Prevention and Remediation of Methane Leakage from Abandoned Wells

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The presented views are not necessarily the views of the companies I work for

R2

Outline

1. Introduction
2. Scene setting
3. Risk Factors, regulations, practices
4. Options for remediations
5. To remediate or not
6. Conclusions/Recommendations

Scene setting Well P&A

- Objectives of well closure are identical between operators, regulator, society:
  - No leaks of underground fluids to surface, or into useable water layers
  - No harm to the workforce
  - Low environmental impact (emissions, noise, eco-disturbance)
  - Low cost

- Operators will first and foremost comply with regulations.
  Their objective is to prevent remaining liabilities.
  (the simplistic frame that leaks are caused by cost cutting is not true)

Scene setting Leaks from Well P&A

- Well P&A is regulated, designed and executed for zero leakage. There are no tolerable leak rates defined.
- There is no requirement for long term monitoring of wells. Leaks are discovered by incident or by special investigations.
- In case of leakage, there are no tolerable leak rates defined, neither in absolute nor in relative terms (surroundings), until:
- The EU Methane Regulation mentions for Leak Detection and Repair (LDAR) an absolute value of 17 g/hr (0.15 t /yr) (0.62 m^3/d) (226 m^3/yr) for subsea components

- Information on leakage from offshore wells is limited.
- Onshore, observation campaigns have found very few wells that leak.

