analysis – probability assessments

Reliability models



Parameter probability assessments



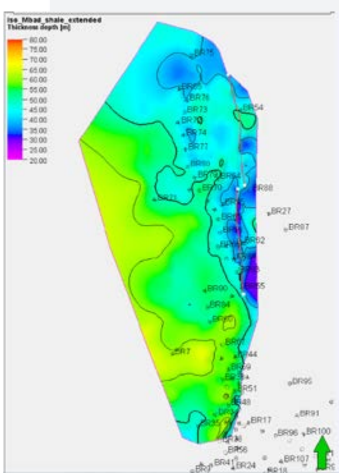
Probability classification table

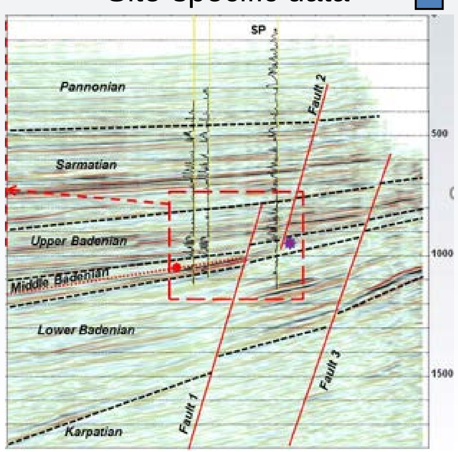
Class	Frequency of occurrence range (per year)	Description
1 - Improbable	$< 10^{-6}$	Virtually improbable and unrealistic
2 - Remote	$10^{-6} – 10^{-4}$	Not expected nor anticipated to occur
3 - Rare	$10^{-4} – 10^{-3}$	Occurrence considered rare
4 - Probable	$10^{-3} – 10^{-1}$	Expected to occur at least once in 10 years
5 - Frequent	$> 10^{-1}$	Likely to occur several times a year

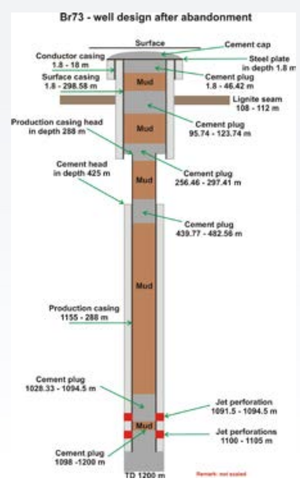
Coarse probability assessments

Leakage scenario	Classification
Leakage from an injection well to atmosphere	Not expected nor anticipated to occur
Blowout from an injection well during drilling	Not expected nor anticipated to occur
Leakage from an abandoned well to the atmosphere	Occurrence considered rare / Expected to occur at least once in 10 years
Leakage through the caprock due to gradual failure	Virtually improbable and unrealistic
Leakage through the caprock due to rapid, catastrophic failure	Virtually improbable and unrealistic
Leakage through existing faults due to increased pressure	Virtually improbable and unrealistic
Leakage through induced faults due to increase pressure	Virtually improbable and unrealistic
Leakage through spill points	Virtually improbable and unrealistic

Site-specific data

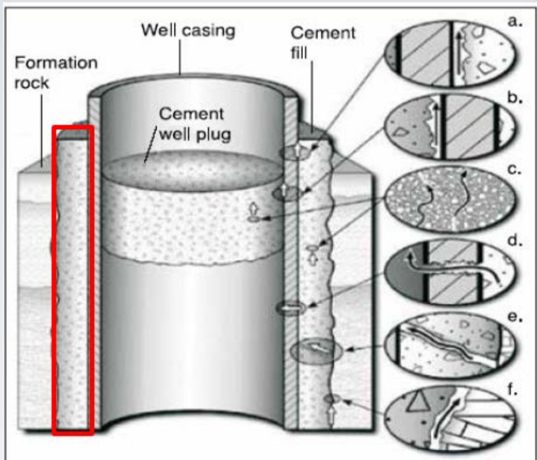






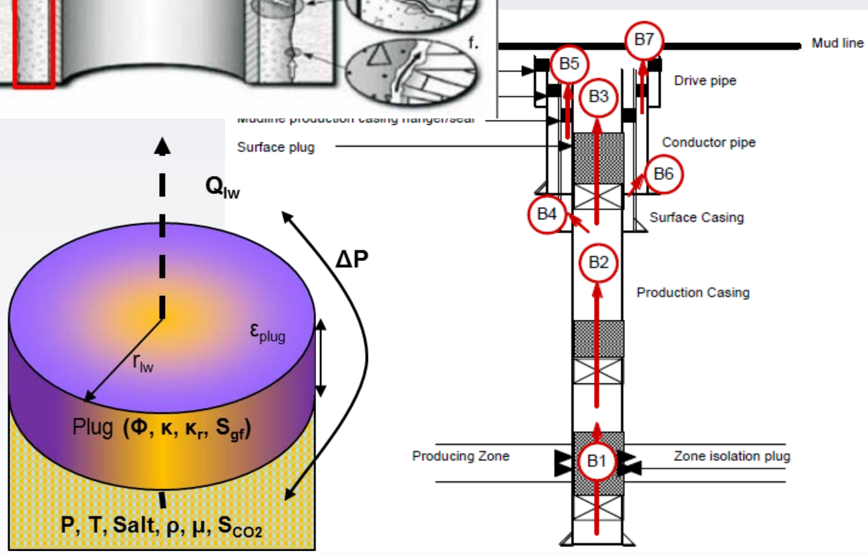
Abandoned wells – Leakage simulation framework

Objective: Quantify uncertainty on leakage-related parameters based on available information, and quantify CO2 leakage rate and duration through the cement plug



