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Greenhouse Gas Control Technologies
13th International Conference on

ghgt-13

Conference Programme

13th International Conference on
Greenhouse Gas Control Technologies

November 14th - 18th, 2016
SwissTech Convention Center - Lausanne, Switzerland

ORAL SESSION DETAILS

TECHNICAL SESSION 3 | TUESDAY 15 NOVEMBER | 16:10 - 17:50

2G Oxy-combustion (2)

Chairs: Andrea Ramirez & Kari Myöhänen

Demonstration of the Allam Cycle: an update on the development status of a high efficiency supercritical carbon dioxide power process employing full carbon capture
Rodney Allam*, Jeremy Fetvedt, Mr. Brock Forrest, Mr. Scott Martin, 8 Rivers Capital; Mr. Takashi Sasaki, Mr. Masao Itoh, Toshiba Corporation

Oxy-turbine for power plant with CO_2 capture
Noemi Ferrari*, Luca Mancuso, Amec Foster Wheeler; John Davison, IEAGHG, Paolo Chiesa, Emanuele Martelli, Matteo Romano, Politecnico di Milano

Oxy-combustion carbon capture for pulverised coal in the integrated environmental control model
Kyle Borgert, U.S. EPA; Edward Rubin*, Carnegie Mellon University

Oil heavy residues oxy-combustion with CO_2 capture demonstration project and perspectives
Mourad Younes*, Aqil Jamal, Tidjani Niass,Saudi Aramco; Armand Levasseur, Olaf Stallmann, Gianluca Di Federico, GE

Development of high-efficiency oxy-fuel IGCC system
Yuso Oki*, Hiroyuki Hamada, Makoto Kobayashi, Isao Yuri, Saburo Hara, CRIEPI

3A Capture Pilot and Demonstration Projects

Chairs: Frank Morton & John Litynski

KM CDR process project update and the new novel solvent development
Osamu Miyamoto, Cole Maas, Mitsubishi Heavy Industries America, Inc; Tatsuya Tsujiuchi, Masayuki Inui, Takuya Hirata*, Hiroshi Tanaka, Takahito Yonekawa, Takashi Kamijo, Mitsubishi Heavy Industries, Ltd

Chilled ammonia process scale-up and lessons learned
Barath Baburao*, Sanjay Dube, David Muraskin, Steve Bedell, GE Power

Developing CCS in the UK and beyond: insights from the UK CCS Research Centre
Ciara O'Connor, Hannah Chalmers*, Bruce Adderley, Jon Gibbins, UK CCS Research Centre

Fluor's econamine FG Plus completes test program at Uniper's Wilhelmshaven coal power plant
Satish Reddy*, Joseph Yonkoski*, Fluor Enterprises Inc; Helmut Rode, Robin Irons, Wolfgang Albrecht, Uniper Technologies GmbH

Operating experience in la Pereda 1.7 MWth Calcium Looping pilot
Borja Arias, Maria Elena Diego, Alberto Méndez, Juan Carlos Abanades*,CSIC-INCAR; Luis Díaz, María Lorenzo, HUNOSA; Andres Sánchez-Biezma, Endesa Generación

3B Risk Assessment for Geological Storage

Chairs: John Hamling & Owain Tucker

A comparison of FEP-analysis and barrier analysis for CO_2 leakage risk assessment on an abandoned Czech oilfield case
Øystein Arild*, Eric P Ford, Hans P Lohne, International Research Institute of Stavanger; Vaclava Havlova,UJV Řež

Monetizing leakage risk with secondary trapping in intervening stratigraphic layers
Jeffrey Bielicki*, The Ohio State University; Hang Deng, Jeffrey Fitts, Catherine Peters, Princeton University; Elizabeth Wilson, University of Minnesota

Informing geologic CO_2 storage site management decisions under uncertainty: demonstration of NRAP's Integrated Assessment Model (NRAP-IAM-CS) Application
Rajesh Pawar*, Philip Stauffer, Shaoping Chu, George Guthrie, Los Alamos National Laboratory; Robert Dilmore, Grant Bromhal, National Energy Technology Laboratory; Yingqi Zhang, Curtis Oldenburg, Lawrence Berkeley National Laboratory

