Quantitative Assessment of Potential CO_2 Leakage Volumes in the Dutch North Sea

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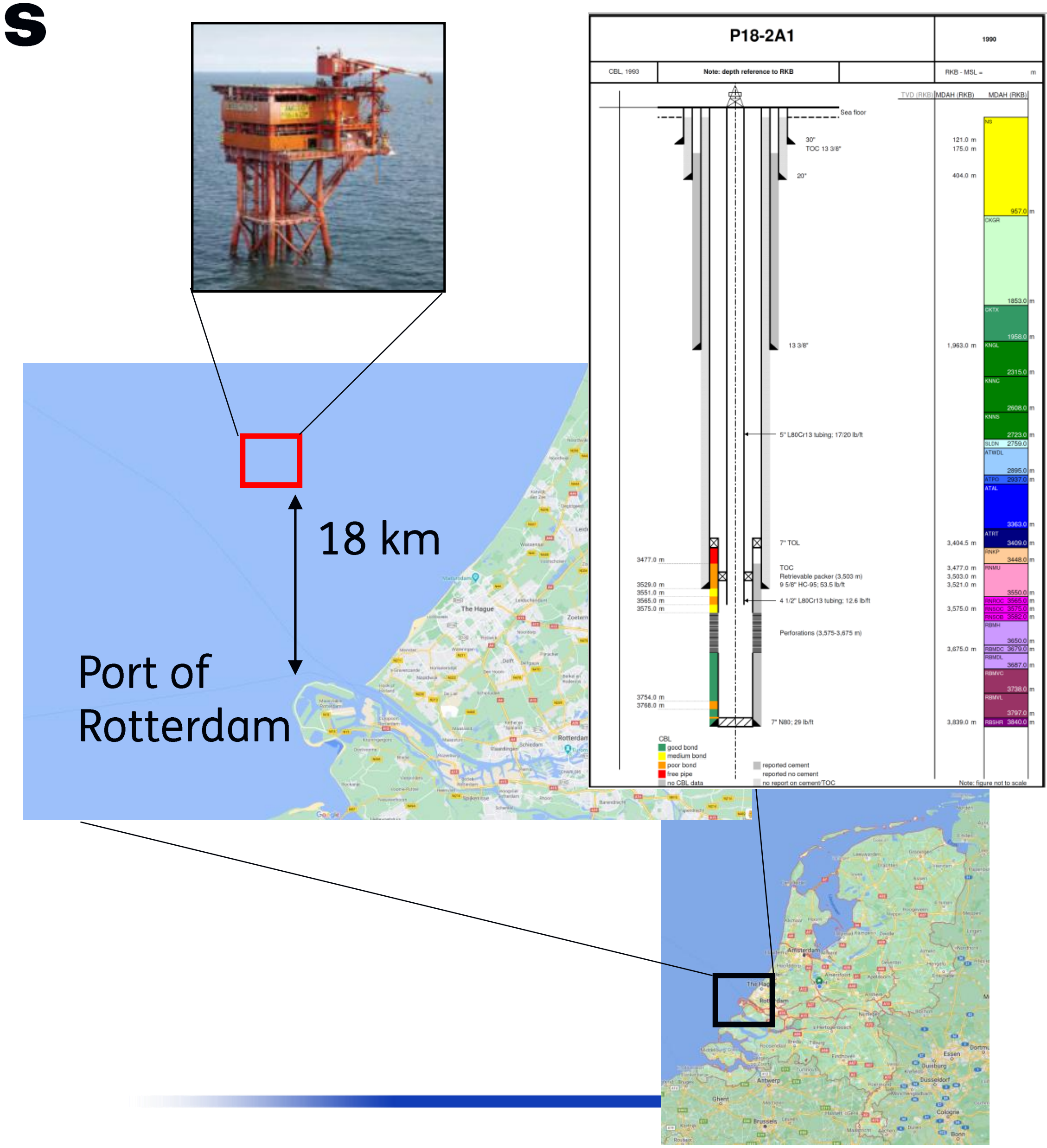
TNO innovation for life

