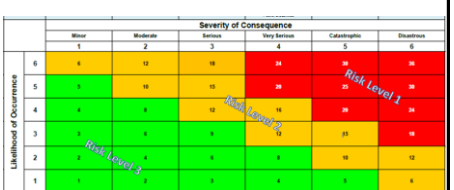
Accurate and Reliable Management of Legacy Wells using Numerical, Risk-based Models – a case study

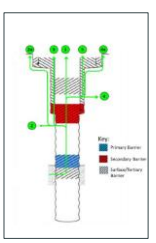
Dr Morteza Sefat – Associate Professor, Heriot Watt University
Stephen Patterson – Lead P&A Engineer, TotalEnergies

1

Problem Statement – Current Situation

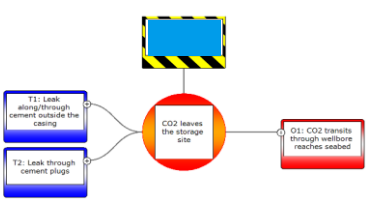
- Current risk-based approaches mostly rely on:
  - ***Qualitative* assessment:** such as 6 x 6 Risk Matrix, with the risk described using numbers, colours and terms such as 'unlikely occurrence with a very serious consequence' or a 'Remote possibility of a Catastrophic incident'
  - **Bow Ties Analysis:** sometimes coupled with simplified flow simulation along pre-defined leak paths.
- A clear leakage risk-assessment is required to <u>support decision-making</u> and <u>facilitate communication</u> amongst operators, regulators and other stakeholders.





Relative Frequencies of CO2 Leakage from the Storage Site

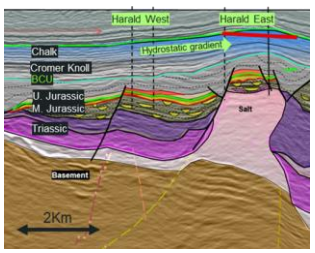
Descriptor	Indicative Frequency (/year)[1]
Physically not possible	0
Remote (barely credible)	1 x 10^{-5}
Highly unlikely	1 x 10^{-4}
Unlikely	1 x 10^{-3}
Possible	1 x 10^{-2}
Probable	1 x 10^{-1}
Likely / continuous	1



2

Project Bifrost, The Harald Field and Legacy Wells

- Project Bifrost aims to inject and store CO2 into Harald field which consists of two geologically disconnected developments, Harald West and Harald East.
- Assessment of 5 legacy P&A'd wells from 1980s in 2 different gas depleted structures. All wells have WH and casing severed below seabed.
- The 5 wells could be impacted by injected CO2 with risk of leakage to seabed and/or crossflow to other formations.
- Qualitative Integrity assessment of the Wells against OEUK Guidelines was done showing 3 wells on the west structure compliant and 2 wells on east structure non-compliant
- Joint project with HWU to quantify the leakage risk to optimize project planning and remediation operation.