The genesis of the CO_2 storage resource management system (SRMS)
Scott Frailey*, Illinois State Geological Survey; George Koperna, Advanced Resources International, inc; Owain Tucker, Shell Global Solutions

Risk-based monitoring network design for geologic carbon sequestration sites
Ya-Mei Yang, Robert Dilmore, Grant Bromhal*, National Energy Technology Laboratory; Kayyum Mansoor, Susan Carroll, Lawrence Livermore National Laboratory; Mitchell Small, Carnegie Mellon University

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

Øystein Arild, Eric P. Ford, Hans Petter Lohne,
Mohammad Mansouri Majoumerd, Vaclava Havlova

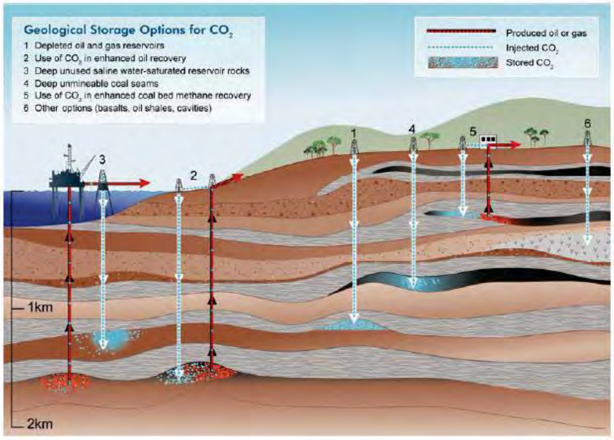
REPP CO_2 norway grants IRIS 60 1955–2015 ÚJV ŘEŽ

Outline

- › Background & objectives
- › Context: risk management
- › A specific case
- › FEP approach
- › Barrier approach
- › Comparison & conclusions

Background & Objectives

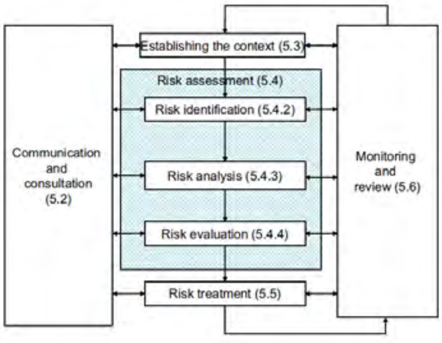
- › A risk management process is one of several activities that supports decision-making for CO_2 storage
- › As part of the REPP CO2 project, an old oilfield was subject to a CO_2 storage feasibility study
- › Two of the partners in the project had experience with risk management from different applications; IRIS with main experience from the oil & gas industry and barrier analysis and UJV Rez with main experience from storage of nuclear waste and FEP analysis
- › Advantages and disadvantages of the two approaches are therefore explored



Different geological storage alternatives (courtesy of CO2CRC)

Context: Risk management

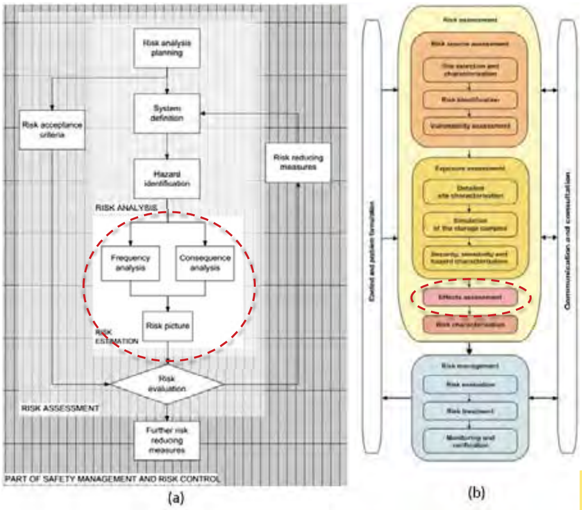
- Running a risk management process is compulsory, however…
- Most regulatory bodies do not state specifically how to undertake risk management. Operators or storage owners need, therefore, to demonstrate and convince the regulators that the CO_2 storage site is safe in terms of environment and human health
- Most risk management processes will comply with ISO31000, but it is so general that leaves the analysts with a wide range of alternatives to perform risk assessment