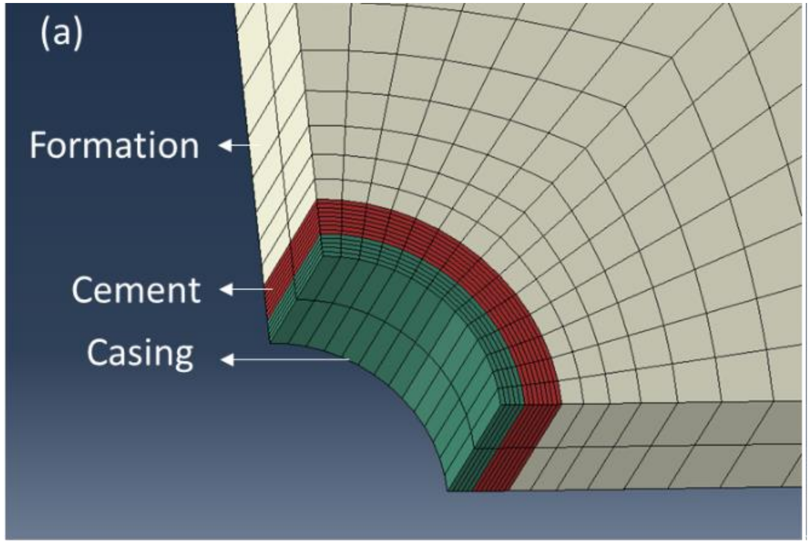
CO_2 storage – The Netherlands

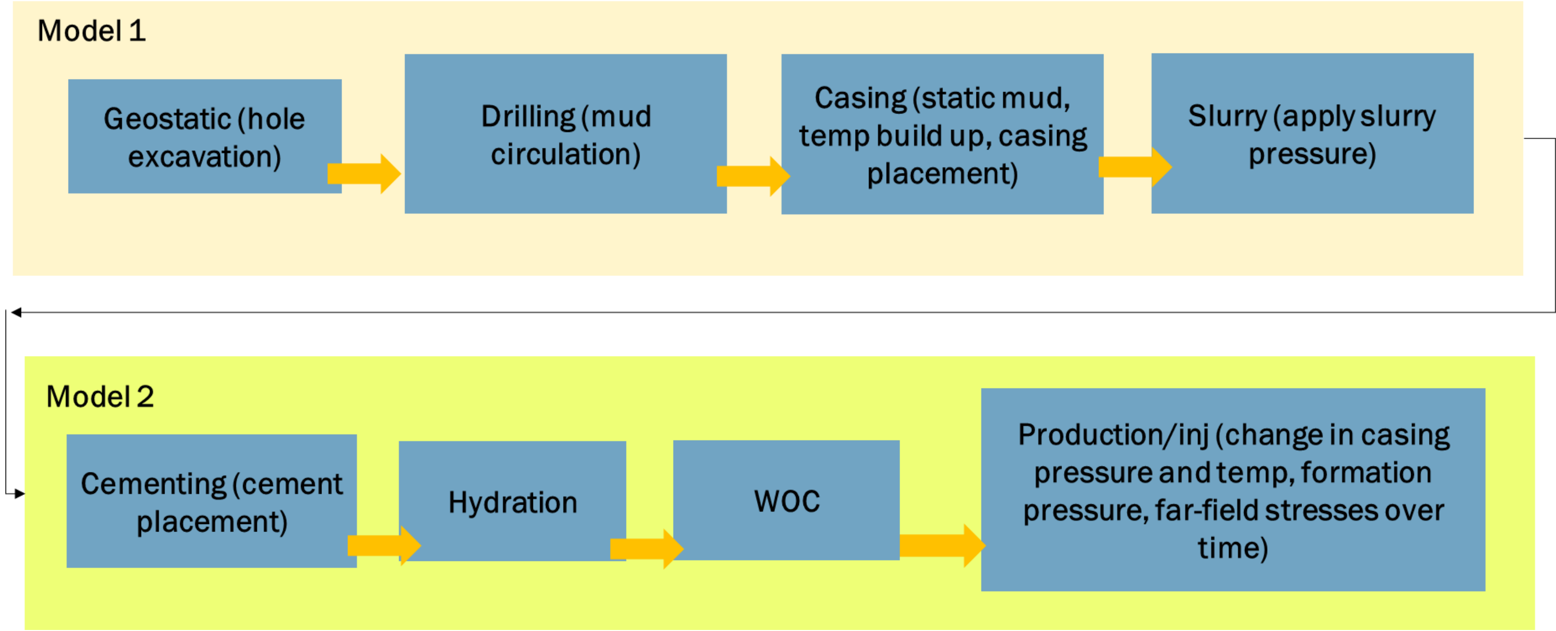
- Overview of CCS projects in NL
  - Focus on depleted fields for CO_2 storage (estimated capacity ~1.5 Gt)
  - Exploration for suitable aquifer structure just started
- Projects
  - Porthos
  - Aramis
- Current policy in NL
  - Current regulation is to limit pressure in depleted fields to hydrostatic
  - Avoid pressure drive for leakage
  - Regulator open to adjust policy as projects develop



CREST

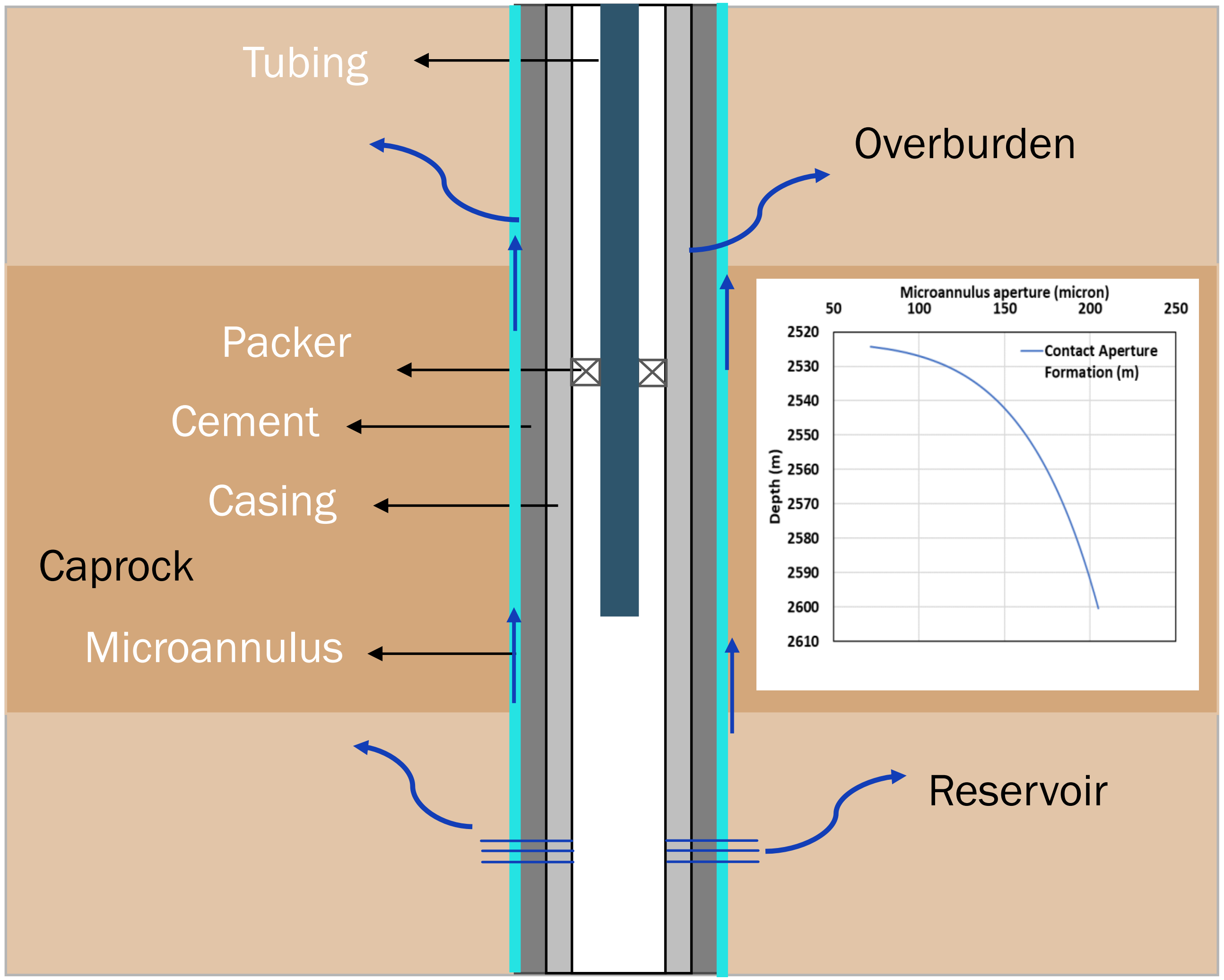
- CREST is a staged finite element well integrity tool developed by TNO.
- CREST generates a hydro-thermo-mechanical staged FEA model based on user inputs that capture all stages of the wells life.
- Critical information such as casing failure and deformation, time dependent events, and cement failure can be captured under complex scenarios.





