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Relief well planning for subsea applications

Acknowledgements

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About

Relief well requirements can vary from country to country based on local regulations, environmental conditions, and specific characteristics of oil and gas operations in that region.

Various industry organizations and regulatory bodies provide standards and recommended practices for relief well planning and execution. This Report recommends considerations for relief well planning and available resources specifically for subsea application. The Report is intended to be used by operators and service companies.

The following relief well topics are within scope:

- planning
- approaching
- locating
- following
- intercepting
- killing operations
- plug and abandonment

The topics below are outside the scope of this Report:

- routine well construction techniques
- specific country regulations
- recommendations to relief well planning and execution

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Revision history

VERSION	DATE	AMENDMENTS
1.0	October 2024	First release

Contents

Introduction

Relief wells are drilled from a secure location with the objective of intercepting a problematic well to regain control and/or plugging it (Figure 1). Importantly, they serve as the last line of defence in case of a blowout when other intervention methods are considered unsafe or ineffective in restoring well control.

While serious well integrity failures necessitating relief wells are comparatively infrequent among the numerous wells drilled globally each year, understanding the basics of relief well drilling remains crucial. Industry standards and recommended practices often call for the inclusion of a relief well plan in the well planning process for critical wells. For many oil and gas companies, this is a standard procedure integrated into internal processes. Relief wells are drilled worldwide each year, underscoring their continued importance.

Relief wells have been a part of the oil and gas industry since its early days, representing one of the oldest methods for blowout intervention. Historically, when a well experienced a total loss of control, adjacent vertical wells were drilled down to the reservoir and produced at high rates to reduce pressure and deplete the reservoir until the blowout ceased. This practice gave rise to the term "relief wells." In modern times, most relief wells directly intersect the target wellbore, allowing mud to be pumped into it, thereby increasing pressure to halt the blowout. Although modern relief wells do not seek to relieve pressure, the term "relief well" has endured. Throughout the history of relief well drilling, there have been numerous developments and milestones, but this document will only focus on modern practices and technology.

Successful planning and execution of a relief well is not simple. Relief wells present distinct objectives involving unconventional operations and posing unique challenges that set them apart from conventional drilling. Should a blowout occur, the relief well strategy must be tailored to the specific circumstances, necessitating prompt mobilization of a multidisciplinary team consisting of relief well specialists, hydraulic modelling experts, wellbore surveying experts, reservoir engineers, plug and abandonment (P&A) specialists, among others. Typically, there will be multiple planning cycles when planning a relief well, which involve continuously evaluating new data and hydraulic modelling results, improving the understanding of the well scenario, evaluating alternative plans and trade-offs, risk assessment, and seeking approvals.

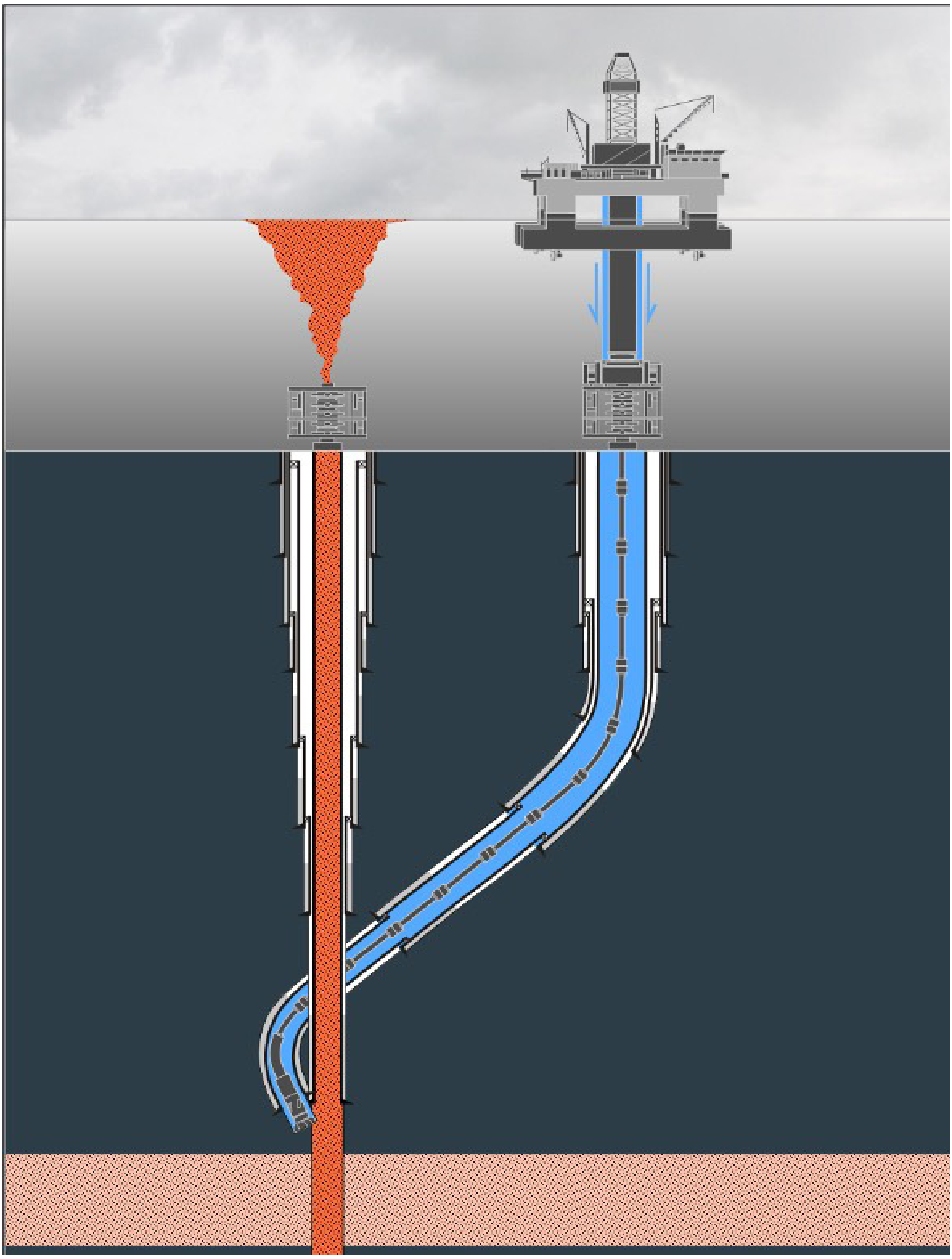


Figure 1 – Illustration of a relief well making hydraulic communication with an out-of-control well

1. Relief well contingency planning

A relief well contingency plan is commonly divided into two parts, often referred to by different terms depending on people, companies, and publications. In this Report, they will be denoted as the Relief Well Response Plan and the Relief Well Feasibility Assessment.

The Relief Well Response Plan serves as a general strategy that may be tailored to a company, specific region, or drilling campaign. It forms an integral part of the overall emergency response framework, typically linked to either an incident command system or an incident management system (see Figure 2 as an example). IOGP Report 594 – *Source Control Emergency Response Planning Guide for Subsea Wells* describes the framework for the incident command system, which describes the relief well group as part of the source control branch. The Relief Well Response Plan outlines the personnel that will be deployed as part of the relief well group. It typically features multiple flow charts and tables describing various roles, their corresponding responsibilities, as well as the required tasks and procedures. The required training, competencies, and skills for each role are provided in IOGP Report 591 – *Guidance for Subsea Source Control Competency and Skills.*