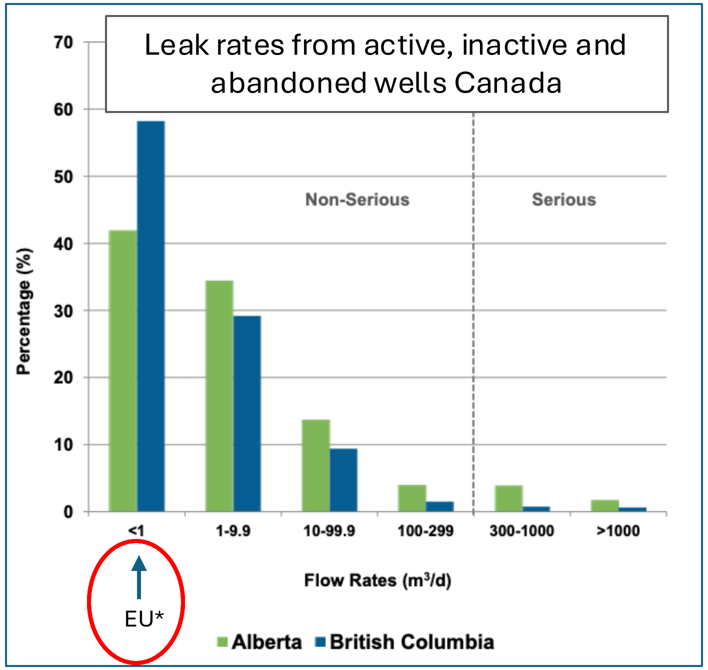
Examples of leak observations

Extensive overview available in KEM-18

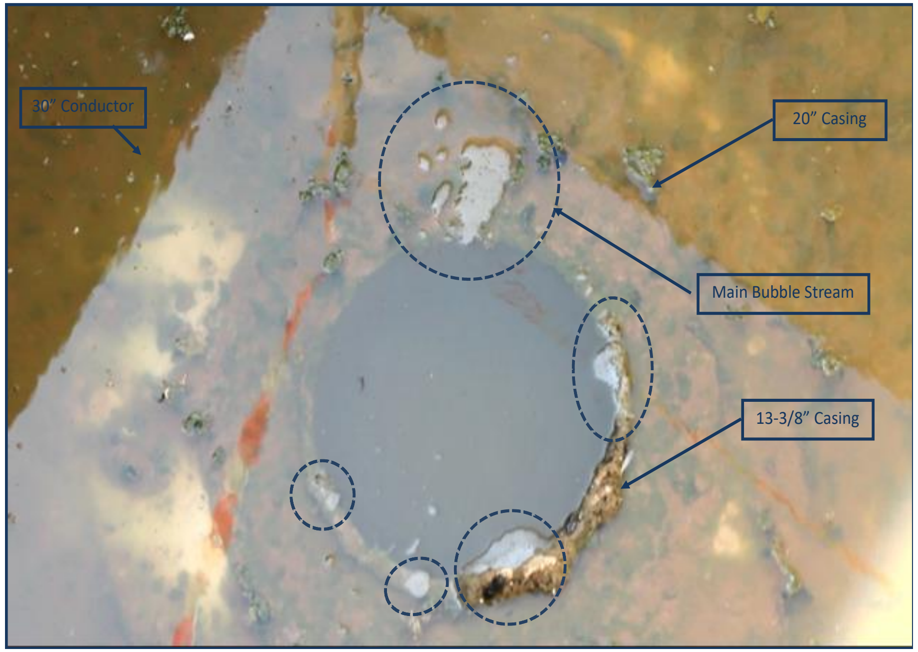
- **8030** wells in Pennsylvania:
  1.27% leaked to the surface. (Davies et al. 2014)
- **435** wells in Canada, tested for surface casing vent leakage:
  22% were leaking. Erno and Schmitz (1996)
- **316,439** wells Alberta,Canada, drilled between 1910 and 2004
  4.6% of wells had leaks (Watson and Bachu, 2009)
- **103** wells UK rural areas:
  30% had CH4 above, and **39%** below control sites (Boothroyd, 2016)
- **185** wells onshore NL(14% of P&A'ed wells) using emission measurements:
  0% had elevated methaan emissions. (ECN report for SodM,2017)
- **1430** wells onshore NL, summary of various investigations
  **0%, **1 leaking well ~50 ltr/d, 18 m^3/yr re-plugged. (SodM, 2022).
- **57** wells offshore North Sea, The Netherlands
  2% show leakage, 18% if wells through shallow gas (de Bruin, 2025)

Leaks observed

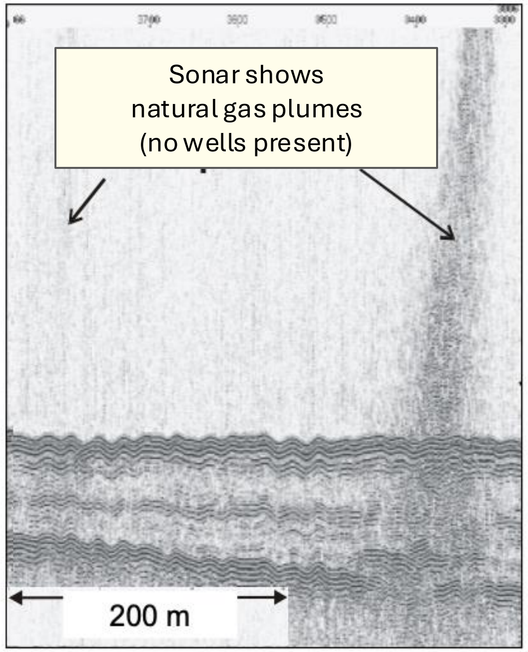
- Observed leakages are mostly small, in comparison with environment (better described as seepage, bubbles, ebulliation, gas migration)
- A leak is almost always methane (95%-99%, Canada), sometimes oil or drill mud.
- It is common fun to express a well leak as a cow equivalent (~100 m3/yr)



Serious leakage requires action with 90 days
Non-serious leakage requires annual monitoring
*EU sets 0.6 m3/d as a threshold (5 day action)



Ebullition of methane from 550m
(stopped after earthquake)



TNO/Deltares: Dutch block B13

Risk factors for Well Seepage after P&A

Key risk factors (in no specific order):

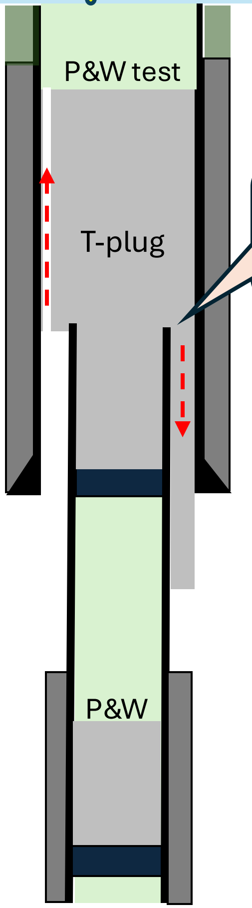
- ❑ Age (proxy for technology, e.g. pre- and post 1975)
- ❑ Previous leakage (Sustained Casing Pressure/ Vent Flow)
- ❑ Geology (gas traces in overburden, unsaturated, ppm's),
- ❑ Uncemented or poorly cemented casing (path through annulus)
- ❑ Prescriptive regulations

My experience: Almost all wells that leaked had gas from the overburden through cement barriers that complied with regulations (including verification).