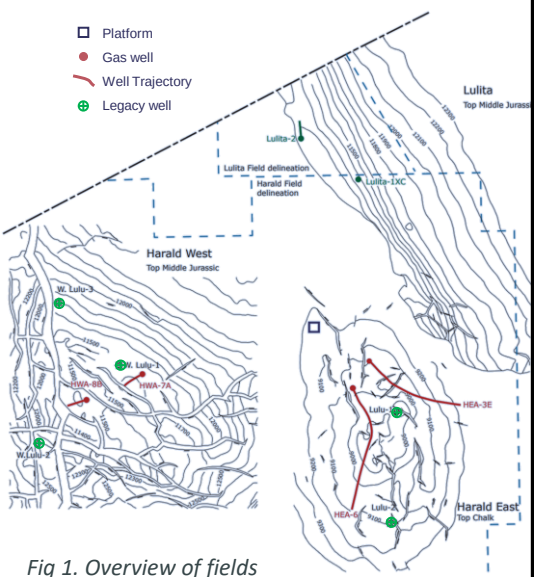


Fig 1. Overview of fields

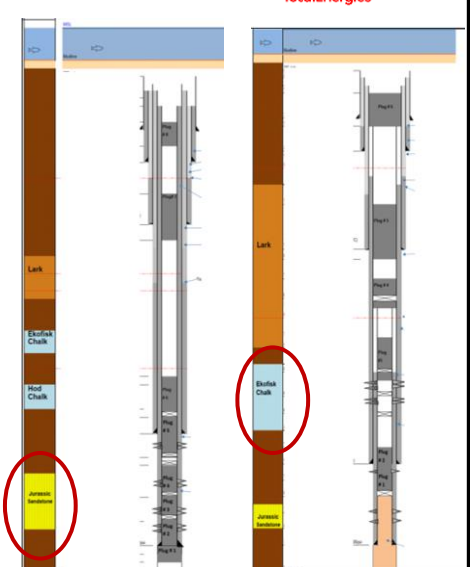
Well Configurations and Numerical Modelling

- Well-1 (Harald West)
  - Four permeable formations (Lark, Ekofisk, Hod Chalk and Jurassic).
  - The storage formation is the Jurassic.
- Well-2 (Harald East)
  - Three permeable formations (Lark, Ekofisk and Jurassic).
  - The storage formation is the Ekofisk.

- Numerical modelling is used by TotalEnergies as a complementary quantitative model along with the 6 x 6 Risk Assessment Matrix to support the application process and approval of CO2 storage permit in Bifrost Project, Danish Sector.

- The models quantify CO_2 storage confinement and assess risk of leakage/crossflow as part of the risk-assessment process.

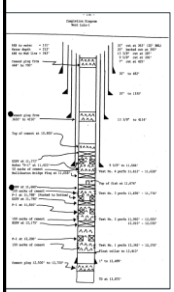
- The numerical modelling has been previously supported decision making for fit-for-purpose well P&A design and well integrity assessment and presented to different regulators in North Sea and globally.

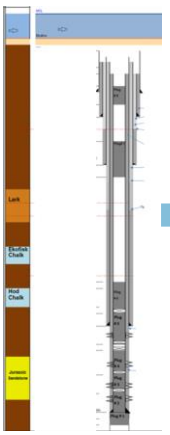


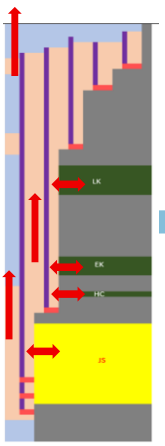
Well-1 (Harald West) Well-2 (Harald East)

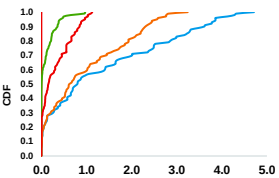
In Short…..

- The risk-based numerical modelling approach has been employed to quantify risk or leakage to surface and crossflow over a specified time period.
- This allows probabilistic evaluation and comparison of alternative scenarios.



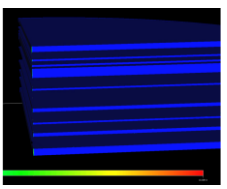


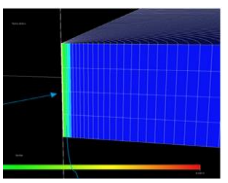




CDF results of cumulative CO_2 crossflow from worst case assumptions combination

Mt CO_2 after 3000y	Jurassic to Annular	Annular to Lark	Annular to Ekofisk	Annular to Hod Calk	Annular to Surface
Average	1.37	0.00	0.11	0.96	0.31
P10	0.01	0.00	0.00	0.01	0.00
P50 (median)	0.80	0.00	0.01	0.64	0.16
P90	3.61	0.00	0.36	2.31	0.85





- Well data
- Reservoir and overburden formation data

- Model Construction
- Flow simulation

Quantify risk of leakage to surface and cross-flow

Risk assessment: e.g. P50 chance of leakage to surface over 3000 years is 0.5% of the stored CO2.

