HALLIBURTON | Sperry Drilling

Relief Well Planning
&
Magnetic Ranging

October 2020

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1. Introduction

The continued success of the WellSpot active magnetic ranging service is a combination of technology, process and experience gained from over 30 years and 300+ intercept wells. Drilling a relief well (RW) for blowout control is an exceedingly rare event; from 2012-2019 there has been on average 1.5 blowouts per year that have required a RW. While initially invented as a tool for blowout (BO) relief wells, the WellSpot ranging service has been used extensively on other projects that require a well interception and/or re-entry. Over the same 2012-2019 period the WellSpot ranging service has completed an additional 84 well intercept projects that require the same processes and precision as a blowout RW.

2. Overview

To be successful, a well interception must be completed at the correct depth, orientation and incidence angle. This document is a guide for using the WellSpot magnetic ranging services to drill a P&A intervention well (IW) or a RW for blowout control. It contains the theory of operation, the characteristics of the ranging tools, and the processes used to complete a well interception. The WellSpot ranging service remains the only active ranging service to complete a blowout RW, and the only ranging service in the market today that can still claim a 100% success rate for all well intercept projects.

While written from the Interception and ranging stakeholder perspectives, this document does discuss RW objectives managed by the other participants of the RW planning team: well control, directional, survey management & wireline. To ensure we are well prepared to work with these other stakeholders we have integrated into our WellSpot team a diverse background of personnel who were trained in or held SME status in MWD, DD, SM, Bits, WC or WL services.

To avoid unnecessary repetition the term RW is used through this document in place of IW, as most aspects of a well drilled to manage a BO or P&A are operationally the same. Where there are differences they have been detailed individually in the relevant sections.

3. Relief Well Planning

3.1 Relief well design

The design of a RW must provide a flexible well plan that is able to react in real time to both drilling performance and ranging results. Unlike a traditional directional well, a RW well plan must be continually updated to account for both the drilling performance of the RW and the proximity data (acquired by ranging) of the TW.

An effective RW plan accounts for all the requirements and restrictions from each stakeholder. The goal is to create a balance of ranging detection, drilling performance and the ultimate goal of intersecting the target wellbore at the desired depth.

3.2 Relief Well Planning Personnel

While it is possible for this planning to be completed remotely, the recommended method is to have all the stakeholders meet at one location to collaboratively plan the relief well, taking into account each stakeholders requirements and limitations. *It should be noted that the relief well planning/ operations is composed of two teams: Well Intersection and Well Control; this section is focused solely on the Intersection.* The following is a list of the personnel required and the key responsibilities of each:

- Drilling Engineer
    - Preferred and alternate interception methods
    - What is required as proof of interception for regulatory board
    - Surface location options and limitations
    - Geology and casing depths
    - Contingency casing options
- Interception Specialist
    - Assist drilling engineer with surface location selection
    - Designing approach and intersection phases of the well plan
    - Coordinate hydraulic communication with well control engineer
    - Estimate drilling intervals / ranging runs required
    - Recommend primary and alternate interception methods

- Ranging Specialist
    - Model the depth of investigation
    - Using the ellipse of uncertainty of both the target well and relief well, develop the anti-collision (accidental interception) plan
    - Recommend changes to the well plan to improve the ranging
    - Provide recommendations on the type of ranging tools required
    - Assist the Interception Specialist with planning the drilling intervals / ranging runs required
- Well Control Engineer
    - Assist Interception Specialist with the interception depth selection
    - Create contingency plans in case of premature hydraulic communication
    - Provide the kill plan for when a BO well is intercepted
- Directional Provider
    - Provide knowledge of the local drilling environment which is key to developing a workable plan
    - Recommend changes to the well plan to meet local drilling environment
    - Recommend BHA to accomplish relief well planned trajectory
- Well Planner
    - Build the requirements from all the stakeholders into a workable relief well plan
    - Provide alternate well plan options if drilling/ranging milestones are not met

3.3 RW Ranging Plans SOW

Relief well ranging plans are a component of the overall RW plan and are used as either an operational outline or as part of an overall contingency planning strategy. Irrespective of the intended use, the ranging plan provided by Sperry is engineered to be implemented as written.

The final work product for both contingency planning or relief well operations is the 'Ranging Plan'. This document is derived using our 30+ years of relief well ranging experience and our proven WellSpot™ modeling software. This document will include:

- Relief Well Summary - An overall understanding of the relief well requirements
- Data collection summary - Table of data collected to complete the relief well ranging plan
- Relief Well Summary by Phase - Ranging requirements for each phase including the key depths
- Equipment and Services - Required from Sperry or 3rd party
- Analysis of any pre-existing RW trajectories and recommendations to optimize the well path for ranging and interception
- Recommended well path that is optimized for ranging and intercept operations
- Uncertainty Analysis - Determination of the depth that ranging must be used to maintain anti-collision
- Relief well path considerations - Design considerations that incorporate the drilling restrictions and the requirements for ranging
- Detection range – Modeled detection range based on the well geometry, resistivity, ranging assembly, and Target well casing. Used primarily to determine the depth that first detection is possible.
- Summary of ranging phases - A predicative overview of each RW milestone, including the ranging strategy, operational goals, and depth targets for each phase
- Tool specifications - Summary of the ranging tool specifications (range, temperature, pressure, and assembly configuration)
- Ranging operations requirements - A concise overview on how a ranging run takes place including details such as necessary equipment and recommended third party services and methods of deployment

3.4 RW Planning Key Decisions

A successful RW plan is not designed to meet the exact requirements for any individual stakeholder. To optimize a RW plan the first step is to establish what is possible from each stakeholder and then, by making adjustments, create a balanced plan that will achieve the objective. The key decisions for a RW plan are represented in the following RACI chart:

Key Decision	Drilling Engineer	Well Control	Interception Spec	Ranging Spec	Directional
Intercept depth	A	R	C	I	I
Surface location	A	C	R	I	I
Well Path	A	C	R	C	C
Ranging Plan	A	I	C	R	I
Casing plan	A	R	I	C	C
Kill Plan	A	R	I	I	I

Note: for a P&A the responsibilities of well control are typically assumed by the Drilling Engineer

3.4.1 Intercept Depth

The decision on where to intercept the TW will generally be given as a target depth with an acceptable window. The larger the window the less precise the drilling performance has to be in the approach and this will reduce the number of ranging runs required for the interception. Before assigning an intercept window, the stakeholder (WC for a BO or DE for a P&A) must consider the following:

- What is the minimum TVD depth required for the kill plan
- Are there any obstructions (tubing, packers, existing plugs, or known damaged sections) that must be avoided
- Are there formation restrictions that require the intercept to be completed before/after
- What are the KOP and DLS restrictions
- The primary method of establishing hydraulic communication
- For a milled re-entry is the casing cemented at the intercept depth

3.4.2 Surface Hole Location

The selection of a surface hole location (SHL) is a critical component of the RW design process. While the operator is ultimately responsible for the final selection of the SHL, there are requirements from the other stakeholders to consider. Before the final SHL is determined, it is critical that rest of the RW team confirms the desired location will meet their operational requirements.

The following are general guidelines for selecting a potential SHL:

- For nominally vertical wells the orientation of the SHL to the TW will have no impact on the intercept plan.
- For directionally drilled TWs, the orientation of the SHL and TW must be carefully considered. Whenever possible the RW should be spudded in the TW VSD; this will eliminate the high DLS required to converge on the deviated TW.
- A high ratio of SHL separation to steerable TVD (KOP to intercept) will:
  - Increase the DLS required
  - Increase the EOU
  - Require a shallower locate phase (more ranging runs)
  - Increase the risk of a sidetrack
- A BO RW, in almost all cases, will require a new SHL. The significant differences in the SHL selection for a BO are:
  - The inclusion of regulatory/insurance minimum separation restrictions
  - Considerations for the uncontrolled release of hydrocarbons:
    - Prevailing winds
    - Ocean Current
- For a P&A well the selection of a starting point to complete an intercept well will generally depend on: the TW geometry, TW survey quality, intercept depth, hole size restrictions and available surface hole locations. There are 3 SHL categories of P&A intercept wells:

  - **Sidetrack from the existing well** - For many P&A wells with surface casing integrity, it is possible to use the existing surface hole, sidetracking above the obstruction and drilling around and re-entering the well to set the P&A plug(s). Generally, this is the most cost effective as it reduces lease preparation costs and will reduce the number of ranging runs.
  - **Spudding a new well** – For a P&A well there are generally few regulatory restrictions on the placement the SHL. For most P&A intercept wells the primary considerations for the SHL are availability and practicality.
  - **Sidetracking from an existing offset well** - It may also be possible to use an existing offset well to sidetrack from and intercept the TW but this should only be considered if the offset well is close enough and the intercept is deep enough to make the drilling\ranging practical.

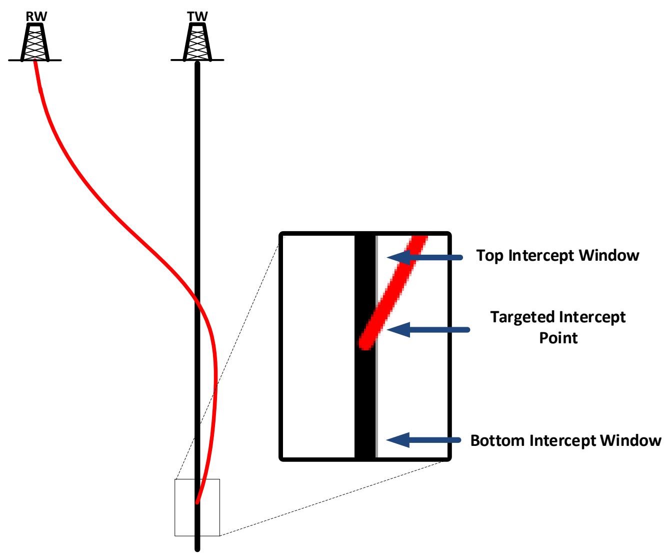
3.4.3 Well Path

Once the intercept window and potential SHL(s) are established, the next step in the RW design is to determine the well path. The Interception Specialist works with the other stakeholders and collates their requirements and restrictions; these include:

- **Directional:**
  - KOP
  - The DLS restrictions
  - Expected drilling performance
  - What tools are required for each hole section
  - What MWD services are required for each hole section
- **Well Control:**
  - Is there a risk of hydraulic communication through the formation
  - Will the well path impact the casing or kill plan
- **Ranging:**
  - How will the well path (trajectory) effect the detection range
  - Will the well path allow for OH WL logging or will TPL (Tool Pushed Logging) be required
  - Are there formation changes that will impact the WellSpot signal
  - Are there offset wells that will influence the WellSpot signal
  - Are there any possible electrical discontinuities (casing damage) that will impact the ranging plan

Once these points are considered, the Interception Specialist will draft the initial well path. This well path is designed using the following points:

- **Intercept Phase**
  - Intercept point – The interception point should be selected in the upper section of the acceptable range (window) designated by the Kill Plan. As the relief well approaches the Interception Phase, the interception point can be adjusted for optimal alignment.



- Incidence angle – The required incidence angle will depend on the end goal of the interception:
    - Re-entry – To effectively mill into a well for re-entry, the incidence angle should be kept between 3° and 5°. This angle will allow a window to be milled while leaving the back side of the casing intact and used for a re-entry guide.
    - Hydraulic communication – Incident angles below 3° will risk a low lateral force on the casing and could result in the mill following along the casing OD without entry. While angles between 4-8° are recommended, any angle up to 90° may be used if necessary.
- Approach Angle-The final approach to the intersection point should be planned:
    - In a section of the target well that has minimal inclination/azimuth changes, when possible, the final 50m of relief well will be planned with minimal or no directional changes. This will allow the Interception Specialist to make slight changes in the relief well trajectory to optimize both the incident angle and orientation.
    - To approach the target well from the low side of the hole. While counter intuitive, approaching from the low side will allow the interception point to be delayed to a deeper depth if alignment is not optimal. If approached from the high side, any unexpected changes in target or relief well alignment may force a decision between milling at a less than optimal alignment and a second alignment attempt (deeper or plug back).
    - To be inside the modeled gradient detection range. This depends on both the proximity and signal strength and will vary with the well parameters.