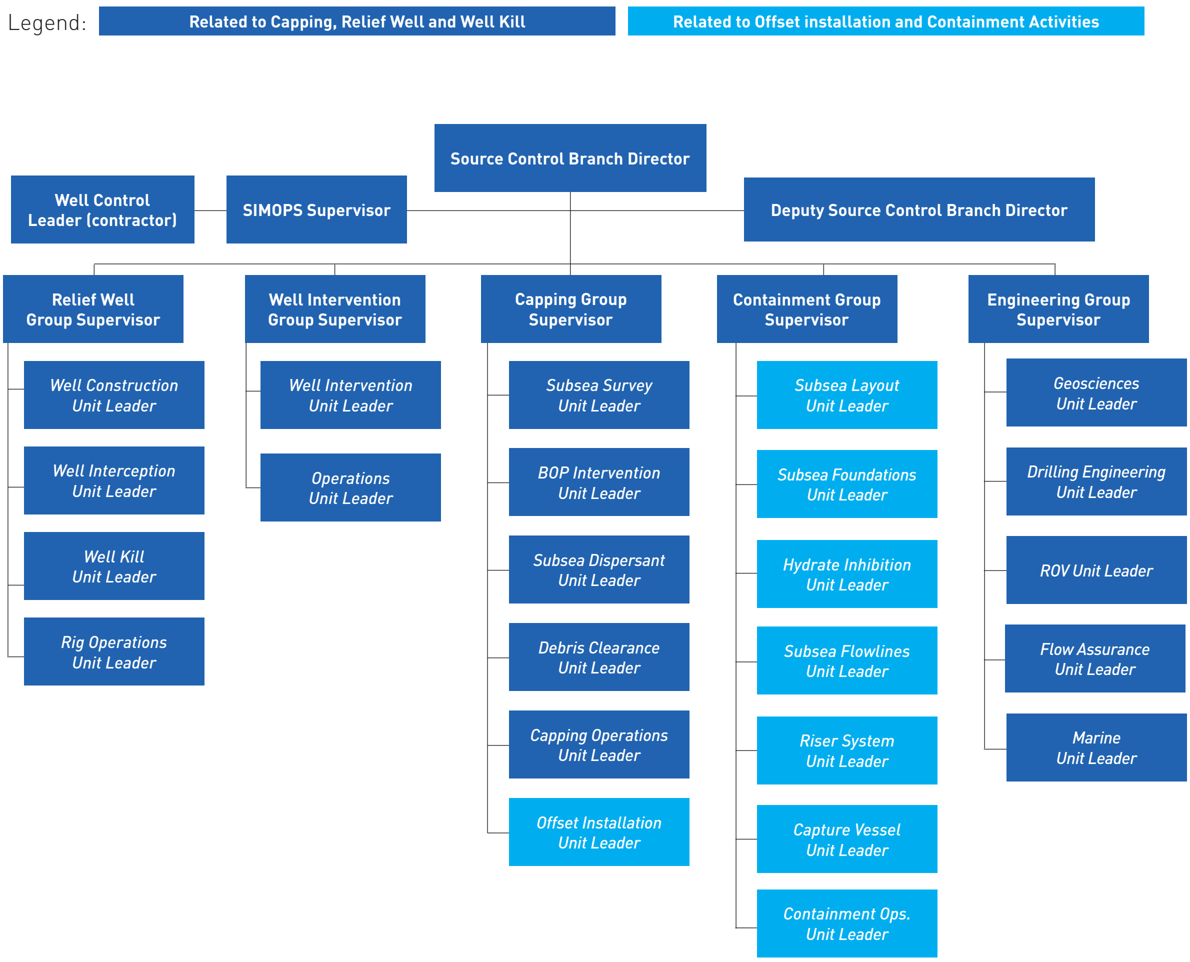


Figure 2 – Example of the source control team in the incident command system

The Relief Well Feasibility Assessment is uniquely tailored to a specific well, a site, or sometimes a representative well for a field development. For instance, when an operator plans to drill an offshore exploration well, this assessment scrutinizes potential blowout scenarios specific to the expected reservoir(s) and planned well design. Furthermore, the Relief Well Feasibility Assessment evaluates the feasibility of executing a relief well operation to mitigate such scenarios. The resulting report offers insights into the viability of the relief well in fulfilling its objectives, identifies potential obstacles, and offers recommendations for overcoming these challenges.

A Relief Well Feasibility Assessment that is prepared as part of planning a well will typically serve as a first-iteration design if a blowout occurs. A proper contingency plan will improve response time and decision-making during crises. More importantly, it will ensure that the worst-case blowout scenario is killable with one or more relief wells. The plan should demonstrate that a relief well can be drilled from a safe location, the target well will be located with a downhole ranging technique, and hydraulic communication will be achieved at an optimal location that will facilitate a safe and efficient kill operation based on the target well's remaining integrity. Figure 3 shows an example planning process for a contingency relief well as part of the Relief Well Feasibility Assessment. If the relief well planning process does not provide a qualified solution, then the target well design should be re-evaluated.

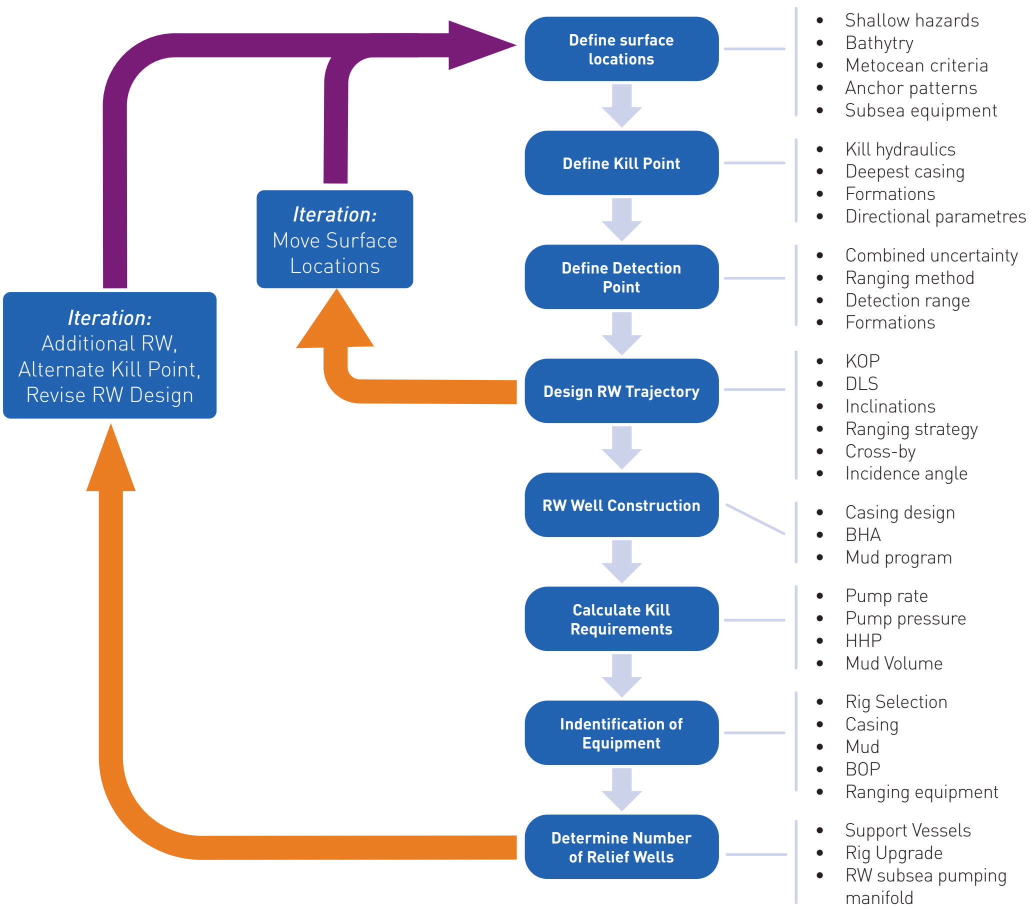


Figure 3 – Example relief well planning process

References include:

Number	Relief well contingency planning
IOGP 594	Source Control Emergency Response Planning Guide for Subsea Wells
OEUK	Guidelines on relief well planning for offshore wells
SPE 156768	ICS SYSTEM – Blowout Response
SPE 173532	Emergency Preparedness for Oil and Gas Exploration and Production
SPE 181460	International Regulations and Compliance for Relief Well and Blowout Contingency Planning
SPE 195757	Enhancing Industry Subsea Well Intervention Response Capabilities

2. Relief well drilling rigs

Operators are encouraged to join mutual aid agreements to secure access to rigs in the event of a blowout. The rig involved in a blowout may become damaged and unusable after the incident. Even if the rig is undamaged and operational, additional rigs may become necessary for redundancy or for well kill operations.

The selection of relief well drilling rigs depends on factors such as availability, mobilization time, specifications, and pumping requirements. Thorough hydraulic modelling of the actual blowout scenario should be conducted to assess kill requirements and ascertain whether potential relief well drilling rigs have the necessary capacity. Critical aspects of drilling rig selection include the size of choke and kill (C&K) lines, the quantity and capacity of rig pumps, hook load capacity, blowout preventer (BOP), and mud storage capabilities. Hence, in some cases, it may be better to immediately start relief well (RW) operations with the first available rig and later switch to a kill rig with the required specifications for the final intercept and kill operation.

In offshore blowout scenarios, when conditions allow, dynamically positioned drilling rigs are typically favoured due to the need for multiple vessels to operate in the area. When using multiple anchor-moored vessels, careful consideration should be given to the arrangement of the anchor patterns to prevent overlapping cables and risks to subsea equipment.

Semi-submersible rigs are also often prioritized over drillships due to their greater rig-floor elevation, which is advantageous where there is a likelihood of oil contamination in the surrounding water, which could become a breathing hazard to rig personnel.

If the target well was drilled using Managed Pressure Drilling (MPD) or Pressurized Mud Cap Drilling (PMCD), similar capabilities will often be required for the relief well rig. Selecting rigs with MPD capabilities may also be necessary in fields that have narrow pore and fracture pressure margins, or if it is necessary to drill through naturally fractured vuggy carbonate reservoirs, depleted reservoirs, cross-flowing reservoirs, super charged formations, etc.

3. Relief well surface location

Selecting the site for a relief well is critical. Improper selection could lead to drilling a substantial portion of the relief well, only to realize that the location is unsuitable, requiring the entire well to be plugged back. Subsequently, the rig would need to be repositioned to a more suitable site to restart the relief well, potentially delaying the kill operation significantly. Moreover, an ill-chosen location may expose the rig crew to hazardous working conditions.

In the event of a blowout where a relief well is needed, choosing the relief well site should be one of the first decisions made. Often, this decision is rushed if there is not a proper Relief Well Feasibility Assessment in place. In comparison, other milestones, such as the first ranging run, well intercepting, and kill operation, will occur at a much later stage, allowing ample time to plan, optimize, and finalize. Including pre-qualified RW locations in the source control plan will enhance RW trajectory planning and reduce engineering tasks at the start of RW operations.

Before commencing drilling of any well, the surface location should be assessed considering environmental constraints such as bathymetry, shallow hazards, shipping lanes, and existing subsea production equipment. The relief well site selection should include careful analysis of known and potential constraints, which will be different for all projects. A relief well's surface location, typically determined from a single subsea point, introduces additional environmental constraints based on the blowout scenario, while also needing to facilitate the relief well trajectory.

Important information for selecting the relief well locations includes:

- exclusion zone and simultaneous operation (SIMOPS) constraints
- directional drilling and ranging constraints
- bathymetry and geohazard conditions
- metocean condition and in-water plume constraints
- proximity of shipping lanes and subsea infrastructure

3.1 Exclusion zone and SIMOPS constraints

In the past, insurance requirements and industry guidelines typically recommended that a relief well should be spudded at least 500 metres from the target well. For offshore blowouts, the exclusion zones around the spill site will often be determined by experienced personnel, and various assessments, including:

- measurements of toxic gases
- oil fate and gas dispersion modelling
- heat radiation
- noise
- smoke
- risk of explosion

While the distance can vary significantly, it often falls within the range of 500 to 1,000 metres around the blowout (when H_2S is not present).

Source control operations may include relief well drilling, well capping, spill management, monitoring, and well containment, which require safe and easy access to the incident site and careful considerations of SIMOPS (Figure 4). The relief well location should allow for a safe operating space and not adversely affect the ingress and egress of essential and support vessels.

