Risk-based Assessment of Leakage Rates from Legacy Wells for CO2 Storage

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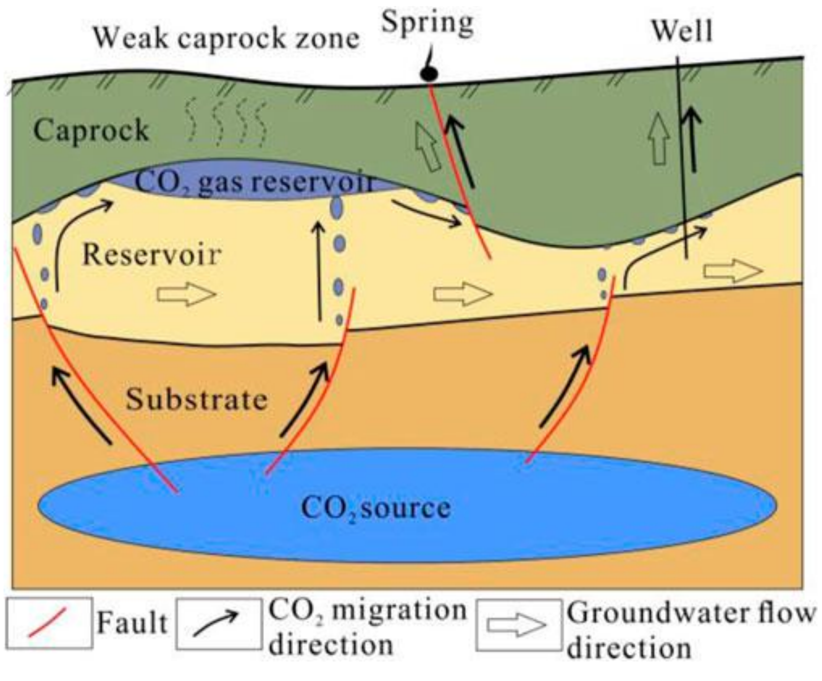
Problem & context

- CO_2 storage in the underground is one way of reducing CO_2 emissions
- Many new CO_2 storage licenses have been given in Norway in addition to the existing ones
- Understanding and managing risks of CO_2 leakage is crucial to gain public trust and regulatory approval



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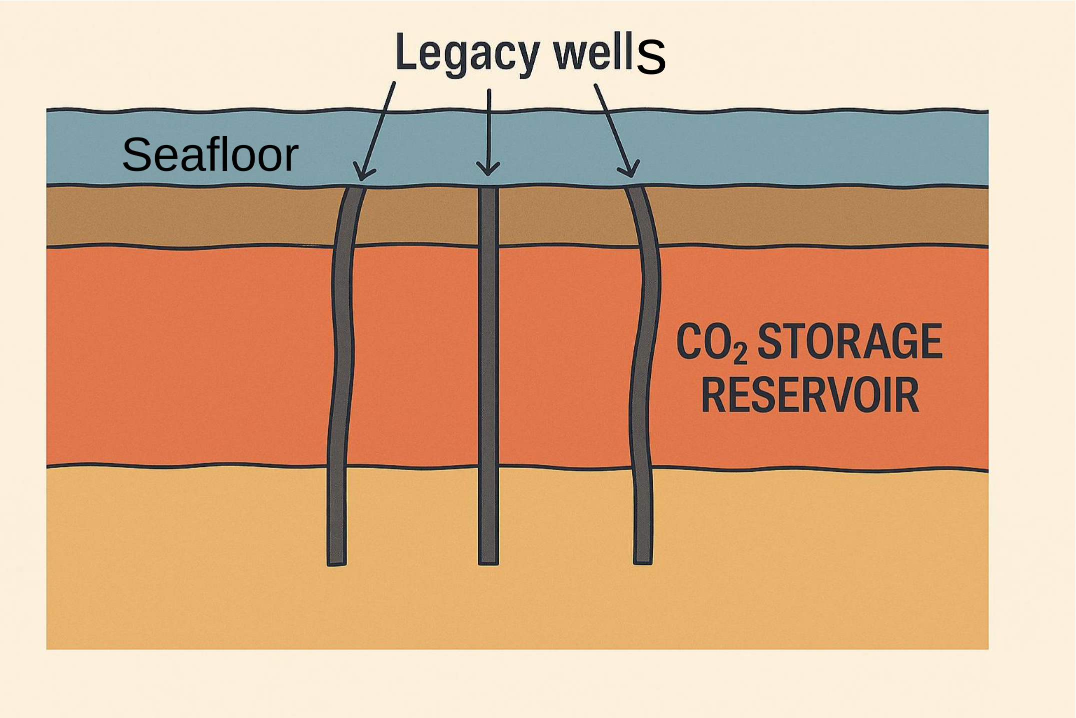
Problem & context