- **Locate Phase**
    - Kick off point – Selected at the depth required to reach the first detection point before the SF=1 (separation factor where the ellipse of uncertainties overlap) and at an orientation to pass-by the target keeping it inside detection range. If this is not possible, the first detection point must be before the pass-by.
    - First detection depth - Depth and orientation limitations may prevent the target well to be inside detection range before the SF=1.
    - Close Pass-by – Designed to be completed after detection is established; it is used to reduce the uncertainty between the two wells. The WellSpot model uses the signal intensity and rapid changes in the high side to target to reduce positional uncertainty prior to the start of the Follow Phase. *Note: This may not be possible if there is insufficient TVD between the locate and intercept phases*
- **Follow Phase** – The follow phase is intended to bridge the gap between the Locate and Interception Phases. Design of this phase is based on:
    - Keeping the target well inside of the modeled detection range while keeping the drilling intervals as long as possible.
    - Following the target well in the center of the modeled detection range provides the best option for long drilling intervals while avoiding an early interception or leaving the detection range.
    - Design of the follow phase should also include the option to extend the distance between WellSpot runs by attempting ranging with the MWD sensors (PMR).

With an initial well plan in place the RW team will analyze it for their own requirements and will make any recommendations to the Interception Specialist who, based on feedback from the entire team, will reissue another draft proposal. This process is repeated until all requirements are met and a balanced (optimized) plan is presented to the customer.

3.4.4 Casing Plan

With the well path established the WC engineer (or Drilling Engineer for a P&A) will determine the casing depth for each hole section; and for the vast majority of RW plans the casing depths will have little to no impact on the ranging performance. Before a casing plan is finalized, the Ranging Specialist must confirm that the casing depths will not affect the ranging signal during any critical sections of the well. There are two areas of concern:

- If the casing is to be set before the locate phase (WellSpot detection is established) will there be enough MD for the WellSpot assembly to clear the casing shoe before the SF=1 depth
- Will the final casing depth impact the ranging in the intercept phase

If either of these ranging requirements are not achieved in the existing plan, the Interception Specialist and the WC Engineer will modify the casing depths and/or the well path to meet the objective.

3.4.5 Ranging Plan

Once the well path has been finalized, the ranging plan is developed to optimize the services that will be used for each RW phase. The primary purpose of this plan is to present to the RW team the ranging strategy used to establish and maintain ranging detection while minimizing the impact on the drilling operation. Details will include:

- Summary - An overall understanding of the customers challenge and the solution to be provided
- Operations overview - A discussion of well plans, formations, casing, and resistivity
- Modelled Results – a presentation of the signal modeling and discussion of how the detection range and 1st ranging depth are determined
- Phases of Ranging - Provides a predicative overview of each ranging run interval throughout the course of the project
- Ranging Runs Operational Outline - A concise overview on how a ranging run takes place includes details such as necessary equipment and recommended third party services

3.4.6 Kill Plan

The kill plan is a process designed to kill a blowout by pumping heavy mud into the wellbore at high rates to suppress the flow. The kill plan design and its execution are the sole responsibility of the well control provider and are not discussed in detail in this document.

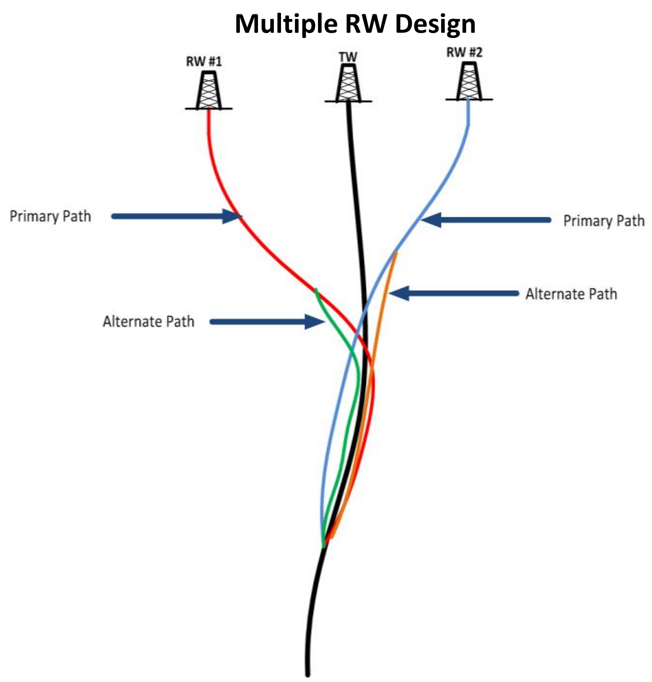
3.5 Multiple Relief Wells

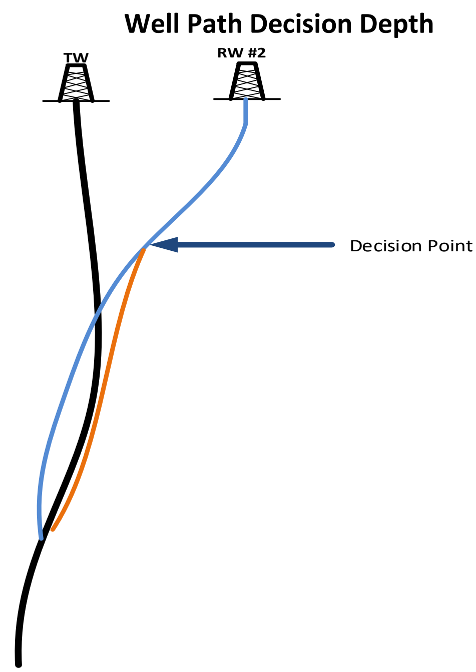
The vast majority of RW projects are completed using a single RW; the use of a main and backup RW has been limited to high profile RWs where the environmental, financial or social impact would justify the additional costs. Planning for multiple RWs will require an advanced design and coordinated execution plan.

3.5.1 Multiple RW Design

The objective of drilling multiple relief wells is to reduce the impact of nonproductive time on the overall objective. In the design of the RWs, the planning team will:

- Select a primary and alternate intercept point of the TW. These should be made at opposite ends of the intercept window and opposite orientations (highside and lowside)
- Each well will be designed to intercept either the primary or alternate intercept point
- At a designated depth the decision must be made which intercept point will be targeted
- The first well to reach this decision point will continue onto the primary intercept point and the other RW will be directed to the alternate





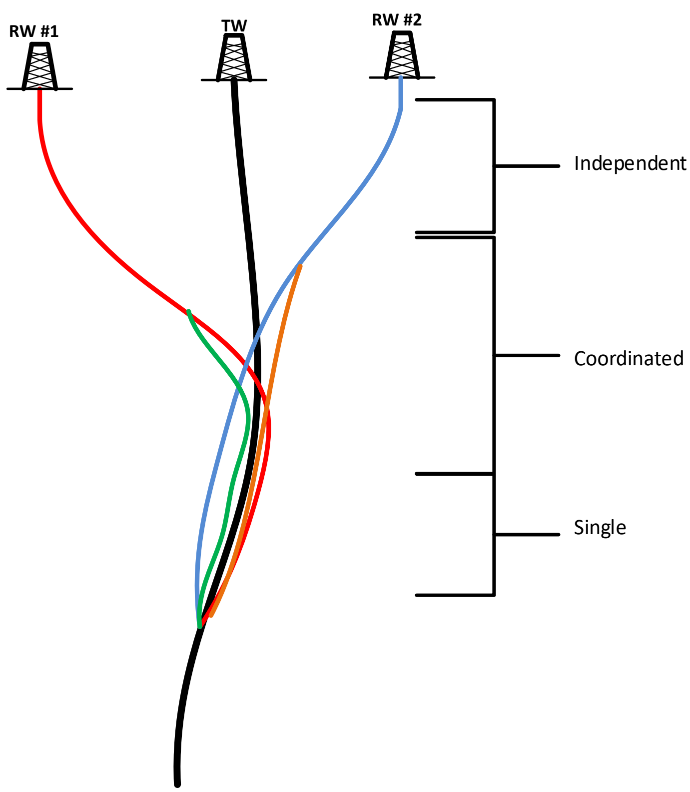
3.5.2 Multiple RW Coordination

The coordination of multiple RW is required to ensure the well closest to completing the objective is not restricted by the operations on the other. As part of the RW design, there are target depths that will determine how drilling and ranging operations can proceed.

For the following example: RW #1 is the closest to completion and is now considered the primary RW. Coordination for these well will be as follows:

- **Independent Operations** – Up to the end of the independent operations depth both RW # 1&2 can be drilled without any concern of impacting the other RW progress
- **Coordinated Operations**:
  - RW #1 (Primary) – As the closest well to completing the objective the operations for this will not be limited.
  - RW#2 (Alternate) – Progress of this well must be planned around the operations or RW#1 and will be restricted as follows:
    - While RW#1 is drilling RW #2 can continue drilling
    - When RW#1 is ranging RW#2 must halt drilling and pull back to the shoe
    - Ranging on RW #2 can only be completed when RW #1 is on a bit trip.
- **Single Well** – Once the single well depth threshold is reached by RW#1 all operations on RW#2 must be halted.

Note: At any point in the progress of RW# 1 or 2 a decision can be made to designate either as the primary RW.



3.6 Survey Management

Wellbore position uncertainty for both the RW and TW increase until the ranging detection is established. For most shallow RW operations (< 5000'), the relative positional uncertainty of the TW does not require any additional analysis. For these wells the WellSpot detection threshold will be established before the SF=1 depth. For deeper wells with the associated larger ellipses of uncertainty, survey management can be an effective tool to optimize the RW progress.

Survey management (SM) is a technique used to reduce the uncertainty for both the TW and RW prior to ranging. SM is an advanced analysis of the surveys and the application of corrections such as Multi Stage Analysis, Sag correction and IFR will reduce the uncertainty and extend the progress of the RW before ranging is required. These corrections are applied to the historical data of the TW and in real time as the RW is drilled. Once ranging detection has been established the interception specialist will use Gyro While Drilling and WL Gyro to confirm, or in place of, magnetic MWD surveys; therefore survey **management** is no longer required**.** For the remainder of the RW all relevant uncertainty is now represented in the ranging call box.

3.7 Gyro Requirements for a relief well

The use of magnetic surveying tools on a RW will work for the majority of the drilling program but will encounter cross axial interference as the RW approaches the TW; the solution is to use a gyro to eliminate the impact of magnetic interference.

Gyro services comes in two configurations: WL gyro and Gyro While Drilling (GWD). While either one by themselves can be employed to reduce the time (days) it takes to drill a RW the most efficient employment of gyro services is to have both available.

Gyro While Drilling – is used to steer the RW and will:

- Provide the accurate azimuth that is required for the intercept phase
- Reduce the number of ranging runs by allowing for longer drilling intervals.
- Accurate azimuth will reduce the risk of a sidetrack by allowing the directional team to stay on the planned interception path

Wireline Gyro – Is used to:

- Reduce the ellipse of uncertainty prior to the first ranging determination. Reducing the uncertainty of the RW will save time by delaying the requirements for ranging
- In the intercept phase the WL gyro is used to survey to bottom at the end of the drilling interval. This on bottom survey eliminates the projection to bit positional error and will allow for longer drilling intervals and reduce the number of ranging runs required to complete the intercept.

While it is possible to complete a RW without the use a gyro the increase in the number of ranging runs required and the increased sidetrack risk will justify the additional expense.

3.8 Ranging Operations Outline

To reduce the impact of ranging on the overall operations (trips for ranging), ranging operation should be integrated in to the drilling program where ever possible. Coordination of the ranging runs should include:

- Casing - trips for casing can be integrated in to ranging program; this would generally be available in the locate and intercept phases. Depths must be preplanned and adjusted in real time to meet the requirements of both the well control and ranging stakeholders
- Bit trips – Whenever possible the timing of a bit trip should be coordinated with the depth requirement for ranging.
- TPL – In the follow phase, unlike the locate and intercept phases, ranging data is generally not required on bottom. Running a ranging BHA above the drilling BHA allows for WellSpot data to be taken without tripping the drilling BHA.

The following operations outline is provided as a sample work flow for the three ranging phases.

