Central Mining Institute, Katowice - Poland

Theoretical Approach to Risk Asseessment in MOVECBM Project

European Commission

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Objectives and activities of the MOVECBM project

- To prove that the CO_2 is safely stored in the coal, understand the adsorption rate into the coal matrix, where it is physically bound to the coal.
- To improve the physical accessibility to methane for optimal production.
- To improve reservoir models using field data from this pilot, resulting in better tools to analyse CO_2 storage and ECBM economics in the future.
- Determine optimal monitoring for characterising migration of CO_2 and CH_4 in coal.
- Determine optimal monitoring for possible leakage to the surface: sides of the reservoir, through the cap rock, along the wells, from surface to atmosphere.
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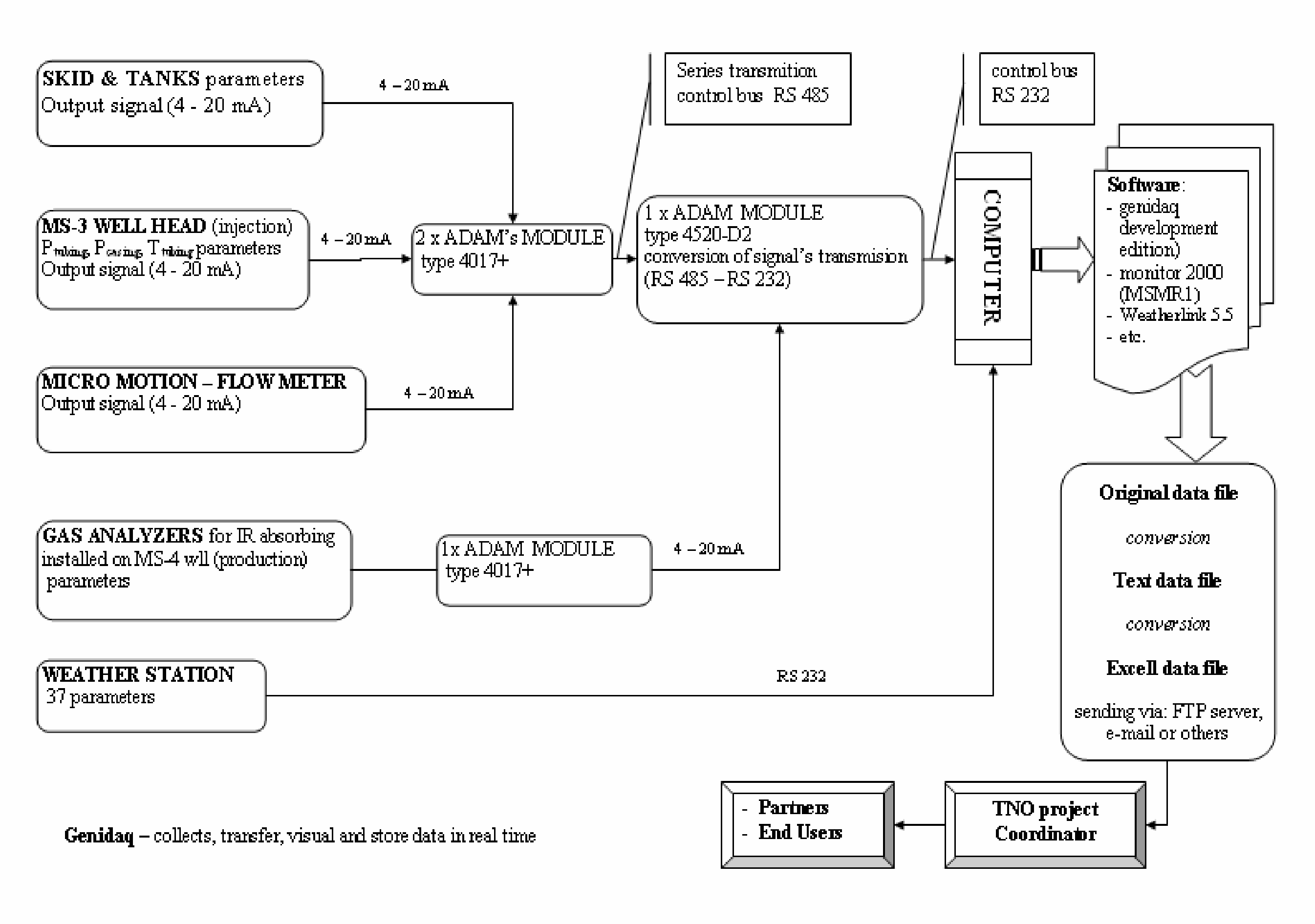
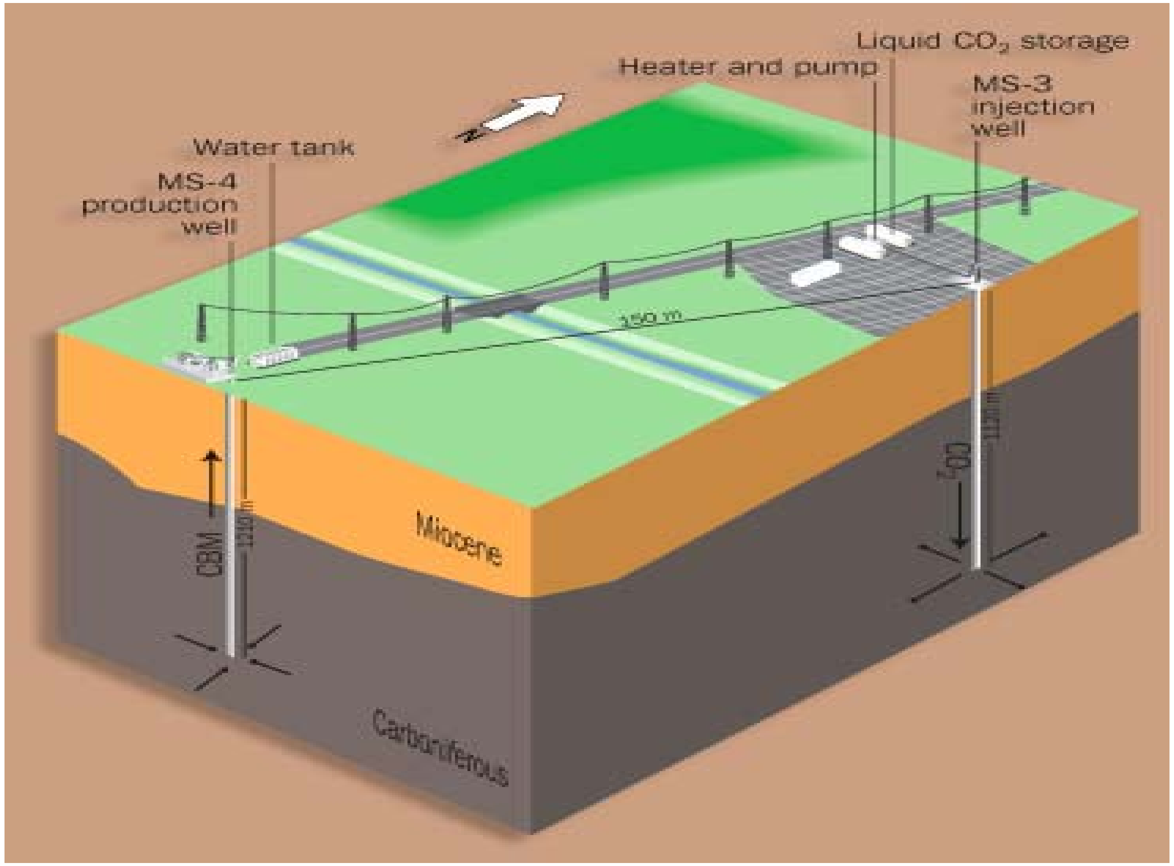
CO_2 monitoring system in the MOVECBM (RECOPOL) projects