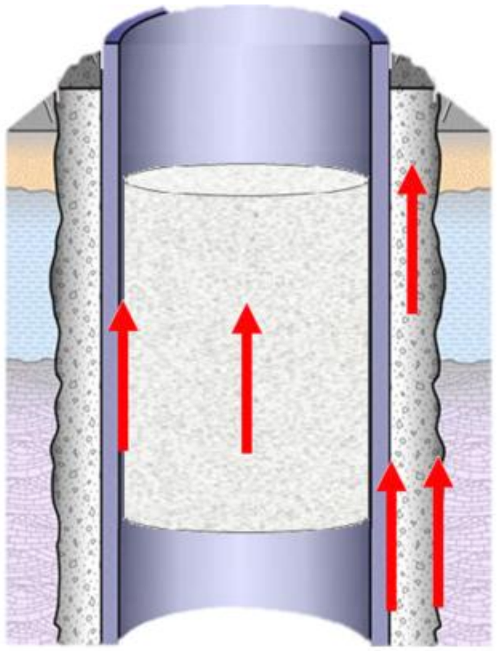
- **Leakage pathways can be classified in two main categories;**
  1. ***Paths through wells due to lack of well integrity***
  2. **Paths due to geological leakage (caprock failure, faults and fractures, lateral migration)**



Legacy wells

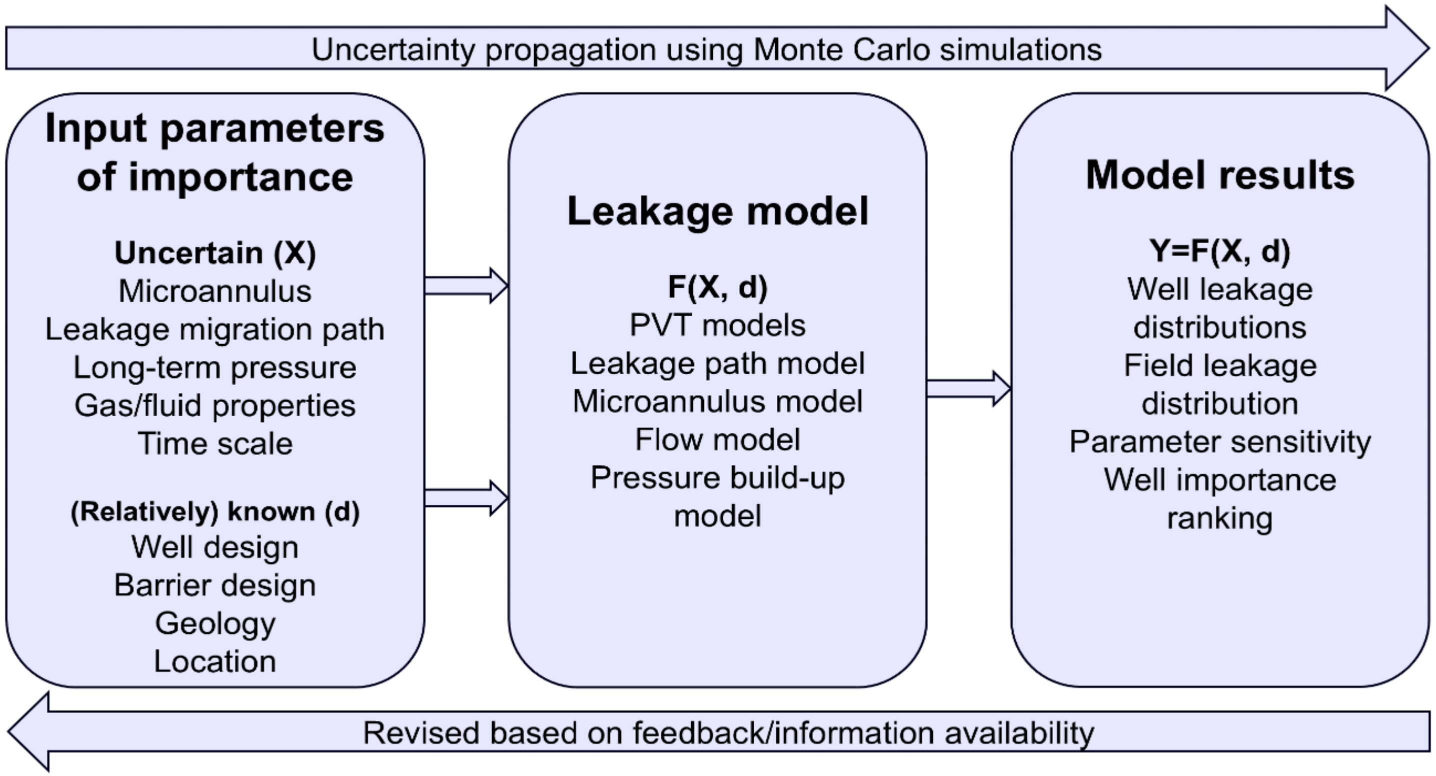
- Old oil or gas well that is no longer in use, but may not have been properly decommissioned or documented