3.8.1 Locate Phase

- Prior to first planned ranging depth
  - Interception Specialist monitor surveys from KOP to first ranging depth. Update trajectory if required
  - MWD monitor surveys for cross axial interference. If interference is detected halt drilling and report findings to Ranging Specialist
- Drill to ranging point
- Trip out of hole
- Ranging Specialist uses MWD/GWD surveys to develop ranging plan
- Ranging Specialist to brief ranging/WL crew on ranging plan for next ranging interval
- Rig-up wireline for open-hole logging with WellSpot
- Run WellSpot in open hole
- Stop at shoe to take ranging data for in run depth control
- Take high density ranging data in the bottom section of the hole.
- Take low density ranging data, including overlapping data, in the upper hole.
- Ranging data is taken at the shoe for out run depth control
- Pull out of hole and rig-down wireline and clear catwalk for drilling operations
- While POOH:
  - Use the ranging data and the MWD/Gyro surveys to plan the next drilling interval
  - New well-plan is developed by directional, well planning and the Interception Specialist
  - Interception Specialist to deliver drilling plan to customer for approval of the next drilling interval
  - Interception Specialist to brief team (customer, DD, MWD, GWD, WC, Tool Push) on requirements for the next drilling interval
- Drill to next ranging interval depth

3.8.2 Follow Phase

- Add ranging BHA to drilling BHA
- Drill to ranging point
    - Ranging specialist brief MWD on PMR data requirements
    - MWD monitor surveys for cross axial interference
- If PMR signal is detected:
    - Ranging Specialist will provide MWD with PMR data collection plan
    - Ranging Specialist will model PMR data and deliver to Interception Specialist
    - Interception Specialist will analyze ranging results and determine if a WellSpot run is required.
- If WellSpot run is required
    - Pull drilling BHA up to top of the ranging interval
    - Ranging Specialist uses MWD/GWD surveys to develop ranging plan
    - Ranging Specialist to brief ranging/WL crew on ranging plan for next ranging interval
    - Rig-up wireline for TPL logging with WellSpot
    - Rig-up side entry sub
    - Run WellSpot in Pipe and land in ranging BHA
    - Align WL depth to drillers depth
    - Run BHA to bottom
    - Take high density ranging data in the bottom section of the hole.
    - Trip drillstring out to side entry sub
    - Trip WL out to side entry sub
    - Rig-out side entry sub
    - Lay down WellSpot tools
    - rig-down wireline and clear catwalk for drilling operations
- While POOH:
    - Use the ranging data and the MWD/Gyro surveys to plan the next drilling interval
    - New well-plan is developed by directional, well planning and the Interception Specialist
    - Interception Specialist to deliver drilling plan to customer for approval of the next drilling interval
    - Interception Specialist to brief team (customer, DD, MWD, GWD, WC, Tool Push) on requirements for the next drilling interval
- Drill to next ranging interval depth

3.8.3 Intercept Phase

- Drill to ranging point
- Trip out of hole lay down drilling BHA
- Trip in gyro BHA (GWD or Open pipe for WL Gyro)
- Gyro bottom hole section
- Ranging Specialist uses MWD/GWD surveys to develop ranging plan
- Ranging Specialist to brief ranging/WL crew on ranging plan for next ranging interval
- Rig-up wireline for open-hole logging with WellSpot
- Run WellSpot in open hole
- Stop at shoe to take ranging data for in run depth control
- Take high density ranging data in the bottom section of the hole.
- Take low density ranging data, including overlapping data, in the upper hole.
- Ranging data is taken at the shoe for out run depth control
- Pull out of hole and rig-down wireline and clear catwalk for drilling operations
- While POOH:
    - Use the ranging data and the MWD/Gyro surveys to plan the next drilling interval
    - New well-plan is developed by directional, well planning and the Interception Specialist
    - Interception Specialist to deliver drilling plan to customer for approval of the next drilling interval
    - Interception Specialist to brief team (customer, DD, MWD, GWD, WC, Tool Push) on requirements for the next drilling interval
- Drill to next ranging interval depth

4 Relief Well Magnetic Ranging Services

4.1 WellSpot™ Active Magnetic Ranging (AMR) Service

WellSpot is the industry's leading access independent active magnetic ranging service. WellSpot works by exciting an AC current on the target well, which in turn creates a magnetic field. From this induced magnetic field, both distance and direction can be determined.

4.1.1 Advantages

The advantages of WellSpot AMR include:

- Detection is based on a signal that is generated by the WellSpot assembly.
- Detection range is typically an order of magnitude greater than PMR.
- Planning is developed around a calculated detection range significantly reducing the likelihood of a sidetrack.
- Works equally well on steel and non-magnetic tubulars.
- Detection range not significantly impacted by the target well tubular size.
- Ranging service that can take a direct distance measurement.
- Lowest risk of an accidental collision as the ranging is taken on bottom with the greatest depth of investigation.

4.1.2 Disadvantages

The disadvantages of AMR include:

- While the ability to perform AMR exists in a directional drilling BHA, the deployment of this service is not appropriate for all applications. On a typical relief well the majority of ranging runs will require an open hole wireline trip.
- Service may not work when run in ultra-high resistivity formations such as pure salt. This constraint is generally not an issue when ranging in close proximity of the target well. This concern may also be mitigated by the design of the ranging assembly that has the excitation source above the salt zone.

4.1.3 WellSpot Data Collection

For each ranging run, a unique data collection plan is designed to ensure the data requirements are met while also making the overall logging time as short as possible. Factors that influence the overall data collection time include:

- Phase of the relief well. The three phases of ranging operations are Locate, Follow, and Intercept. The respective goal of each phase is to determine the location of the target before uncertainty ellipsoids overlap, to safely converge on the target, and to guide the relief well into the target well. Ranging determinations in the locate and interception phase require a higher data density to tightly map the trajectory. In the follow phase the proximity between the relief and target well is typically large enough so any deviations from the expected position of the target well have limited impact on the overall drilling plan.
- Survey quality of the target well – For a target well with limited or no available surveys the ranging determinations must be made from high density data. This data is used to both determine the proximity between the relief and target wells, and to predict the deeper trajectory of the target well.
- Physical limitations – The WellSpot™ tool has a temperature gradient limitation that will impact the available logging time. For wells with temperatures in the higher limits of the tool, the shortened logging time may limit the available data collection time increasing the size of the call box. In extreme cases this may increase the overall ranging runs required to intersect the target well.

Under normal operating conditions the data collection plan will require high data density for the deeper sections of the ranging interval. This data will typically be taken at 1 foot intervals for the bottom 10-20 feet and increased to 5 foot intervals up to 50 feet off bottom. Any subsequent data points in unlogged sections will be taken at 25-50 foot intervals. This data will be analyzed by the ranging specialist and any infill data will be taken on a 2nd descent if required.

The estimated time for a ranging run is as follows:

- 30 minutes for tool and wireline handling
- 150'/minute descent time to deploy the tool to the logging interval
- 3 hours of data collection
- 150'/minute assent time
- 30 minutes of tool and wireline handling time

Under challenging logging conditions, deploying the WellSpot tool inside the drill string will increase this time. An additional 30 minutes of surface handling for deploying the tool via a side entry sub should be added for deploying and retrieving the tool. Additional time for circulating cooling mud through the ranging BHA may also be required.

4.1.4 Reasons to Select WellSpot Service

- WellSpot (AMR) offers the highest success rate for intersections in the industry. If minimizing time is critical to the operation, using the WellSpot AMR system offers less risk of additional sidetracks.
- WellSpot AMR has the greatest detection range.
- Eliminates the risk that an unproven ranging service may present

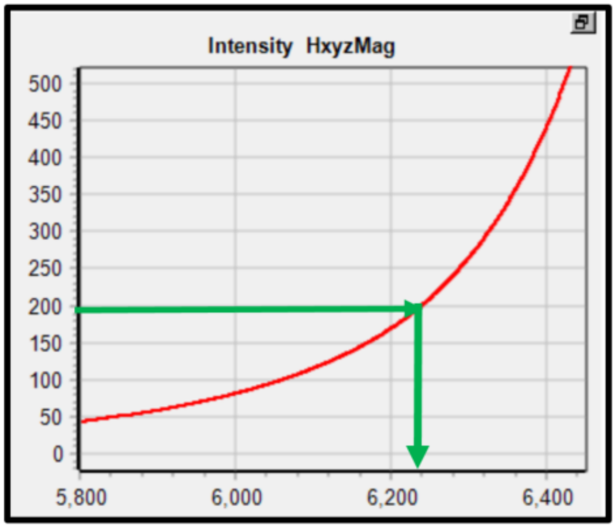
4.1.5 Detection Range

The detection range for WellSpot is dependent on the following factors: Incidence angle, size and length of target well tubulars, formation resistivity, bridle configuration, and excitation method. The expected detection range is determined by a model of induced magnetic field. This induced field is a non-naturally occurring AC magnetic field that exists only when the target well is being excited by the WellSpot ranging assembly. *Accurate estimation of the range of detection is a key component in creating an effective relief well ranging plan.*

Two key plots from the modeling software used to determine the detection range are the Signal Intensity (uA\m\A) and the distance to target. The following graphs are examples of the custom analysis that are included in the relief well ranging plan. The modeled detection range, in this case 65ft, is established by determining what the separation of the wells are when the detection reaches 200 uA/m/A.

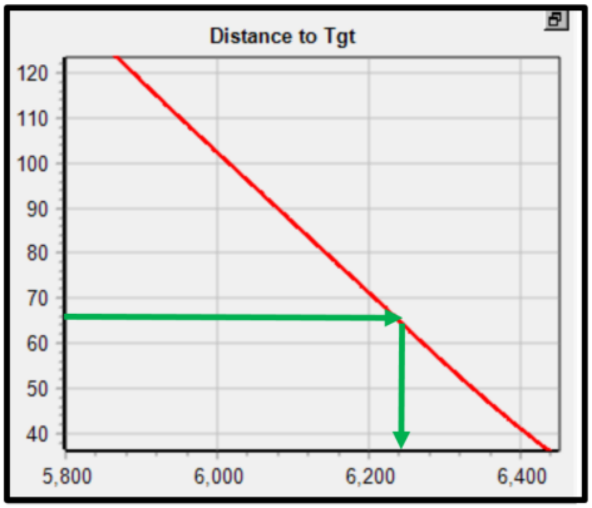
While it is possible to establish ranging detection at 100 uA/m/A, thus increasing the modeled detection range, a RW must never be designed around the lower threshold of any critical service.

Signal Intensity Plot



200 uA/m/A @ 6240 ft

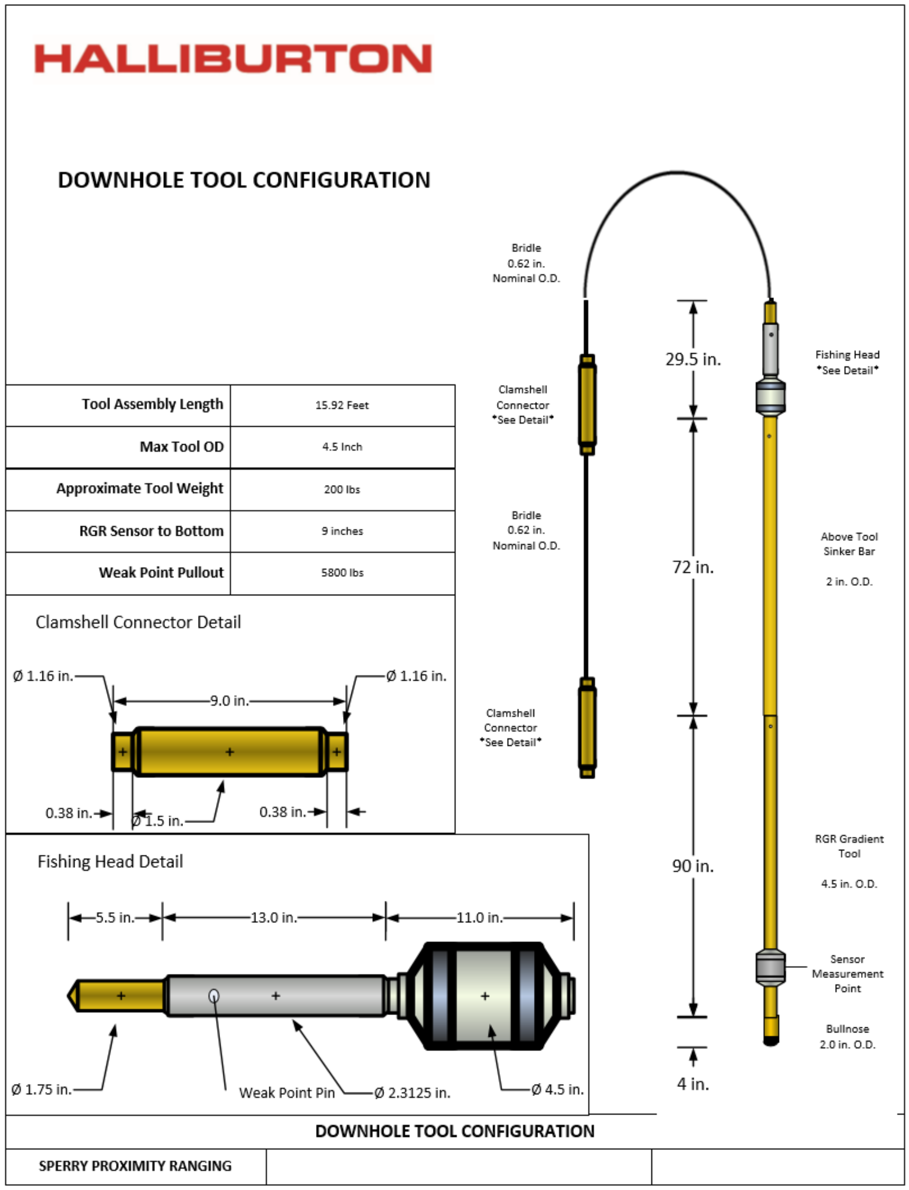
Ladder Plot



@ 6240 ft the seperatiion between the wells in 65 ft

4.1.6 WellSpot™ Tool and Wireline Assemblies

WellSpot is deployed into an open hole via a 7 conductor wireline. The bridle assembly contains the tool assembly, isolation section, and excitation components.