When drilling two relief wells, it is typically preferred to maximize the distance between their sites to enhance logistical operations in the area for other vessels. Additionally, their locations should allow for continued drilling if one rig experiences downtime, such as unexpected changes in wind direction. Moreover, during the mobilization of the relief well rig, it is advisable to employ remotely operated vehicles (ROVs) to conduct a thorough resurvey of the location, checking for potential debris or wreckage that may have settled on the seafloor during the blowout or initial recovery efforts. When using ROVs, it is important to pay attention to the tethers. If the ROV's need to cover long distances, traditional tethers may not be sufficient. In such cases, buoyed tethers may be necessary to facilitate horizontal movement.

In general, when drilling conditions permit, the distance may be increased to enhance logistics for oil-spill vessels and offer better protection against flammable and toxic substances. However, in certain situations, such as a shallow interception, it might be beneficial to move the surface location closer to the target well, provided it doesn't compromise safety, and approval is granted from regulatory authorities, rig contractors, and insurance agencies. Historically, relief wells have been spudded as near as 125 m and as far away as 2,000 m from the target well surface site.

Figure 4 – Example of multi-vessel SIMOPS during blowout containment and relief well operation in deepwater (relief well rigs are in this case ~850 m from spill site).

3.2 Directional drilling and ranging constraints

In a conventional relief well design, the trajectory of the wellbore should be meticulously planned to approach the target well and maintain close proximity during the detection and parallel section (following the blowout well) above the kill point, facilitating detailed ranging and triangulation. Navigating from the kick-off point to the initial ranging point should be done while adhering to inclination and dogleg constraints. Ultimately, the vertical distance allowing for directional steering will be important when selecting relief well locations; that is, as the depth to the interception point becomes shallower, adjusting the relief well's surface location closer to the target well may be necessary if employing a standard ranging programme and relief well design.

In some scenarios, the target well can be deviated with a long horizontal step-out to the optimal kill point. Typically, selecting a relief well surface site close to the interception target, which is also aligned with the general azimuthal direction of the target well, will usually facilitate a relief well trajectory with reduced dogleg severity (DLS), sail angle, and shorter horizontal displacement. This will provide benefits for torque and drag (T&D), hydraulics, directional control, running casing and wireline, and so on. For situations where the relief well surface site is at a relatively great distance from the interception target, the relief well requires high DLS, or when the interception occurs at a high inclination, a detailed relief well feasibility assessment, which includes T&D and hydraulic analysis, is recommended to verify that the selected rig is capable of drilling the planned relief well.

Relief well ranging and surveying will often involve wireline tools. For relief wells that require the use of wireline tools, it is recommended that the well inclination angle not exceed 60°, so the tool could fall freely to the wellbore total depth (TD). If that is not the case, it may be necessary to pump wireline downhole through open-ended drillpipe using a side-entry sub at surface. To mitigate the risk of prolonging rig time, it is advisable to avoid highly deviated relief wells. Moreover, efforts should be made to maintain low doglegs to improve confidence in the interpretation of ranging data.

To mitigate the risk of prolonging rig time, it is recommended to avoid relief well trajectories, such as with inclinations above 60 degrees, or with high doglegs that can limit getting wireline tools to desired depth(s). Moreover, efforts should be made to maintain DLS within limits appropriate for the ranging method (due to the ability to interpret data) and mode of deployment, e.g., wireline or drillpipe, to improve confidence in the interpretation of ranging data. An alternative to running wireline may be to use a wired drillpipe while drilling the relief well, which will be beneficial when high inclinations are necessary and to significantly reduce ranging time.

3.3 Bathymetry and geohazard conditions

The location of the relief well should be surveyed to ensure that the seabed condition is acceptable for spudding a well and the risk of encountering shallow hazards is minimal. The blowout scenario may involve the potential for hydrocarbons to flow on the outside of the wellbore casing. This flow could transverse into shallow formations or fault lines that could become migration paths for formation fluids and ultimately broach to the mudline. It is therefore good practice to avoid placing a relief well rig up-dip of shallow faults and/or formations.

If the seabed slopes at a prevalent angle, it may be necessary to place the relief well down-dip from the potential spill location. This position allows the relief well rig to safely move from its location if an emergency disconnect becomes necessary. Ideally, the rig would move directly away from the spill location. However, if the mudline slopes upward, the lower marine riser package could potentially hit the seafloor and effectively become an anchor.

3.4 Metocean condition and in-water plume constraints

During relief well drilling operations, oil, gas, and smoke should be prevented from reaching the drilling rig. This is crucial for personnel safety and to minimize downtime. Immediately following a blowout, oil fate and gas dispersion modelling should be conducted based on factors such as fluid composition, release rate, water depth, and prevailing wind, waves, and currents for the season. In ultra-deep waters, a potential scenario involves gas released into the sea forming hydrates and being carried by currents several kilometres away from the spill site. As a general recommendation, however, the relief well's surface location should be selected opposite or perpendicular to the predicted wind and current direction from the release point (Figure 5).

Following a blowout, one of the most perilous threats to personnel safety is the uncontrolled release of H_2S to the surface. In the event of a substantial gas blowout, even a small amount of H_2S in the fluid composition could require a large-scale evacuation and safety zone. If the gas ignites, whether intentionally or accidentally, it will generate an equivalent volume of SO_2, which is also toxic but tends to disperse more rapidly.

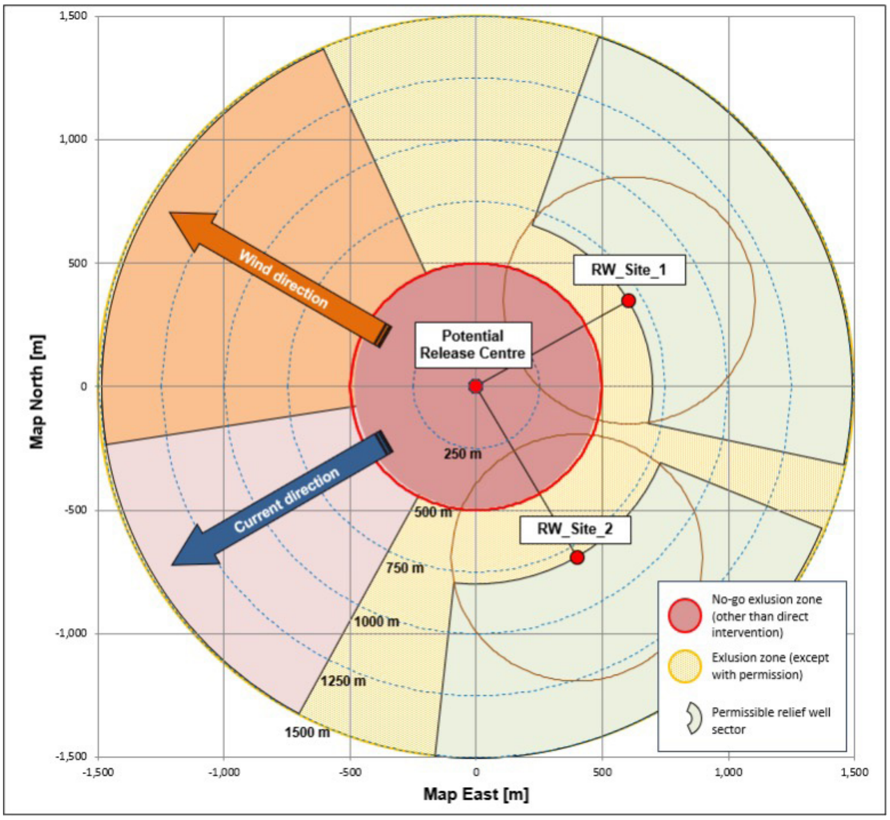


Figure 5 – Example graphic of exclusion zones and working areas during a blowout intervention

3.5 Proximity of shipping lanes and subsea structures

Generally, the relief well location should not obstruct shipping lanes, which would interfere with other commercial activities. Source control and relief well operations are resource-intensive and require significant support vessels. It is important to minimize the disruption to the established shipping lanes. The distance from the shipping lanes should include a safety zone around the relief well location and a staging area for support vessels.

In areas where pipelines are laid on the seabed, the relief well location should be a safe distance from these pipelines and other installed subsurface structures. Development plans, such as laying pipelines, subsea building, and new wells, could affect the originally selected relief well locations. Offset wells or side tracks could be drilled in the path of a planned relief well, increasing collision risks and affecting ranging operation. Also, laying pipelines and installing production facilities during the field development might necessitate changes to the originally planned relief well locations. If this should occur, it is recommended to review the planned relief well locations and trajectories to ensure that they are still valid.

References include:

Number	Relief well surface location
APPEA	Australian Offshore Titleholders Source Control Guideline
IOGP Report 373-18-1	Guidelines for the conduct of offshore drilling hazard site survey
OEUK	Guidelines on relief well planning for offshore wells
SPE 168029	Relief Well Planning
SPE 173160	Multiple Relief Well Planning for an HPHT Blowout in Southern Mexico
SPE 174890	Blowout Prevention and Relief-Well Planning for the Wheatstone Big-Bore Gas-Well Project

4. Relief well targets

During an actual blowout, the selection of the kill point is guided by diagnostics from hydraulic modelling to ensure that the relief well can control the blowout and, perhaps even more importantly, that the relief well itself does not blowout when gaining hydraulic communication with the target well. Other factors influencing the selection process include:

- Minimizing the risk of drilling into a flowing or potentially supercharged formation when choosing the interception point.
- Opting for a competent formation for the intersect to mitigate the risk of:
  - openhole collapse upon establishing hydraulic communication with the target well.
  - fracturing at the casing shoe of the relief well during the dynamic kill operation; ensure the target well has proven annular isolation (competent cement or squeezing formation) at the interception depth to prevent communication with the annular space during the dynamic kill operation. Without this, kill fluid may move upwards behind the casing, exiting at the mudline or fracturing a shallower formation, thus hindering the dynamic kill efforts.
- Avoiding intersecting the target wellbore in sections with high DLS.
- Considering the completion configuration for production wells, such as intersecting at perforations versus above the production packer. Arrangements should also be made so that the intercept point will facilitate an efficient plugging process after the kill operation.
- The risk of drilling through geohazards should be minimized. Some of the geohazards that are more specific to relief wells are flowing formations, depleted formations, crossflow formations, and supercharged formations.
- The ability to detect the target well using ranging operations and intercepting the target well at the required kill point.