- Key potential challenges of legacy well with respect to well integrity:
  - *Poor or degraded cement integrity*
  - *Corrosion of casing and tubing*
  - *Incomplete or improper abandonment*
  - *Unknown or poorly documented well status*



https://doi.org/10.1016/j.petrol.2018.10.049

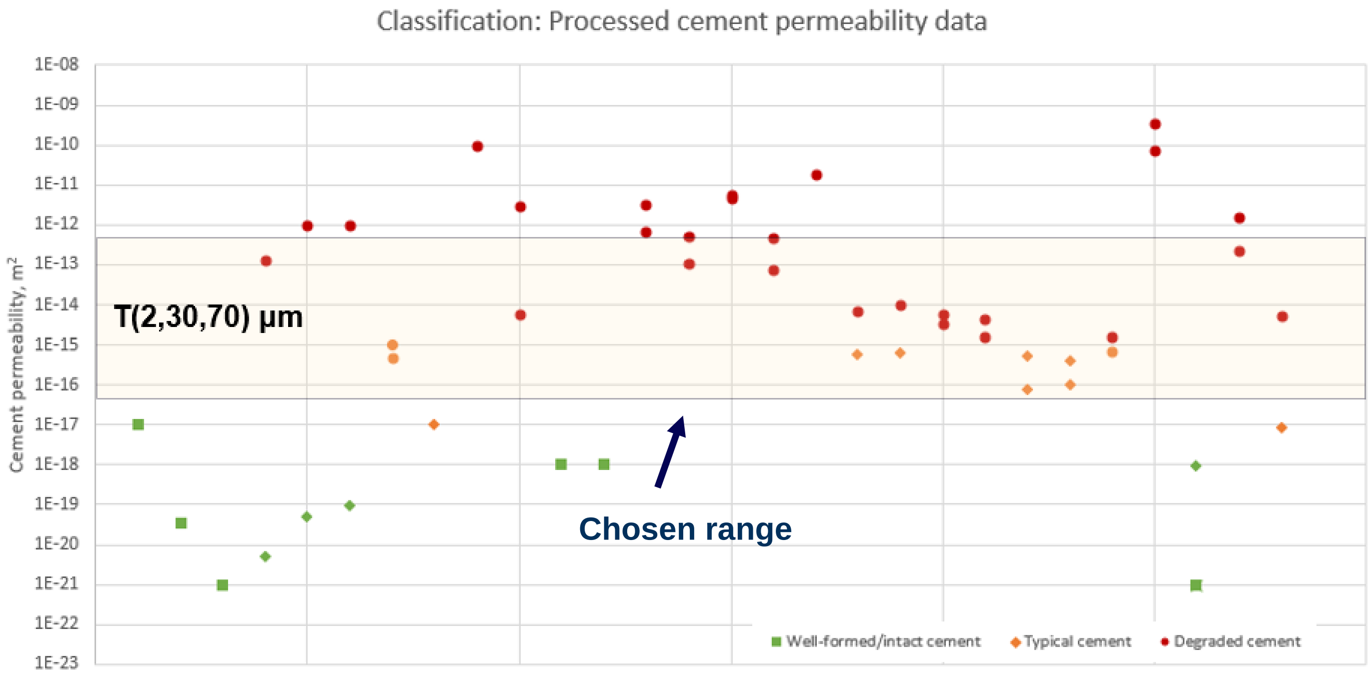
Model for quantifying leakage potential



Concept model

Assessment of key uncertainty - microannulus size

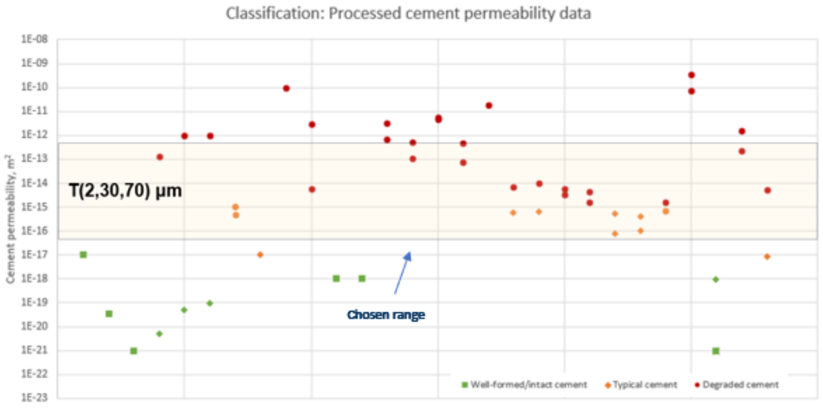
- **We don't know the size of microannulus hydraulic aperture**
- **For lack of knowledge, CBL could be used to make some inference**
- **Old legacy wells have limited documentation – assume large uncertainty, base size on some published data from experiments of various cement quality**
- **Experiments mostly based on short cement lengths**