Leakage through plug or casing cement

- Framework: *Wertz (2012): Report on analytical computation of leakage on a cement plug*
- *Model parameters as probability distributions*
- *Use a Monte Carlo framework to propagate uncertainty in the model*



Input parameters to the model:

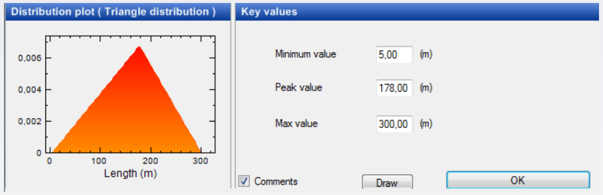
- *Overpressure (ΔP) of the reservoir due to CO2 injection.* Not meant to exceed 20-30% of initial pressure.
- *Buckley-Leverett front propagation saturation (S_{gf})*
- *Relative permeability at propagation saturation κ_r (S_{gf})*
- *Cement plug thickness (ε)*
- *Cement porosity (Φ)*
- *Cement permeability (κ)*
- *CO2 density (ρ_{CO2})*
- *CO2 viscosity (μ_{CO2})*
- *CO2 solubility (S_{CO2})*
- *Aqueous CO2 well potential (CO_{2aq})*

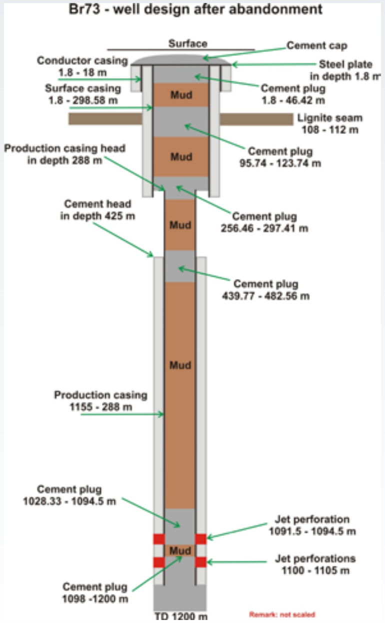
Leakage simulation framework - parameters

Input parameters to the model:

- *Overpressure (ΔP) of the reservoir due to CO2 injection. Not meant to exceed 20-30% of initial pressure.*
- *Buckley-Leverett front propagation saturation (S_{gf})*
- *Relative permeability at propagation saturation κ_r (S_{gf})*
- ***Cement plug thickness (ε)***
- *Cement porosity (Φ)*
- *Cement permeability (κ)*
- *CO2 density (ρ_{CO2})*
- *CO2 viscosity (μ_{CO2})*
- *CO2 solubility (S_{CO2})*
- *Aqueous CO2 well potential (CO_{2aq})*

- Use specified plug thickness where these data are known, i.e. for re-abandoned wells.
- Otherwise, create statistical distribution on the basis of the known plugs, to represent the unknown wells





Well name	Plug thickness [m]	Total plug thickness [m]
BR-7	T(5, 178, 300)	T(20, 430, 1100)
BR-20	T(5, 178, 300)	T(20, 430, 1100)
BR-22	T(5, 178, 300)	T(20, 430, 1100)
BR-27	47,2	168,1
BR-34	T(5, 178, 300)	T(20, 430, 1100)
BR-35	T(5, 178, 300)	T(20, 430, 1100)
BR-38	T(5, 178, 300)	T(20, 430, 1100)
BR-43	T(5, 178, 300)	T(20, 430, 1100)
BR-44	T(5, 178, 300)	T(20, 430, 1100)
BR-45	48,5	341,5
BR-47	T(5, 178, 300)	T(20, 430, 1100)
BR-48	T(5, 178, 300)	T(20, 430, 1100)
BR-49	T(5, 178, 300)	T(20, 430, 1100)
BR-50	T(5, 178, 300)	T(20, 430, 1100)
BR-51	T(5, 178, 300)	T(20, 430, 1100)
BR-52	T(5, 178, 300)	T(20, 430, 1100)
BR-54	238,5	T(20, 430, 1100)
BR-55	20	295,5
BR-57	T(5, 178, 300)	T(20, 430, 1100)
BR-58	T(5, 178, 300)	T(20, 430, 1100)
BR-59	250	T(20, 430, 1100)
BR-60	38	155,9
BR-61	50	214
BR-62	140	605,2
BR-63	T(5, 178, 300)	T(20, 430, 1100)
BR-64	55	569,1
BR-65	53	263,8
BR-66	365,2	1131,88
BR-67	T(5, 178, 300)	T(20, 430, 1100)
BR-68	45	1112,17
BR-69	50	376,2
BR-70	189	315
BR-71	25	1134,3
BR-72	1173	1173
BR-73	102	324,53
BR-74	1157,6	1157,6
BR-75	T(5, 178, 300)	T(20, 430, 1100)
BR-76	120	164,3
BR-77	33	296,1
BR-78	60	310
BR-79	200	261,4
BR-80	298,4	369,1
BR-81	54	184,9
BR-82	140,8	392,9
BR-83	183	311
BR-84	60	60
BR-85	80	110
BR-86	74	249,2
BR-88	T(5, 178, 300)	T(20, 430, 1100)
BR-89	122,1	255,9
BR-90	54	191,7

Leakage simulation framework - parameters

Input parameters to the model:

- *Overpressure (ΔP) of the reservoir due to CO_2 injection.* Not meant to exceed 20-30% of initial pressure.
- *Buckley-Leverett front propagation saturation (S_{gf})*
- *Relative permeability at propagation saturation κ_r (S_{gf})*
- *Cement plug thickness (ε)*
- *Cement porosity (Φ)*
- ***Cement permeability (κ)***
- *CO_2 density (ρ_{CO2})*
- *CO_2 viscosity (μ_{CO2})*
- *CO_2 solubility (S_{CO2})*
- *Aqueous CO_2 well potential (CO_{2aq})*

- Degraded cement = 10^{-16} m^2 (*Fabbri*)
- Typical well cement = 10^{-18} m^2 (*Fabbri*)
- Well-formed cement = 10^{-20} m^2 (*Celia & Bachu*)
- Assumed that re-abandoned wells in 2015 are «good» quality
- Assumed that BR-62 & BR-64 (blowout wells) are «bad quality»
- Remaining wells could be anywhere within this region.