Establishing the context (5.3)
Risk assessment (5.4)
Risk identification (5.4.2)
Risk analysis (5.4.3)
Risk evaluation (5.4.4)
Risk treatment (5.5)
Communication and consultation (5.2)
Monitoring and review (5.6)

Risk management process (ISO 31000:2009)

Context: risk management

- Risk management processes have been described differently by different industries
- Examples are (a) NORSOK Z-013 in the oil & gas industry and (b) IEAGHG in the «Climate industry».
- Z-013 clearly focuses on both frequency and consequence, resembling the classical approach where risk = frequency x consequence
- IEAGHG focuses on «effects assessment» and not as much on frequency by itself


Risk analysis planning
System definition
Risk acceptance criteria
Hazard identification
Risk reducing measures
RISK ANALYSIS
Frequency analysis
Consequence analysis
Risk picture
RISK ESTIMATION
Risk evaluation
RISK ASSESSMENT
Further risk reducing measures
PART OF SAFETY MANAGEMENT AND RISK CONTROL

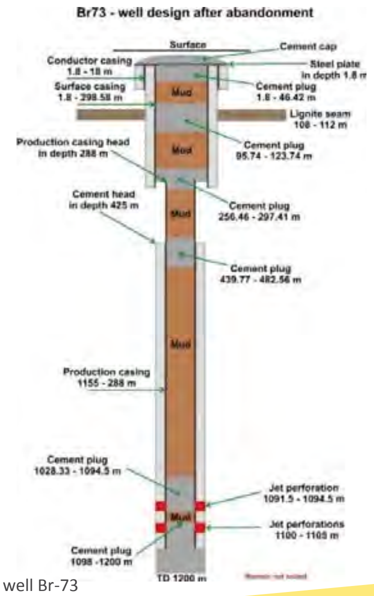
(a) (b)

A specific case

- An abandoned oil field (the Brodske LBr-1 field) a part of the Vienna Basin in the southeastern part of the Czech Republic is considered for CO_2 storage
- The reservoir is just below 1000 meters, and was produced from the mid-50s and the late 70s.
- The caprock has been perforated by ca. 50 wells, which have been abandoned with various cement plugs
- The primary goal of the risk assessment activity is to assess the risk of CO_2 leakages from the storage system situated in the selected reservoir

A specific case

- › Well Br-73 is a former oil and gas production well, with production occurring between 1958 and 1977
- › The Br73 well has been permanently abandoned in the year 2000 with several cement plugs
- › In the following slides, we have applied the FEP and barrier approaches, using this case for illustrative and comparative purposes



Well abandonment schematic for well Br-73
(courtesy of Pereszlényi and Francŭ)

FEP approach

The FEP approach consists of six basic steps:

i) FEP identification,
ii) FEP classification,
iii) FEP ranking and specification,
iv) FEP screening,
v) FEP interaction and grouping and
vi) scenario formation

FEP terminology (courtesy of CGS Europe) and relevant examples for the case

Term	Short explanation	Examples
Features	Physical characteristics, properties or components of the system of interest	Cement plug Fault Caprock
Events	Discrete occurrences in time (the duration being short compared to the time frame of consideration) which may impact the system	Cement plug leakage Blowout Earthquake
Processes	Gradual or continuous changes, due to interactions between features, which influence the evolution of the system	Forming of microannuli in cement plug Displacement of formation fluids CO_2 phase behavior

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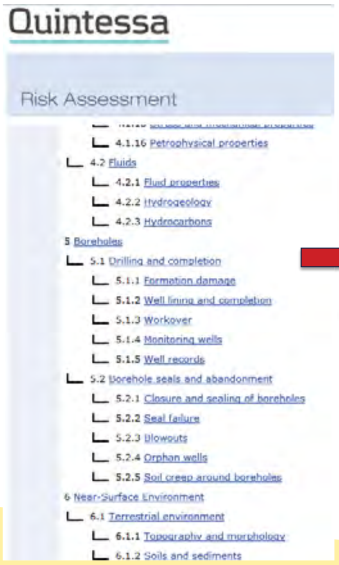
FEP approach workflow