Selected published effective cement barrier permeability data

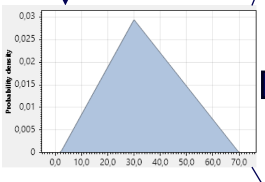
Microannulus size – use in simulations

Selected published effective cement barrier permeability data

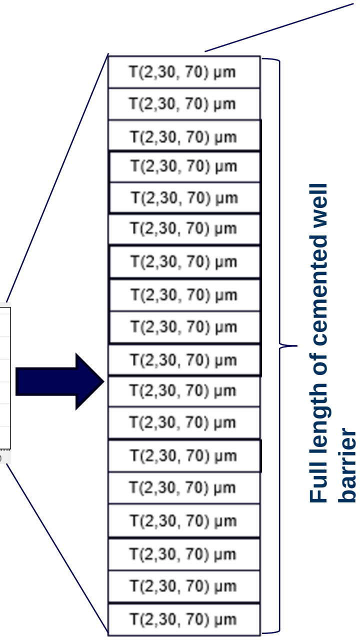


Selected published effective cement barrier permeability data

Stochastic representation of range, relating effective cement permeability with microannulus hydraulic aperture

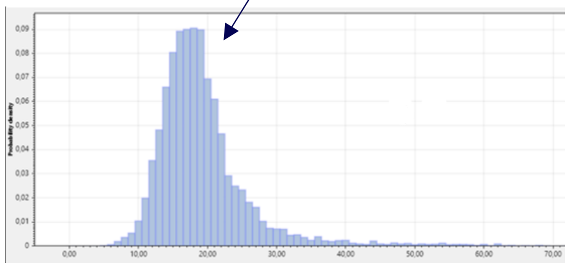


Choose a representative segment length, represent full-length barriers as a stack of such lengths with microannuli size of each segment = selected range:

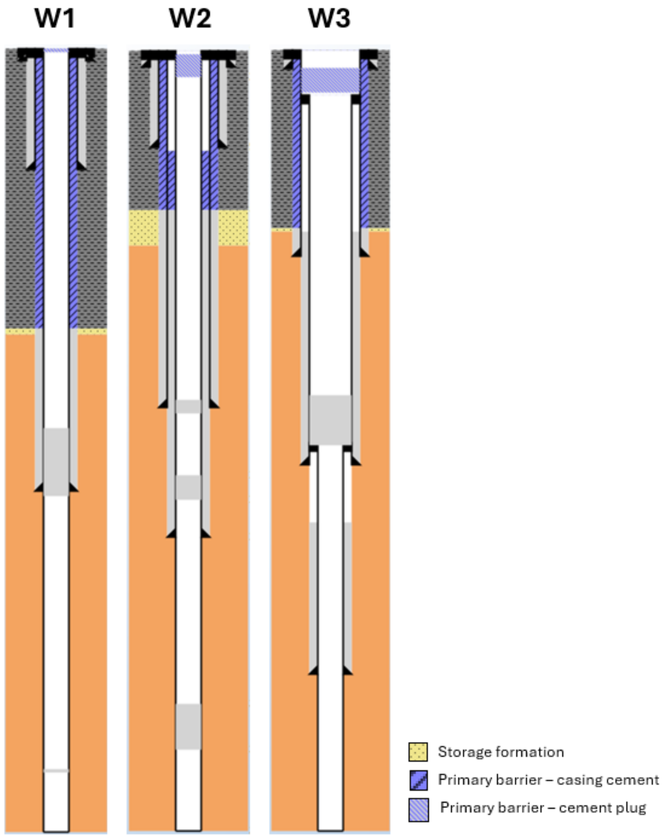


a) 12m segments

Equivalent microannuli size distribution for full length of cemented well barrier



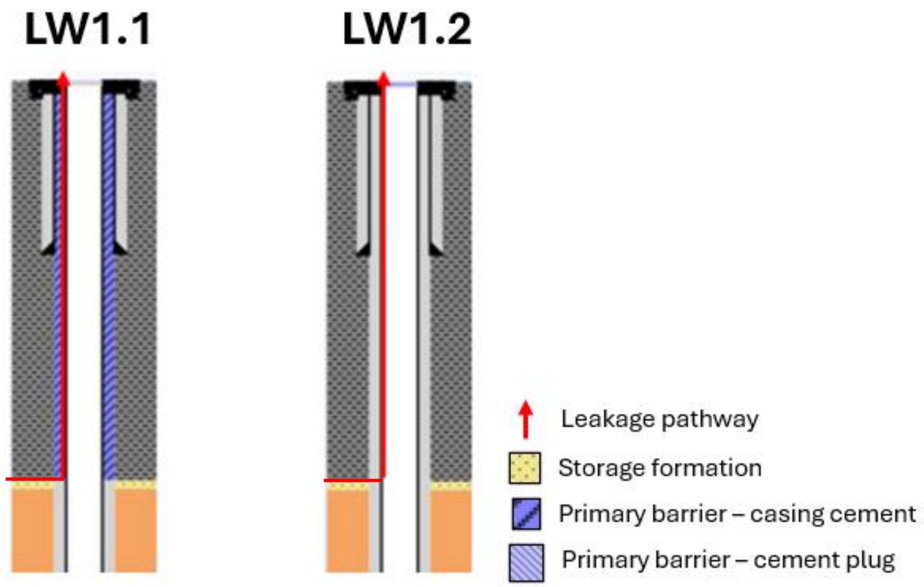
Real case study



- Three legacy wells from a prospective NCS CO_2 storage site
  - *W1: Older well with large leakage potential*
  - *W2: Relatively old well with medium leakage potential*
  - *W3: Relatively new well with low leakage potential*