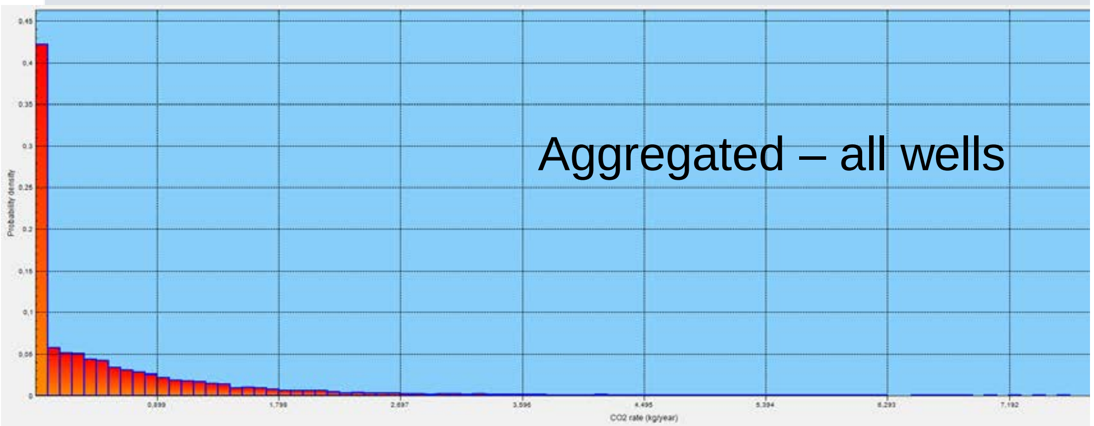
Good: U(1e-20, 1e-18)
Unknown: T(1e-20, 1e-18, 1e-16)
Bad: U(1e-18, 1e-16)

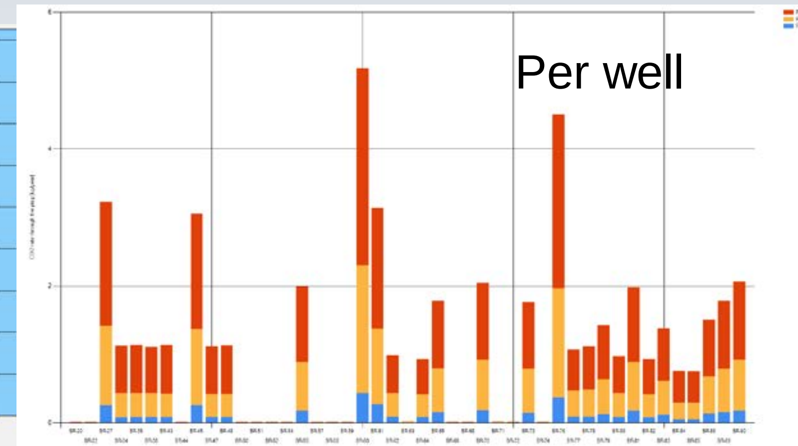
Well name	*Plug permeability [m2]*
BR-7	U(1E-18, 1E-20)
BR-20	U(1E-18, 1E-20)
BR-22	U(1E-18, 1E-20)
BR-27	T(1E-16, 1E-18, 1E-2
BR-34	T(1E-16, 1E-18, 1E-2
BR-35	T(1E-16, 1E-18, 1E-2
BR-38	T(1E-16, 1E-18, 1E-2
BR-43	T(1E-16, 1E-18, 1E-2
BR-44	U(1E-18, 1E-20)
BR-45	T(1E-16, 1E-18, 1E-2
BR-47	T(1E-16, 1E-18, 1E-2
BR-48	T(1E-16, 1E-18, 1E-2
BR-49	U(1E-18, 1E-20)
BR-50	U(1E-18, 1E-20)
BR-51	U(1E-18, 1E-20)
BR-52	U(1E-18, 1E-20)
BR-54	U(1E-18, 1E-20)
BR-55	T(1E-16, 1E-18, 1E-2
BR-57	U(1E-18, 1E-20)
BR-58	U(1E-18, 1E-20)
BR-59	U(1E-18, 1E-20)
BR-60	T(1E-16, 1E-18, 1E-2
BR-61	T(1E-16, 1E-18, 1E-2
BR-62	U(1E-16, 1E-18)
BR-63	U(1E-18, 1E-20)
BR-64	U(1E-16, 1E-18)
BR-65	T(1E-16, 1E-18, 1E-2
BR-66	U(1E-18, 1E-20)
BR-67	U(1E-18, 1E-20)
BR-68	U(1E-18, 1E-20)
BR-69	U(1E-18, 1E-20)
BR-70	T(1E-16, 1E-18, 1E-2
BR-71	U(1E-18, 1E-20)
BR-72	U(1E-18, 1E-20)
BR-73	T(1E-16, 1E-18, 1E-2
BR-74	U(1E-18, 1E-20)
BR-75	U(1E-18, 1E-20)
BR-76	T(1E-16, 1E-18, 1E-2
BR-77	T(1E-16, 1E-18, 1E-2
BR-78	T(1E-16, 1E-18, 1E-2
BR-79	T(1E-16, 1E-18, 1E-2
BR-80	T(1E-16, 1E-18, 1E-2
BR-81	T(1E-16, 1E-18, 1E-2
BR-82	T(1E-16, 1E-18, 1E-2
BR-83	T(1E-16, 1E-18, 1E-2
BR-84	T(1E-16, 1E-18, 1E-2
BR-85	T(1E-16, 1E-18, 1E-2
BR-86	T(1E-16, 1E-18, 1E-2
BR-88	U(1E-18, 1E-20)
BR-89	T(1E-16, 1E-18, 1E-2
BR-90	T(1E-16, 1E-18, 1E-2