4.1.7 WellSpot™ Wireline Requirements

The WellSpot kit comes fully equipped to connect to a Halliburton, Baker Hughes, or Schlumberger 7 conductor logging unit. Connecting to other units is possible but will require detailed pre-planning to ensure the correct crossovers are sourced.

4.1.8 Physical Limitations:

For any relief well plan that will utilize the WellSpot™ service, it is important that the physical limitations of the tools and the challenges in tool deployment are understood so they can be incorporated into a relief well plan.

- Pressure – The maximum pressure for a WellSpot™ tool is 25,000 psi.
- Temperature – The highest temperature rating in the suite of WellSpot tools is the RGR III 2-in tool. This tool is designed to have the electronics protected in a dewar flask and the sensor package exposed to the static well temperature. With this design the tool has two maximum temperature ratings. The temperature limits and practical application of them are as follows:
    - The maximum recommended external temperature is 180°C. If absolutely necessary, the tool can be operated in external temperatures to 200°C, which is the expected fail temperature of the sensors.
    - This tool also has a maximum internal temperature rating of 125° C. The temperature inside the flask will increase from the heat of the electronics and the external temperature. The overall temperature limitation is impacted by the time that the electronics are turned on (logging time) and the wellbore temperature.
    - When operating below the max external temperature the practical limitation of tool is time. For runs that are in a low temperature wellbore the time limit to reach the max internal temperature can be over 24 hours. At high temperatures the logging time will be limited and reduce the available data density. To extend the logging time limit the tool may be deployed inside a dedicated ranging BHA that will allow for circulation and reduce the impact of the static wellbore temperature. The procedure for deploying the tool in a ranging BHA is discussed in the "Tool Deployment" section of this guide.
- Hole Conditions – Typically the WellSpot tool is deployed into open hole. Under optimal conditions, the tool may be deployed at inclinations up to 60°. Swelling formations, uneven wellbores, or fill will reduce the ability to deploy the tool. All efforts must be made to clean the wellbore prior to a WellSpot run to ensure the critical on bottom data is collected.

4.1.9 Alternate Methods of Deployment

If the wellbore conditions prevent the standard open hole ranging assembly from being deployed to TD there are three alternate methods that are used:

- Weighted Sleeves – The WellSpot™ tool may be fitted with a weighted sleeve assembly that will increase the tool weight from 150lbs to 500lbs. The increased weight will reduce the impact of high inclinations on the tool deployment and overcome some wellbore quality issues. The extra handling precautions required while picking up and laying down this weighted assembly will add less than 15 minutes to the tool handling time.
- Open Ended Drill pipe –To deploy the WellSpot assembly through high sail angles or past problem hole sections, the drill string can be deployed to a depth past the challenging hole section. The 2" OD ranging assembly is run inside the pipe and out the open end into open hole. Considerations for this method are:
    - If required a wireline side entry sub may be used for well control purposes or to pump the tool past high inclination sections.
    - This method of deployment will also require the construction of a wireline entry guide to prevent the tool from catching on the pin end when pulling out of the hole. This wireline entry guide can be easily constructed at the rig site from the box end of a joint of drill pipe.
    - Overall ranging time is increased so this method should only be considered when the weighted sleeves are proven ineffective.
- Dedicated Ranging Assembly – High temperatures or hole conditions that would prevent the tool from reaching TD using the other deployment methods will require the WellSpot assembly to be run in a dedicated ranging BHA. Because of the increased time to deploy this assembly and the increased surface handling time this method should only be used when other methods have been eliminated as an option or have been proven unsuccessful in previous attempts. The following is an overview of the procedure for running a dedicated ranging BHA (detailed instructions will be issued if this method becomes necessary).
    - A section of non-magnetic pipe is required for the bottom section of the BHA where the WellSpot tool will be seated.
    - Isolation subs are used throughout the BHA to isolate the WellSpot tool from the excitation section of the WellSpot assembly.
    - The ranging BHA is deployed to within a couple of joint lengths of TD and the ranging tool is deployed into the pipe via the side entry sub.
    - The BHA is lowered to TD and the tool is pumped into position.
    - The bottom hole section is logged with the tool seated into the non-magnetic BHA.
    - Upper sections of the hole may be logged by repositioning the ranging assembly in the BHA and/or repositioning the BHA.
- Ranging BHA – For the follow phase the dedicated ranging assembly can be added on top of the drilling BHA. This method of deployment will:
    - Save significant time as the drilling assembly can remain in the hole during ranging operations
    - Only be appropriate for the follow phase as this is the only section of the well that will not require on bottom ranging data.

4.1.10 Ultra High Resistance Formations

One of the factors that impacting the detection range of the WellSpot™ tool is formation resistance. There have been several documents published that state "salt formations will prevent WellSpot tool from being used"; this is not necessarily the case. While it is true that pure salt will prevent the excitation from reaching the target well there are both exceptions and procedures to mitigate the impact of high resistance formations. These procedures are as follows:

- Dirty Salt – Salt formations with lenses of conductive formation will reduce, but not eliminate, the WellSpot signal intensity. To mitigate the impact of this loss of signal strength the relief well plan must be designed to close the separation between the target well and relief well before entering this formation.
- Pure Salt Above the Planned Interception Depth – Pure salt formations will prevent the collection of current on the target well but it will have no impact on the signal if the excitation current is already on the pipe. With preplanning, the ranging assembly can be designed to keep the excitation source in the ranging assembly above the salt layer. This method can be used for up to 300 meters into a salt layer. WellSpot detection below the salt layer can be re-established earlier by shortening the distance between the excitation on the WellSpot tool.
- Interception in Pure Salt / Extended Salt formations – If ranging operations are required over 100 meters into a salt formation, then PMR ranging must be used. This does not eliminate the use of WellSpot as an effective component in a ranging plan:
    - The superior detection range of WellSpot can be used above the salt in the Locate and Follow Phases of a relief well to greatly reduce the likelihood of requiring a sidetrack to establish or re-establish ranging detection.
    - Using the WellSpot tool for the sections above the salt will allow the separation of the target well and relief well to be maintained at a greater distance than PMR. This will extend the drilling intervals and eliminate the early interception risk associated with the close proximity required while ranging with PMR.
    - Planning the relief well with both WellSpot and PMR will allow the sections above the salt to use the advantages of WellSpot. Before entering the pure salt zone, the proximity between the target well and relief well is reduced to be within the PMR detection range.

4.1.11 High Ellipse of Uncertainty

The highest positional uncertainty in the ranging procedure is before the target well is detected by a ranging run. Once a ranging determination is made, the ellipse of uncertainty is reduced to the ranging call box. Typically the first ranging depth is selected by calculating the depth at which the edges of the ellipse of uncertainties from the relief well and target well touch, expressed as separation factor (SF) =1. For most relief well operations, this depth occurs within the detection range of the WellSpot™ tool. For some relief well operations, this is not possible as the combined ellipse of uncertainty for both wells at the SF=1 is outside the detection range of the tools. To allow further drilling, an anti-collision ranging run is used to ensure the next drilling interval will not result in an accidental intersection. The next drilling interval is designed so the wells will not get any closer than half the modeled detection range; this process is repeated until the TW is detected by the WellSpot tool. Based on previous planned and executed relief wells, most operations require only one anti-collision ranging run. The large detection range and the WellSpot modelling accuracy allow the anti-collision section concern to be mitigated without numerous ranging determinations.

For some relief well operations this process of locating the target well can be complicated by an extremely large ellipse of uncertainty that is many times large than the WellSpot detection range. This larger than normal ellipse of uncertainty can be a result of a combination of the following factors:

- Low quality or no surveys on the target well.
- Uncertainty in the target well or relief well surface location that cannot be reduced. This would include land blowouts that have cratered or offshore blowouts that cannot be approached for resurveying.
- Large separations between the target well and relief well surface locations. This large separation may be necessary based on geology, hydrology, economic and/or regulatory requirements; it could also be a result of planning a relief well location without considering the operation parameters of the selected ranging service.
- Committing to a drilling plan that has not been reviewed by a ranging SME.

Locating a target well in the case of an extremely large ellipse of uncertainty will require a methodical approach that will also include a complete examination of all the input data to eliminate gross errors. While recommended for all relief well operations, the following items are critical for any relief well operations that involve an extremely large ellipse of uncertainty:

- Resurveying of the target well surface location - This can eliminate a gross error and can also improve older wells surface accuracy as the surveying quality may have improved since the well was spudded.
- Visual Confirmation – Whenever possible the surface proximity between the relief well and target well will be confirmed by comparing the published plan and physical measurements taken at the well site. Several gross errors have been eliminated by simple compass bearings and physically measuring the distance between the planned relief well location and the target well wellhead. This is especially true for relief well's that are planned in a crowded field.
- For target wells with MWD surveys, the declination must be confirmed, and if the raw data is available, an analysis can identify any sensor bias.
- If the target well's BHA is known, the surveys can be sag corrected.
- For wells with either no surveys or low quality surveys, an offset well(s) can be surveyed with a gyro to determine any drift trends in the field.
- Generating an updated target well survey by applying the data from any of these methods must be cautiously applied as any incorrect assumptions can compound the impact of the already existing uncertainty.

The optimal method to locate a target well in an extremely large ellipse of uncertainty is based on the statistical fact that the target well will be most likely found near its center. The recommended method for running the WellSpot service is to investigate the center of the ellipse in incremental steps:

- Starting at the outer edge of the ellipse, if the target well is not detected, the relief well / target well separation is closed by half of the modeled detection range.
- The process is repeated to investigate the entire center of the ellipse.
- If the well has not been located, a sidetrack will be required to sweep the uninvestigated section of the ellipse of uncertainty.

Alternate methods for locating a target well in an extremely high ellipse of uncertainty such as a spiral sweep along the outer edge of the ellipse are unnecessary as it disregards the economics and probability of aiming for the center of an ellipse using a high detection range WellSpot tool.

4.1.12 Crowded Ranging Environment

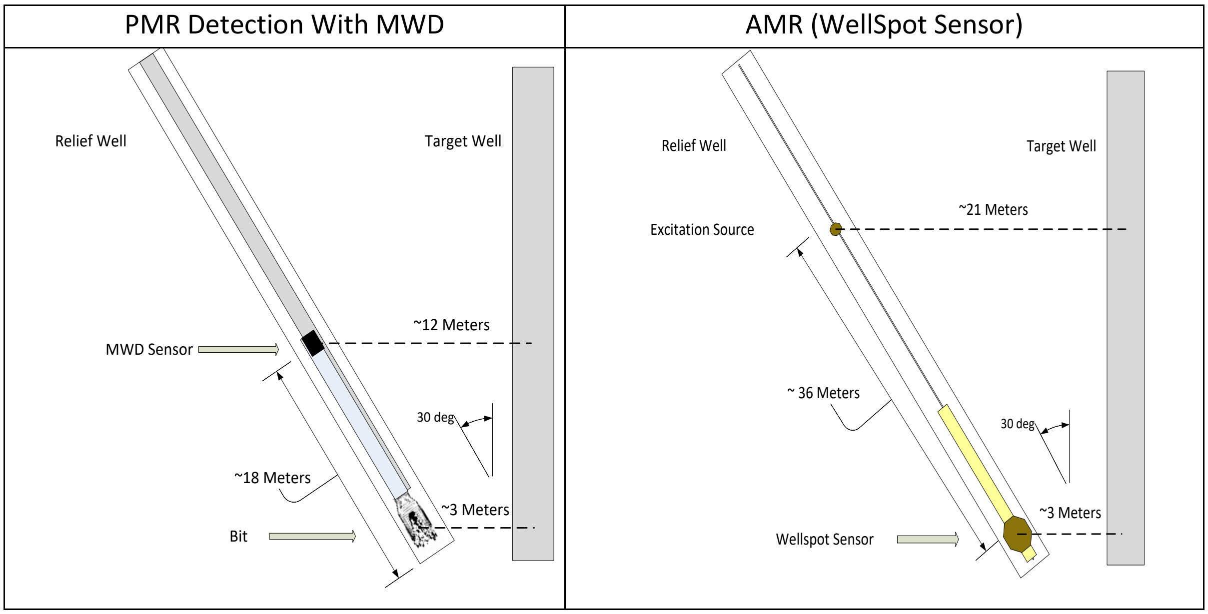
The ability to distinguish a target well from any offset wells is a feature unique to WellSpot. Identifying a single well in a crowded field can be accomplished in two ways:

- Surface hole location selection – Pre planning the relief well so the vertical section direction will place the target well in the same direction as the offset well.
- Vector subtraction – The process of identifying the vector component of a ranging signal that is generated by an offset well. This is not available for any PMR service as the direction and distance accuracy are not sufficient and the measurements from both wells must be taken at the same depth. The vector component of an offset well can be determined by:
    - Direct excitation of the offset well– This is the most accurate method as the vector component of the offset well is measured separately. While this method is limited by depth, it is likely that any offset well inside the detection range will only be inside the detection range in the upper section of the hole.
    - Downhole excitation of both wells – This method requires a survey of the offset well to be included in its calculated position. The combined model vector position of each well should match the measured vector when exciting both wells. This downhole excitation technique is dependent on survey quality, as the overall positional certainty in relation to the offset well and the target well is reduced when both wells are at equal distances from the relief well.
    - As the relief well is drilled toward the target well, the offset well vector component of the overall ranging measurement is reduced until it is made irrelevant in the calculation of the target well location.