- Assessment procedure for each well:
  1. *Localize points in well where CO_2 can migrate from storage formation into well*
  2. *Identify barriers/elements acting as resistance to CO2 migration into well and to outer environment (sea floor)*
  3. *Establish possible CO_2 leakage paths*

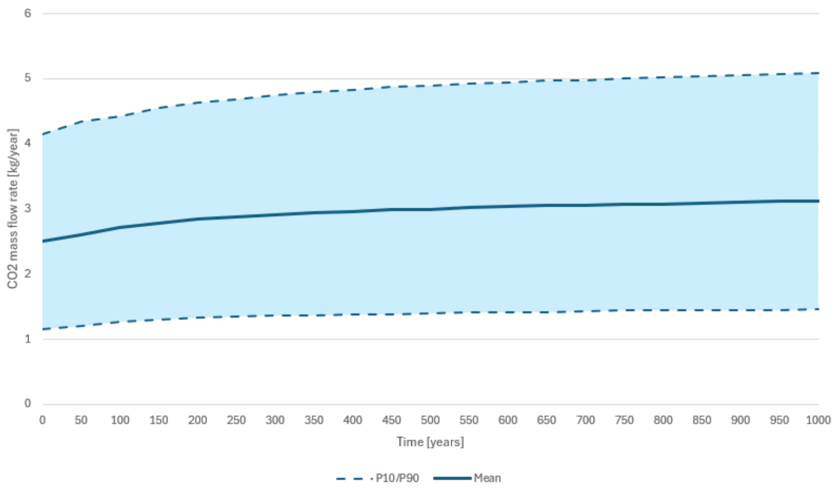
Well W1: Leakage pathways



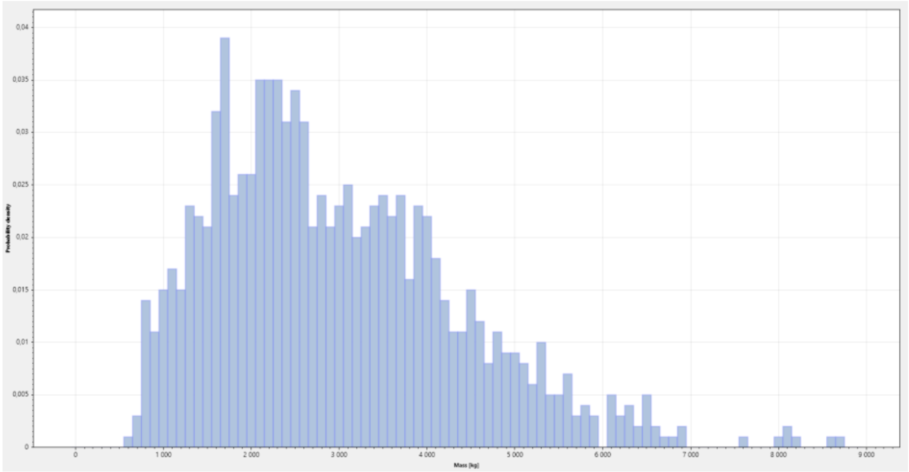
Leakage pathways, W1

- **Cement barrier in the well, but this is not an active barrier against CO_2 leakage**
- **Two main leakage pathways:**
  - ***LW1.1: Flow from storage formation into 13 3/8" annulus, migration through 13 3/8" casing to seabed. (more likely)***
  - ***LW1.2: Flow from storage formation into 13 3/8" annulus, migration through casing steel, migration between 13 3/8" casing and cement plug to seabed. (less likely)***
- **Neither cases are conventional barrier cases as per NORSOK D-010**

Leakage simulations: LW1.1



Simulated CO2 mass flow rate @ seabed over time=1000 years for well W1, based on leakage scenario LW1.1 expressed in kg/year.