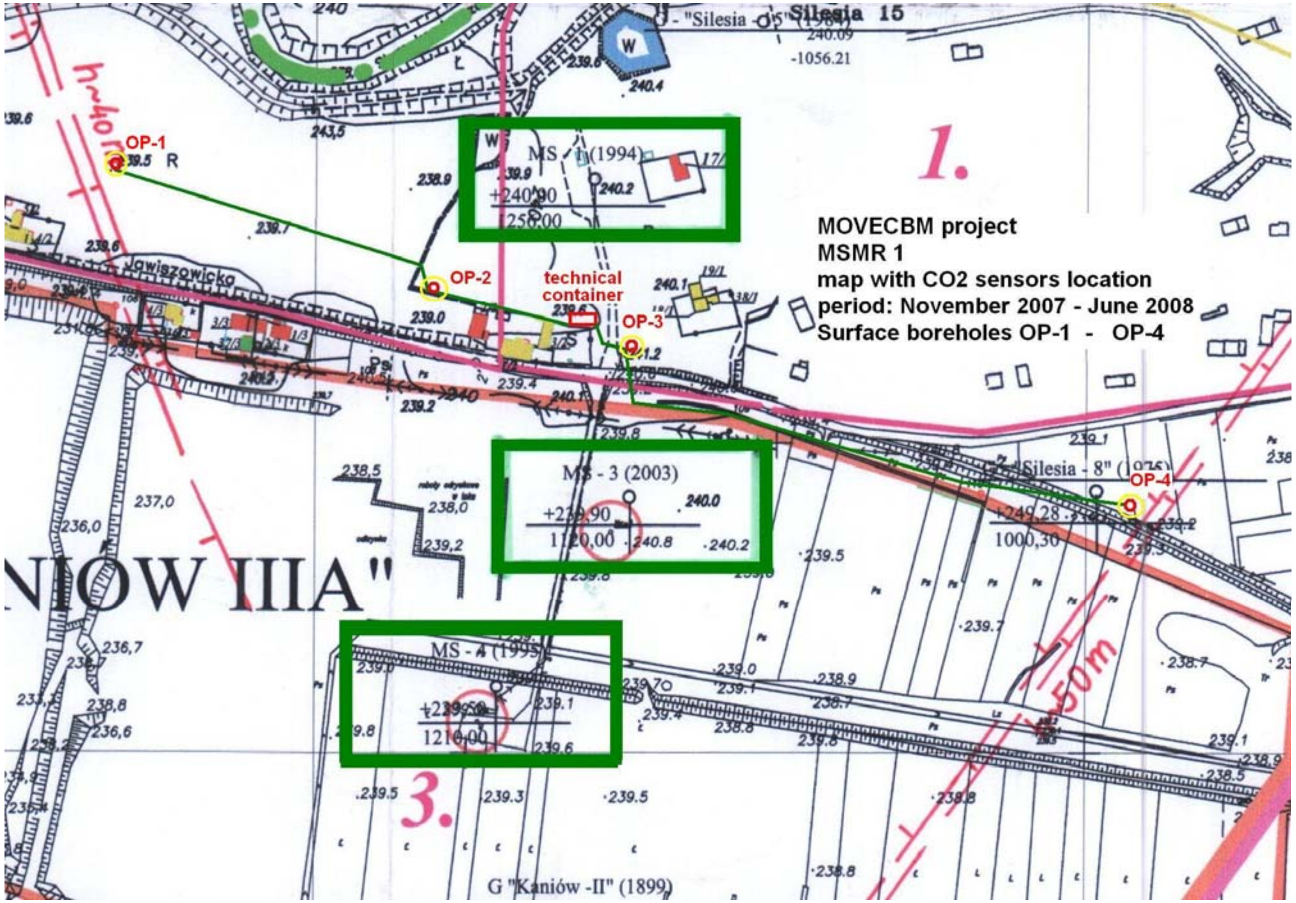


Schematic picture of the field experiment in the RECOPOL project Poland

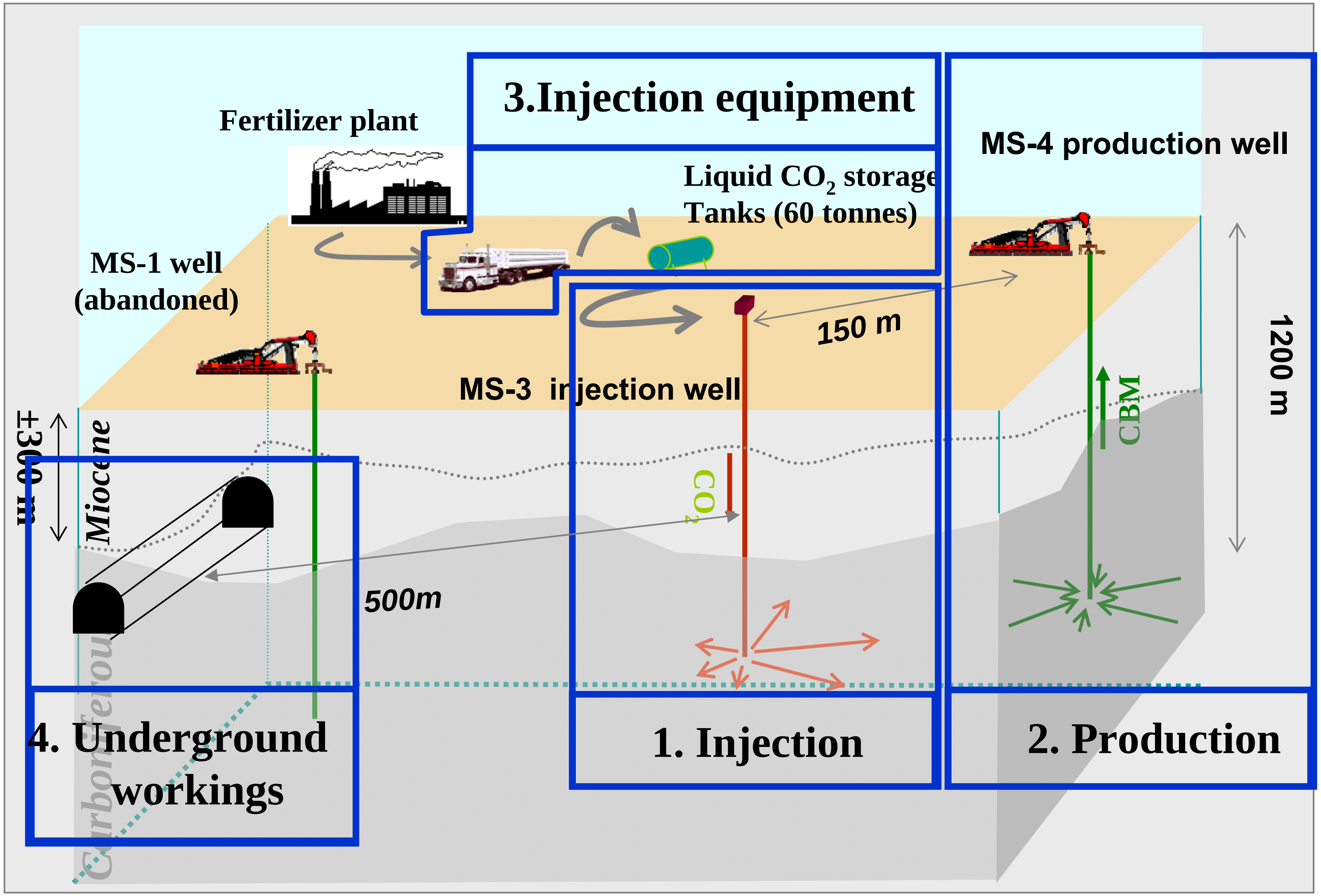


Within the MOVECBM project the injection well in this picture was used for monitoring and verification

Arrangement of wells on the projects MOVECBM (RECOPOL) site



Design of field experiment – Risk assessment objects



Types of initiating events

Geological conditions

- CO_2 gas pressure exceeds capillary pressure and passes through siltstone
- CO_2 escapes through „gap" cap rock into higher underground workings,
- CO_2 escapes via poorly plugged old abandoned well,
- Dissolved CO_2 escapes to atmosphere from pumped water

Equipment failure

- CO_2 tank, piping, heater failure due to fatigue or corrosion
- CO_2 tank, piping, heater failure caused by manufacturing defects or overpressure

Human failures

- Failure to execute steps of task property, in the sequence or omitting steps,
- Failure to observe or respond appropriately to conditions or other prompts by the system or process

Principles of risk assessment

Methodology is based on the following:

- **ALARP principles for determining criteria of acceptability of risks occurring in the CCS processes,**
- **elucidation of a scenario for the dangerous event – releases of CO_2,**
- **selection of the proper prevention methods at every stage of the scenario,**
- **determination of shares of different systems in risk reduction.**

Types of protective barriers

- material or physical – preventing or taming the effects of dangerous events — ie. passive means as buildings, walls, fences, containers and actives ones which require activation, as for example block valves on the pipelines,
- functional (electric, electronic, and electronic programmable control instruments) – actively regulating the process in the range of established parameters, stopping the undesired run of the process by the established logical and temporary feed backs,
- non-material – depending on operator's knowledge and experience; the typical ones are for example. the regulations, instructions of safety behavior (safety culture)

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Recommended Levels of Confidence for unique protective barriers and result of prevention measures used (based on EN 61508 series)