CO2 leakage through plug

CO2 rate:
Mean = 0,6 kg/year
Max = 30,7 kg/year

CH4 rate:
Mean = 0,3 kg/year
Max = 2.6 kg/year



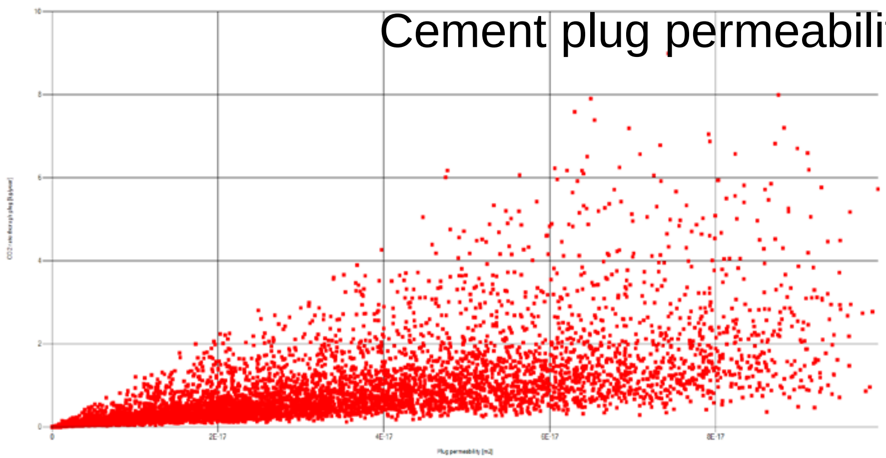


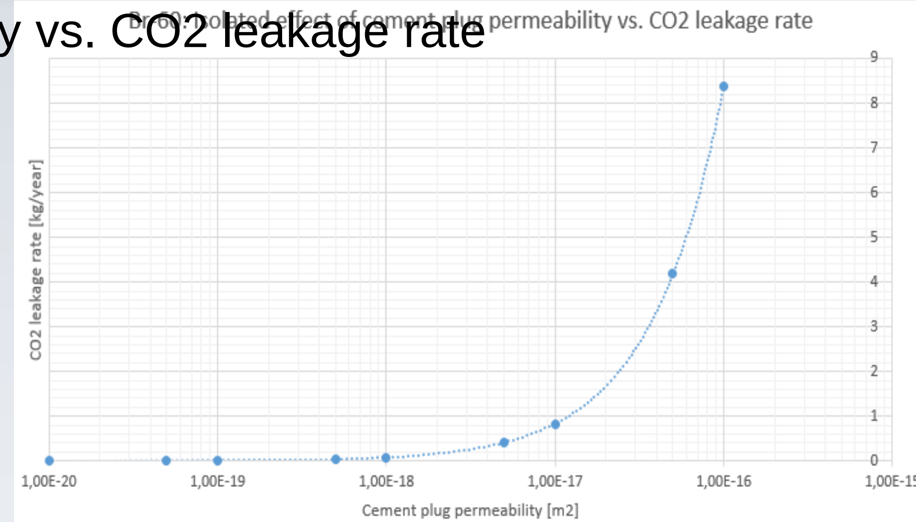
CO2 duration:
Mean = 300 000 years
Min = 10 years