Prescriptive regulations can be a cause of leakage

Every well is different from the next, but regulations use one size fits all. Mining companies will comply with regulations, but these may fall short and can be a root cause of leakage, e.g:

1. Regulations (used to) only mention the reservoir, not require identification of all potential sources of inflow. Overlooked background gas and accepted unchecked annulus cement.
2. Regulations prescribe(d) casing cuts and a T- plug over the casing stump. This can create slurry slumping into the open annulus and creation of a channel.
3. Regulations prescribe 'cement' without further specification as a sealing material, irrespective of the situation. Other materials are rarely accepted.
4. Regulations rely on meaningless verification and ignore QA/QC as the most important verification method.



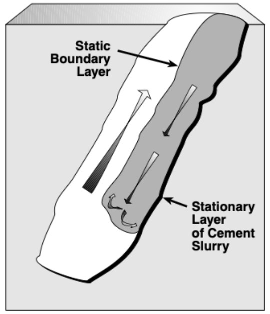


Fig. 4—Circulation/extrusion effect, thick fluid.

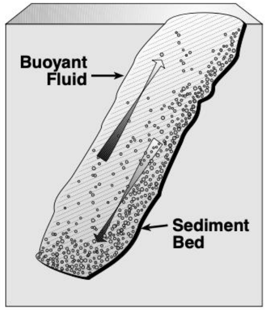


Fig. 3—Boycott effect, thin fluid.

SPE 30514

Poor execution practices

- Omit to check the overburden for gas sources and assess the isolation.
- Ignore signs of poor cement job, e.g. early arrival of cement at surface.
- Rely on non-engineered Viscous Pills for slurry support

  - in mud

  - in seawater (very difficult)
- Perforate and squeeze annulus without slurry support
- Use of simple neat cement in demanding applications
- Use excessive pressure for verification; damages annulus cement

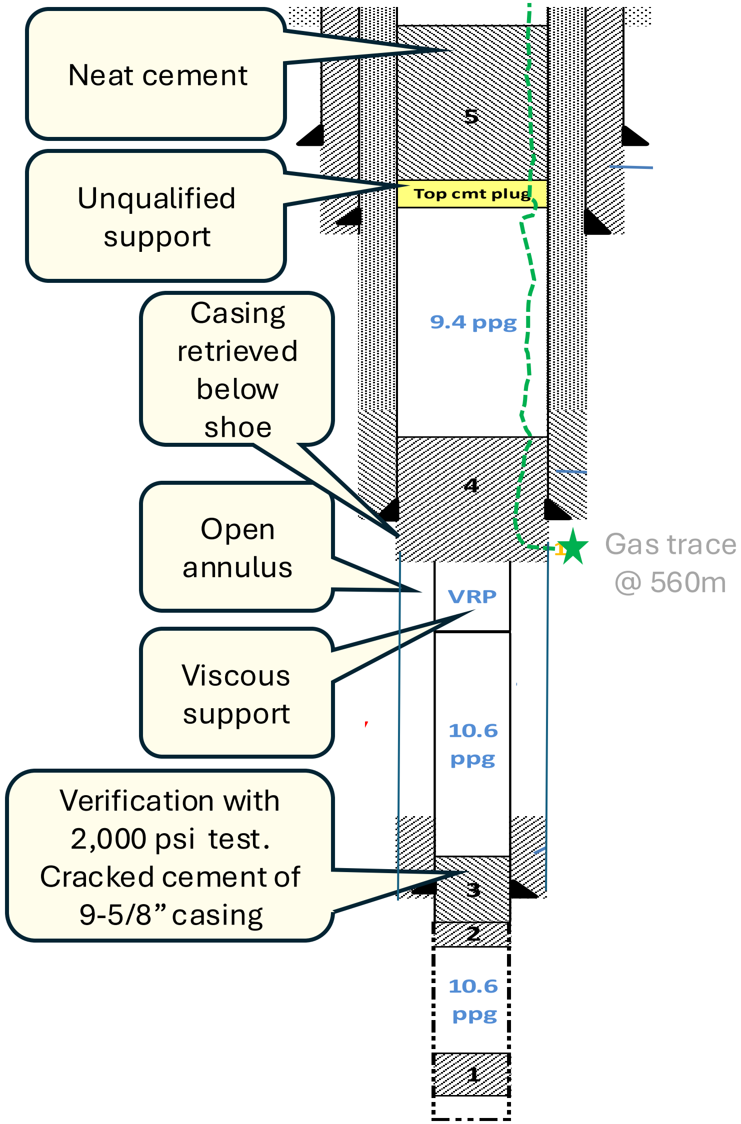
Root cause is lack of knowledge and understanding of placement/sealing physics