Integration with Subsurface Flow Model

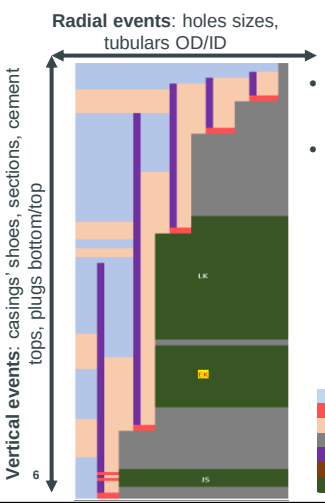
Analyzing Impact of Cross-flow in Overburden Horizon. E.g. CO2 Plume crossflows 90ft in 100 years in Ekofisk – no threat to other wells.

5

Risk-based Well Integrity Modelling Framework

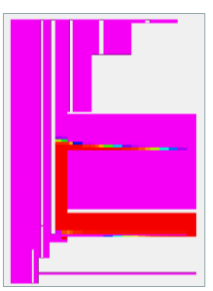
1- Well P&A System Model

2- Flow Simulation Outputs



- Grid-based numerical modelling.
- Well components and any possible integrity defects (micro-annuli, cable encapsulation, channels or fractures in cement, casing leak) all explicitly defined.

0	Annular
1	PoorCement
2	GoodCement
3	InactiveCells
4	Casing
5	CapRock
6	Formation

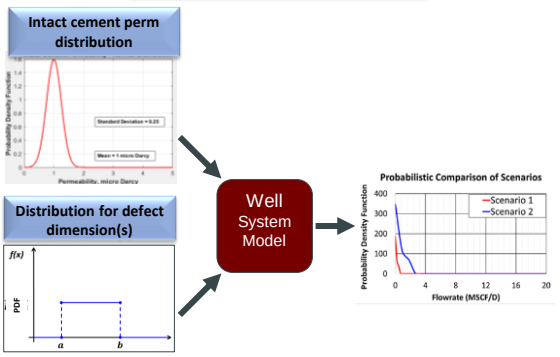


- Any user-defined outputs (e.g. flowrate, bubble rate, cumulative leakage, crossflow)
- Animation of fluid migration vs time to identify dominant leakage pathways.
- Uncertain parameters are fixed during deterministic simulations (e.g. most-likely or pessimistic values).

6

Risk-based Well Integrity Modelling Framework

3- Probabilistic Add-ons



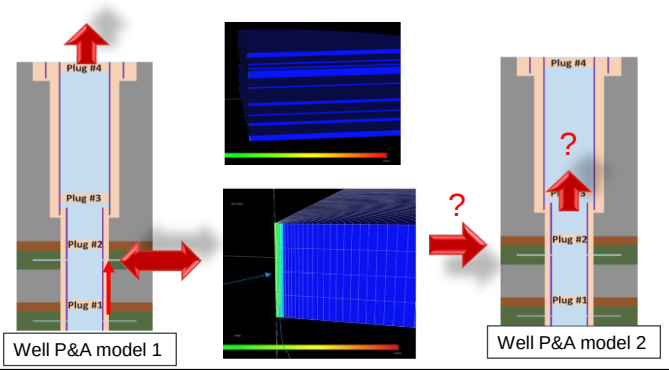
- Probabilistic assessment of leakage and crossflow risks
- Probabilistic comparison of alternative scenarios (different wells, CO2 storage vs natural recharge)
- Analyse Impact of uncertain parameters.

7 |

4- Coupled Well P&A and Subsurface models

Well P&A model(s) ⟷ **Subsurface Flow Model**

- Coupled models with full feedback loops.
- Analyzing Impact of Cross-flow and fluid migration in Overburden Horizon and assess risk of leakage to surface from nearby wells.