4.1.13 Impact of Incidence Angle on Detection

Approaching a target well at a high incidence angle has an impact on the detection for both PMR and AMR. Drilling towards a TW at a high approach angle should only be done when it is necessary. For the WellSpot™ sensor, the reduced signal intensity will require shorter drilling intervals to avoid drilling outside the tools detection range. For PMR using MWD, the early collision risk is unacceptable so a wireline survey method or dedicated ranging BHA with the MWD positioned at the bottom is required.

To illustrate the differences, the following diagram considers a locate phase with a 30° pass by that is intended to come within 3 meters of the target well.



The high incidence angle for an AMR ranging measurement will mean that the excitation source will be farther away from the target well, thus reducing the signal intensity. While this may cause some possible detection issues at greater distances from the target well, as the case illustrated above, the WellSpot sensor is only 3 meters from the target well, reducing the signal intensity requirements for a ranging determination. Ranging with AMR at this well geometry does not pose an unintended collision risk.

The high incidence angle for a MWD PMR ranging measurement will mean that the sensors are much farther from the target well than the bit. In the case above it can increase the possibility of an unintended collision as a PMR ranging determination at 12 meters may be of reduced accuracy or in many cases unattainable.

4.1.14 WellSpot Shipping Details

- The WellSpot kit comes complete in a 2.67m x 1.32m x 1.32m box.
- The shipping weight is approximately 950 kg.
- Kit contains no hazardous chemicals or radiation.
- Kit is air transportable.

4.1.15 WellSpot Tool Specifications

Name	Detection Range		Direction Precision	OD	Temp	Pressure
	Distance	Gradient Distance				
RGR-G III (Gyro)	200’ (60m)+/- 20%	15‘ (4m) +/- 5%	+/- 3°	2 in / 51mm	200° C / 390° F	25,000 psi
RGR iV	200’ (60m)+/- 20%	30’ (9m) +/- 5%	+/- 3°	4.5 in / 114mm	200° C / 390° F	20,000 psi

4.2 Passive Magnetic Ranging (PMR)

The basic concept of PMR is to take the existing raw magnetic values from a standard 6 axis survey tool, then reanalyze the data to determine if there is enough magnetic field (interference) above the level of the expected earth's magnetic field to develop a ranging determination. PMR measures the aggregate magnetic field of the tubular (drill string, casing, fish, etc.) and the earth's magnetic field. Through a series of magnetic measurements (surveys) over a prescribed measured depth (a given interval) distance and direction can be calculated.

4.2.1 Advantages

- PMR can use the existing sensors in a standard MWD system
- PMR data collection may not require a trip if off bottom data is acceptable to accomplish the objective
- PMR will function in any formation.
- PMR data analysis can be completed off location.

4.2.2 Disadvantages

- With the limited detection range of PMR, the relief well and target well ellipse of uncertainty may have overlapped before establishing detection range.
- There is no guarantee that there will be any significant PMR signature; the remnant magnetism of steel deteriorates over time, in the presence of cyclical temperature, and can be significantly reduced with corrosion.
- Pre-planning ranging runs with PMR can be challenging as the detection range is based on a wide range of estimates and assumptions on remnant magnetic field strength.
- Additional dedicated ranging trips may still be required as attempting an intersection with MWD data positioned at 20-30m behind the bit has an uncertainty that can lead to sidetracks or unintended intersections. If an intersection is attempted with PMR a separate ranging run with the sensors positioned within 1 meter of the bottom is highly recommended.
- The unpredictability of the remnant magnetic field and the higher risk of requiring multiple sidetracks may increase the overall cost and time requirements to complete a relief well.
- A PMR run may still require a significant amount of time for data acquisition as high density surveys are often needed for resolving the distance and direction.
- Caution must be taken when evaluating the effective range of PMR. The detection range of PMR varies greatly between ranging along the body of a tubular versus ranging to the end of pipe.
- Does not work on non-magnetic material (non mag collars or most parts of a directional drilling BHA)

4.2.3 Reasons to select PMR

- When this service is appropriate the cost savings may be significant.
- When a ranging study proves that AMR will not work.
- As a companion service it can be used to reduce the number of AMR runs (typically in follow phase).

4.2.4 PMR Data Collection

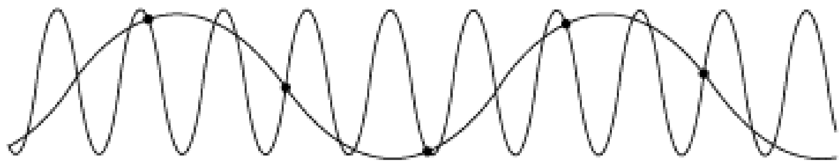
While PMR ranging can often be conducted using the existing drilling BHA there are circumstances where the sensor to bit distance may render this method ineffective. There are two alternate methods for collecting PMR data:

1. PMR Ranging BHA – Data may be collected by tripping out the drilling assembly and running in a dedicated PMR BHA.
    a. The advantages of this method are:
        i. Data can be collected near bottom of the BHA
        ii. Data can be collected with the MWD tools so no additional equipment is required.
        iii. PMR Ranging data can be taken when hole conditions are problematic.
    b. The disadvantages of this method are:
        i. Trip required to reconfigure the BHA.
        ii. Data collection is time consuming.

2. Wireline Continuous Magnetic Logging (CML) – The WellSpot tool can be used to collect both AMR and PMR data. Using WellSpot as a CML tool has several advantages when compared to a PMR Ranging BHA:
    a. Logging data is taken at a high rate in a continuous pass of the ranging interval. Typically in-run and out-run data can be collected in significantly less time compared to hours of pump cycles for a ranging BHA.
    b. Tripping time to get the sensor into the ranging interval is significantly lower.
    c. The cost of a Wireline run can be easily offset by the time savings.

4.2.5 Survey Interval for PMR

One of the keys to a successful PMR ranging call is in collecting sufficient data. As the diagram below indicates all efforts must be made to avoid aliasing the data. A balance must be made between the time it takes to collect the data and the density needed to make the ranging call (determining distance and direction).



Aliased Signal Due to Undersampling

As a rule of thumb the magnetic signature of the target well will be effectively mapped using the 1/3 rule where the interval of the surveys must be no more than 1/3 the expected separation. The depth interval for this PMR mapping is based on the joint length. Using the formula below, if the expected separation of the pipe is 1m then there will be 54 surveys required to capture the entire PMR signature.

$$Number\ of\ Surveys\ Required = \frac{2\ \times\ Joint\ Length}{Expected\ Seperation\ \times\ 1/3}$$

Example: 9.0 Meter Joint Length, 1 Meter Expected Separation: $Number\ of\ Surveys\ Required = \frac{2 \times (\,9.0\ Meters)}{(1.0\ Meters) \times \frac{1}{3}}$

$$Number\ of\ Surveys\ Required = \frac{18.0\ Meters}{0.33\ Meters}\ Number\ of\ Surveys\ Required = 54$$

4.2.6 Data Acquisition Time

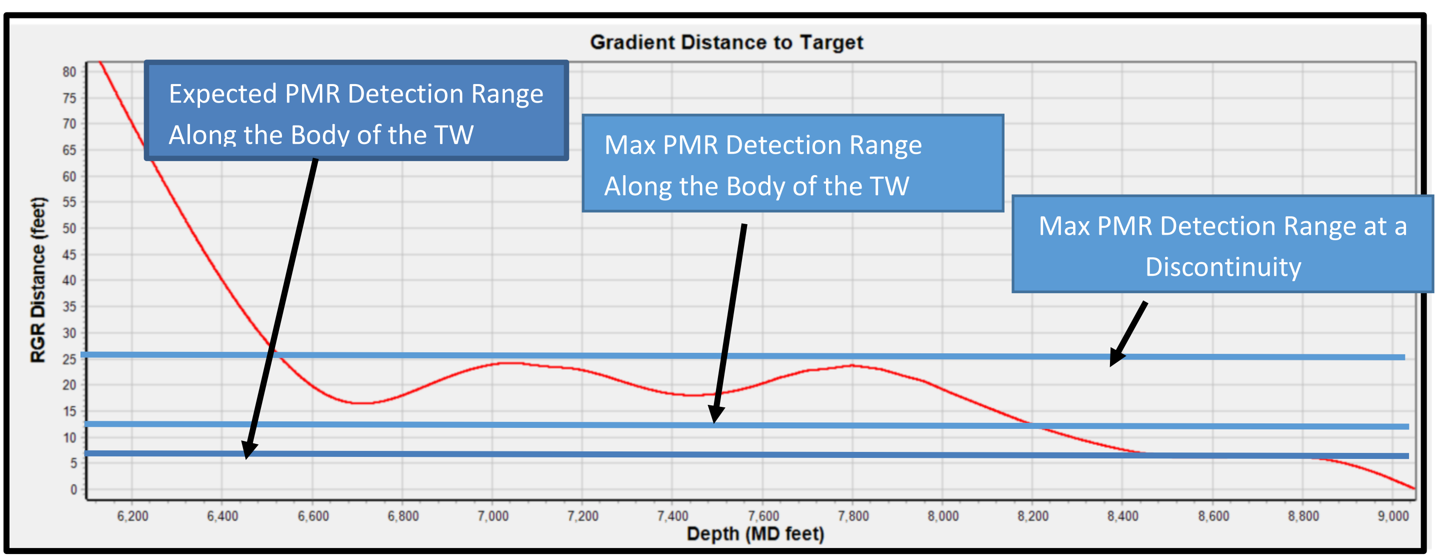
When considering the overall costs of PMR ranging, the data acquisition time (rig time) will vary greatly depending on the specific ranging requirements. In some cases logging a ranging interval with the MWD may save time when compared to wireline while in others it is either more time consuming or inappropriate as the data must be taken at the bottom hole location to be effective. A customized data collection plan must be completed before any determination can be made on the economics of this ranging service.

4.2.7 Detection Range

PMR detection range is estimated using the weight/length characteristics of the target tubular. An expected detection range is determined from a field strength chart. Key points about the PMR detection range include:

- Range is an estimation based on a theoretical remnant magnetic field
- Range estimation is given in both an expected and maximum range
- Range to a physical break or end of tubular or casing shoe is approximately twice of that along the body of the tubular
- No minimum range exists as it is physically possible that a tubular may have little or no remnant magnetic field. It is also possible that the arrangement of the tubulars (north/south magnetic poles) minimize each other's dipoles out
- Detection range is not typically dependant on the survey instrument as any 6 axis MWD/wireline tool can provide readings that can be utilized for PMR
- Generally, the resolution of the MWD tool has no impact on the detection range as the precision is typically 6Nt, which is well below the common earth field noise
- Casing condition due to corrosion can significantly reduce the available PMR signal
- **Care should be taken not to accept detection ranges based on an externally magnetized casing model**

The following distance to target plot shows the expected detection range based on the three separate determining criteria: discontinuity, possible detection range along the body, and expected detection range along the body. Note: This is based on the target well casing weight of 17lb/ft.