Over the past 50 years, the most common ranging technique has used a form of magnetic detection to locate the target well. To effectively locate and navigate a relief well to the point of interception, the target wellbore must contain steel components, such as casing or drillpipe, for the magnetic ranging operations to function. A deep intersection point is typically preferred as it maximizes frictional forces and hydrostatic head in the target well during a dynamic kill operation. Hence, the primary kill point for contingency planning is often selected close to the deepest casing shoe. In situations where the drillpipe is out of the hole, this may become the deepest point where magnetic ranging operations can be conducted.

The interception and ranging strategy for the relief well will also play a significant role in determining the kill point. For instance, in a conventional relief well trajectory where the relief well parallels the target well as it aligns for the intersect, the general recommendation is to plan for an intercept just below the deepest casing shoe. However, if the relief well approaches the target well at a steep angle, aiming for a direct intercept without paralleling the target well, the initial target might be at the shoe, a casing joint, or just above the shoe.

References include:

Number	Relief Well Target
ISCWSA	Wellbore ranging technologies, intercept, applications and good practice
OEUK	Guidelines on relief well planning for offshore wells
SPE 189654	Probability of Wellbore Intercept Made Easy
SPE 21991	Re-Entry and Relief Well Drilling To Kill an Underground Blowout in a Subsea Well: A Case History of Well 2/4-14

5. Intercept strategy

A direct intercept, either through casing or into the openhole of the target well, is normally preferred and also the most common method of achieving hydraulic communication with the target well. An intercept into openhole can be performed using a conventional drill bit, eliminating the need to trip out of the hole to replace the drill bit with a mill.

When intersecting the target well through casing or drillpipe, a concave mill can be used to make a slot through the steel. In this case, the selected interception point is in a competent cemented section, providing a rigid section for milling, and preventing hydraulic communication with the exposed formations above the interception depth with lower fracture gradient. Another direct intersect method is to parallel a casing seat, set a kill liner, and gain communication by shooting through both strings of pipe using orientated perforating guns.

At the point of interception, the relative incident (attack) angle between the two wells is typically planned to be lower than 8°. However, in some cases, e.g., where the intersection point is shallow or a direct interception is attempted, the incident angle may be significantly higher. As a general rule, as the incident angle increases, the likelihood of missing the target on the first attempt increases.

The incident angle will also depend on the interception strategy. That is, if an oriented perforation gun will be used to gain hydraulic communication, the relief well should be nearly parallel and near the target well, where charges can successfully penetrate through the cased relief well into the target well. If milling is required, the incident angle will typically be somewhat greater to allow a concave mill to get a bite on the target well steel.

After achieving hydraulic communication with the target well, drilling fluid will often U-tube rapidly into the target well due to the hydrostatic pressure difference between the relief well (weighted mud) and the target well (oil, gas, and/or water). When this happens, there may be a risk of wellbore collapse, especially in unconsolidated formations. Therefore, a final casing (kill string) should be set in the relief well, and the length of the openhole section in the relief well should be reduced to preferably less than 30 metres. After intercepting the target well, this will allow tripping the drillstring back inside of the casing shoe, without breaking a connection, to protect it and mitigate the risk of getting stuck.

References include:

Number	Interception Strategy
ISCWSA	Wellbore ranging technologies, intercept, applications and good practice
SPE 189654	Probability of Wellbore Intercept Made Easy
SPE 198760	Efficient Placement of Relief Well Using Combination of Tools
SPE 21991	Re-Entry and Relief Well Drilling To Kill an Underground Blowout in a Subsea Well: A Case History of Well 2/4-14

6. Survey programme

Accurate surveying and positional control are important for a relief well to reach its intended target. The planned interception will require rotary steerable and/or motor operations from the ranging zone to the intersection point, which necessitates rigorous quality control of Measurement While Drilling (MWD) data. Gyroscopic systems will also be used, particularly when magnetic-interference errors are unacceptable, minimizing the potential for inaccuracies.

The target well survey is usually performed with MWD with quality control, and sometimes survey correction is applied to reach a narrow target. The available raw survey data should be reviewed and corrections performed to reduce the ellipse of uncertainty for detecting and intercepting the target well. The relief well is usually drilled with MWD for the top-hole section, and subsequently Gyro While Drilling (GWD), to eliminate the effect of tubulars in the target well on the survey data.

The size of the ellipse of uncertainty affects the required number of ranging runs for detecting the target well and consequently increases the drilling time and the risk of drilling side tracks. It is recommended to follow an accepted wellbore surveying programme and maintain all raw data. The objective of the survey programme is to reduce the size of the combined ellipse of uncertainty at the first ranging depth to be equal to or less than the ranging tool capability at 95% confidence. Where this objective cannot be achieved, possible changes to the survey programme should be reviewed to reduce the ellipse of uncertainty size to as low as reasonably practicable, which may include running gyros and/or survey data redundancy. Figure 6 provides an example of the ellipse of uncertainty before and after applying survey correction methods on collected raw survey data, which may result in a change in the well position and a smaller ellipse of uncertainty.

When detecting the well with the ranging tool, a survey run with gyro is often performed concurrently or afterwards to determine the well location at the wellbore TD. This may be necessary as the survey sensor in the MWD or GWD tool is often placed behind the motor, and MWD data may be corrupted by magnetic interference from the target well. After measuring the actual hole orientation at the bit, the relief well plan should be updated, and the next depth for performing ranging should be determined. A wellbore surveying specialist should be on location during this phase to evaluate all surveying procedures based on the type of instruments used.

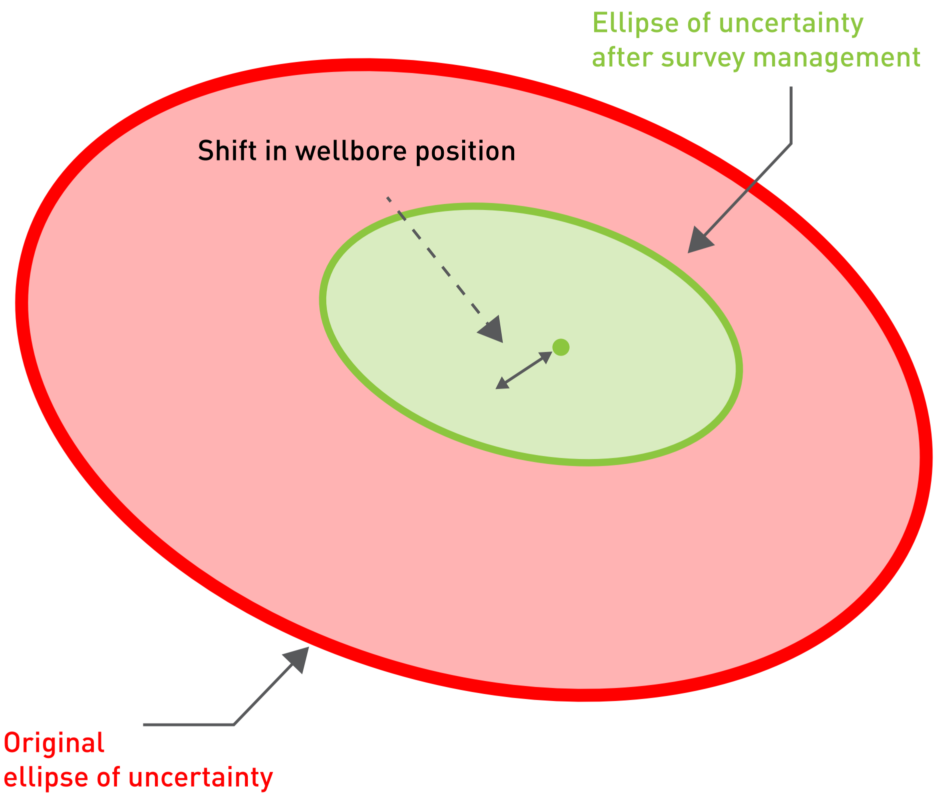


Figure 6 – Example of survey correction and shift in wellbore position

References include:

Number	Wellbore Surveying
API RP 78	Wellbore surveying and positioning
ISCWSA	Introduction to wellbore positioning
SPE 216288	In Field Referencing Study by Drone Aeromagnetic Measurement

7. Ranging operations

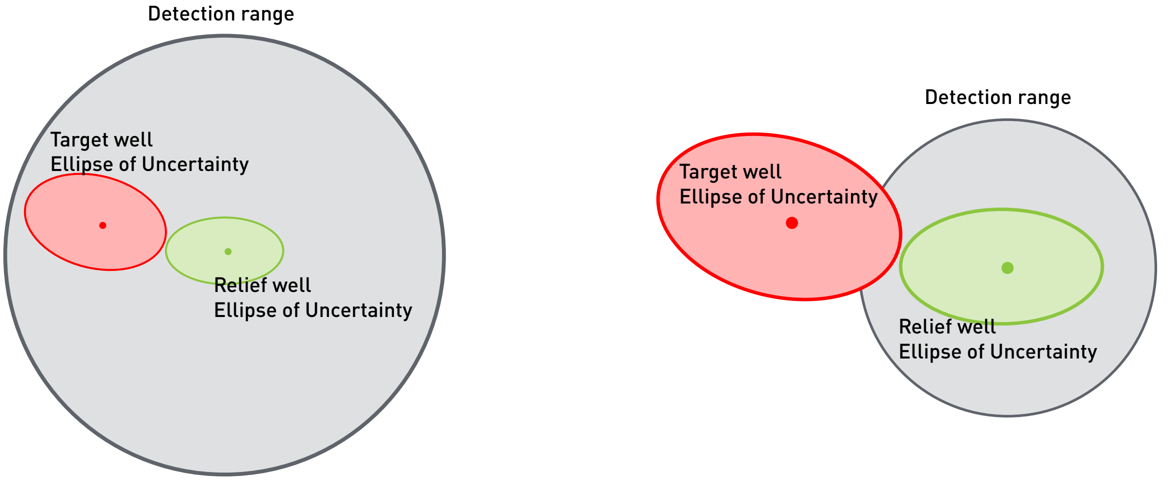
Determining the distance and direction of adjacent wellbore(s) is a critical task while drilling relief wells or preventing wellbore collisions. Because of the cumulative and systematic errors inherent in MWD or gyroscopic tools, the measured survey coordinates of both the target well and the relief well will have increasing uncertainty with depth. In most cases, the combined positional uncertainty is such that there is a very low probability of successfully intersecting the target well by relying on the survey data. Instead, homing in must be accomplished by a downhole ranging technique.