Remediation of a leaking well

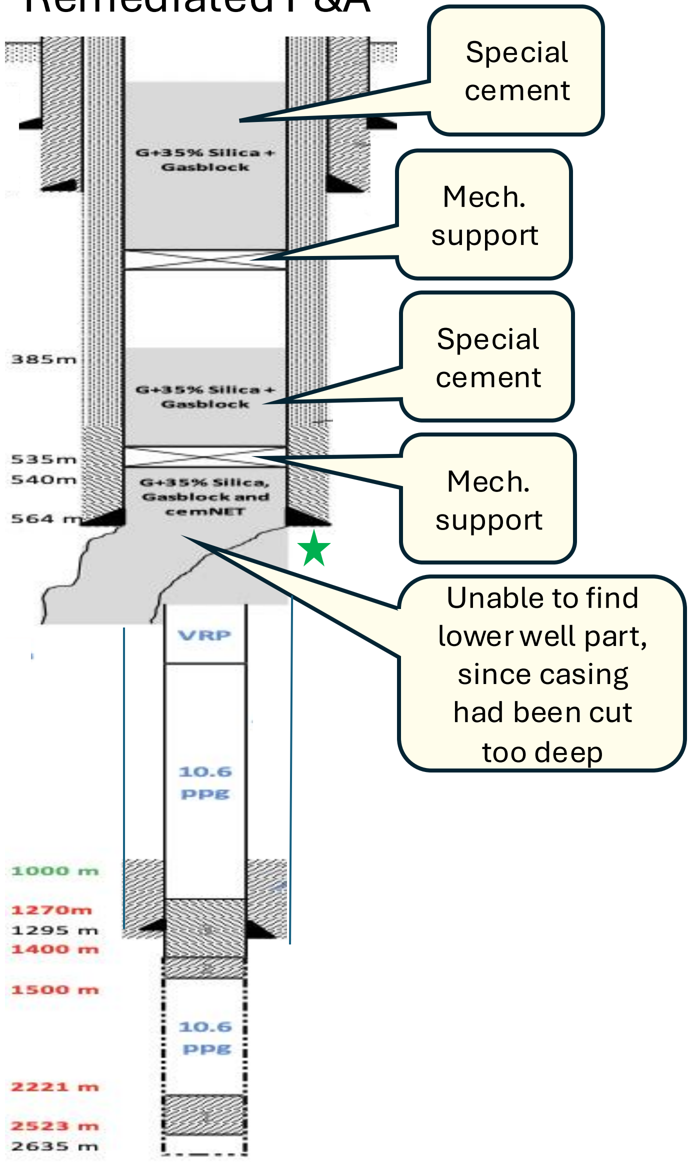
- Very few publications exist of remediation of wells after P&A
- Technical Options:
  1. Remediate when wellhead/platform is present ('Dry')
     If leak is observed during voluntary monitoring period, many options are available, including monitoring the repair.
  2. Reconnect to a well that was severed below seabed ('Wet')
     No offshore well reconnects have been reported.
     We will explain the process for an onshore situation.
  3. Drill an intercept well
     Cases have been reported for hurricane damaged platforms.
     A few cases have been reported onshore