7

Summary of Modelling Assumptions and Uncertainties

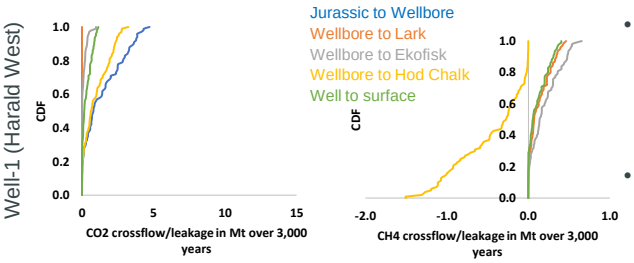
- Compositional fluid model is used to allow simultaneous presence of water, CO2 and CH4 (representing gas and light oil as a conservative assumption).
- Fluid charging the storage formation:
  1. The storage formation is instantaneously charged with CO2. This is a conservative assumption.
  2. The storage formation is charged gradually with CH4 over a 50-year period (CO2 mobilized CH4, or natural recharge with CH4 over 50 years)
- Over-burden or under-burden formations are all assumed to be charged with CH4 as a worst-case scenario.
- Assumed ranges and probability distributions for uncertain input parameters.

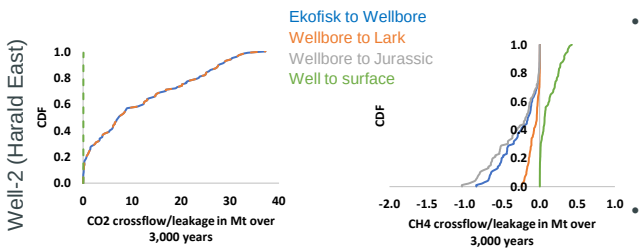
Uncertain Parameter	Considered Range	Probability Distribution
Cement Permeability	0.003 mD - 0.035 mD	Normal distribution
Size of Micro-Annuli (cement-casing contact)	0 - 100 µm	Uniform distribution
Probability of Micro-Annuli presence	100% in all scenarios and along the entire section for all cement-casing contacts. This is a conservative assumption as axial variation of the MA is expected in an actual well, reducing the flow of CH4 or CO2.	N/A

8 |

8

Well 1 & 2 Probabilistic Results for CO2 Storage Scenario





- Most of CO2 leaving the storage formation (Jurassic) is expected to crossflow.
  - Small risk of leakage to surface under assumed worst-case conditions → ~0.4% (P50) of the total volume of CO2 stored, over 3000 years.
- Risk of CH4 crossflow is higher than leakage to surface.
  - Risk of CH4 crossflow/leakage to surface decreases in general, due to the higher density of CO2 at well condition providing a higher hydrostatic head.
- Risk of CO2 leakage to surface is expected to be very low.
  - CO2 tends to crossflow to the Lark formation under assumed defective cement condition, due the proximity of these formations, also higher density of CO2 and therefore lower buoyancy forces.
- There is a low risk of CH4 crossflow and leakage to surface in general.
  - The risk is irrespective of CO2 storage.

Project Bifrost Legacy Wells Recommendations and Future works planned

- Results were cross-checked with the following studies
  - Internal Well Integrity Study based on compliance with OEUK Guidelines and TotalEnergies Company Rules
  - Independent study by Well Examiner.
- No further assurance work required on ***Harald West wells.*** All three wells are compliant and the risk of well integrity issues as a result of CO2 Injection into Harald West is small.
- The risk of crossflow from the zones receiving CO2 injection up into the Lark is expected to be higher in ***Harald East wells***
  - More detailed subsurface modelling for these wells, to assess impact of cross-flow and fluid migration in overburden horizon is ongoing to support discussion with regulators.
- Planned ROV Survey over P&A'd well sites.
  - This will allow us to refine the model with actual data points.

Conclusions

- The well P&A model offers quantitative assessment of the risk of leakage to surface and crossflow over a specified time frame.
  - Significantly enhance discussions with regulators and stakeholders as compared to the qualitative assessment.
  - Facilitates the examination of different assumptions and to support scope reduction.