CH4 duration:
Mean = 3.2 years
Min = 27 000 years

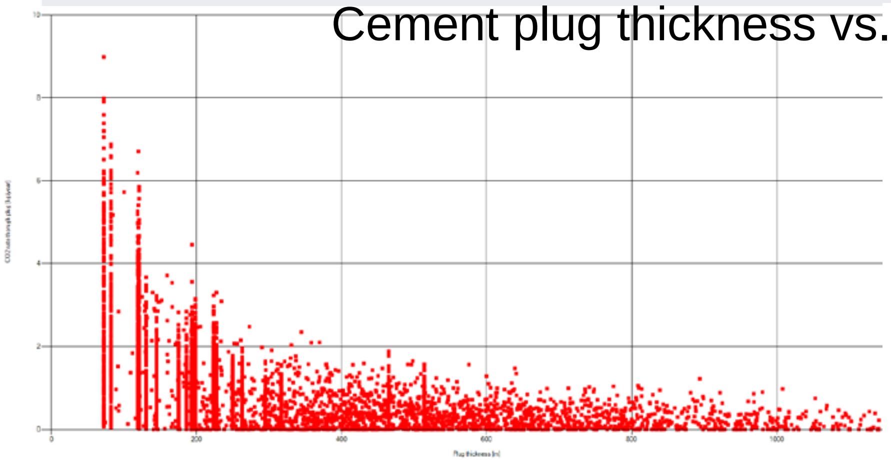
Sensitivity analysis

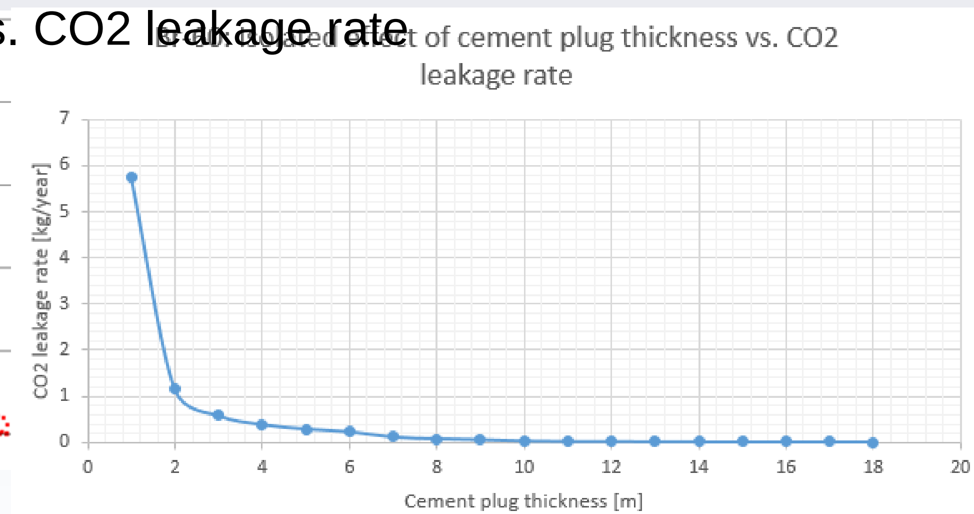
Cement plug permeability vs. CO2 leakage rate





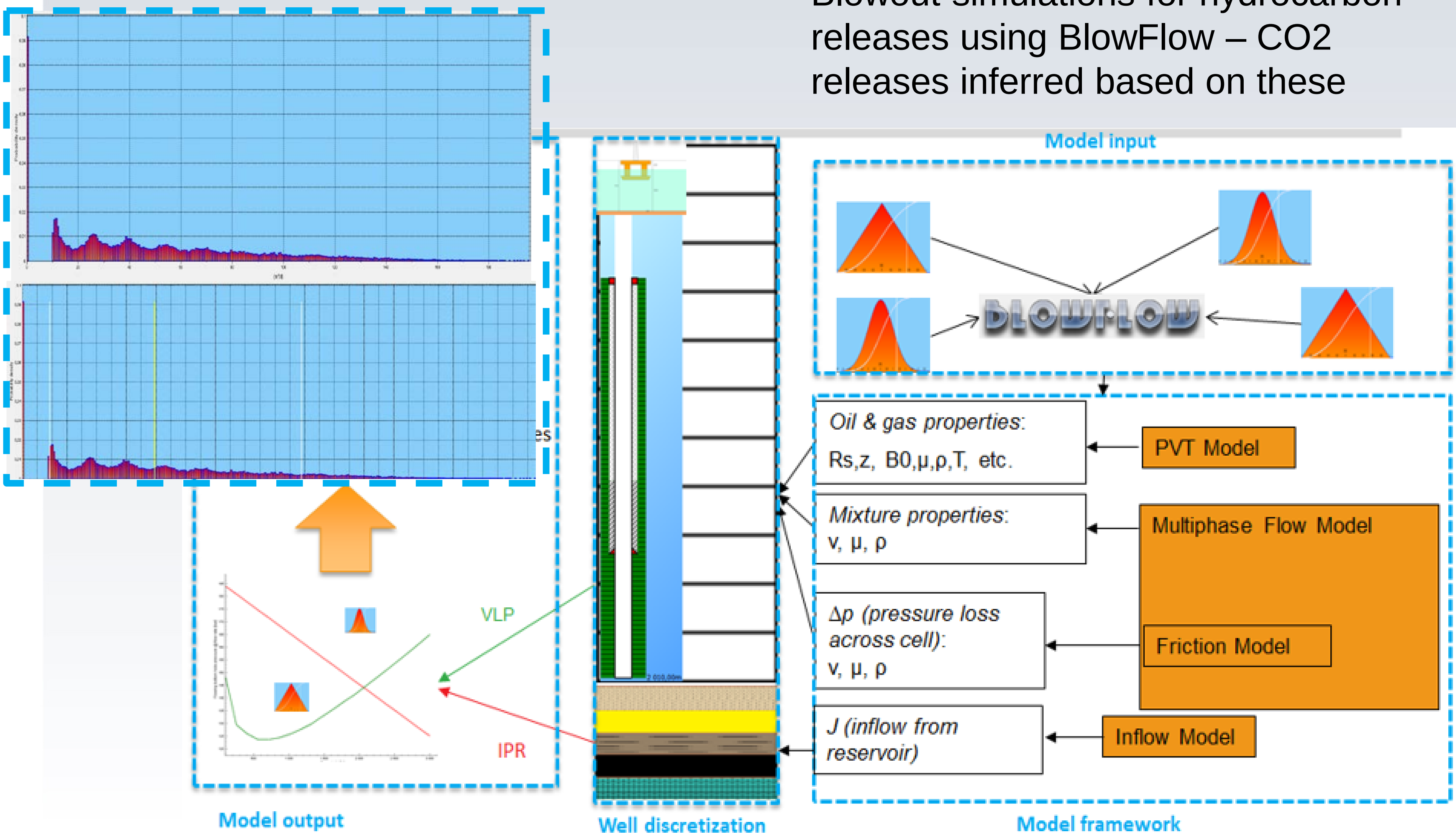
Cement plug thickness vs. CO2 leakage rate