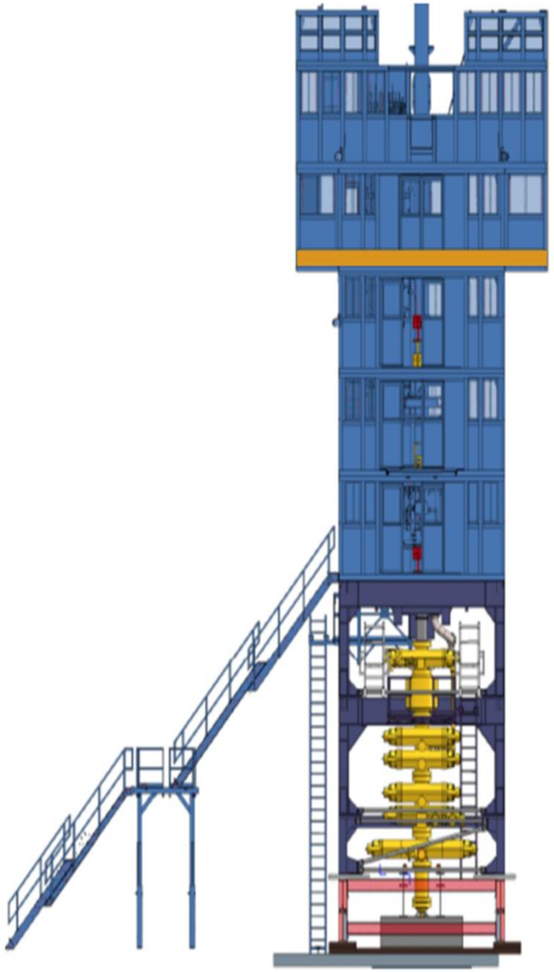
Example: Re-enter ‘dry’ exploration wells in remote jungle location

Leaking P&A



Remediated P&A





Work unit had to be mobilised from The Netherlands

Ref: SPE-173672-MS

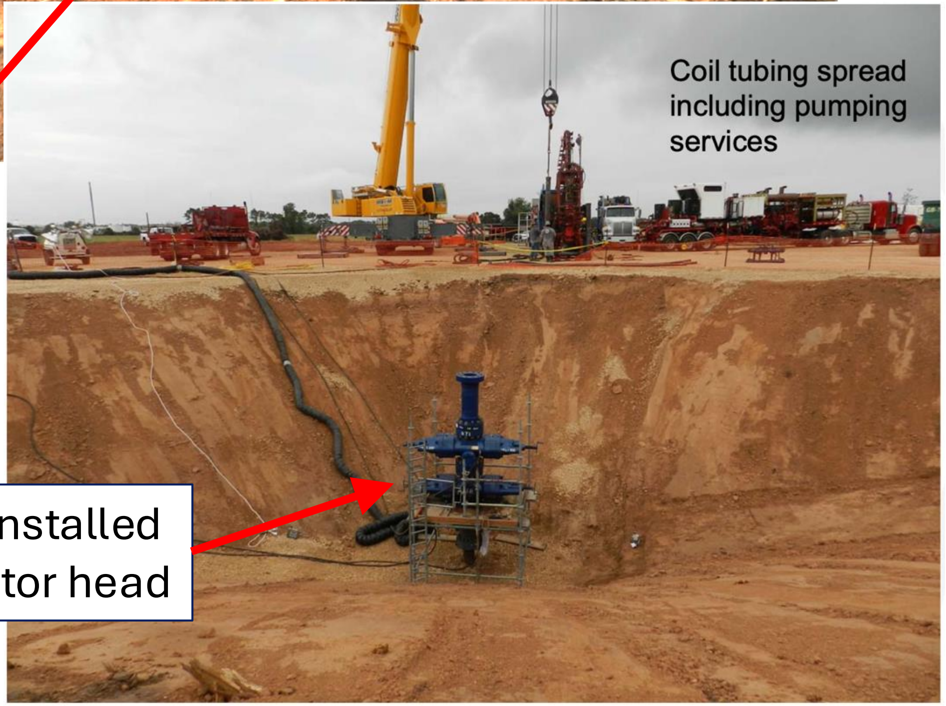
Typical steps of remediation a leaking P&A well – onshore

1. Make location safe. Measure leakage (rate, constituents)
2. Study files of P&A operations and geology. Determine possible/likely leak path scenario's. Puzzling.
3. Locate the well as precisely as possible.
   Note: GPS surface coordinates may not be available for old wells.
   Onshore wells used land measuring techniques. Offshore is less accurate.
4. Lease land, arrange permits, make HSE plans.
5. Build temporary access roads and location for rig.
   Excavate sloped space to expose conductor (to ~3 m for NL). Construct cellar and rig support.
6. Cold cut conductor and casings into wedding cake shape, possibly freeze to stop gas flow.
7. Tieback key casings. Force fit wellhead onto non-centralised casing, energise seals, test.
8. Move in drilling rig, hoist, or HWU or Coiled Tubing unit
9. Drill-out surface plug under BOP protection. Be ready to handle gas and pressure.
10. Clean-out well to first barrier. Perform diagnostics to confirm/reject possible leak paths.
11. As required, drill-out next cement plug. Repeat previous step.
12. Once leak path has been established, re-abandon well. This may involve annulus repair.
13. Evaluate isolation (extended verification) and monitoring.
14. Demob rig, restore location and temporary roads