Downhole ranging techniques can be classified as either access-dependent or access-independent. Access-dependent ranging techniques rely on the ability to run tools such as a magnetic source or a detection tool inside the target well. Access-independent ranging is used when the target well cannot be entered, which will normally be the case when drilling a relief well. There are several access-independent ranging tools and techniques currently in commercial use and new concepts that are under development, which all have different limitations/advantages and applications.

Common considerations that will dictate the optimal ranging strategy include:

- presence of steel in the target well
  - Is steel continuous or are there breaks (parted casing, etc)?
  - location of casing shoes
- geologic formations (salt formations)
- relief well target location (shallow vs deep intersect)
- incident angle between target well and relief well
- positional uncertainty of target well
- the mud type in the relief well
- pressure and temperature limitations
- ranging tool specifications (detection distance, accuracy, reliability)
- deployment method and time to complete a ranging run

When planning a relief well, it is important to choose optimal tool(s) and tailor the ranging strategy for the job. This should include determining the depth where ranging will begin, which should be chosen to prevent an accidental, premature interception or collision with adjacent wells. Furthermore, it should be chosen such that the ranging tool will detect the target well location, which will depend on the combined positional uncertainty of the relief well and target well, and the effective distance that the ranging tool is capable of scanning for adjacent wellbores. In a worst-case scenario, both the relief well and target well will be located at the opposite sides of their error ellipsoids, which will give the maximum theoretical separation between the wells. The probability of both wells being at the worst-possible locations is low, but it should be considered for planning purposes to ensure that the relief well will not drill past the target well without detecting it. For most relief wells, the ranging service provider will be able to estimate the practical detection distance for the project and support the development of an optimal ranging plan.



Detection range covers the ellipse uncertainty of the target well and the relief well

Detection range partially covers the ellipse uncertainty of the target well

Figure 7 – Detection range geometry against the positional uncertainty of the target well and the relief well

The number of required ranging runs and the actual depths will be determined based on the survey and ranging data while the relief well is being drilled. Typically, as it approaches the target, the interval between each ranging run shortens. Historically, the total number of ranging runs has often been between 12 and 20, but it has been more or less in rare cases.

References include:

Number	Ranging operation
BSEE 761AA	Recommendations for improvement to wellbore surveying and ranging regulations
ISCWSA	Wellbore ranging technologies, intercept, applications and good practice
SPE 159404	Well Planning Based On Passive Magnetic Ranging And Magnetized Casing
SPE 167994	Relief Well Drilling Using Surface Seismic While Drilling (SSWD)

8. Relief well directional plan

To increase the likelihood of achieving the relief well objectives, the directional plan should be practical and simple. Considering the well design, steering tools, formations, and general drilling experience in the field, conservative drilling parameters should be used for DLS, inclinations (sail angle), and kick-off point (KOP).

The KOP selection depends on the vertical and horizontal distance from the relief well site to the intercept target or, more importantly, the depth which allows for precise directional control of the steering system. Other considerations include hole size, casing programme, formation competency, directional tool performance, and ensuring that the KOP allows the safe start of the build section while maintaining a low inclination and DLS. In cases of shallow interceptions, the relief well location is selected to be closer to the interception depth and/or the KOP is selected as shallow as practically possible.

A conventional relief well trajectory should be designed with the following basic phases:

1) Approach phase: The approach phase is the planned drilling section from the kick-off depth toward the target well. The end of the approach phase depends on the operator's interception policy, which could be a separation factor of between 1.0 and 1.5. The ISCWSA Committee recommends a separation factor of 1.2 for the approach phase.

2) Initial locating phase: This is where the target well is located. The number of required ranging runs depends on the detection distance of the magnetic ranging tool and the combined ellipse of uncertainty. If the location of the target well is not within the expected ellipse of uncertainty used for planning the relief well, side tracks may be required to determine the target well position with high confidence and avoid high DLSs, which could constrain drilling and magnetic ranging operations.

3) Pass-by phase: In this phase, the relief well traverses past the well and is triangulated to get an accurate fix on the target well position. It is recommended to perform a ranging run analysis to minimize the risk of colliding with the target well. The common planned distance between the wells is 3 metres to 10 metres, which provides high-quality ranging data.

4) Follow phase: where the relief well parallels the target well path near the planned kill point. The follow phase provides space to align the relief well with the target well and acts as a buffer for any required direction changes/corrections prior to intercepting the target well. Apart from vertical wells, the relief well is usually aligned on either the high-side or low-side of the target well, which minimizes directional work during the interception.

   The length of the follow phase should, at minimum, be sufficient to align the relief well with the target as it approaches the intended target. The length of the follow phase depends on the ellipse of uncertainty and the detection range of the magnetic ranging tool. That is, with higher positional uncertainty and shorter detection range, a longer follow phase is required.

The distance between the relief well and the target well during the follow phase is usually maintained between 3 metres ot 10 metres. This distance allows for drilling ahead without overlapping updated ellipses of uncertainty. It also provides a margin of error for directional control.

5) Interception phase: where the two wells will be aligned for the interception. An accurate survey of the relief well's bottomhole trajectory is critical in this phase. The interception phase is planned as a slant section with a length of 30 metres to 40 metres, which mitigates the risk of complicated directional correction in the interception phase. The interception phase requires accurate prediction of the distance and direction between relief and target wells Therefore, multiple ranging runs may be required during the interception phase.

There may be several indications that the relief well has contacted the target well, including increased drilling torque, metal on ditch magnet, and changes in weight on bit (WOB). However, the primary and most common confirmation that the relief well has gained hydraulic communication with the target well is a rapid loss of drilling fluid in the relief well. When this occurs, the bit will be pulled back into the deepest casing to safeguard it against openhole collapse.

When drilling a relief well that requires a shallow interception or high-inclination, a pass-by and/or low incident angle may not be feasible. Planning a relief well trajectory for these wells will in most cases be very challenging and likely require side tracks. One strategy is to drill directly to the planned intercept, attempting to get as near the target well as possible, but purposely miss. After drilling 30 metres to 40 metres past the target well, a ranging run can be done to triangulate the exact location of the target well. Subsequently, the bit is pulled back and a side-track is performed to attempt to hit the target well. Multiple side tracks may be required, which increases both risk and complexity of this strategy.

References include:

Number	Directional planning
APPEA	Australian Offshore Titleholders Source Control Guideline
HAVTIL	Shallow Reservoirs in the Barents Sea – Chapter 8
ISCWSA	Wellbore ranging technologies, intercept, applications and good practice
OEUK	Guidelines on relief well planning for offshore wells
SPE 168029	Relief Well Planning
SPE 173097	A Guide to Relief Well Trajectory Design using Multidisciplinary Collaborative Well Planning Technology
SPE 186901	Managing Risks in Relief Well Operations: From Planning to Execution

9. Relief well casing design

The relief well's casing design follows the industry standard and often utilizes a similar design to the target well's casing design. However, there are several differences that could affect the casing design for relief wells, which are as follows:

- additional contingency strings for encountering charged formations
- accommodating the kill operation
  - dynamic kill operation, which includes pumping kill fluid at the kill rate and maximum expected pump pressure at the surface (burst load)
  - maximum pump pressure at the surface with the kill fluid in the wellbore and collapsed openhole (burst load)
  - evacuated wellbore which could occur either as part of initial U-tubing from the relief well into the target well (collapse load)

Table 1 provides an example of expected maximum burst and collapse loads for a relief well kill string during a dynamic kill operation. The loads can be modified based on the operator's internal guidelines.

In the event of underground crossflow or flow behind the target well casing, there may be a risk of drilling into a zone that could be supercharged. Thus, a contingency string may be required to safely drill through the over-pressured formation. The casing seat depth and casing/liner selection should be able to safely shut in the well. This scenario would be an additional load that needs to be included in the analysis.

During dynamic kill operation, kill fluid is pumped at high rates, which causes significant frictional pressure loss in the relief well and consequently requires high pumping pressure. Pumping during dynamic kill is not a common load for casing design, which should be considered during the planning. Common methods for reducing the frictional pressure through the relief well are:

- Planning to set a larger casing string for the kill operation.
- Setting a liner as the last string.
- Combination of setting a liner and a tapered drill string for the interception.

Figure 8 illustrates different options for constructing a relief well and drillstring design. Using a larger casing for the final kill string may, in some cases, significantly reduce the required pump pressure. This, however, is often impractical as it will require the size of previous casing strings to also increase or use specialty strings with a long lead time. Furthermore, it may increase drag and bending forces when running the casing.

The commonly preferred option is to set a liner as the last string in the relief well, which reduces frictional pressure at the upper section of the relief well. However, both liner and the upper casing will be exposed to the pumping pressure during the dynamic kill operation and the burst loads and ratings should be considered in the design.