Quintessa

Risk Assessment

- 4.1.16 Petrophysical properties
- 4.2 Fluids
  - 4.2.1 Fluid properties
  - 4.2.2 Hydrogeology
  - 4.2.3 Hydrocarbons
- 5 Boreholes
  - 5.1 Drilling and completion
    - 5.1.1 Formation damage
    - 5.1.2 Well lining and completion
    - 5.1.3 Workover
    - 5.1.4 Monitoring wells
    - 5.1.5 Well records
  - 5.2 Borehole seals and abandonment
    - 5.2.1 Closure and sealing of boreholes
    - 5.2.2 Seal failure
    - 5.2.3 Blowouts
    - 5.2.4 Orphan wells
    - 5.2.5 Soil creep around boreholes
- 6 Near-Surface Environment
  - 6.1 Terrestrial environment
    - 6.1.1 Topography and morphology
    - 6.1.2 Soils and sediments

Checklist/brainstorming

Focus: What are the relevant scenarios?

Initial set of FEPs for well Br-73, prior to screening

Class	Sub-class	Sub-Sub-class	FEP's identified (high level abstraction)
1 - External factors	Future human actions	Motivation and knowledge issues	Inadvertent damage to wellbore caused by humans Sabotage/intrusion to storage site, causing damage to wellbore
		Social and institutional developments	Changes in legislation requiring operations on abandoned wells
2 - CO_2 storage	Pre-closure	Quality control	Verification procedures related to borehole integrity
		Accidents and unplanned events	Incomplete sealing of borehole, leading to free pathway for CO_2 and hydrocarbons Destruction of wellhead, caused by vehicle in motion
3 - CO_2 properties, interactions and transport	CO_2 interactions	Mechanical processes and conditions	Borehole lining collapse

Scenarios generated from the FEP analysis for Br-73

Leakage path sub-type	Leakage scenario
Abandoned wells	Leakage between cement fill and outside of casing
	Leakage between cement plug and inside of casing
	Leakage through cement well plug
	Leakage through casing
	Leakage in cement fill fractures
	Leakage between cement fill and formation rock
Injection wells	Leakage in casing wall due to corrosion
	Leakage through the safety valve and xmas tree due to failure in safety valve, xmas tree or related equipment
	Blowout through the well due to failure in downhole safety equipment

Barrier approach

The well barrier approach consists of following main steps:

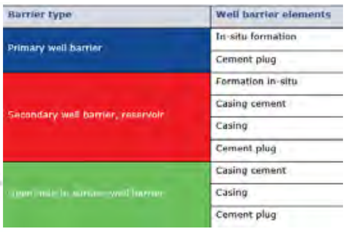
1. Define and become familiar with the system
2. Identify failure modes and failure causes
3. Construct a reliability model (e.g. fault tree) of the well barrier system
4. Perform a qualitative analysis of the fault tree
5. Perform a quantitative analysis of the fault tree
6. Report results


Different leakage pathways through an abandoned well (S.E. Gasda et. al. 2004)

Well barrier elements for Br-73

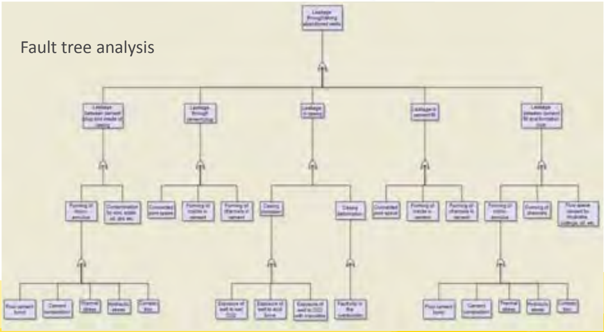
Barrier classification	Well barrier element type	Element name	Depth range
Primary well barrier	Formation	Lower Badenian	Ca. 1190-1105 m
	Casing	Production casing	288 – 1155 m
	Cement plug	Lower isolation plug	1098 – 1200 m
	Cement plug	Upper isolation plug	1028 – 1095 m
	Cement plug	Mid cement plug #1	440 – 483 m
Secondary well barrier	Formation	Pannonian	Ca. 0-440 m
	Casing cement	Cement, surface casing	2 – 290 m
	Casing	Surface casing	2 – 290 m
	Cement plug	Mid cement plug #2	256 – 297 m
Tertiary well barrier	Formation	Pannonian	Ca. 0-440 m
	Casing cement	Cement, surface casing	2 – 290 m
	Casing	Surface casing	2 – 290 m
	Cement plug	Upper cement plug	96 – 124 m
Surface well barrier	Cement plug	Surface plug	2 – 46 m
	Casing cement	Cement, surface casing	2 – 290 m
	Cement cap	Cement cap	0 – 2 m