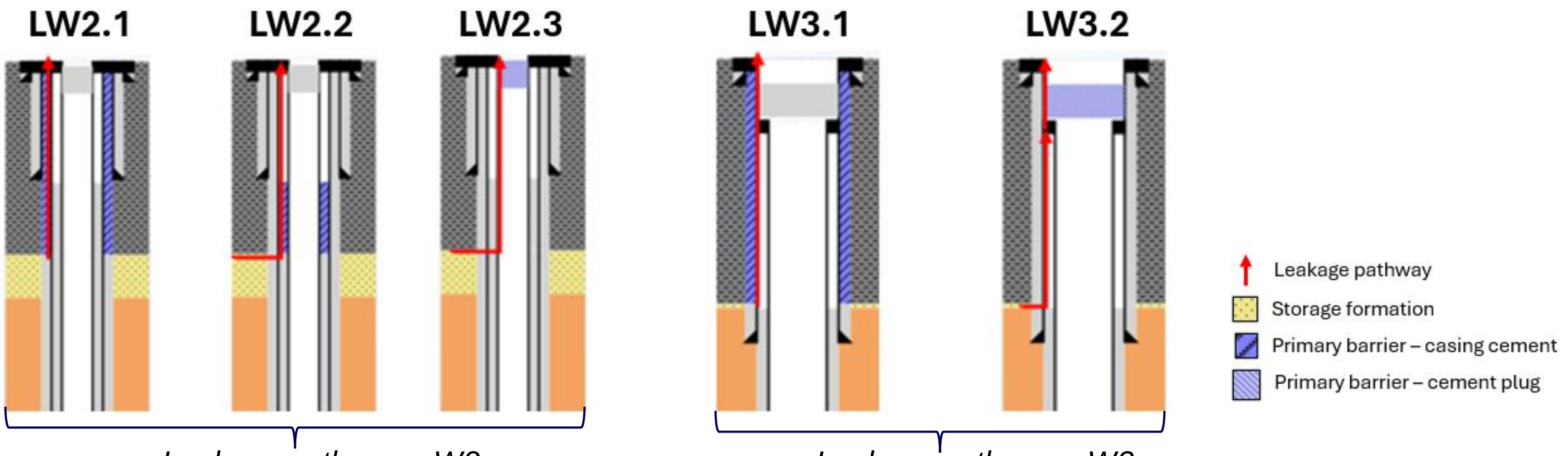


Simulated cumulative CO_2 mass released to seabed after 1000 years for well W1, based on leakage scenario LW1.1

- **Simulations indicating 1-5 kg CO_2/year (if undetected) to seabed**
- **Main uncertainties: microannuli size, long-term pressure**
- **Note: Highly conservative assumptions on long-term pressure**
- **Pressure-reduction due to leakage not accounted for**

- **If undetected and leaking for t=1000 years with simulated mass flow rate, mean = 3 000 kg CO_2, range 500-8 500 kg CO_2**
- **Same conservative assumptions apply!**

Wells W2 & W3: Leakage pathways



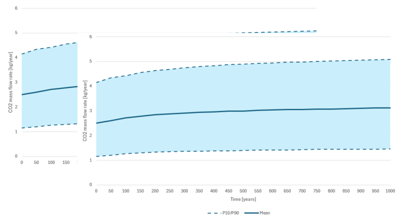
Leakage pathways, W2

- ***LW2.1: Storage formation => 13 3/8" annulus => through 13 3/8" casing => seabed***
- ***LW2.2: Storage formation => 13 3/8" annulus => casing steel => 9 5/8" casing => seabed***
- ***LW2.3: Storage formation => 13 3/8" annulus => casing steel, => 9 5/8" annulus => casing steel => between 9 5/8" casing and cement plug to seabed***

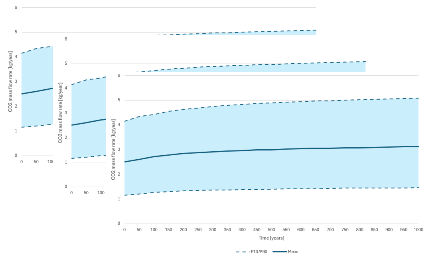
Leakage pathways, W3

- ***LW2.1: Storage formation => 20" annulus => 20" casing => seabed***
- ***LW2.2: Storage formation => 20" annulus => casing steel => 13 3/8" annulus => between 13 3/8" casing and cement plug => seabed***