4.3 Ranging Decision Matrix

Performance Measure	Operations Impact	
	PMR	AMR (WellSpot™ Tool)
Detection Range Estimate	Selected from a chart representing the possible max magnetic field	Calculated using geometry and magnetic model
Detection Along Body of the Target Well	Detection range up to 5 meters (1/2 joint length), 6 meters on 12 meter casing	Up to 60 meters
Detection Near Break or End of Pipe	Detection range up to 15 meters	Limited range within 1 meter of top and bottom of pipe ends
Wireline Required	Only for high density or on bottom data	Yes
Data Acquisition Time	6 to 30 hours for MWD logging	30 hours (assuming 4500 meter well)
Sensor Measurement Point	15 meters to 20 meters from bottom hole for MWD logging	On Bottom
Non Magnetic Target Pipe (Including Non-Mag Drill Collars and M/LWD BHA)	Detection not possible	No effect, same as steel pipe
Target Casing Corrosion	Detection may not be possible	Minimal impact on detection range

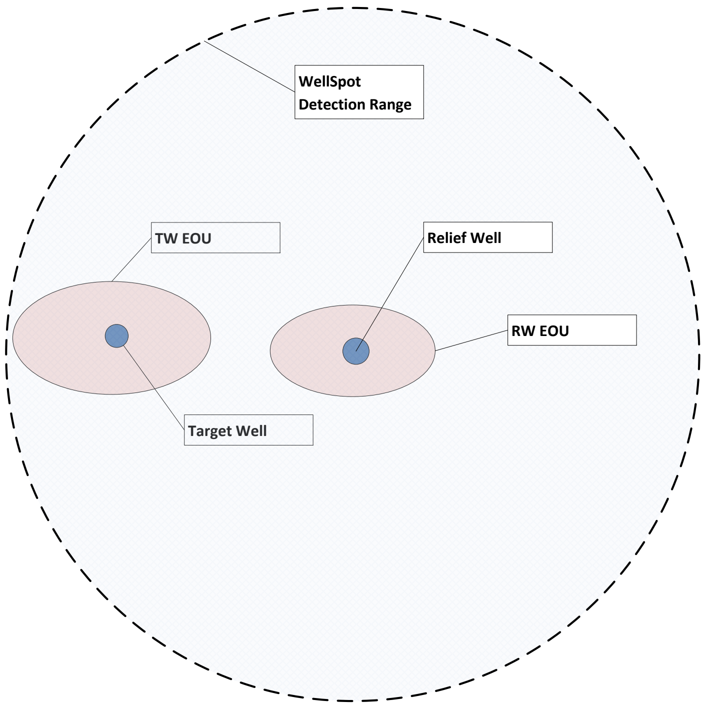
Performance Measure	Operations Impact	
	PMR	**AMR (WellSpot™ Tool)**
Presence Of Breaks Or Discontinuities In Target Pipe	Potential to increase detection range from the magnetic signature	Detection range reduced for sections of the target well
Effects of Different Casing Sizes and Weight	Casing weight has a direct impact in range: 20 Lbs/Ft has an expected max range of 2 meters along the body 40 Lbs/Ft has an expected max range of 3 meters along the body	Negligible Effect
Effects of Other Nearby Wellbores	Eliminates possibility of using service	Direct excitation method mitigates impact
Effects of Highly Insulating Formation	No effect	Detection range is largely reduced
Effects of High Incidence Angle Between Target And Drilling Well	High incidence angle increases sensor to target distance thus greatly reducing the effective detection range	AMR signal reduced by increasing distance between excitation source and target well
Effects of OBM Mud	No Effect	No Effect

4.4 First Ranging Run Depth Selection

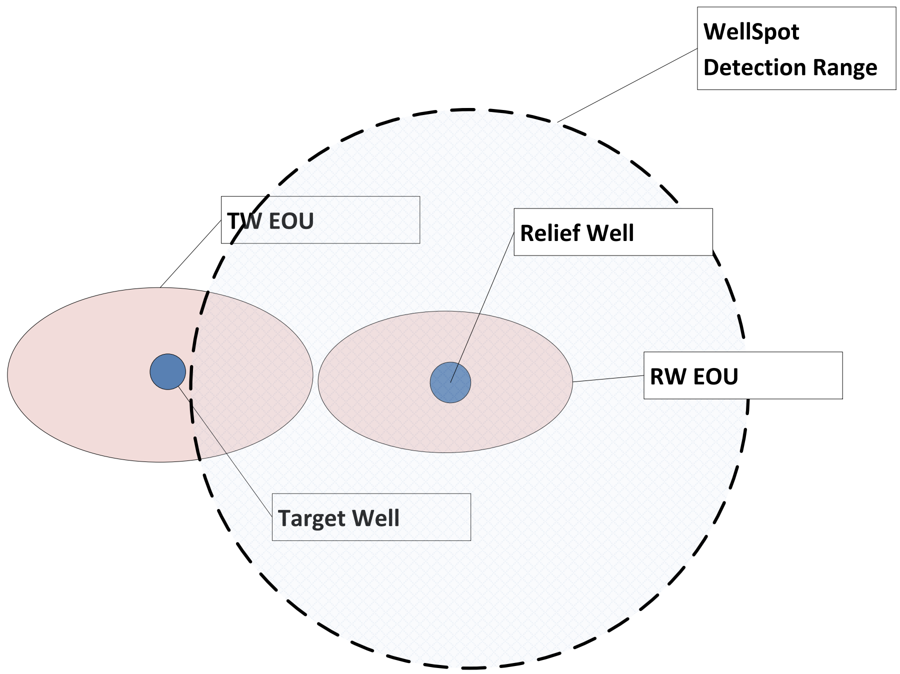
The depth of the first ranging run will depend on:

- The detection range of the WellSpot™ tool as modeled on a case by case basis.
- Ellipse of uncertainties of the target well and relief well.

Typically the first ranging run will take place just as the entire ellipse of uncertainty of the target well falls inside the modeled detection range. This can be safely done as long as the separation factor remains higher than 1.

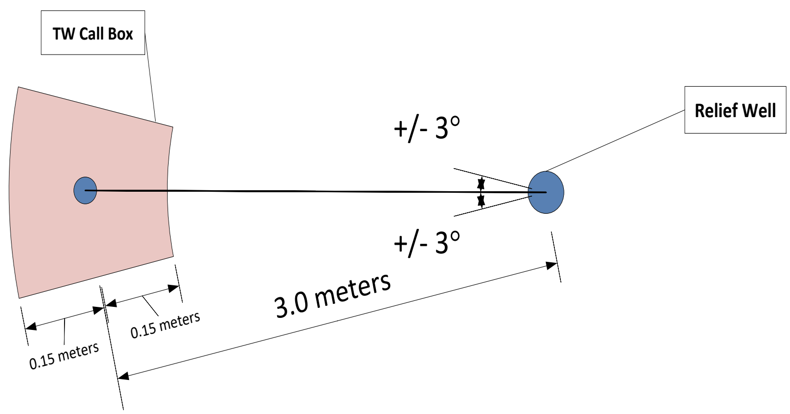


The diagram below illustrates an anti-collision run with the target well and relief well in the center of their ellipses and detection is less than the center to center (C2C) separation of the wells. In this instance, the first run will be used as an anti-collision run that will take place outside expected detection range. Ranging will determine if the target well is in a part of its ellipse which could potentially cause an accidental interception. Completing this ranging run will allow drilling to continue without the risk of accidental collision.



4.5 Ranging Call Box

Once a ranging determination is complete, the results are reported in the ranging report as a direction and distance that have an associated +/- ambiguity. The diagram below shows a ranging call with a direction of 270° +/- 3° and a distance of 3.0 meters +/- 0.15m

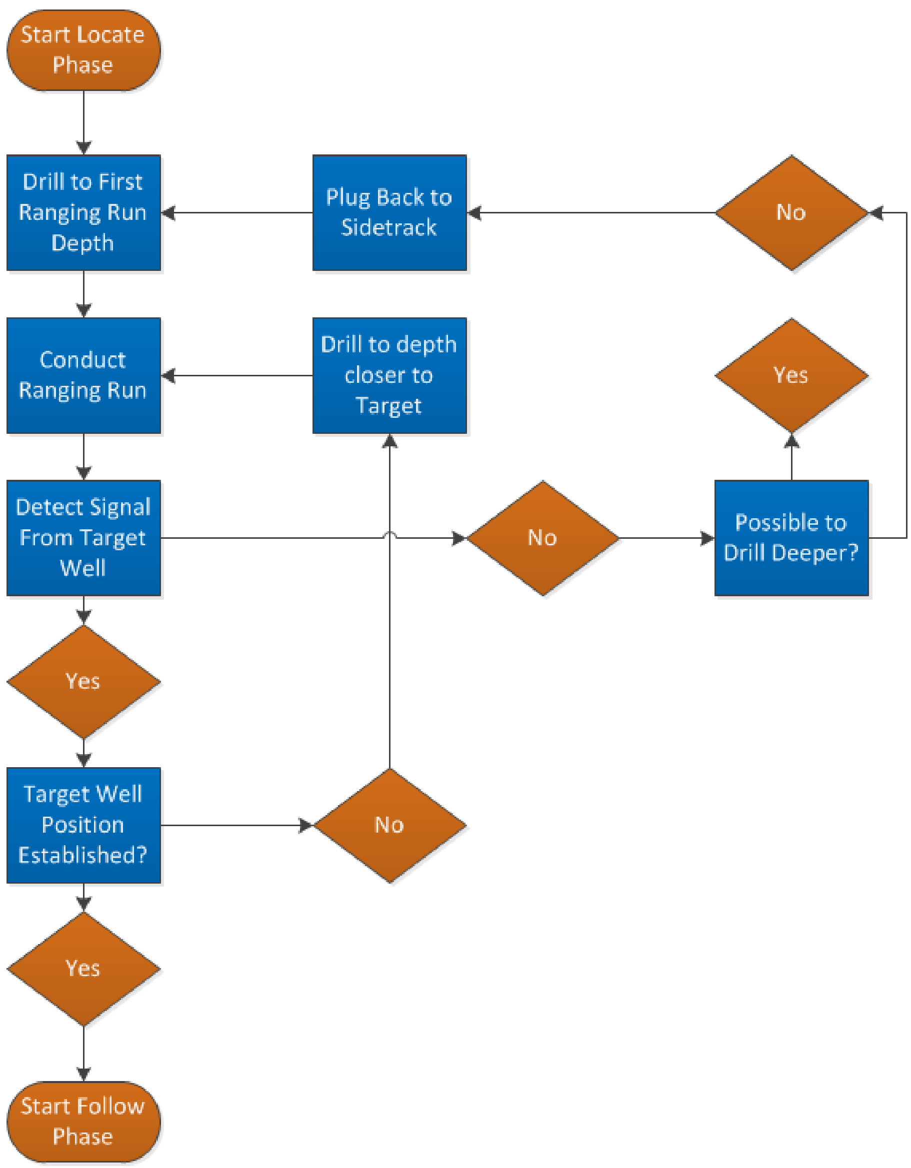


4.6 Ranging Operation Phases

4.6.1 Locate Phase

The purpose of the Locate Phase is to establish positive identification of the target well. The initial ranging runs are designed to locate the target well by seeing an increase in active magnetic signal strength and direction that can be positively identified to be emanating from the target tubular.

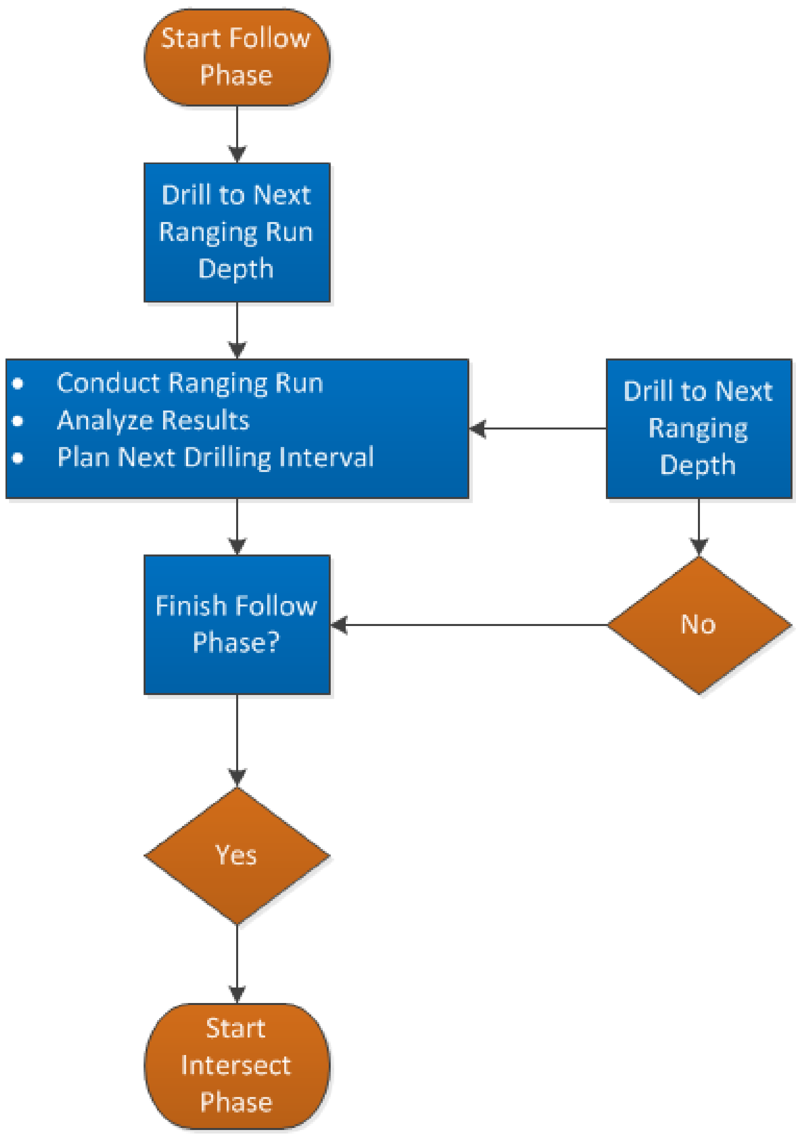
Note that the first ranging run should be determined by the ellipse of uncertainty of both the target and relief wells. This is to prevent an unplanned intersection.