Table 1 – Example maximum casing/liner burst and collapse loads during the dynamic kill operation

Load Case	Loading Mode(s)	Description	Pressure and temperature profiles
Relief well screenout, burst	Burst and Tension	This is a burst load reflecting the dynamic kill operation from a relief well into a blowout well. It involves pumping down the drillstring or casing annulus of a relief well at high pressure with a kill fluid until the bottomhole pressure (BHP) exceeds the flowing well reservoir pressure. Internal pressures are highest in the event of a screenout. Axial tension loads are affected by temperature change (cooling and contraction) and ballooning (from internal differential pressure.	**Internal pressure:** The maximum pump pressure (at applicable height, usually rig floor) acting on a column of maximum density kill fluid. **External pressure:** The minimum foreseeable external pressure profile (usually pore pressure). **Temperature:** Thermal effects of the kill operation should be included. Relief well is typically cooled, contracts, and (together with ballooning), significantly increases tension loads.
Relief well screenout, collapse	Mud drop collapse	This is a collapse load reflecting the dynamic killing of a blowout well. The load considers the case of losses where kill weight (density) mud in the relief well evacuates to a level that balances the flowing pressure in the relief well at point of intersection (also known as "mud drop").	**Internal pressure:** A drop in mud level such that the resulting column of drilling mud (lowest density drilling mud) balances the flowing pressure in the blowout well. **External pressure:** The original hydrostatic column of mud used to land the casing, or any foreseeable external pressure profile caused by the blowout well or any other source, whichever produces the highest external pressure profile. **Temperature:** Thermal effects of the drilling/kill operation should be included.
Notes: 1. Commonly used industry-accepted software including at least differential pressure, temperature and well path should be used in the design work/design checks. 2. Casing/liner connections should be included in the analysis.			

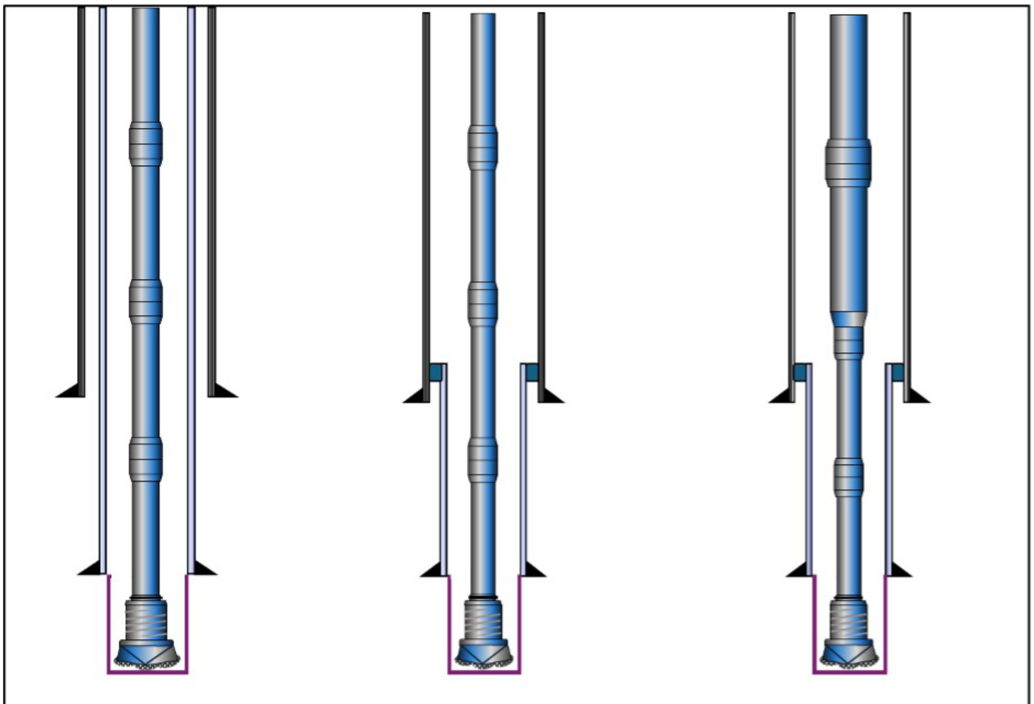


Figure 8 – Different casing design options for accommodating dynamic kill operation in the relief well casing design

Another way to reduce pumping pressure in the annulus may be to use a tapered drillstring during the interception phase and kill operation. However, the frictional pressure and pumping pressure through the drillstring may be increased by including a smaller diameter pipe size. In cases where the required kill rate requires pumping through both the annulus and the drillstring, hydraulic analysis is required to evaluate the overall pumping capability within operational limits. The tapered drillstring used for interception should be evaluated for expected loads, direction control, and expected torque loads during the milling operation. Other considerations may be to reduce the length and outer diameter (OD) of the bottomhole assembly (BHA) including removal of directional, survey, logging tools, etc., immediately before intercepting the target well.

The casing design for the relief well is an iterative process between the casing design requirement and the planned dynamic kill operation. As mentioned in Section 10.1, options may be available to reduce the frictional pressure and pumping requirement.

Another consideration for the relief well's casing design is casing wear. The relief well's complex trajectory and potential side tracks could result in excessive wear and affect the pressure rating of the casing.

References include:

Number	Casing Design
OEUK	Guidelines on relief well planning for offshore wells

10. Well kill operation

After the relief well gains hydraulic communication with the target well, a well kill is often necessary to regain control of a blowout.

10.1 Dynamic kill

The dynamic kill is one of the oldest well intervention methods and has successfully been used to bring many challenging blowouts under control. This technique uses frictional pressure in addition to the hydrostatic weight of the kill fluid to overcome the reservoir pressure and stop any formation fluids from entering the well.

A dynamic kill operation must be tailored for the blowout scenario, but may include the following phases:

1. **Ramp up:** Prior to intercepting the target well, the relief well should be filled with drilling fluid. After establishing hydraulic communication, the choke manifold should be arranged to pump kill fluid down the C&K line and/or annulus of the relief well, and subsequently the pumps should be ramped up to begin pumping kill fluid.
2. **Dynamic kill:** Once the required kill rate is achieved, the pumps should run at a constant rate while carefully monitoring/calculating the bottomhole flowing pressure (BHFP). This should continue until the BHFP exceeds the pore pressure and inflow from the exposed reservoir(s) is stopped without exceeding the fracture pressure of exposed formations.
3. **Ramp down:** Once all reservoir influx has ceased, the pump rate should be gradually reduced to stabilize the BHFP between the pore pressure and fracture pressure of any exposed weak zone.
4. **Slow circulation:** Pumping should continue at a relatively low rate until all hydrocarbons have been circulated out of the wellbore. It may take a long time for the hydrocarbons below the relief well intersect depth to swap with kill fluid. If circulation is stopped prematurely, a deep gas bubble could migrate, unload the wellbore, and restart the blowout.
5. **Static condition:** Pumping can stop when all the hydrocarbons have been displaced and a static condition has been achieved.

For deepwater relief-well pumping operations, the preferred flow path for the kill fluid is from the mud tanks and high-pressure pumps down the relief well C&K lines, and into the subsea BOP. The kill fluid then flows through the relief well annulus between the wellbore and drillpipe down to the interception point where it enters the target well. During the kill operation, it is preferred to slowly pump down the drillpipe to keep it full and keep the float open, while using the drillpipe gauge as an indicator of the BHFP. Pumping kill fluid at high rates through both drillpipe and annulus is generally not recommended, however, for high kill rates, it may be necessary. In this case, a downhole pressure-while-drilling (PWD) tool should be used, and care should be taken not to pump faster than the operational rating of this tool. Increasing hydraulic horsepower can be achieved either by using modular pumps on the relief well drilling rig or by hydraulically connecting a stimulation vessel.

10.2 Kill mud selection

The kill fluid should be formulated to have the lowest possible viscosity, to reduce friction in the relief well, while also high enough viscosity to prevent solids from settling in the mud tank. Ideally, the mud weight should be greater than the pore pressure but less than the fracture gradient of the exposed formation below the last casing shoe. To successfully bring a subsea blowout to static condition, the final pressure gradient, after the pumps stop, should consist of seawater hydrostatic to the mudline and kill mud from mudline to TD. The kill mud should be sufficient to prevent any further reservoir influx. When the pumps stop, the fluid in the relief well will U-tube until an equilibrium is reached between the air and kill mud in the relief well, and the kill mud and seawater on the target well side.

Using a mud weight that exceeds the fracture gradient is generally discouraged, as it can complicate the kill procedure. Rapid increases in flowing bottomhole pressure might cause formation fracturing, leading to losses and crossflow that could jeopardize the operation's success. However, there are situations where a density exceeding the equivalent fracture gradient might be considered to reduce pump requirements. This approach, referred to as a staged kill operation, involves pumping a heavy fluid ahead of a lighter one that will not fracture the shoe. However, results from blowout and staged kill simulations may indicate that fracture and losses to weak zones may occur after the dynamic kill sequence.

Accurate planning, diligent downhole monitoring, and careful execution will be key to switching the fluids before the formation is fractured while successfully stopping reservoir influx. For a relief well feasibility study, it is generally recommended against using kill mud weights above the estimated fracture gradient due to increased complexity and risk, although it may be necessary in some situations. Note that a heavy kill mud must be practical for mixing and storage for extended periods offshore. Additionally, heavy and ultra-heavy muds can push pump pressures and casing burst pressures to their limits.

10.3 Kill simulations

A transient multiphase flow simulator will be a critical tool to plan the dynamic kill and ensure that the operation is successful on the first attempt. Every blowout is different, and it is therefore important to use a simulator that has both proven accuracy and the necessary flexibility to be able to assess complex blowout scenarios and kill operations. As part of the well planning process, a blowout and kill study should be performed to address a worst-case blowout scenario and demonstrate that a dynamic kill from a relief well will be able to regain control of the well. The study should determine:

- the required kill fluid density
- the kill rate
- pumping pressure and hydraulic horsepower
- minimum required volume of kill fluid

- With some margin for contingency, the above results should be compared with the pumping capacity of the rig and support equipment to conclude on the potential number of relief wells that may be required.

Critical inputs for the dynamic kill analysis are the flow path, reservoir fluid properties, and reservoir pressure. In most cases, the flow path is known based on well structure and fluid exit condition. However, these observations do not provide any insight to potential restrictions inside the well. As a general recommendation, restrictions to the flow are not considered in the dynamic kill analysis. Reservoir fluid and pressure affect the flow rate, which could change during the relief well effort. As the flow from the well continues, the near wellbore reservoir pressure decreases, as illustrated in Figure 9, and consequently reduces the flow rate. The magnitude of reservoir pressure depletion and reduction of the flow rate depends on the reservoir size and pressure drive mechanism. If reliable data on reservoir depletion is available, the dynamic kill analysis should be updated to optimize the kill operation. In general, as the reservoir depletes, the likelihood of a successful kill increases. However, when severe reservoir depletion is expected, the risk of fracturing the reservoir, and sustaining losses, increases.