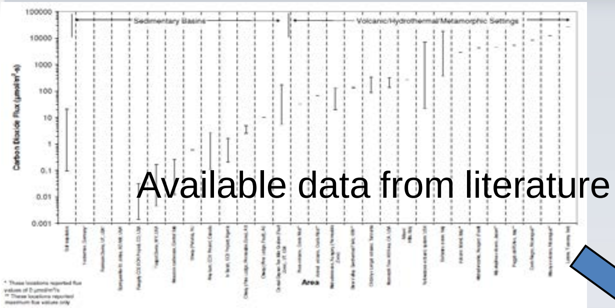


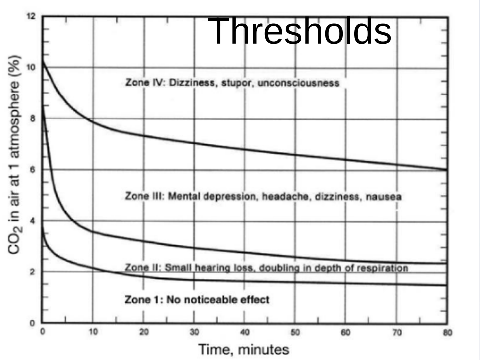
Blowout simulations

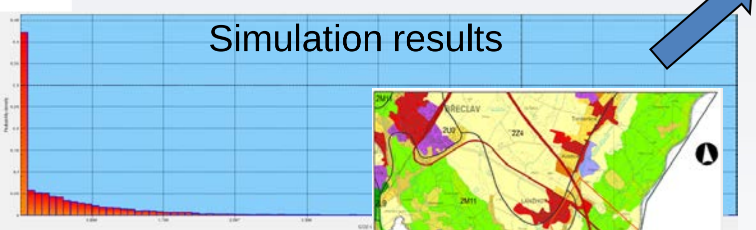
Blowout simulations for hydrocarbon releases using BlowFlow – CO_2 releases inferred based on these

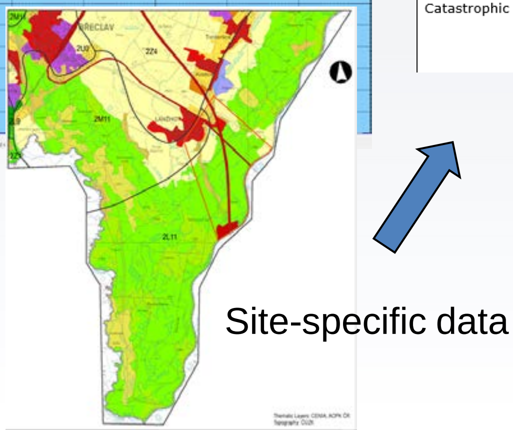


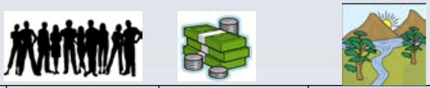
Consequence assessments











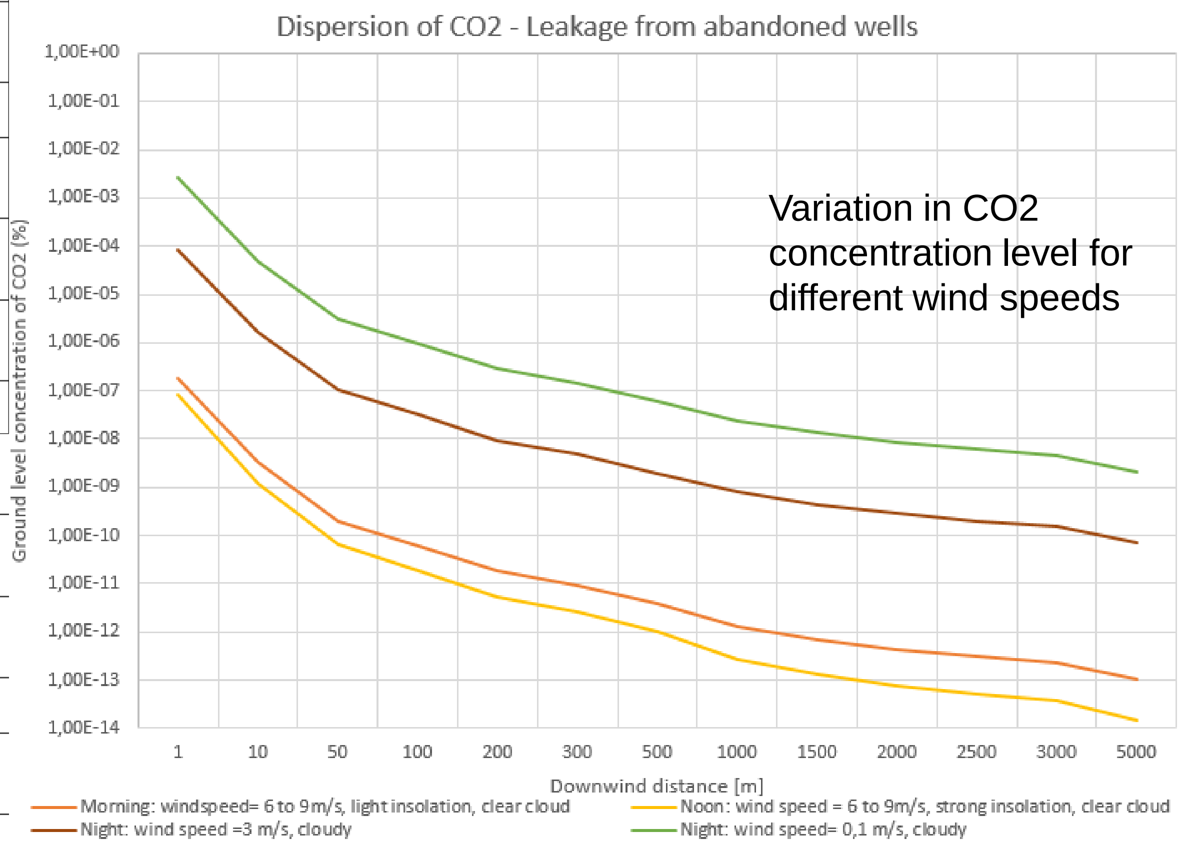
Class	Safety consequences	Operational consequences	Environmental consequences
1 - Insignificant	Medical treatment, minor health effects, first aid case, or less	0-10M USD	Small scale and short recovery time
2 - Minor	Medical treatment with restricted duty or medium health effects	10-100M USD	Large scale and short recovery time
3 - Moderate	One or more lost time workday cases or significant medical treatment	100M-1MM USD	Short scale and long recovery time
4 - Major	Permanent disability, multiple hospitalizations, or major health effects	1-10MM USD	Large scale and long recovery time
5 - Catastrophic	Fatality, Public hospitalization, or severe health effects	> 10MM USD	Large scale and long-lasting effect or permanent damage