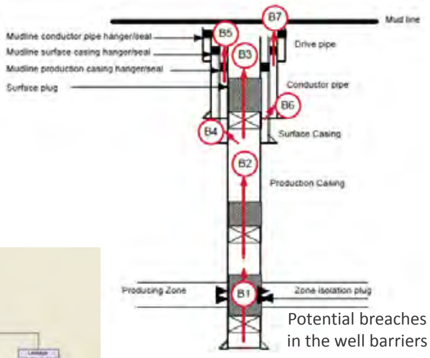
Barrier approach workflow



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

Generic example of well barrier elements for permanently P&Aed well (NORSOK D-010:2013)


Fault tree analysis



Potential breaches in the well barriers

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

Similarities/Differences of two approaches

Similarities	Differences
Both FEP and barrier approaches are sub-activities taking place within a risk management process	Performing risk identification using FEP approach relies more on checklist/brainstorming, while checklists are not required for well-defined systems such as wells using barrier approach
These approaches share common objectives (although utilizing different means)	The uncertainties addressed in an FEP context are often in relation to the consequences of the variant scenarios, and perhaps have a lesser focus on the probabilities of failure.
Both approaches are most influential in the establishment of context and risk identification steps	Although the barrier approach explicitly states that barriers can be technical, operational or organizational, such analyses often gravitates towards the former type as such analyses are common in engineered systems (e.g. wells).
	The barrier approach to a stronger degree outlines how the subsequent risk analysis step shall be conducted, and also (especially when the analysis concerns primarily technical barriers) the focus is of a more quantitative nature than what is the case for an FEP approach.
	The barrier approach is more preoccupied with failure frequencies, as these often constitute mandatory inputs, at least when using fault trees with the objective of obtaining system reliability.

Comparison highlights

	FEP approach	Barrier approach
System definition	Part of identification System is refined based on identified FEPs.	Initial activity Barriers are established from barrier elements
System suitability	Difficult to abstract the system into a model, or the ambiguity in system borders are high.	Clearly defined systems that can be described in terms of barriers, or when engineering systems.
Identification	Open search screened for relevance Heavily dependent on checklists to ensure coverage	Restricted to impact on barriers. Aspects not included as barriers may be neglected.
Focus	Attributes of the system and their interactions	Components of the system and how they might fail
Methods	Process influence diagrams, interaction matrices	Hazard-barrier matrices, FMECA, Event trees, Fault trees, Bowtie diagrams
Uncertainty focus	Focus on consequences	Focus on failure frequency
Challenges	To ensure all relevant FEPs are considered. Requires more experience	Avoiding purely technical focus. Defining the barriers, in particular for non-physical barriers. Only considers the barriers, thus a limited system view
Legislation suitability	Acceptance criteria of exposure	Requirements on barriers in place, and reliability of barriers
Communication	Risk matrix seems implied Focus on risk acceptance	Bowtie and trees Focus on system engineering

Main conclusions

- Both the FEP and barrier approaches are valid approaches to risk assessment (their origins are different)
- The overall message is that the FEP and the barrier approach simply represent two different means to the same end (different ways to represent/analyze a given system)
- FEP approach features:
  - Well-suited for complex system
  - Focus on the system attributes
  - Challenges for considering all relevant FEPs
- Barrier approach features:
  - Well-suited for clearly defined systems (e.g. engineered systems)
  - Focus on the system components
  - Challenges for non-technical barriers

Thanks for your attention!

Q&A?

The authors are grateful to Norway Grants for financial support of "Preparation of a Research Pilot Project on CO_2 Geological Storage in the Czech Republic (REPP-CO2)" with project number NF-CZ08-OV-1-006-2015. We would also like to express our gratitude to MND, a.s. and Palivovy kombinat Usti, s.p. for provision of site-related (or well-related) data., and to the invaluable work of Miro Pereszlényi and Juraj Franců, for providing essential data used in the risk assessment of the project.