Example well excavation

This re-entry was for building, not for remediation

Source: Wild Well Control

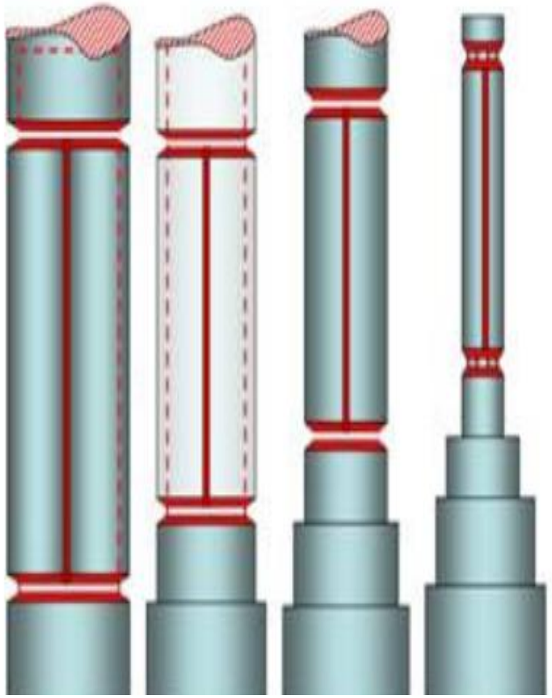


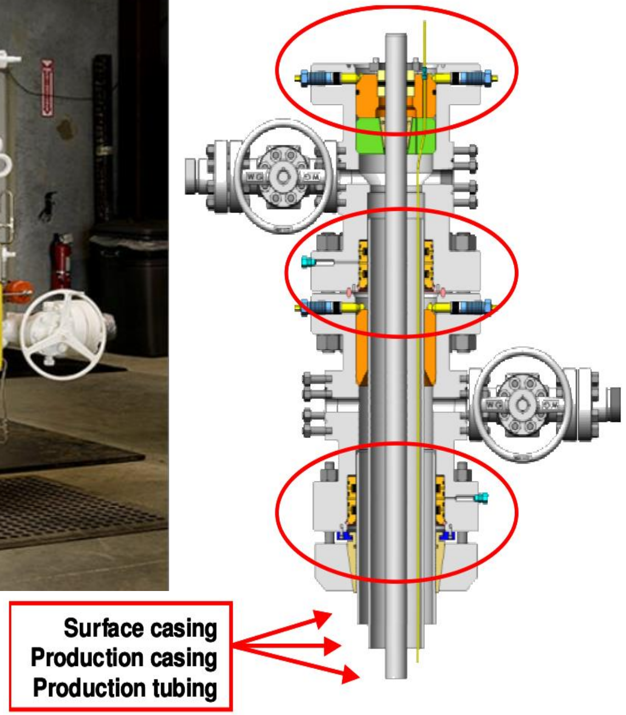
Well

Slip-on wellhead & BOP installed
ready for Coiled Tubing injector head

“Wedding cake” of well casings to accept a new wellhead

Subsea wedding cake for new wellhead after hurricane damage
(requires extensive diving operations)





- Casings will be eccentric and need to be forced in the wellhead spool.
- If gas is present, freezing the wellhead is used onshore, not possible offshore.

Condition of the conductor cut – how to connect?

Cuts made with
high pressure abrasives jetting.
(Not all cuts are as clean as shown in the picture)