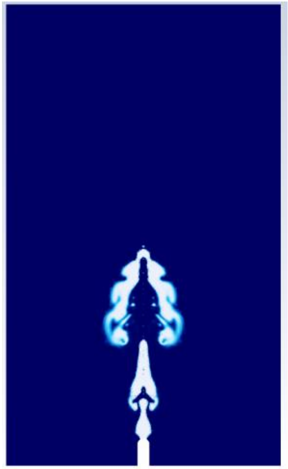
Leakage pathway

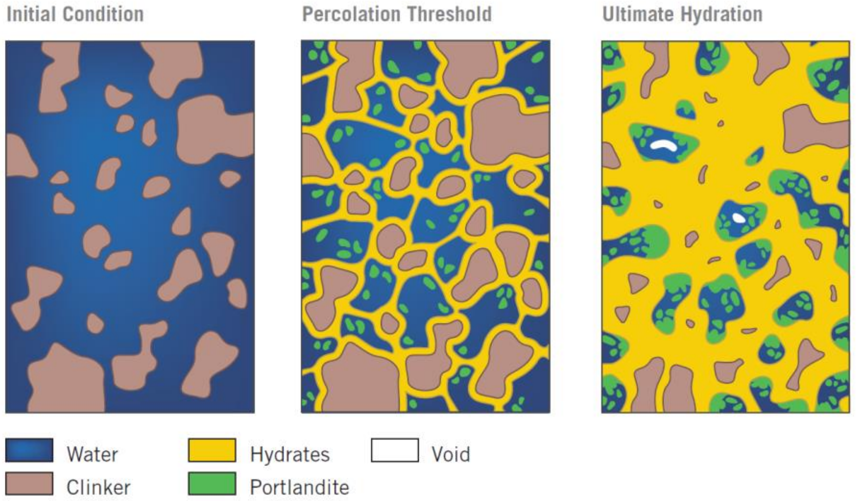
- Currently, CREST only considers a simplified leakage pathway across the caprock and into the overburden.
- The initial size of the microannulus is determined by modelling cement hydration and shrinkage.
- The impact of P&T changes inside the casing throughout the life of the well is then applied.
- If a pathway is open, the flow rate is calculated iteratively considering compressible flow and the impact of flowing pressure on the MA size.

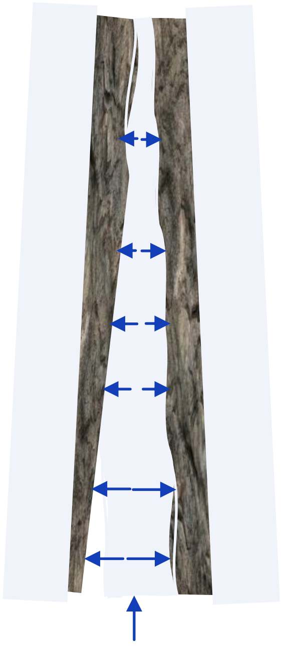


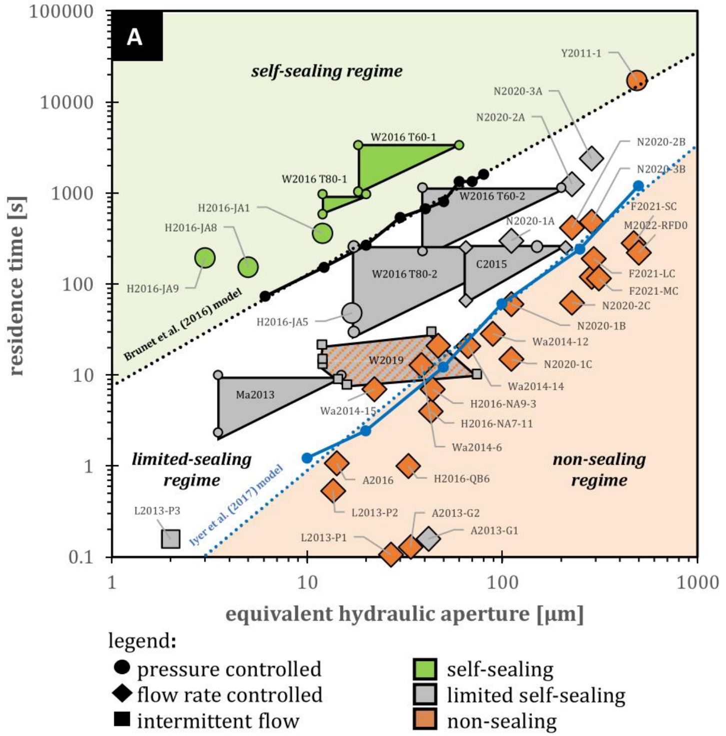
Important mechanisms

- Typical well leakage calculators require an “estimate” of cement permeability as an input.
- Physical models are superior as they can provide an assessment of the leakage pathway (most commonly a microannulus).
- In our experience, cement hydration process must be modelled appropriately to estimate cement stress after curing.
- Appropriate flow models that consider compressible behavior of gas, two-phase flow mechanisms in microannuli, etc.
- The impact of changes in casing pressure and temperature on microannuli.
- However, the leaking fluid can also expand or shrink the microannulus.
- Chemical effects such as self-healing due to the presence of CO2 should also be considered.