Level of Confidence	Risk reduction coefficient	Probability of failure
4	10 000	$\geq 10^{-5}$ to $< 10^{-4}$
3	1000	$\geq 10^{-4}$ to $< 10^{-3}$
2	100	$\geq 10^{-3}$ to $< 10^{-2}$
1	10	$\geq 10^{-2}$ to $< 10^{-1}$

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Level of Confidence (LC) for selected protective layers

Kind of protective layer	Probability of failure	Barrier's Level of Confidence
Carbon dioxide dispatching system	$\geq 10^{-3}$ do $< 10^{-2}$	2
Mine ventilation	$\geq 10^{-3}$ do $< 10^{-2}$	2

Examples of LC for human actions

Kind of human barrier	Probability of failure (from literature, industry)	Barrier's Level of Confidence
Prevention	$\geq 10^{-3}$ do $< 10^{-2}$	2
Normal operation	$\geq 10^{-3}$ do $< 10^{-2}$	2
Intervention	$\geq 10^{-2}$ do $< 10^{-1}$	1

HAZARDOUS EVENT SEVERITY MATRIX

(based on EN 61508 series)

Number of independant safety related systems and external risk reduction facilities [E]

Minor

[E]			
3	[C]	[C]	[C]
2	[C]	[C]	LC1
1	LC1	LC1	LC2
	LOW	MED	HIGH
	Event likelihood [D]		

Serious

[E]			
3	[C]	[C]	[C]
2	[C]	LC1	LC2
1	LC1	LC2	LC3
	LOW	MED	HIGH
	Event likelihood [D]		

Extensive

[E]			
3	[C]	LC1	LC1
2	LC1	LC2	LC3
1	LC3	LC1	LC3
	LOW	MED	HIGH
	Event likelihood [D]		

Minor Serious Extensive

Hazardous event severity

Risk on the surface connected with storage operations

CO_2 storage parameters:

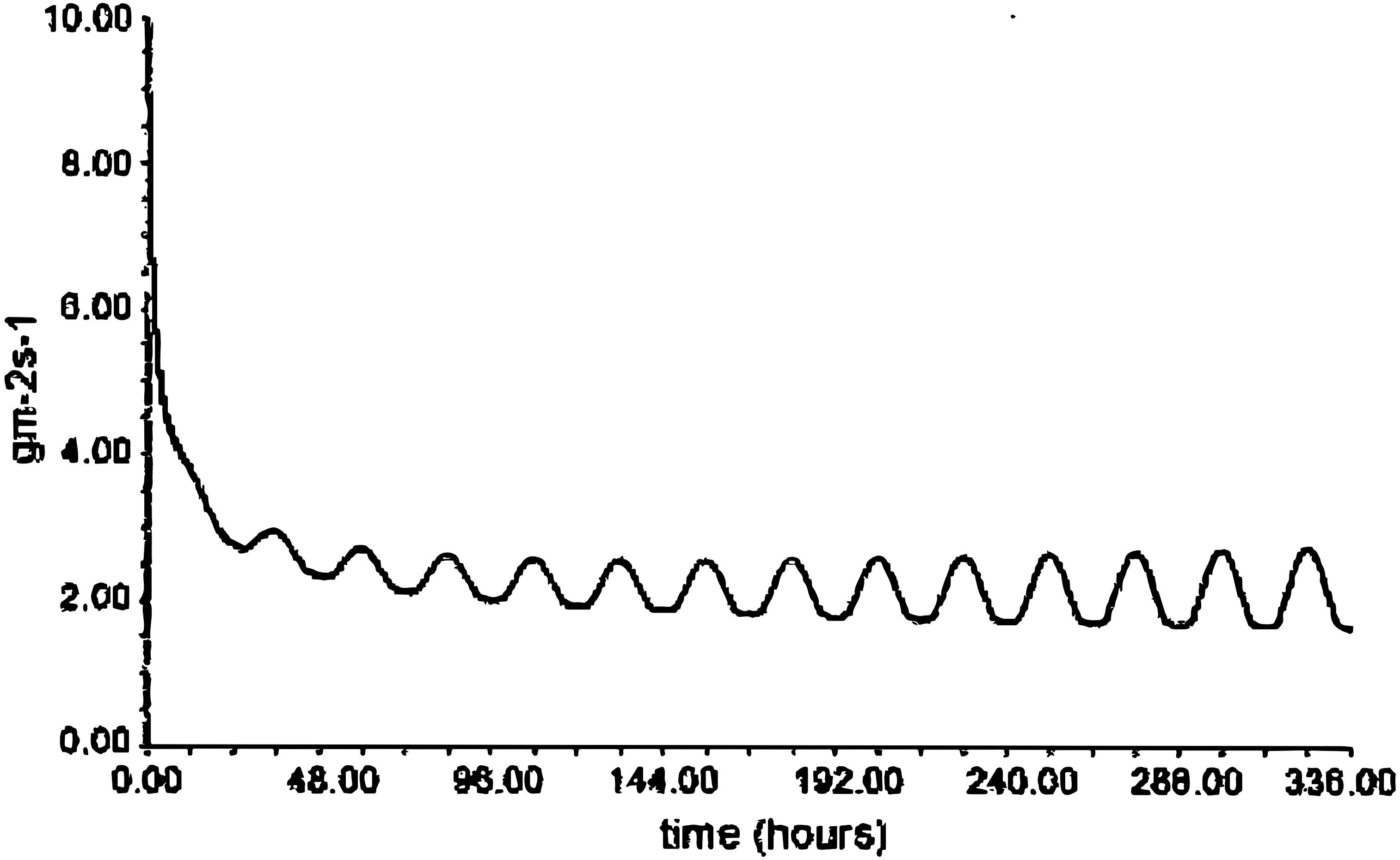
- liquid form
- temperature - (-20) º C
- Max. amount – 60 Tonnes