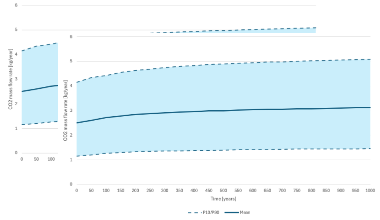
Leakage simulations – per scenario



W1: Leakage simulations, LW1.1., LW1.2

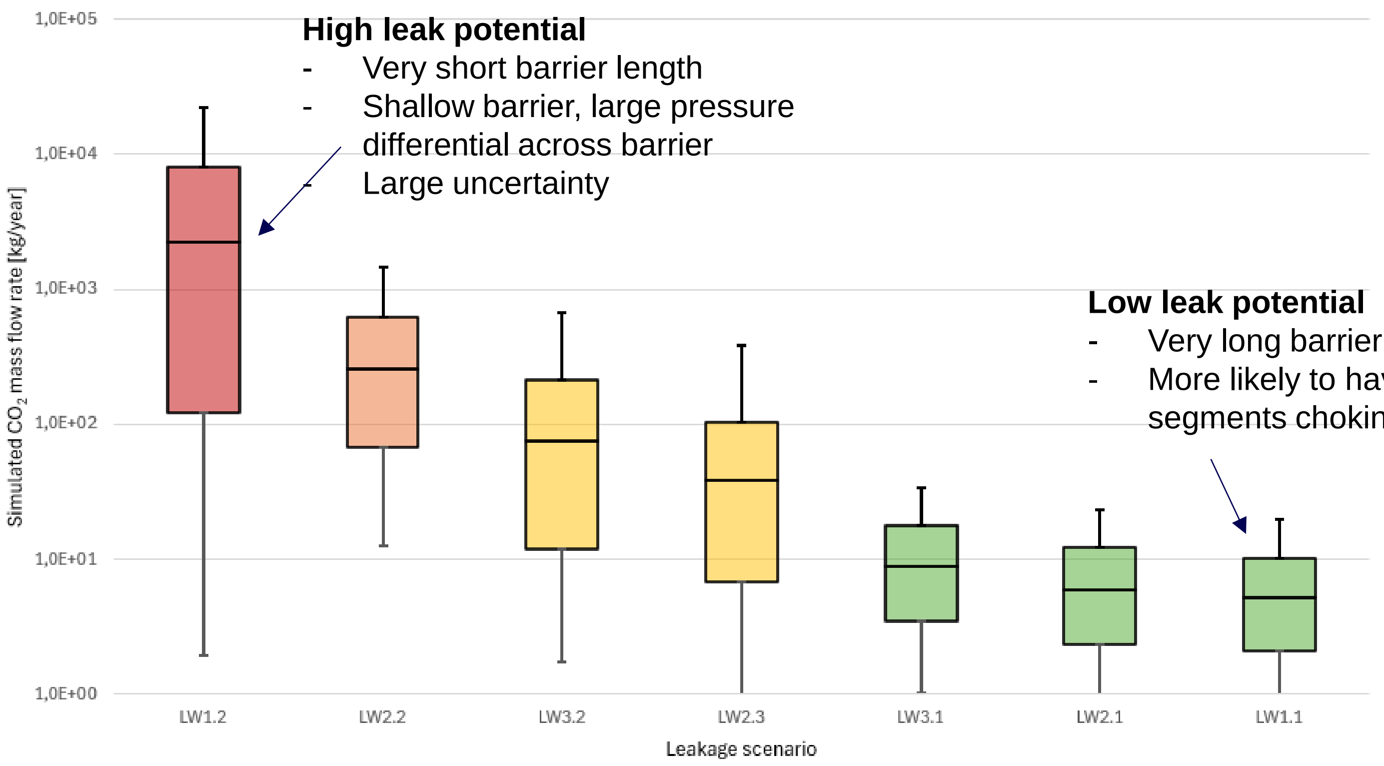


W2: Leakage simulations, LW2.1., LW2.2, W2.3

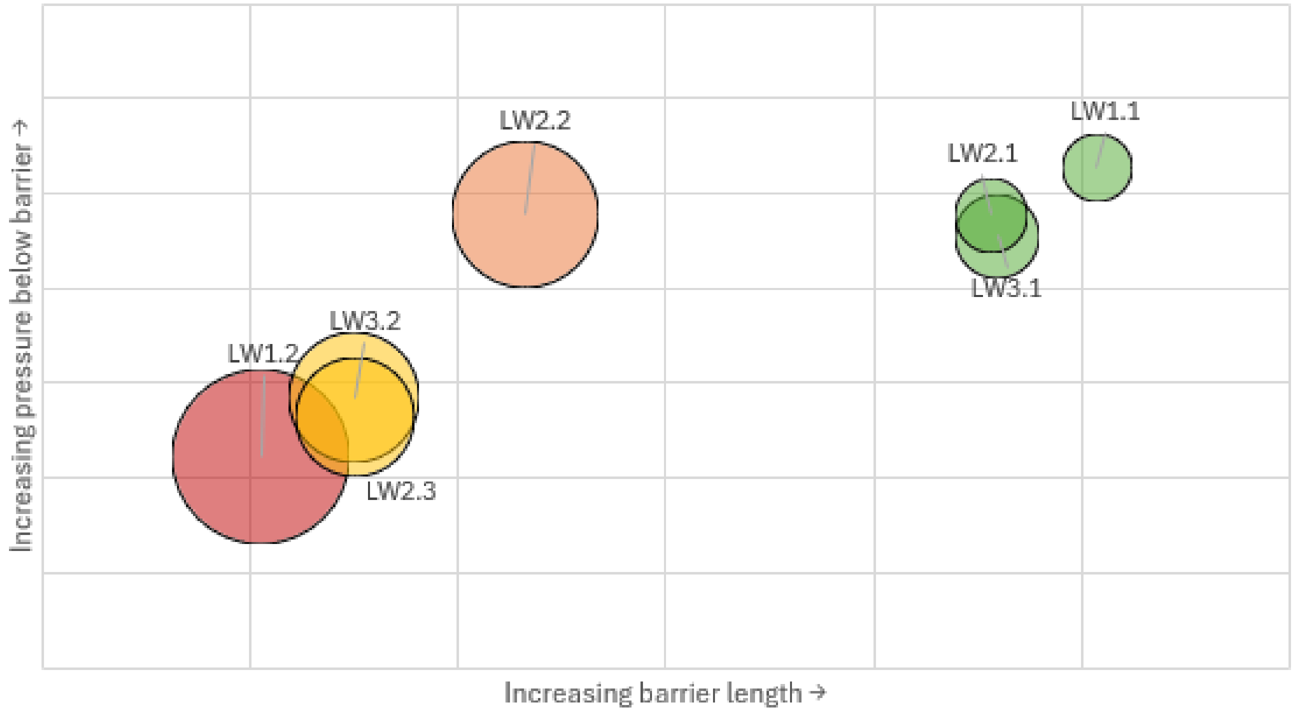


W3: Leakage simulations, LW3.1., LW3.2

All leakage pathways



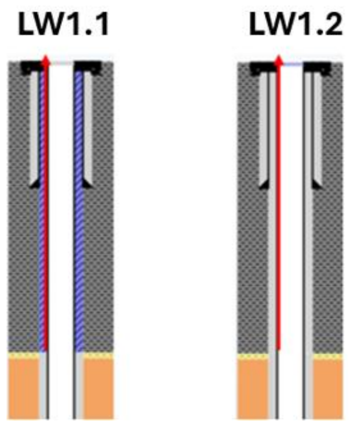
Effect of barrier length and pressure below barrier

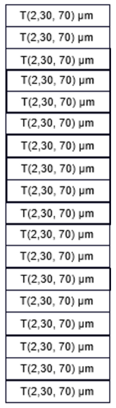


Larger leakage potential

Lesser leakage potential

- *Barrier length most important factor, lower length increases likelihood of segments with large microannuli*
- *Pressure differential across barrier also important but secondary to barrier length*





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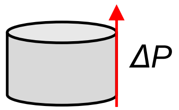

Interpreting the results – what is acceptable?

Current situation

- **No prescribed allowable leakage rates or volumes**
- **"Storage of CO_2…shall take place in line with prudent technical and sound financial principles and such that the risk of leaks …from the storage location is avoided insofar as possible" (Norwegian Offshore Directorate)**
- **EU Requirements: "No significant leakage" – but what specifically is significant?**

Possible contexts to evaluate leakage rates:

1. A *local environmental context:* Focus on the marine ecosystem surrounding the leakage sites. Studies should be conducted to understand the resilience of valued ecosystem components with respect to CO_2 concentration in the water column.
2. A *natural seepage context*. Where there are natural CO_2 seepage points in the vicinity, acceptable leakage rates and volumes could be discussed in a context with natural seepage rates and volumes as the reference.
3. An *economic context of storage of CO_2*. Failure to safely store CO_2 can incur cost (penalties and fines) related to storage agreements as well as potential CO_2 tax which can become significant in the future.
4. A *stored volume context*. Evaluation of the possible leakage volume relative to the total volume stored and combining this with the break-even point with respect to positive climate effects is another possible context.

Case study results: Stored volume context

Severity level	CO_2 storage performance goals