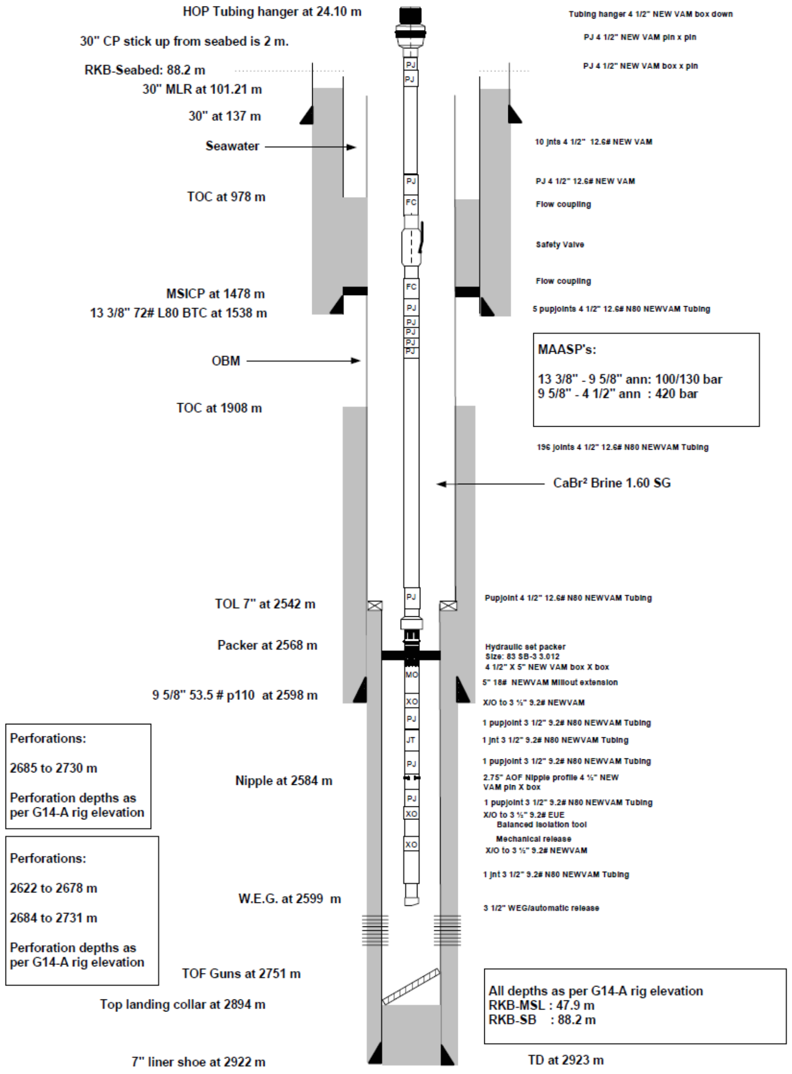




Wolterbeek et al., 2024

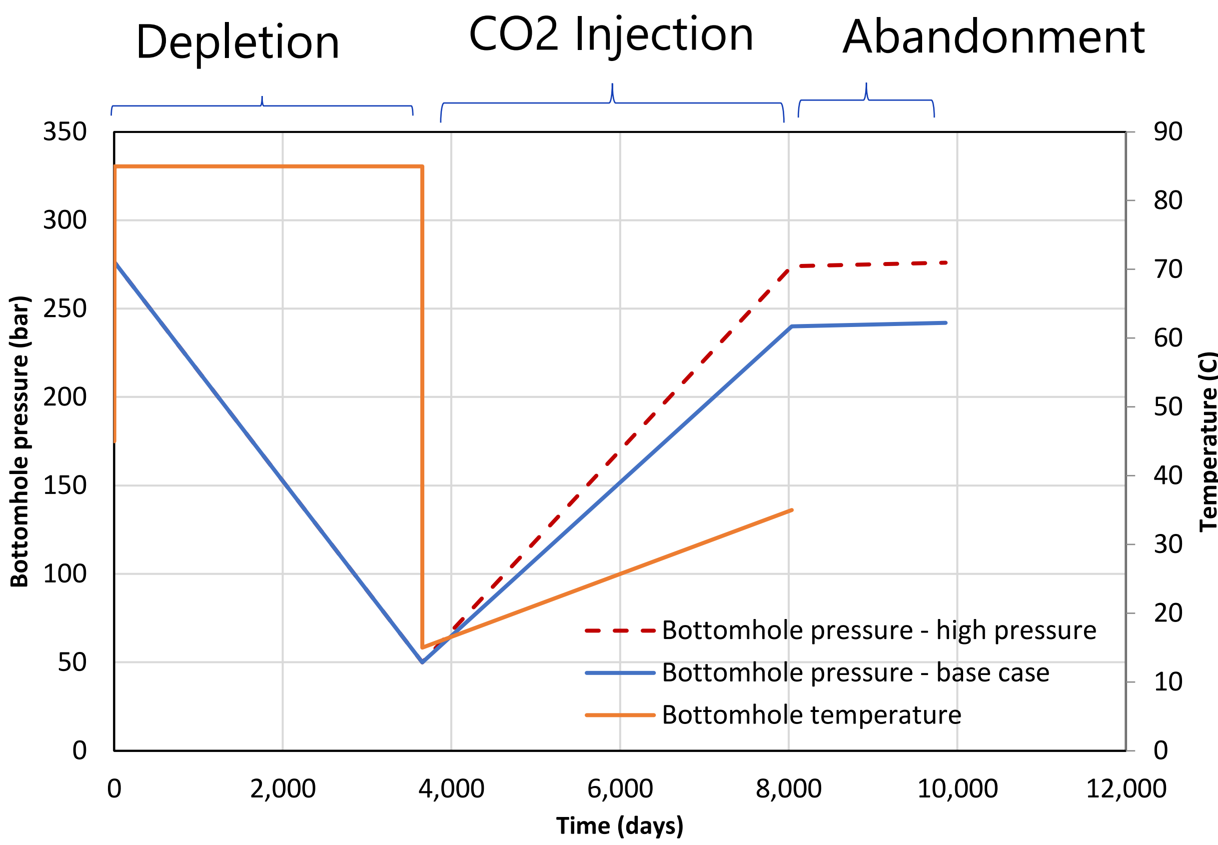
Case study – CCS in a depleted field

- We created a synthetic injection well, inspired by the wells in the North Sea.
- The reservoir is assumed to be at 2500 m depth.
- Caprock (shale) is 100 m thick.
- A 7” liner is cemented against the caprock.
- Initial pressure is assumed to be 274 bar, depleted to 50 bar.
- We consider cases where CO_2 injection will raise the reservoir pressure to 240 and 274 bar (initial pressure) .