Risk on the surface connected with storage operations

The following assumptions have been made:

- The surface of the dry ice bank is at a constant temperature of −78.8 °C (CO_2 sublimation *T* at *P* = 0.1 MPa).
- leaked dry ice is forming regular shaped cone,
- sublimation rate during the first hour exceeds 8 g/secm2
- sublimation rate during the next hours decreases to 2 g/secm2
- quantity of released CO_2 – 30 tones

Dry ice sublimation rate



Source:A. Mazzoldi et all: CO_2 transportation for carbon capture and storage: Sublimation of carbon dioxide from a dry ice bank”

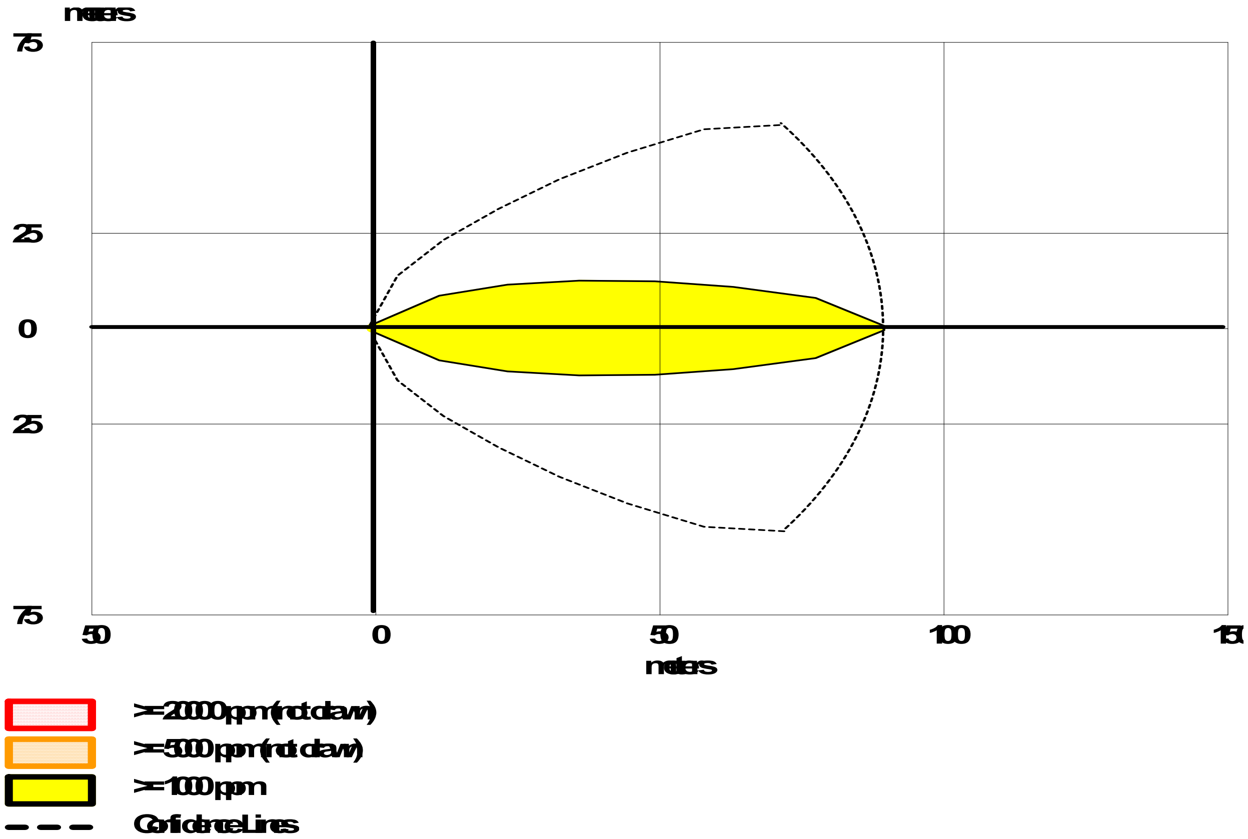
Range and concentration of CO_2 plum around the leakage event for the first leakage model