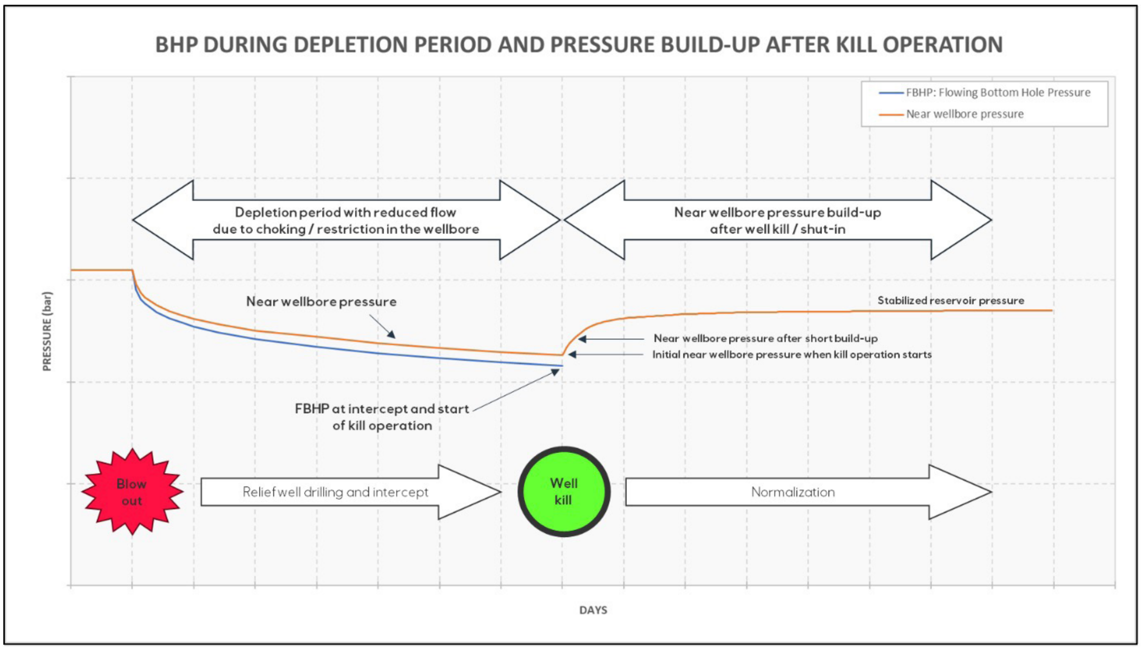


Figure 9 – Near wellbore reservoir pressure with time after a blowout and well kill operation

10.4 Challenging kill operations

Although the combination of a relief well and a dynamic kill technique has successfully been used to stop numerous challenging blowouts, there are limitations on pumping capacity, maximum kill mud density, deepest intersect depth, and so on. Challenges that appear to become more common, such as high gas/oil rates, high-pressure reservoirs, narrow pore and fracture pressure margin, ultra deep water, and shallow reservoirs, could make a standard dynamic kill challenging or unfeasible. If a standard dynamic kill is determined to be unable to kill a given blowout scenario, alternatives, like staged kill, specialty kill fluids, multiple relief wells, rig upgrade with additional pumps, or a relief well subsea pumping manifold may be considered. For contingency planning of an upcoming well, it may also be possible to modify the well and casing design to alter the kill point, enhance the target well's integrity, and/or reduce blowout rate to facilitate a dynamic kill in the unlikely event that a worst-case blowout scenario should occur.

If a capping stack has successfully been installed on the target well and well integrity is maintained, then there may be additional options to kill the well. An example involves slowly circulating kill fluid down the relief well and into the target well, while using the capping stack choke to keep a constant bottomhole pressure, as illustrated in Figure 10. Compared to conventional well control methods, this could be referred to as a "Modified Driller's Method" where the relief well is used instead of the drillstring to convey kill fluid. This method offers advantages such as enhanced downhole pressure control and reduced pumping requirements compared to a dynamic kill. However, in most scenarios, there will be many challenges that would need to be addressed, such as:

- choke erosion and washout, especially in scenarios involving combinations of a gas blowout and sand production
- coordinating SIMOPS for all the necessary rigs and vessels
- effective communication between pump controller and choke operator, who will be on separate vessels
- adequate capacity for capture and storage vessels
- optimization for riser design
- ensuring that flowback equipment can manage both hydrocarbons and kill fluid returns

References include:

Number	Kill Operations
APPEA	Australian Offshore Titleholders Source Control Guideline
Drilling Contractor July/ August 2009	Relief Well Case Study: Modified Drillers Method Used as an Intervention Alternative to Bullheading
OEUK	Guidelines on relief well planning for offshore wells
SPE 180279	Challenging Offshore Dynamic Kill Operations Made Possible With the Relief Well Injection Spool
SPE-189655 MS	Dynamic Kill Method Using Staged Fluid Densities can Improve the Killability of Relief Wells for Challenging Blowouts
SPE 195961	A Case Study Demonstrating Single Relief Well Contingency for a Prolific Gas Well in Ultra-Deepwater
SPE-199550	Relief Well Challenges and Solutions for Subsea Big-Bore Field Developments

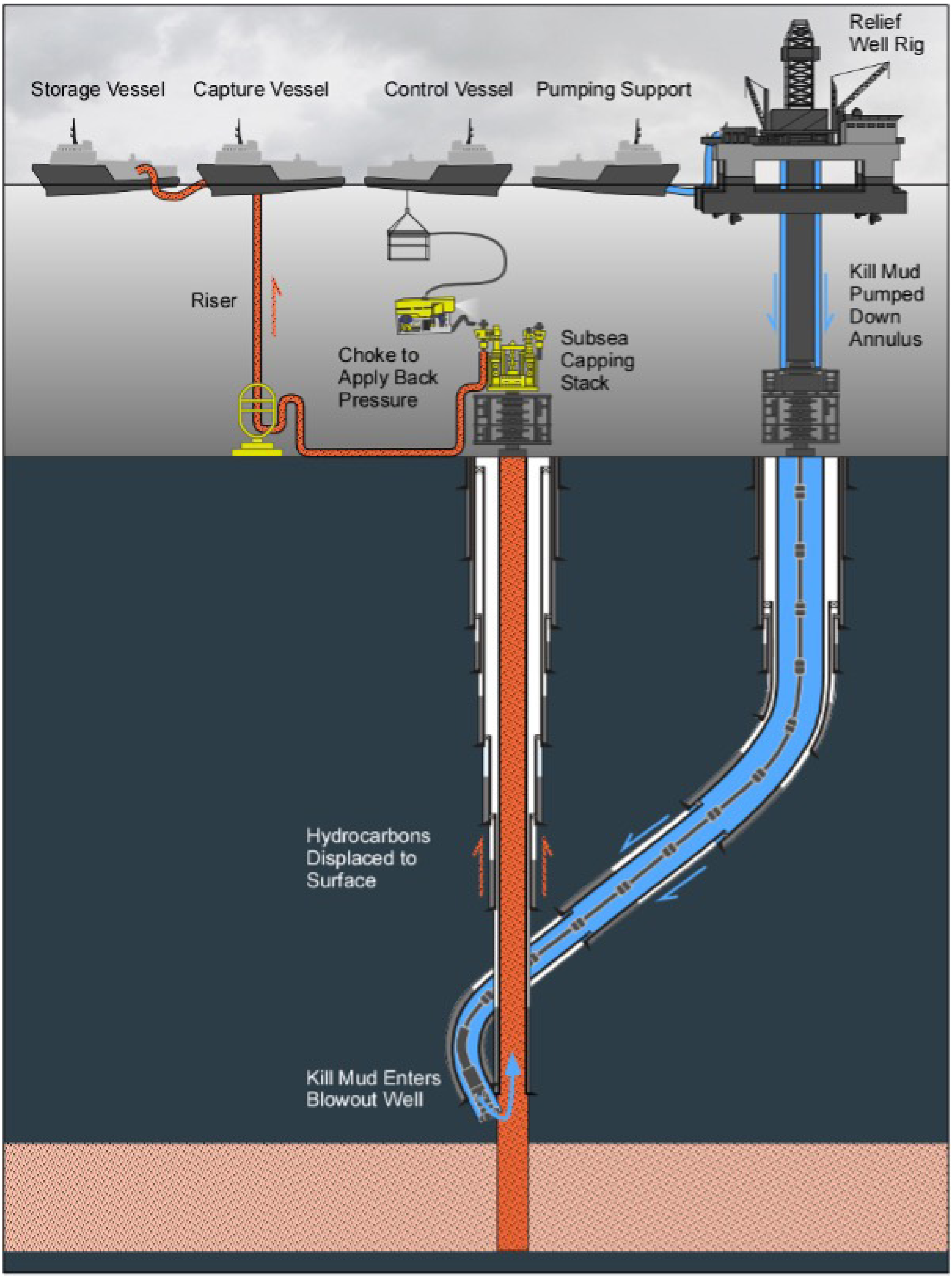


Figure 10 – Example of kill operation using a relief well in combination with a subsea capping stack

11. Plug and abandonment

Following a blowout and subsequent successful well kill operation, a decision should be made regarding what to do with the target well and relief well. In some cases, it may be possible to clean out the target well and continue pursuing its objectives. Some relief wells have also been converted to production wells. However, in most cases, both the relief well and target well will be plugged and abandoned (P&A) following industry recommended practices. This will often involve considerations for establishing a full lateral (rock to rock) barrier across a sealing formation to minimize the risk of future leakage. Companies have internal guidelines for placement of barriers that consider where the minimum safe abandonment depths are, depending on fluid contents of the permeable zones.