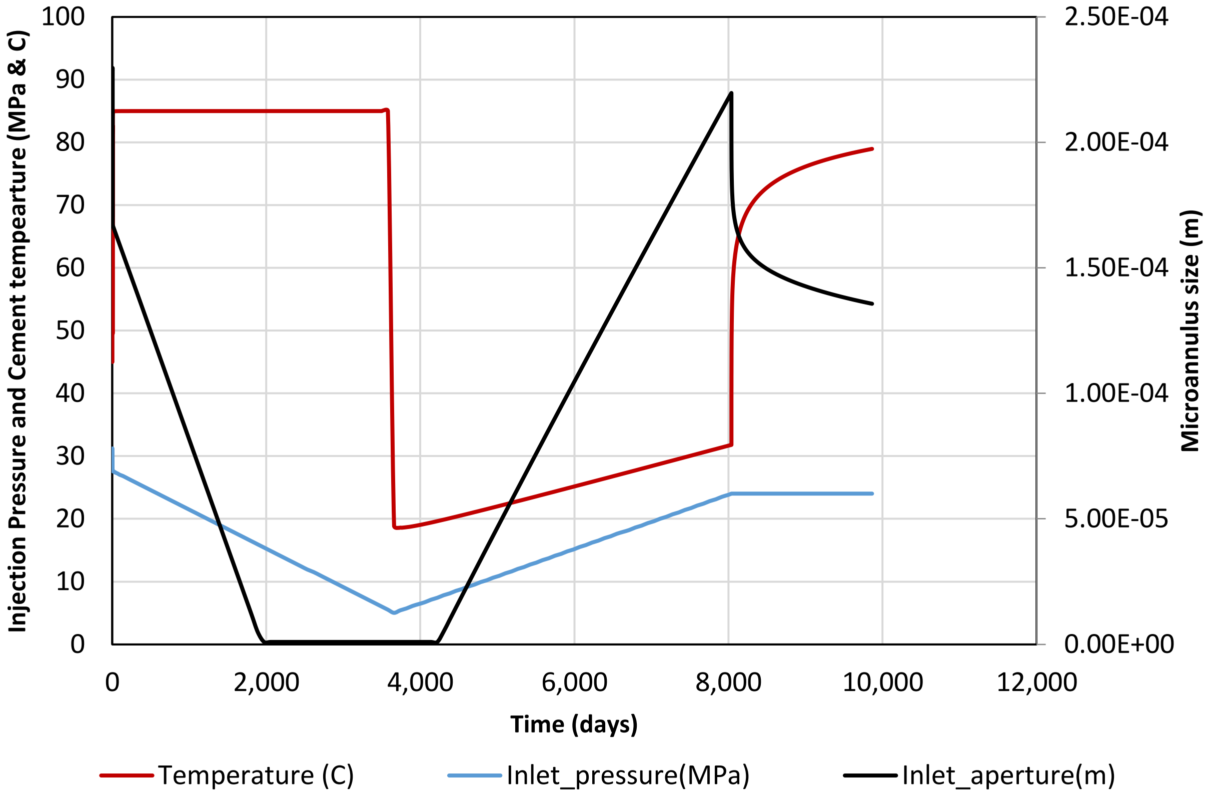
Operations

- Gas is produced for 10 years, with reservoir pressure dropping from 274 to 50 bar.
- CO_2 is injected over 12 years (~23 kg/s rate), increasing the reservoir pressure to approximately 240 bar (base case).
- High-pressure case assumes a final storage pressure of 274 bar.
- Initial reservoir temperature is 85 C.
- Injected CO_2 temperature is 15 C, increasing to 30 C as it is pressurized.
- The simulation continues for 5 years after abandonment.