CO2 exposure level [%]	Effect of exposure on human health	Leakage type	Duration until 1 m³ reaches exposure level
0.5	Maximum allowable concentration at workplaces	Mean leakage – 0.0005 tons/year	6.6 days
		Max leakage – 0.0105 tons/year	8 hours
		Mean blowout – 0.15/tons year	0.5 hours
		Max blowout – 5.7 tons/year	1 minute
1.5	Breathing rate increases to 40% above the normal level	Mean leakage – 0.0005 tons/year	19.8 days
		Max leakage – 0.0105 tons/year	0,9 days
		Mean blowout – 0.15/tons year	1.5 hours
		Max blowout – 5.7 tons/year	2.5 minutes

Consequences - humans

CO2 exposure level [%]	Effect of exposure on human health	Leakage type	Duration until 1 m³ reaches exposure level
0.5	Maximum allowable concentration at workplaces	Mean leakage – 0.0005 tons/year	6.6 days
		Max leakage – 0.0105 tons/year	8 hours
		Mean blowout – 0.15/tons year	0.5 hours
		Max blowout – 5.7 tons/year	1 minute
1.5	Breathing rate increases to 40% above the normal level	Mean leakage – 0.0005 tons/year	19.8 days
		Max leakage – 0.0105 tons/year	0,9 days
		Mean blowout – 0.15/tons year	1.5 hours
		Max blowout – 5.7 tons/year	2.5 minutes
5	Breathing increases to approximately four times the normal rate, symptoms of intoxication become evident, vertigos, slight feeling of choking	Mean leakage – 0.0005 tons/year	66 days
		Max leakage – 0.0105 tons/year	3.1 days
		Mean blowout – 0.15/tons year	5 hours
		Max blowout – 5.7 tons/year	8 minutes
10	Unconsciousness occurs more rapidly; prolonged exposure may result in death from asphyxiation	Mean leakage – 0.0005 tons/year	132 days
		Max leakage – 0.0105 tons/year	6.3 days
		Mean blowout – 0.15/tons year	11 hours
		Max blowout – 5.7 tons/year	17 minutes

Time to reach various CO2 concentration levels (assuming CO2 is trapped)

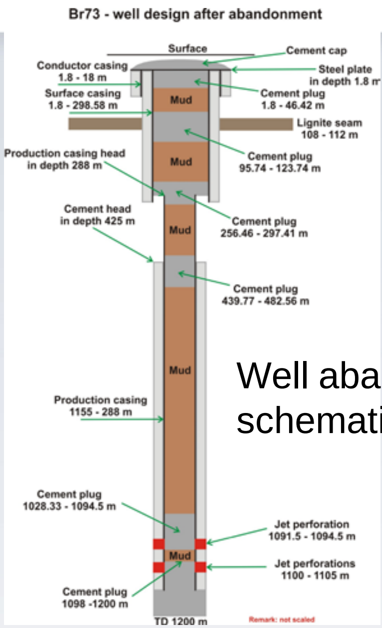


Variation in CO2 concentration level for different wind speeds

Task 4.3 Risk evaluation

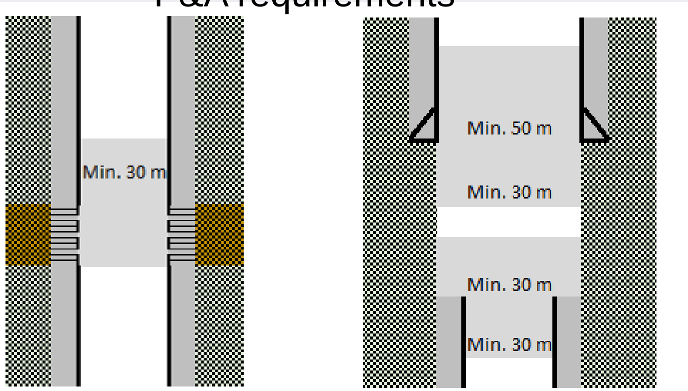
- Dominating risks in the CCS system related to CO2 leakage
- Findings vs. acceptance criteria set for the system
- Is the level of risk presented in a format that is suited to guide relevant decision making?
- What information has the most value? (Can be evaluated from the results of standard value of information (VOI) analysis).

Evaluations – cement plugs



Well abandonment schematics

P&A requirements



Case 2: Perforate casing

Case 5: Uncemented casing removed

CBU Decree No. 239/1998 Coll., safety and occupational health and safety in mining and processing of oil and natural gas and drilling and geophysical work and amending certain regulations to ensure safety and occupational health and safety in mining activities and activities perform mining, as amended by Decree No. 360/2001 Coll CBU, Decree 298/2005 and Decree No. 52/2011 Coll.