Most relief wells in recent years are not drilled with the objective of regaining control of blowouts. Instead, they are more commonly drilled with the intent of placing appropriate barriers to restore integrity in wells where surface access is compromised.

These types of relief wells, often also referred to as intervention wells or P&A wells, have similarities to traditional relief wells, but also many unique challenges. A common example is ensuring that the plug(s) are set according to plan and that the permanent barrier(s) can be tested and verified. Often, the intersect will occur in wells that are fully cased off. Thus, when selecting the point of intersect, consideration should be given to where the main source of integrity is, and where and how the barriers will be placed. Equally important is how the relief well/intervention well will be abandoned considering the proximity to the target well and ensuring that there will be no crossflow occurring between the wells.

For some projects, it may be possible to use a stinger to attempt re-entry into the problem well with slim or coiled tubing. This will often require milling a relatively large window in the target well casing. Another option may be a dual intersect technique, as illustrated in Figure 11. The objective in this case is to establish a circulation path from the relief well into the target well and back into the relief well, using two sets of perforations. This will allow cement, or other plugging material, to be carefully placed at a desired interval in the target well, and, subsequently, pressure testing can be done above and below the plug.

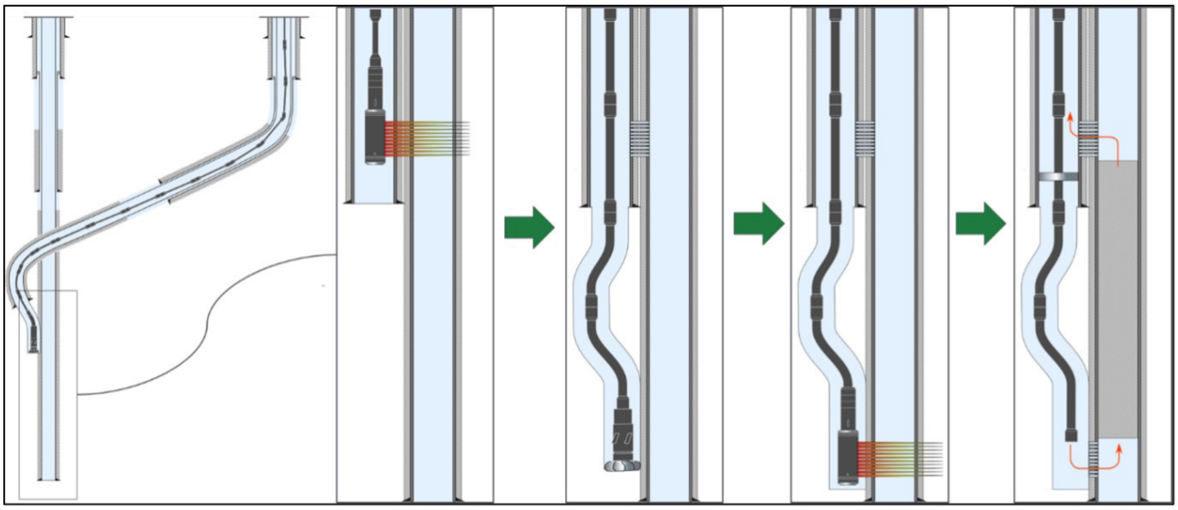


Figure 11 – Dual intersect P&A operation using a relief well

References include:

Number	Plugging and abandonment
API RP 65-3	Wellbore plugging and abandonment
IOGP 585	Overview of international offshore decommissioning regulations, Volume 2 - Well plugging and abandonment
NORSOK D-010	Well integrity in drilling and well operations
OEUK	Guidelines for abandonment
OEUK	Use of barrier materials in well decommissioning guidelines
OEUK	Well decommissioning guidelines
SPE 206311	Complex Subsurface Well Abandonments Using Relief Well Methodologies
World Oil Jan 2002	Relief well drilling operations allow re-entry, control of a blowout well
World Oil Jan 2006	Unique intervention safeguards platform after kick-induced gas broach

12. Time for drilling a relief well

Estimating the required time to drill a relief well is an important task for both source control and oil spill response planning. In some cases, significant reservoir depletion will occur by the time of interception, which should be considered for updating the pore and fracture pressure in the dynamic kill analysis. At a minimum, the relief well project schedule and timing should include the estimated time to:

- mobilize drilling rigs and crew to the relief well spud location
- drill the relief well based on the target well and offset well data
- performing ranging operations
- milling, dynamic kill, and monitoring
- plugging and testing both the target well and the relief well(s)

The time needed to mobilize rigs and crews to drill a relief well will depend on the location and available contracts. Specifically, in remote regions with low drilling activity, and where sufficient resources are not readily available, the required time for mobilizing resources could be long. Hence, it may be preferred to early start RW operations with the first available rig and later switch to a kill rig with required specifications and tools for the ranging, final intercept, and kill operation. Regardless of the availability of resources, proper contracts and agreements should be in place for drilling relief wells to expedite mobilization.

The trajectory of the relief well is generally more complex than the target well. However, offset data can be applied to determine the required time for drilling the relief well. Depending on the risk assessment performed for the relief well, additional time for setting a contingency casing/liner or drilling a side track may be included in the drilling time.

The required time for performing ranging operations depends on the number of runs and type of ranging. When ranging in an openhole, the drillstring is tripped out of the hole, whereas tripping is not needed for ranging in a drillstring or passive ranging using MWD. The required time for ranging operations can be estimated by the ranging tool supplier or a relief well specialist. General guidelines for ranging time can also be found in the ISCWSA: Well Intercept Sub-Committee eBook.

Milling and dynamic kill operations are performed consecutively. Milling requires tripping the drillstring out of the well to change the drill bit to a concave mill. When the bit is out of the well, a ranging run is performed to determine the exact direction of the target well with respect to the relief well at the intercept point. Following a successful dynamic kill operation, the target well is monitored for an extended period to ensure the target well is static. An estimate for milling operation, dynamic kill, and monitoring is between two and three days. If losses are encountered, loss management is performed, which could extend the kill and monitoring period.

At the end of the operation, the target well and relief well will usually be plugged and abandoned. As mentioned in Section 11, it might be possible to mill a sufficiently large window to access the target well below the interception depth to place a packer, a cement retainer, or a cement plug inside the target well.

References include:

Number	Time estimates
ISCWSA	Wellbore ranging technologies, intercept, applications and good practice
OEUK	Guidelines on relief well planning for offshore wells

Appendix A – Required data for relief well planning

The data that are used to plan a relief well will vary depending on several factors, such as objectives, greenfield vs brownfield, available data, blowout scenario and flow path, and compliance considerations. Often the target well data drilling information and wellbore geometry will be obtained from the Well Engineering Manager and/or Rig Superintendent, while information on the source reservoir will come from the Reservoir Engineer.

Before designing a relief well, the following information is typically requested:

- prospect evaluation and well objectives (Basis of Design report)
- drilling programme (wellbore schematic and data diagram)
- site survey and bathymetry maps (seabed obstructions)
- shallow gas hazard survey, shallow seismic study, tophole risk analysis
- metocean, wind, wave, current, tide information (wind, wave, current rose plot)
- directional programme, plans and surveys, geodetic datum
- offset well data (if any), surface coordinates and surveys
- completion schematics for production wells

Furthermore, for blowout and kill simulations, the following data will be necessary or useful:

- if available: worst-case discharge report
- well geometry:
    - casing programme (Internal Diameter (ID), Measured Depth (MD), True Vertical Depth (TVD),
    - BHA configuration
    - roughness factors
    - hole size(s)
- relief well rig specifications:
    - number of pumps and type (liner size, pump performance curve, etc.)
    - mud storage capacity
    - C&K line sizes
    - RW vs Target Well (TW) depth reference point (Mean Sea Level (MSL) or rig floor elevation)
- formation data:
    - reservoir tops
    - gross and net sand thickness
    - rock parameters (horizontal and vertical permeability, porosity)
    - formation pressure (pore/frac) and temperature with depth
    - drainage area and drive mechanism
    - skin factor (damage, deviation, partial penetration, completion, anisotropy, mechanical, Forchheimer gas turbulence)
    - analog well data (production logs, depletion data, etc.)

- reservoir fluid data:
    - primary content (oil or gas), oil/gas ratio, water cut
    - hydrocarbon composition (mole weight and liquid density of plus fraction)
    - American Petroleum Institute (API)/specific gravity
    - bubble/dewpoint pressure
    - formation volume factor
    - gas Z factor
    - viscosity data
- options for flow rate simulation (in recommended order of preference):
    - client specified pre-determined blowout rate (barrels of oil per day (BOPD) and/or million standard cubic feet per day (mmscfd))
    - client specified Production Index (PI) and Gas Oil Ration (GOR), the PI needs to be at the sand face
    - Absolute open flow (AOF) at the sand face and GOR, where AOF is defined as flow rate from the net interval at the sand face with reservoir pressure on one side and atmospheric on the other side
    - client specified inflow performance plot and GOR
    - client specified permeability, porosity, net sand thickness, and GOR to construct inflow performance curve, and use this as drive mechanism in the model
    - client specified flow path (flow in openhole, in wellbore/drillstring annulus, or inside drillpipe)

Glossary

C&K	Choke and kill
BHFP	Bottomhole Flowing Pressure
BOP	Blowout Preventer
DLS	Dogleg Severity
GWD	Gyro While Drilling
H_2S	Hydrogen Sulphide
KOP	Kick-off point
MPD	Managed Pressure Drilling
MWD	Measurement While Drilling
P&A	Plug and Abandonment
PMCD	Pressurized Mud Cap Drilling
ROV	Remotely Operated Vehicles
SIMOPS	Simultaneous Operation
TD	Total Depth
T&D	Torque and Drag

Relief well requirements can vary from country to country based on local regulations, environmental conditions, and specific characteristics of oil and gas operations in that region.

Various industry organizations and regulatory bodies provide standards and recommended practices for relief well planning and execution. This Report recommends considerations for relief well planning and available resources specifically for subsea application. The Report is intended to be used by operators and service companies.

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