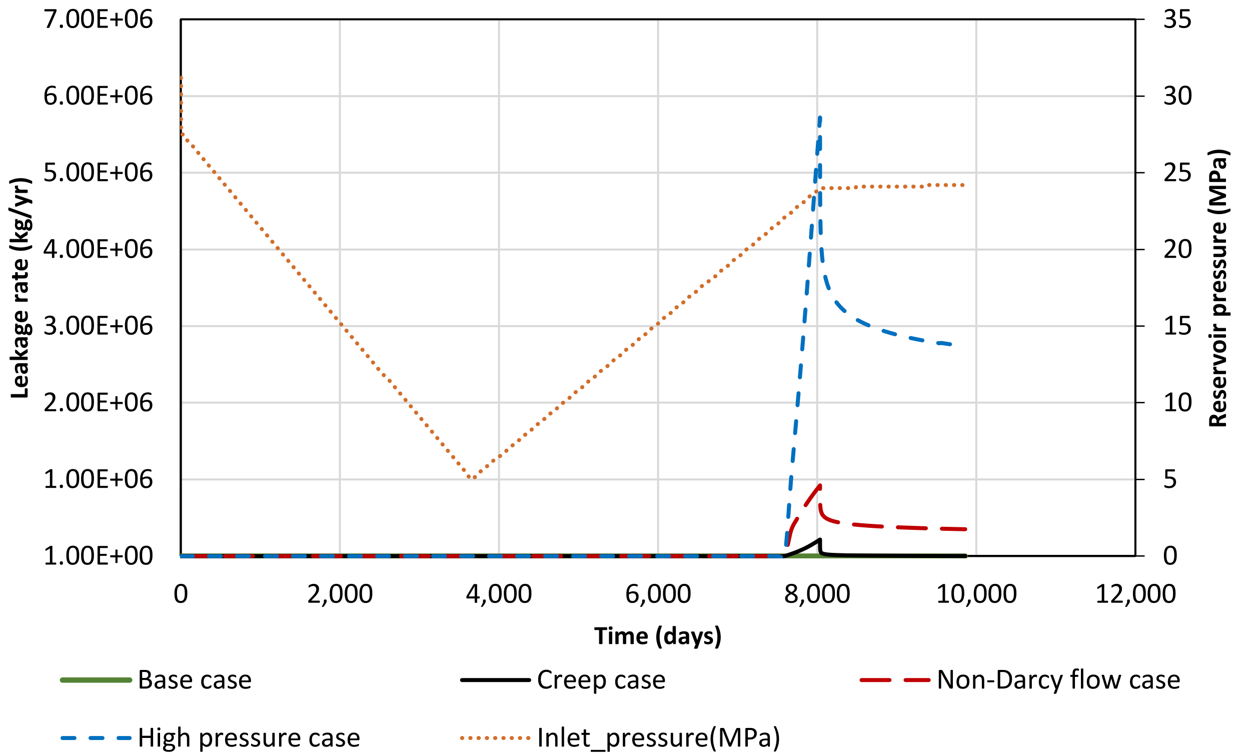
Results – microannuli size

- The results show a microannulus forming shortly after curing.
- During depletion, microannuli gradually closes over time as pressure declines.
- As CO2 is injected, microannuli eventually opens again.
- As CO2 pressure increases the microannuli opens to 220 microns at the end of injection.
- During abandonment, the microannuli closes to 130 microns as the temperature rebounds.
- The size of the leakage pathway is a dynamic parameter that changes over the life of the well



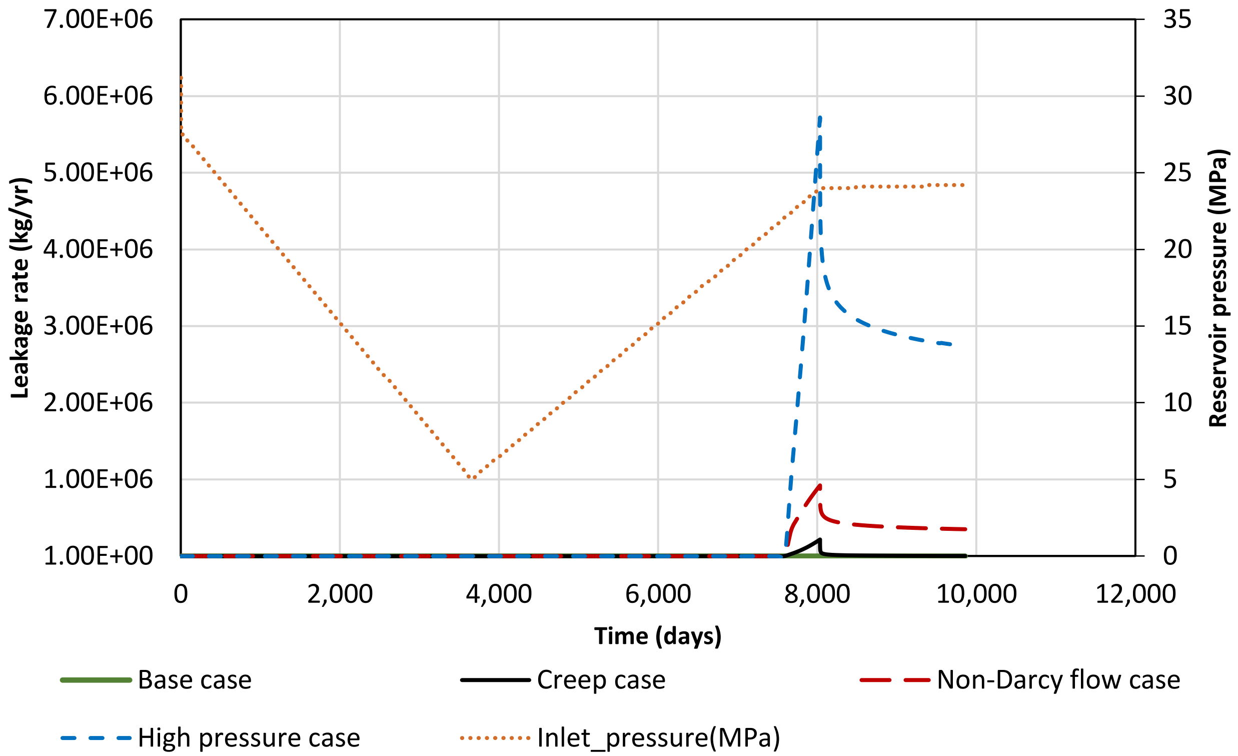
Results

- The base case shows no leakage due to the low pressure in the storage system.
- This does not consider leakage within the well (through the plug after abandonment), only through the annulus.
- The maximum injection pressure of 240 bar does not reach the threshold for CO2 leakage.
- This threshold may need to be determined on a case by case basis as it depends on the stratigraphy and the properties of the overlying formations