Wind speed: 2 meters/second

Sublimation Duration: 60 minutes

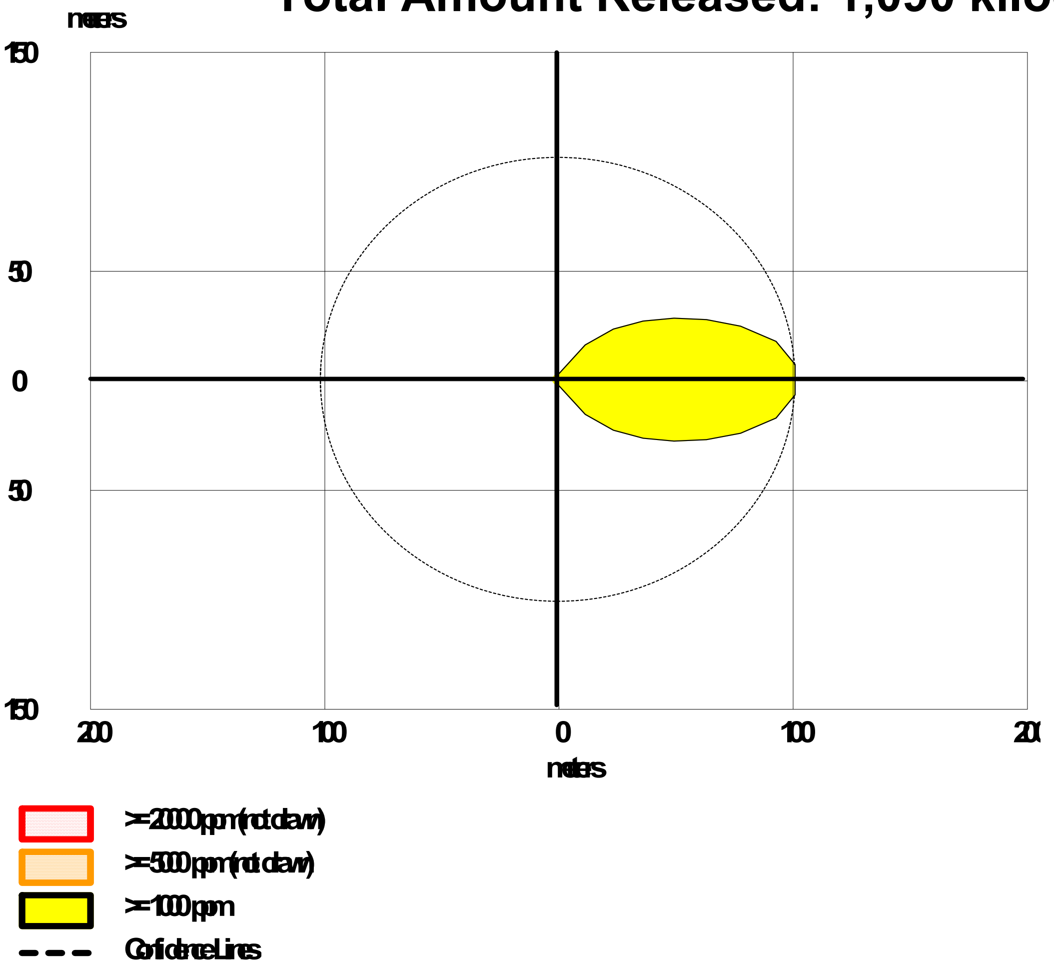
Sublimation Rate: 18.2 kilograms/min

Total Amount Released: 1,090 kilograms



Range and concentration of CO2 plum around the leakage event for the second leakage model