Well barrier evaluations

Vell	Perforation interval [m]		Cement plugs		Length above top perforation	Cement plug covers entire perforation	Evaluation
	From	To	From	To			
BR-64	1066,5	1070	704,69	1072,8	361,81	YES	Length OK, perforations entirely plugged
BR-65	1099	1101	1097	1150	2	YES	Perforations plugged, but length < 30 m
	1083	1093	717,17	775,19	58,02	NO	Length OK, but perforations are not plugged
BR-66	1098,5	1108,5	774,8	1140	323,7	YES	Length OK, perforations entirely plugged
BR-67	No data available						N/A
BR-68	1079	1095	957,3	1104,5	121,7	YES	Length OK, perforations entirely plugged
	1004,5	1006,5	957,3	1104,5	47,2	YES	Length OK, perforations entirely plugged
	744	746,5	672,8	957	71,2	YES	Length OK, perforations entirely plugged
BR-69	No perforations listed						N/A
BR-70	1101	1108	1041	1230	60	YES	Length OK, perforations entirely plugged
BR-71	1933,5	1937,5	1910	1935	23,5	NO	Length < 30 m, perforations only partially plugged
	1904	1906	1837	1877	40	NO	Length OK, but perforations are not plugged
	1771	1776	927,5	1726	798,5	NO	Length OK, but perforations are not plugged
	1067	1706	927,5	1726	139,5	YES	Length OK, perforations entirely plugged
BR-72	1102	1116	2	1175	1100	YES	Length OK, perforations entirely plugged
BR-73	1100	1105	1098	1130	2	YES	Perforations plugged, but length < 30 m
	1091,5	1094,5	1028,33	1094,5	63,17	YES	Length OK, perforations entirely plugged
BR-74	1095,5	1103	2	1118,6	1093,5	YES	Length OK, perforations entirely plugged
	295,5	296,5	2	1118,6	293,5	YES	Length OK, perforations entirely plugged
BR-75	No perforations listed						N/A
BR-76	1096	1097,5	1060	1180	36	YES	Length OK, perforations entirely plugged
BR-77	1102	1104	1043,95	1104,3	58,05	YES	Length OK, perforations entirely plugged
BR-78	1096	1102	982	1057	75	NO	Length OK, but perforations are not plugged
BR-79	1102,5	1105	980	1180	122,5	YES	Length OK, perforations entirely plugged
	1090,5	1094	980	1180	110,5	YES	Length OK, perforations entirely plugged
	1013	1015	980	1180	33	YES	Length OK, perforations entirely plugged
BR-80	1096	1106	915,65	1180	180,35	YES	Length OK, perforations entirely plugged
	1021	1022,5	915,65	1180	105,35	YES	Length OK, perforations entirely plugged
BR-81	1089	1125	1024	1084,9	60,87	NO	Length OK, but perforations are not plugged
BR-82	1093,5	1106	1039,2	1180	54,3	YES	Length OK, perforations entirely plugged
BR-83	1097	1106	1037	1220	60	YES	Length OK, perforations entirely plugged
BR-84	1150	1152,5	???	???			Unknown plug interval
BR-85	1098	1107	1085	1115	13	YES	Perforations plugged, but length < 30 m (partially unknow
BR-86	1103,5	1104,5	998	1070,7	72,7	NO	Length OK, but perforations are not plugged
BR-88	No perforations listed						N/A
BR-89	1084	1102	1057,92	1180	26,08	YES	Perforations plugged, but length < 30 m
BR-90	1147	1151	1097	1155	50	YES	Length OK, perforations entirely plugged

Risk matrix

Consequence Probability			1 - Insignificant	2 - Minor	3 - Moderate	4 - Major	5 - Catastrophic
		Safety	Medical treatment, minor health effects, first aid case, or less	Medical treatment with restricted duty or medium health effects	One or more lost time workday cases or significant medical treatment	Permanent disability, multiple hospitalizations, or major health effects	Fatality, Public hospitalization, or severe health effects
		Operational	0-10M USD	10-100M USD	100M-1MM USD	1-10MM USD	> 10MM USD
		Environmental	Small scale and short recovery time	Large scale and short recovery time	Short scale and long recovery time	Large scale and long recovery time	Large scale and long-lasting effect or permanent damage
1	Improbable	$< 10^{-6}$	Leakage through faults, fractures Leakage into aquifer				
2	Remote	$10^{-6} - 10^{-4}$	Leakage from an injection well to atmosphere Leakage from an abandoned well to atmosphere		Blowout from an injection well during drilling		
3	Rare	$10^{-4} - 10^{-3}$					
4	Probable	$10^{-3} - 10^{-1}$					
5	Frequent	$> 10^{-1}$					

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A comparison of FEP-analysis and barrier analysis for CO_2 leakage risk assessment on an abandoned Czech oilfield

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Abstract

The storage of CO_2 in depleted oilfields is one of the possible measures for reducing CO_2 emissions to the atmosphere. In parallel with the technical feasibility study, a risk assessment focusing on storage risk and reliability need to be undertaken prior to CO_2 storage. This is to demonstrate that the quality of the storage site, often formulated as the risk of CO_2 containment failure, is acceptable. Legislations in various European countries state such risk assessments shall be provided as part of making a decision with respect to accepting a storage site solution. However, the details and the choices on the risk assessment approach itself are often arbitrary. In the REPP-CO2 project, a research cooperation initiative between Czech Republic and Norway, the main goal is to evaluate the feasibility of a storage site in the Vienna Basin, in the southeastern part of the Czech Republic. As part of the REPP-CO2 project, two different approaches have been selected for performing the risk analysis part, namely the features, events and processes (FEP) approach and the barrier analysis approach, to quantify storage risk. This paper elaborates both approaches and presents strengths and weaknesses for each of them, with respect to work process scalability, available analytical modeling tools, their role in a classical risk assessment context, uncertainty treatment, system suitability and their effectiveness with respect to communication of results. To highlight different aspects of comparison, examples from the Czech storage site candidate are also described in the paper.

To be presented at the GHGT-13, 14-18 November 2016, in Lausanne, Switzlerand

Thank you for your attention!

Eric Ford, IRIS
12th October 2016