1 – Minor	Loss ≤ 0,05% of injected CO2 over 1000 years
2 – Low	Loss ≤ 0,1% of injected CO2 over 1000 years
3 – Serious	Loss ≤ 0,25% of injected CO2 over 1000 years
4 – Major	Loss ≤ 0,5% of injected CO2 over 1000 years
5 – Critical	Loss ≤ 1% of injected CO2 over 1000 years
6 - Extreme	Loss > 1% of injected CO2 over 1000 years

LeGuen et al. 2009

Simulated leaked CO_2 from all three wells over 1000 years constitute < 0.003% of total amount planned injected CO_2

Conclusions

- Framework for quantifying leakage risks of legacy wells has been developed and demonstrated on three wells
- Ability to express key uncertainties, mainly the size of defects (hydraulic microannulus) and pressure differential across the barrier
- Microannuli size can be quantified, either based on well-specific information on based on compiled experiments
- Allows for incorporating many possible leakage scenarios (migration pathways), providing a broad spectrum of possible consequences
- Interpreting and applying results in a decision-making context is not a simple process, partly due to a lack of specific performance criteria or allowable risk levels
- To further improve the usefulness of such risk assessments in a decision-making context, we need:
    - Acceptance criteria or performance metrics
    - Information on marine ecosystems being available
    - Strengthening and aligning the model interfaces between leakage simulations and dispersion simulations
    - Systematization of data on natural seeps
    - Efforts to express and relate risks are aligned between industry actors and authorities in a similar manner to what is currently the case for e.g. risk assessments of oil and gas exploration wells

Thank you for your attention!

Questions?

Acknowledgements

We are grateful to the owner of the prospective storage site for the opportunity to share knowledge and experience from the risk assessment of the site. We would also like to acknowledge The Norwegian Ocean Industry Authority, Aker BP, ConocoPhillips, Equinor, Petrobras, Shell and TotalEnergies for financing the development of the P&A Leakage Calculator through the P&A Innovation Program, a program for accelerating P&A technology development.

Thank you. Takk.

Merci. Gracias. Obrigado.

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