Conductors were severed with explosives
some 20-30 years ago

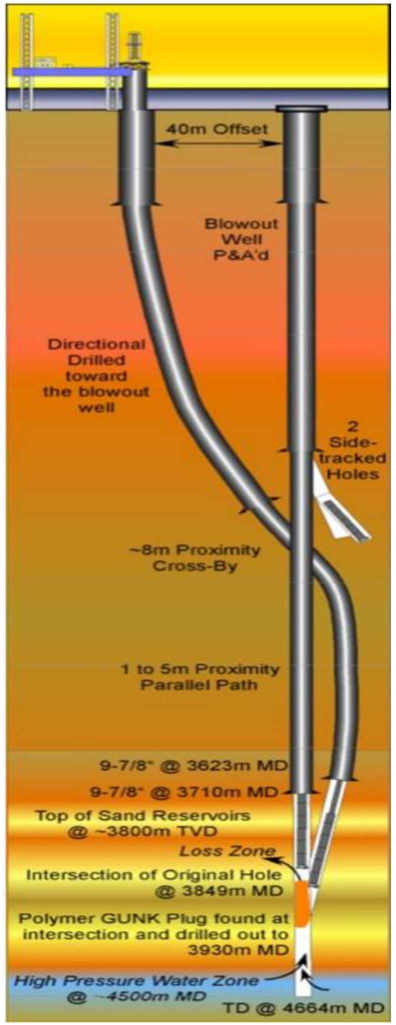
Drill an intercept well if unable to reconnect

An intercept well is used as a relief well to stop a large flow from a blow-out. Remediation is very different from a small leak after well P&A.

Operations:

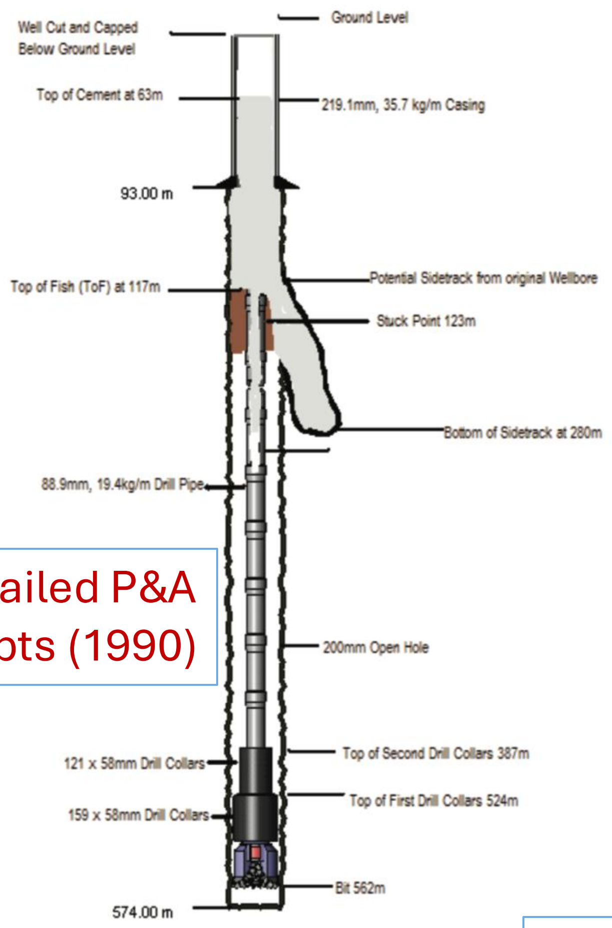
- Drill new well, either using a subsea wellhead, or an MLS system.
- Drill a distance past the target well, locate well with magnetic ranging tools, plug back and sidetrack. Several sidetracks may be required to locate the well at depth.
- Need to intercept target well at 2-8 degree difference in direction for concave mills to enter the casing. Delicate operation.
- Once an intercept has been made, the target well can be entered. Logging, perforating and cement pumping is possible, but other annular remediation options are unproven.
- Intercept well drilling is very elaborate, without guaranteed success that a small gas leak can be effectively stopped.

Onshore examples in SPE-206311-MS by Dorey et al.

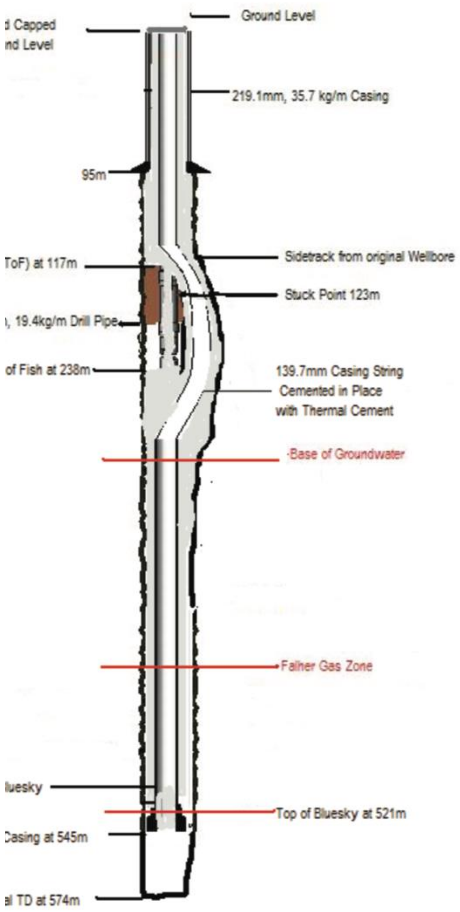


Intercept well is used for relief well drilling

Example of re-abandonment (Canada, land)