Locate Phase

4.6.2 Follow Phase

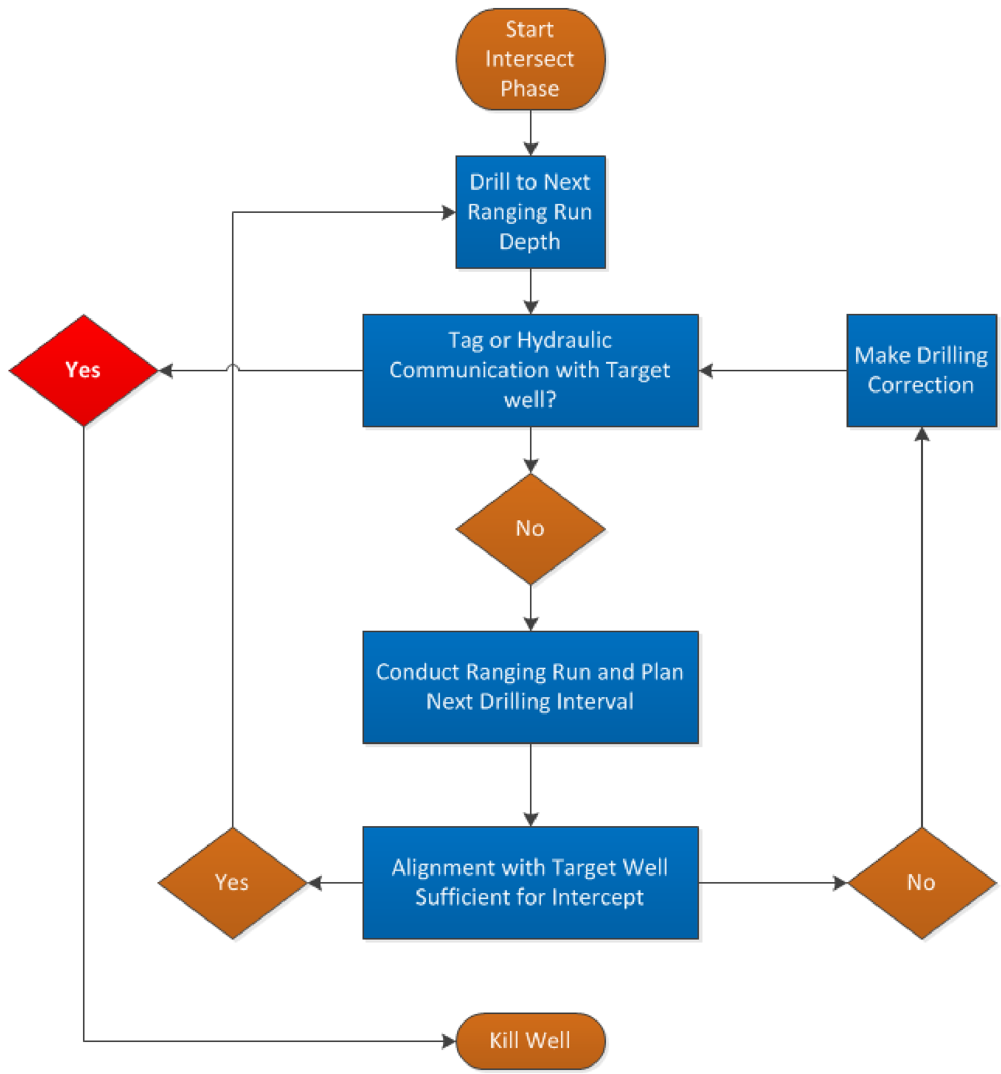
The Follow Phase consists of following the well and iteratively re-planning the relief well to the new target location. The uncertainty of ranging measurements will be reduced as the target well and relief well get closer. Each ranging run results will determine the length of the next drilling interval and will require a new well plan. A pass by with a significant angle change or triangulation to the target well at the beginning of the follow phase will further reduce uncertainties and allow for longer drilling distance between ranging runs.



Follow Phase

4.6.3 Intersect phase

The Intersect Phase consists of the final alignment of the relief well for the intended operation of either re-entry, milling, or perforating. The ranging/drilling intervals in this phase are progressively shortened to verify proximity. Wireline or surveying BHA is used to get on-bottom surveys. At intersection, the recommended incidence angle is 3° to 8°.



Intersect Phase

4.7 WellSpot Ranging Run Report

The Ranging Run Report is a key tool in keeping our customers fully informed on the progress of a relief well project. The objective of this report is to both present the current ranging results with the substantive data; and to provide a basis for the customer to understand the ranging techniques used to achieve an interception.

- Well Information – Lists general information about the relief well including the geodetic values used.
- Crew – Lists all current Sperry PR&I crew
- Summary
  - Ranging call including the dimensions of the call box.
  - Surface shift of the target well surveys required to place the well in the center of the call box.
  - May contain a short summary of the ranging results in achieving the current run objective
- Analysis
  - An explanation of the ranging data quality.
  - Outline of which surveys were used for the relief well and target well
- Technique
  - Overview of the wireline run including any issues with reaching TD or depth tracking

- Attachments
  - Tool Diagram – Fishing diagram of the WellSpot™ assembly. Diagrams issued on site include the bridle lengths.
  - Proximity Diagram – A scaled map view of the well positions at the ranging call depth. This shows the position of the WellSpot tool inside of the relief well and the resulting orientation and edge to edge separation.
  - Map View – Plots the progressive ranging run call boxes
  - AMR Raw Data Plots
    - High Side to Target – Raw data plot of the HSG2Tg as measured by the WellSpot tool. Used as a positional direction reference between the target well and relief well when the relief well has an inclination above 3 degrees.
    - Apparent North to Target Direction – Raw data plot of the magnetic direction between the target well and relief well. Used as a direction reference when the relief well has an inclination of less than 3 degrees.
    - Normalized Intensity – The active magnetic signal strength measured by the WellSpot tool. Used to qualify the ranging data and for wellbore proximity. Measured in uA/m/A, this measurement is independent of the earth's field or the remnant magnetic signature of the target well pipe.
    - Distance to Target – Plot of the raw gradient data. High data scatter will occur outside of the WellSpot gradient range.

    - Cross Axis Magnetic Field – Plot of the earth's field in the WellSpot tool's XY axis. This measurement is used to track perturbations in the expected earth's field to provide a qualitative analysis of the Apparent North to Target reference.
    - Inclination and Azimuth – Plots of the inclination and azimuth as measured by the WellSpot tool are used to correlate the WellSpot data with the relief well surveys. Discrepancies between the relief well survey data and these plots indicate depth or survey positional errors which may skew the ranging results.

- Definitive Surveys – target well and relief well surveys used in the calculation of the ranging results.

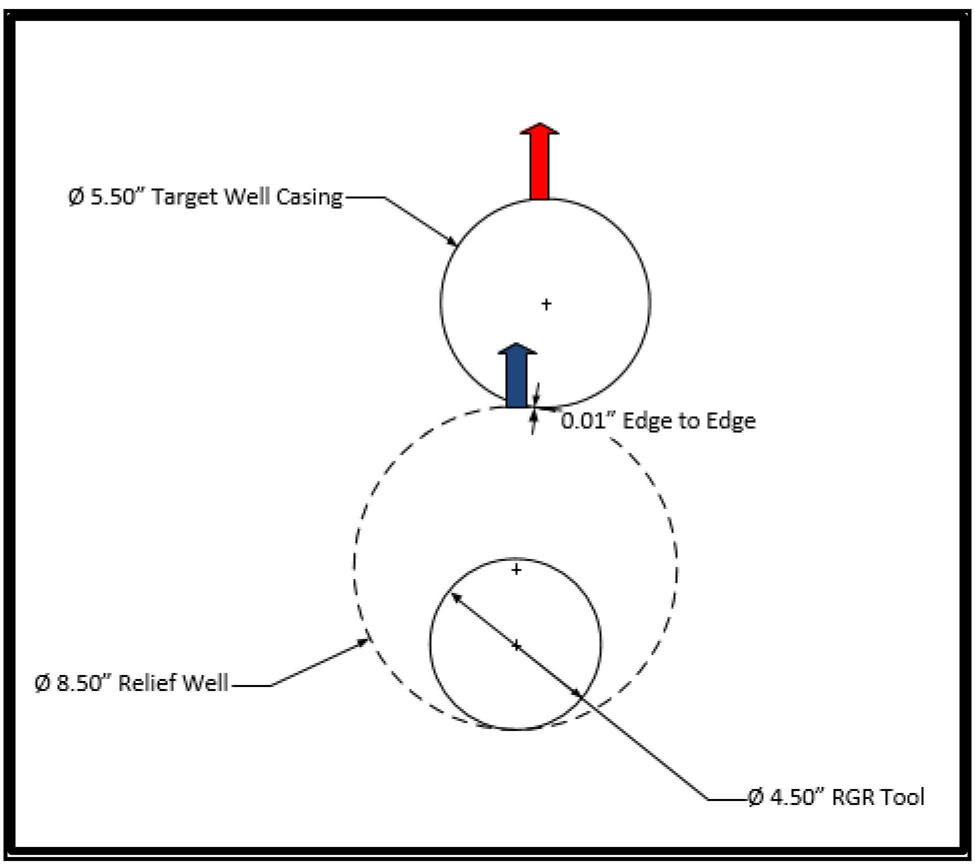
4.8 Plan Forward Report

The Plan Forward Report is a summary of the Interception Specialist briefing which is given before the start of each drilling interval. Details of this report include:

- Recommended drilling interval TD
- Targeted survey position for the end of the drilling interval
- Detailed explanation of what the next drilling interval will accomplish
- Expected proximity at the end of the next drilling interval
- Drilling performance thresholds that must be reached for the drilling interval to continue as planned

For milling operations, this report is used to document:

- The depth that contact was made with the TW
- Milling program:
    - Mill to be used
    - Milling orientation
    - Time milling parameters
    - Projected milled window length
    - Milestone for analysis of milling progress
- Scale diagrams of the current and projected proximity diagrams.



4.9 Drilling & Ranging Operations

Drilling a RW is not substantially different from any other directional well; the main difference in terms of the drilling operations is how the planned well path is updated based off the ranging run results. Once inside the detection range the drilling is halted at specific intervals to complete a ranging determination (Ranging Run).

4.9.1 Drilling Intervals

Before each new drilling interval, the Interception specialist will make a recommendation (Plan forward Report) on how far to drill before the next ranging run is required. Each drilling/ranging interval has a specific goal; the length of the interval and the purpose of the next set of ranging data will be explained in detail.

The drilling interval (distance in MD) between the ranging runs will primarily depend on:

- Ranging phase:
    - Locate Phase – Typically there are 3-4 runs required to complete the locate phase. The locate phase starts with establishing ranging detection and is completed with the pass-by. Intervals of 25m-50m should be expected
    - Follow Phase – The drilling intervals in the follow phase are planned as large as possible, without risking an early interception or loss of ranging detection. The number of runs will vary depending on the overall MD of this phase, TW survey quality, and if there are any directional changes in the TW. Intervals of 100m-500m are possible.
    - Intercept Phase – in the last ~100m before the intercept depth, highly accurate well proximity and directional control are critical for a success. Expect 4-5 intervals starting at 40m spacing and progressively reducing to 5m. A final ranging run after contact is made to confirm alignment before milling,
- Survey quality – The interception specialist uses the TW surveys to predict the TW well path ahead of the current ranging depth; this information allows the RW to be drilled to complete the interception (or phase objective). In the case of wells with poor survey quality, or no surveys, the path of the TW must be projected forward using the ranging data. Based on historical data, a BO with high quality surveys will take approximately 14 ranging runs to complete the interception. For TW with low quality, or no surveys, the expected number of ranging runs may be in the low 20’s.
- TW geometry – Whenever possible the intercept point of a TW should be selected in a tangent section of the well. In a tangent section, the well path is predictable and will take fewer ranging runs to complete the interception. If the intercept must be planned in a section with directional changes, shorter drilling intervals will be required to maintain the alignment.