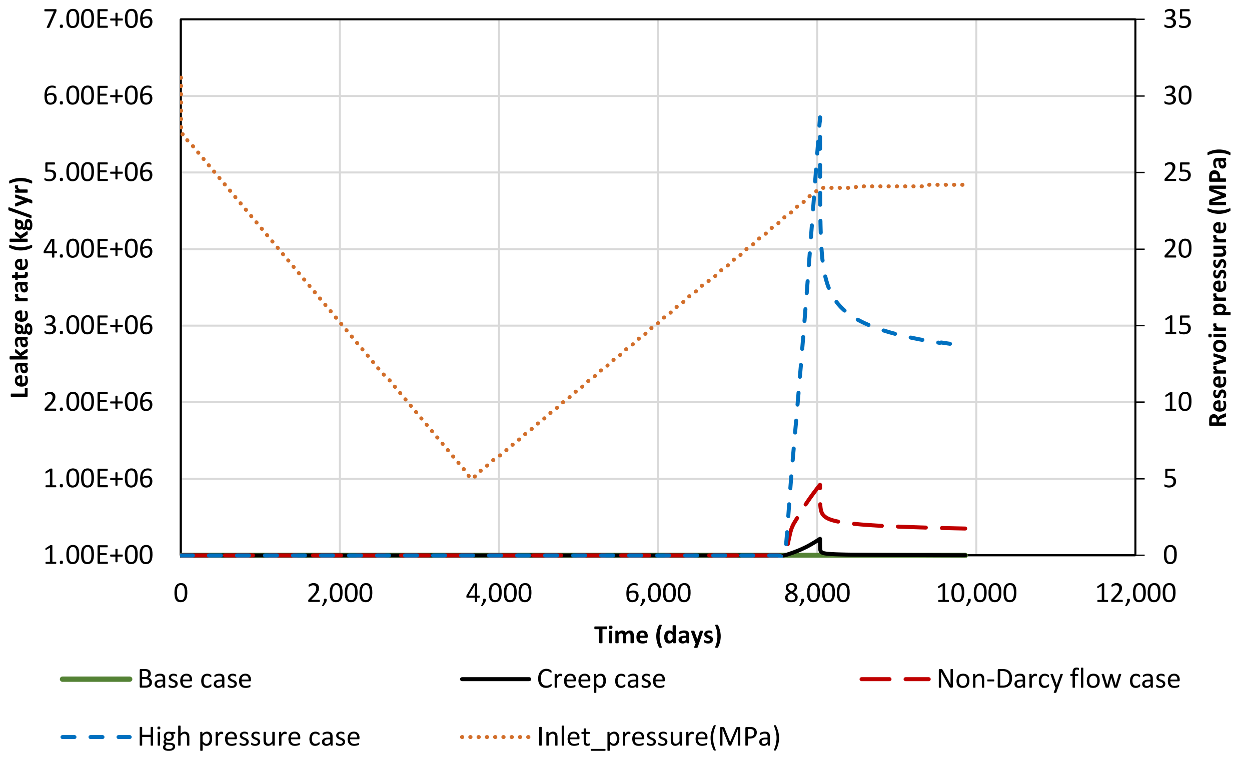
Results

- As CO2 pressure surpasses 250 bar, leakage along the microannulus begins.
- In the worst case scenario, leakage rate may increase to 5700 tons per year as the pressure reaches 274 bar.
- After abandonment, leakage rate decreases to 2400 tons/yr as the microannuli size decreases.
- More realistic scenario shows 2700 tons of CO2 leaking 5 years after abandonment.
- Assuming a 10 Mt/well project, this is equivalent to 0.027% of the storage capacity.