Well after 2 failed P&A Attempts (1990)



Final Well status (2010)

- In 1990 drillstring got stuck. Cemented in place.
- Abandonment started to leak.
- Reentered well but unable to gain access below cement plug.
- Drill exit & intercepted deeper
- Perforated drillpipe and pumped cement.
- Extensive operations took 60 days for an intercept well at 140 m on land

SPE 138287

Complicating factors remediation – offshore

- Absence of good records, poor reporting or lost files, including drilling records (e.g. drill gas recording while drilling)
- Well location uncertainty, and trajectory in case of intercept well.
- Lack of a wellhead is decisive.
  Regulations require wellhead to be removed and conductor/casings cut below seabed.
- Reconnection requires locating, dredging, diving.
- No remediation is known on wells cut below the seabed.
- Multi-year project
- Wells severed by section milling require intercept well.
- Little industry experience with remediation offshore.

NL: -6 m
UK: -10 ft
NO: no Stick-up
USA –15 ft

Remediation is a non-routine operation in itself. Very time consuming, risky and costly.

Decisions: To remediate, or not

Current practice:
Onshore: Remediation is always done, even at minute methane rates
Offshore: Remediation is done provided the wellhead is in place on platform (‘dry’)

Decisions involve many technical issues and uncertainties, environmental gain (emissions) being one.
Below is an example estimate (order of magnitude; actual values will vary significantly)
If assuming :

- Jack-up rig with 1 supply vessel and 2 heli’s per week: ~41 MT CO2equiv (€280,000/d)
- ‘Dry’: wellhead in place. ‘Wet’: wellhead cut-off. Site preparation (dredging, diving, etc) excluded.
- 1 kg methane is equivalent to 80 kg CO2equiv (GWP 20 yr)
- A methane release of 17 gr/hr (EU reg) is equivalent to 12 MT CO2e/yr

Jack-up rig (medium size)	Rig Days	Rig activity CO2equiv (MT)	Years to break even	Cost indication	Success rate
Re-entry dry	30	1240	104	€ 7 mln	High
Re-entry wet	90	3730	313	€ 25 mln	Medium
Intercept well	180	7460	626	€ 50 mln	Low

Conclusions

- Methane detection campaigns show that few wells of recent vintage leak, and if they do, leak rates are relatively small compared to other sources.
- Well risk factors are age, shallow hydrocarbons (ppm's), questionable primary cementations in the overburden, uncertain cement slurry support. Leaks mostly originate from overburden.
- Leaking wells are usually repaired regardless of the leak rate and economics, onshore and also offshore if the wellhead is present.
- Without wellhead present, offshore remediation is unproven. After the conductor has been cut below the seabed, dredging and reconnection becomes a significant project. An intercept well is an option but has limited remediation techniques in the toolkit. The outcome is uncertain.
- Mining companies will first and foremost comply with regulations. Leaks may have been caused by prescriptive, inadequate regulations.
- Regulations have no clauses that facilitate remediation (e.g. location and survey, keep conduit intact, magnetic markers, clean shallow cut of conductor at seabed)
- Records are of prime importance for possible re-entry. It is a public interest to safeguard these in the (very) long term. Records include P&A execution, cementing, (mud)logs and original drilling/sidetrack records, location and trajectory data.

Recommendations

- Confirm accuracy of well trajectory and surface coordinates. Consider e.g. magnetic markers on wells that carry leak risk.
- Keep conduit intact (no casing pulling from open hole, avoid long section milling).
- Cut conductor as shallow as acceptable.
- Viscous pills should be engineered.
- Maximise monitoring while the wellhead is on; this is a cheap insurance. P&A in a timely manner; do not delay.
- Treat a leaking well as an HSE incident, investigate and adjust practices/regulations
- Get it right first time, use meaningful verification methods.

Thank you

Questions?