Wind speed: 1 meters/second
Sublimation Duration: 60 minutes
Sublimation Rate: 18.2 kilograms/min
Total Amount Released: 1,090 kilograms



HAZARDOUS EVENT SEVERITY MATRIX

Number of independant safety related systems and external risk reduction facilities [E]

Minor

[E]			
3	[C]	[C]	[C]
2	[C]	[C]	LC1
1	LC1	LC1	LC2
	LOW	MED	HIGH
	Event likelihood [D]		

Serious

[E]			
3	[C]	[C]	[C]
2	[C]	LC1	LC2
1	LC1	LC2	LC3
	LOW	MED	HIGH
	Event likelihood [D]		

Extensive

[E]			
3	[C]	LC1	LC1
2	LC1	LC2	LC3
1	LC3	LC1	LC3
	LOW	MED	HIGH
	Event likelihood [D]		

Hazardous event severity

The ways of prevention

It is good enough and suggested only one efficient method of prevention – automatically or handle collection the released CO_2 solid ice.

Analysis of risk level in the underground coal mine workings

Probable scenarios in which leakage may occur:

- CO_2 escapes through „gap" cap rock into higher underground workings,
- escapes via poorly plugged old abandoned well, for example MS1,
- Dissolved CO_2 escapes to underground workings from underground water.

Estimation of risk level in the underground coal mine workings

Number of independant safety related systems and external risk reduction facilities [E]

Hazardous event severity: Minor

[E]			
3	[C]	[C]	[C]
2	[C]	[C]	LC1
1	LC1	LC1	LC2
Event likelihood [D]	LOW	MED	HIGH

Hazardous event severity: Serious

[E]			
3	[C]	[C]	[C]
2	[C]	LC1	LC2
1	LC1	LC2	LC3
Event likelihood [D]	LOW	MED	HIGH

Hazardous event severity: Extensive

[E]			
3	[C]	LC1	LC1
2	LC1	LC2	LC3
1	LC3*	LC3	LC3
Event likelihood [D]	LOW	MED	HIGH

Minor — Serious — Extensive

Hazardous event severity

* One LC3 safety related system may not provide sufficient reduction of risk level. Additional hazard and risk analysis are necessary.

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The ways of prevention

Presence of CO_2 in underground workings at high concentrations causes rapid circulatory insufficiency leading to coma and death. Special attention should be turned on different independent methods of prevention (different independent protection layers).

A) Material protective barriers:

- Intensive underground ventilation
- Goafs isolation and galleries sealing
- Auxiliary ventilation systems

B) Active barriers (electronic programmable)

- Carbon dioxide dispatching system,
- Intensity of ventilation dispatching system.

The ways of prevention

c) Non-material protective barriers – human action

- **obligations of supervisors, dispatcher and workers in case of lack of ventilation in blind working,**
- **ways of CO_2 concentration monitoring by supervisors and officers,**
- **obligations of production and CO_2 monitoring dispatchers, and supervisors in case of exceeding the permitted CO_2 concentrations in underground workings,**
- **proceeding of CO_2 monitoring dispatcher in case of occurrence of growing CO_2 concentration,**
- **proceeding of CO_2 concentration monitoring dispatcher to watch the anemometer,**
- **proceeding of CO_2 concentration monitoring in case of damaging of any CO_2 sensor.**

Conclusions

1. The released liquid CO_2 models analysis show, that the plum exceeds distance of about 100m during the best weather condition ie. wind speed below 2 m and temperature from 10 to 20 C^o . CO_2 concentration in the plum don’t exceed 10000 ppm ie. allowable threshold. Greater concentration are only in the immediate nearby of dry ice cone. Consequence severity may be serious don’t due to CO_2 concentration but due to incorrect handling with solid frozen CO_2.

Conclusions

2. Presence of CO_2 in underground workings at high concentrations may cause rapid circulatory insufficiency leading to coma and death. Special attention should be turned on different independent methods of prevention (different independent protection layers). Mining ventilation departments have great experience in control different gas hazards, and in use all kinds of protective barriers.

Thank you for your attention