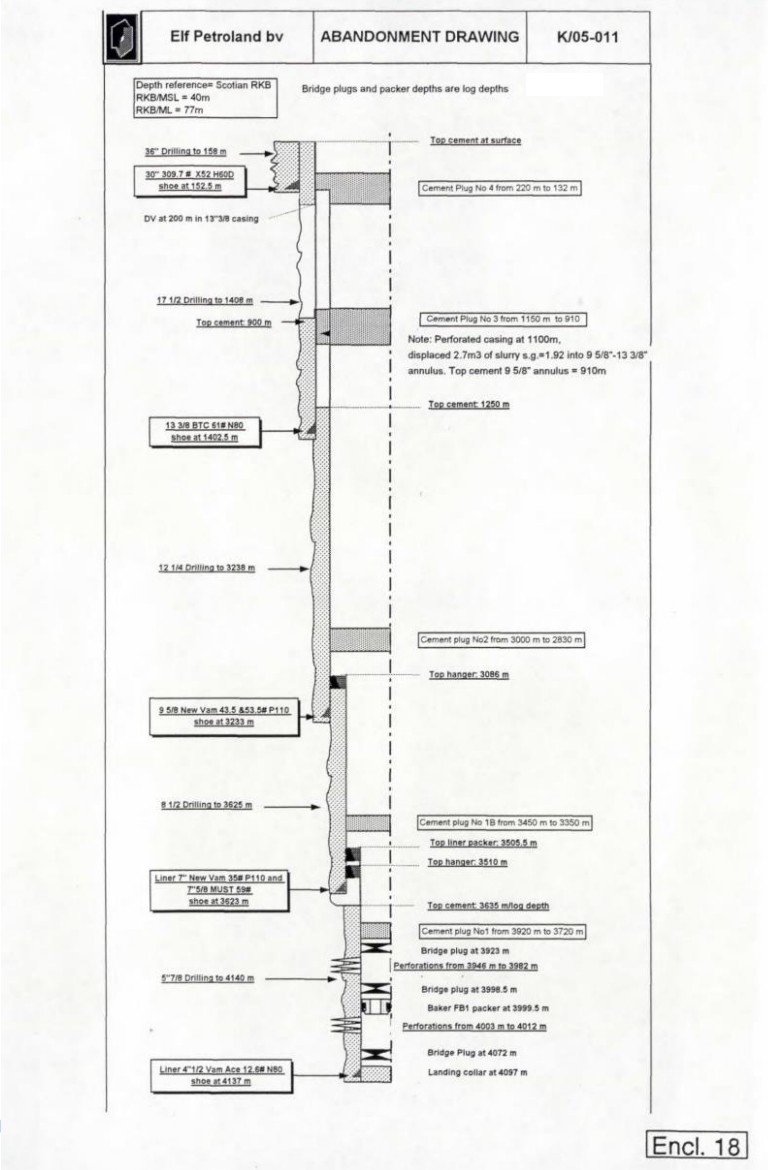
Results

- Presence of creep, clarity on appropriate flow models can lower the leakage estimates by up to 3 order of magnitudes.
- Improving the data and models can improve our estimates of leakage rate with respect to the final storage pressure.
- This type of analysis is necessary to set the appropriate final storage pressure based on the acceptable leakage rate.



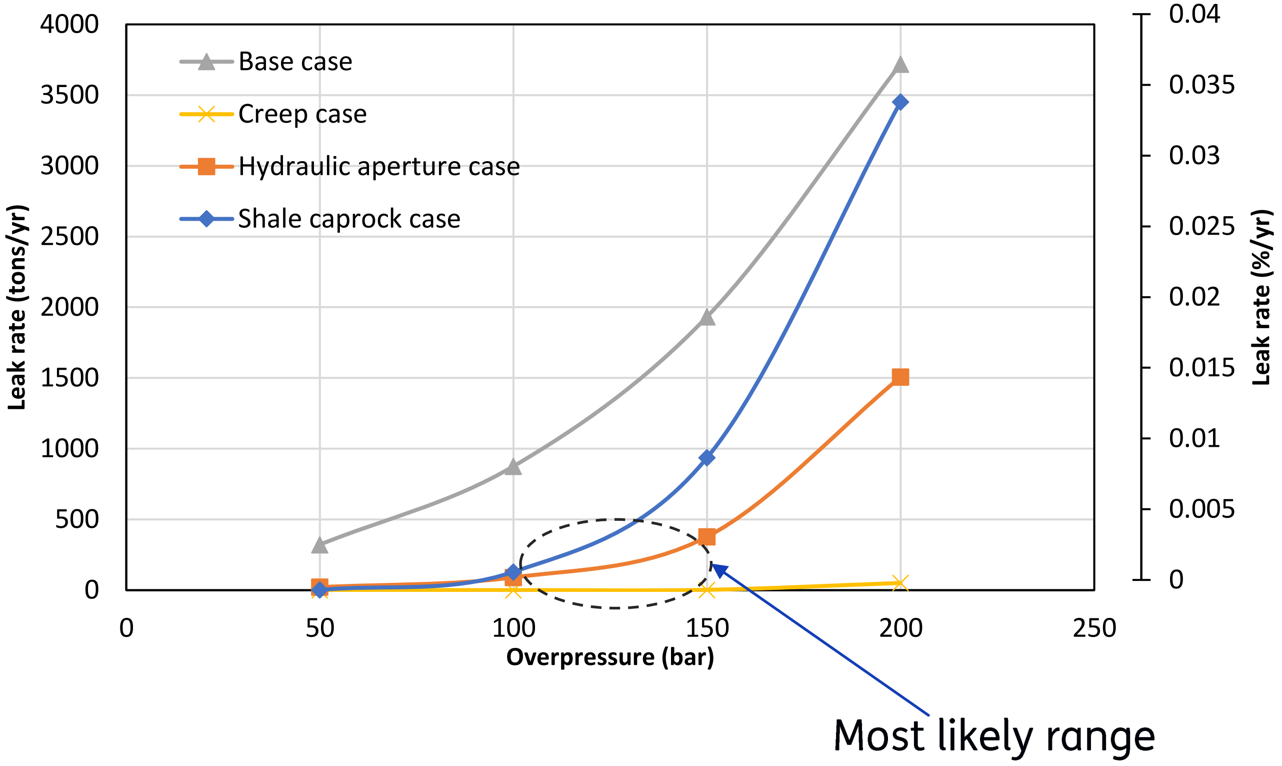
Case study – Legacy well aquifer CCS

- The caprock is Zechstein salt (400 m thick).
- The legacy well has a depth of 4140 m with an inclination of less than 10 degrees.
- The caprock section is drilled with a mud weight of 1.65 and a 7” liner is cemented (3233 – 3623 m).
- Here we assume that the target formation is an aquifer and CO2 will be injected in a nearby well.
- The CO2 plume will reach the well after 2 years of injection.



Leakage vs max pressure

- This plot shows the steady-state CO2 leakage rate at various over-pressure levels.
- The results for several cases are included.
- The base case for salt without creep shows the highest levels of potential leakage followed by shale caprock without creep.
- Formation creep can potential reduce the leakage significantly.
- In addition, other physical phenomena such as hydraulic aperture and visco-inertial flow (non-Darcy) may reduce the leakage rate significantly but more experiments are needed.



Max pressure?

- Current regulation in the Netherlands is to limit pressure in depleted fields to hydrostatic
- This stringent criteria may be subject to change in the future upon improvement of our understanding of the leakage rates and consequences
- An increase in final pressure of the storage complex adds to the storage capacity while increasing the leakage risk.
- Leakage through wells may be a limiting factor in the max pressure target.
- A 10% increase in the final pressure amounts to a 10% increase in storage capacity.
- This can lead to tens of millions of dollars/Euros in additional revenue.
- Quantitative leakage assessment through wells is necessary to evaluate the risk and consequence of well leakage at different pressure levels.


Thank you for your attention
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