4.9.2 Ranging Data Collection Plan

Once the ranging program has started, the Interception Specialist will recommend the target depth of the next drilling interval. Before ranging the newly drilled interval, the Ranging Specialist will custom design a data collection plan to meet the phase goal and minimize the overall time required. As part of the data collection plan the WellSpot team will consider:

- **Data density** – The required data density will be determined by the phase of the RW. For example:
  - For the locate phase, data taken to map the pass-by will generally be evenly distributed over the entire ranging interval. For a 25m drilling interval the data will be collected on bottom and for every meter up to the end of the last interval.
  - During the follow phase, the most important data will be on the bottom depths. For this ranging interval, the data will typically start at 0.5m intervals then incrementally increase in spacing.
  - Near the end of the intercept phase, high-density data may be taken starting as small as 0.1m intervals.
- **Overlap data** - This data is taken at the end of each ranging interval and is used to:
  - Assist the with WL depth control
  - As a QC of the previous runs data
  - To ensure repeatability when the ranging assembly has been modified
- **Infill Data** – In some cases, the first pass of data will be taken at a lower density and will be overlapped with infill data on a second WL descent. This low-density first pass is designed to give the Interception Specialist and Ranging Specialist enough data to make a preliminary determination and start the plan before all the data has been taken. This is typically used on shallow P&A wells to eliminate any potential planning delays.
- **On Bottom Data** - If on bottom data is critical, typically in the locate and intercept phases, the customer will be advised of the additional hole cleaning requirements.
- **Depth Control** – Depth control during a RW is critical for both drilling and ranging operations. With the drilling and ranging depths being tracked by two separate systems (pipe tally & wireline depth), it is critical that any discrepancies be recognized and accounted for. Driller's depth (pipe tally) and wireline refusal depth (WL encoder depth) should match within a few tenths of a meter. Casing shoe depth (both in and out run), WL refusal depth, and the overlap data from previous runs are all used to correlate these two depth-tracking systems.

5 Levels of Contingency Relief Well Planning

The industry wide focus on contingency preparation has most operators looking for relief well planning solutions. A relief well contingency plan has two components:

1. Drill – Includes relief well trajectory design, ranging, and the method used to make hydraulic communication with the target well. This "Drill" plan should also include contingencies for alternate intercept depths, interception methods, contingency casing strings, and possibly an entirely separate relief well planned from an alternate surface location.
2. Kill – Includes the static and/or dynamic kill modeling, required equipment and services, hole/casing design, and procedures to be followed prior to and when hydraulic communication has been established.

The end product delivered to the operator can be separated into three levels of contingency planning, with the suitability of each level dependent upon the local regulatory and/or operator requirements. The three levels of relief well contingency planning and their features are as follows:

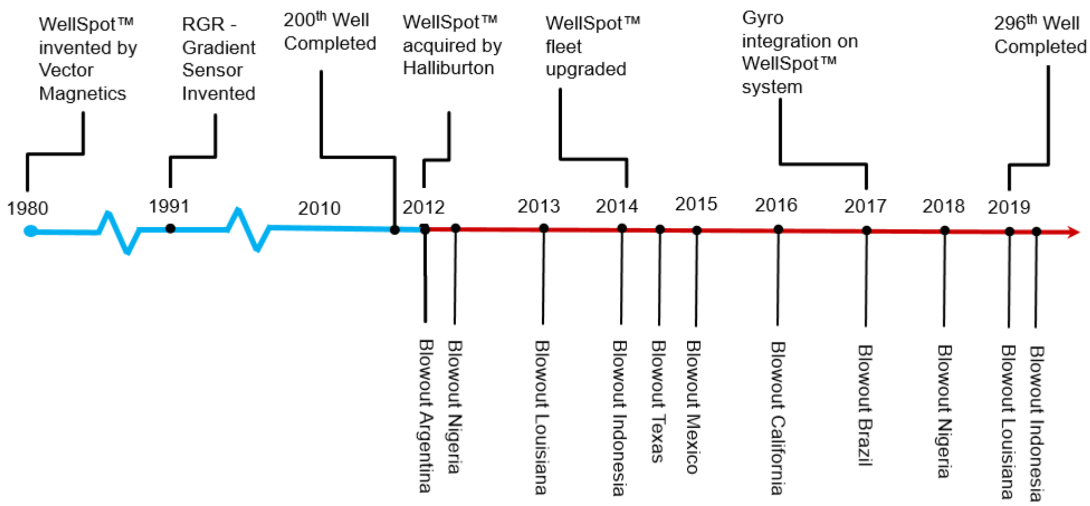
1. Well Plan Only - This is most often produced by in-house or a directional services well planner. This level of planning may include considerations for surface location selection and basic dynamic kill modeling.
    a. Advantage - This plan may satisfy the minimum local regulation requirements for a relief well contingency plan
    b. Disadvantages:
        i. Without the review of an experienced well control provider, this level of planning may not have a fully considered Kill plan.
        ii. It is unlikely that the Drill Plan will include the modeled operating specifications for the selected ranging service.
        iii. Most of the contingency plans designed at this level will not include alternates for either the Kill or Drill components of the plan.
    c. Risk – In the event of a blowout, the decisions made in the execution of this plan may negatively impact the ability to intersect and kill a blowout.

2. Well Plan and Well Control – Most well control service providers offer a detailed relief well planning service that will cover the Kill plan in great detail:
    a. Advantages:
        i. A fully considered Kill plan with the requisite alternates
        ii. A Drill plan that is designed around the operators' general relief well trajectory requirements.
    b. Disadvantage – If the operator is planning on using WellSpot for ranging service, there are no well control providers who have the ability to model the WellSpot signal response.
    c. Risks:
        i. With a trajectory designed without a modeled ranging signal analysis and fully considered operating parameters, the well may reduce or eliminate the viability of this contingency plan.
        ii. Like the well plan only version, this plan may mistakenly guide the operator to action portions of a contingency plan that will negatively impact the ability to intersect a blowout.
3. Well Plan, Well Control, Interception and Ranging – This is the only level of contingency planning that can be considered comprehensive and fully actionable.
    a. Advantages:
        i. With this level of planning in place, the operator may prearrange contracts for all required third party services.
        ii. Commence the drilling of a relief well at the start of an incident.
        iii. Pre arrange the appropriate level of contingency materials such as casing string.
        iv. Once this plan has been established for a field, the lessons learned from the design of a single plan can be used as a template and, in most cases, can be applied to the offset wells.
    b. Disadvantages: Other than costs, there are no disadvantages to this level of planning.
    c. Risks – Applying the lessons beyond the local field may lead to assumptions that will invalidate the Drill and/or Kill plan.

6 Experience

6.1 WellSpot Timeline

Active magnetic ranging was invented by Vector Magnetics in 1980; branded as WellSpot™ it has been the premier choice for relief well operations. WellSpot Operations were taken over by Halliburton in 2012.



6.2 Well History (2012-Aug 2020)

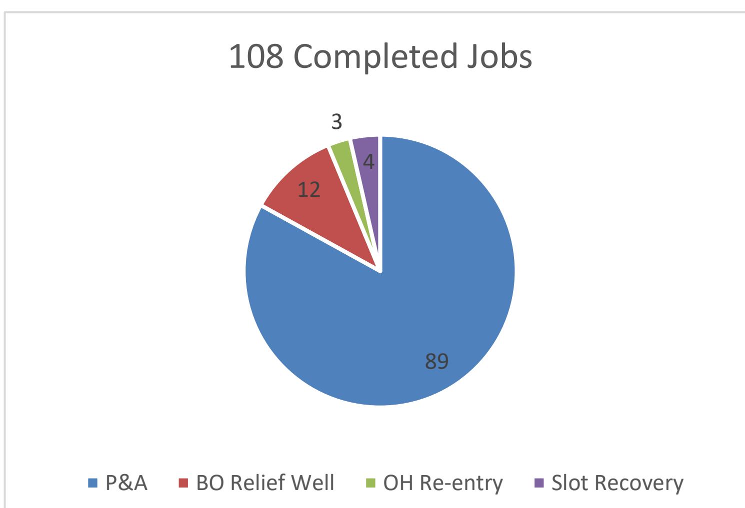
WellSpot was initially developed for blowout relief wells. WellSpot uses have expanded to a variety of other applications. Currently, about 80% of WellSpot jobs are for plug and abandonment (P&A) operations.

6.2.1 Blowout Relief Well Summary

- Completed Wells since 2012: 12
- Average Days to Complete: 47.2 days
- Average Ranging Runs: 16.5 runs
- Success Rate: 12/12 (100%)

6.2.2 P&A Intervention Well Summary

- Completed Wells since 2012: 89
- Average Days to Complete: 20.5 days
- Average Ranging Runs: 12 runs
- Success Rate: 89/89 (100%)



6.3 Team Experience Overview (By Position)

A WellSpot crew consists of four personnel. Each team lead (Interception Specialist) has over 1000 days of **well intercept** field experience; with the entire crew bringing over 2500 days experience to the customers job site.

	# of personnel	Average Experience (Years)		WellSpot Averages	
		Industry	WellSpot	Field Days	Well Intercepts
Interception Specialist	4	14	7	1040	45
Ranging Specialist	7	14	7	549	20
Ranging Support Specialist	3	16	5	716	35

6.4 Blowout Relief Well Summary (2012-2019)

WellSpot has been the primary system used on every major blowout since 1980. Since 2012, approximately 1.5 relief wells per year has occurred globally. WellSpot has been 100% successful on every relief well since its invention.

Year	Well	Location	Intercept Depth	Surface Separation	Runs	Days
2012	Argentina	Land	2053 m	304 m	18	43
2012	Nigeria	Offshore	9220 ft.	1856 ft.	15	49
2013	USA	Land	2995 ft.	1000 ft.	7	10
2014	USA	Land	11632 ft.	1998 ft.	10	24
2014	Indonesia	Land	2000 ft.	450 ft.	17	36
2015	USA	Land	8167 ft.	1480 ft.	29	49
2015	Mexico	Land	3080 m	1278 m	9	37
2017	Brazil	Offshore	3189 m	500 m	17	42
2018	Nigeria	Land	3236 m	330 m	21	87
2019	USA	In-Land Water	14468 ft.	50 ft.	20	94
2019	Indonesia	Offshore	8977 ft.	1022 ft.	11	38

6.5 P&A Intervention Well Data Summary (2012-2019)

Approximately 80% of WellSpot usage is on P&A operations, the majority of these being shallow. These jobs follow the same procedures as relief well operations; the only difference is these wells do not require well control.

Interception Depth >2000 ft.

Year	Number of Wells	Average Runs	Average Days	Success Rate	# Requiring a Sidetrack
2012	3	16	36	100%	0
2013	1	15	27.5	100%	0
2014	5	14.7	23.3	100%	0
2015	2	15	20.6	100%	0
2016	1	16	18.8	100%	1
2017	6	14.8	29.4	100%	0
2018	1	15.8	17.3	100%	1
2019	3	15	18.6	100%	0

***Note: For an intercept of over 2000', a sidetrack is rarely required. The sidetrack rate for the last 8 years is less than 10%.**

Interception Depth <2000 ft.

Year	Number of Wells	Average Runs	Average Days	Success Rate	# Requiring a Sidetrack
2012	0	0	0	0	0
2013	5	15	27.5	100%	0
2014	7	14.7	23.3	100%	2*
2015	10	15	20.7	100%	3*
2016	5	16.2	18.8	100%	2*
2017	10	14.9	29.4	100%	8*
2018	13	14.9	34.3	100%	6*
2019	13	5.8	18.6	100%	2*

***Note: For shallow intercepts a planned sidetrack is often used as a pre-planned technique to reduce the days/runs required**

7 Acronyms and Definitions

Magnetic Ranging – Systems that provide distance and direction (this is the definition of a mathematical vector) to the tubular of a target well. There are two types of magnetic ranging systems: Passive and Active.

Passive Magnetic Ranging – This relies on remnant magnetic properties on a target tubular, or the end of a pipe to disrupt the normal earth magnetic field. Tools with magnetometers see these disruptions as anomalies on their magnetic field data. By collecting enough data can often allow for the interpretation of a distance and direction to the target tubulars.

Active Magnetic Ranging – An alternating electrical current is injected into the formation some distance above a Vector Magnetics receiver. This current flows through the formation and naturally collects on the target tubulars because current flows easier on steel pipe than rock. Once the current starts to flow and oscillate a magnetic field is created. The field is detected by the Vector Magnetic receiver and is converted into a direction number and a magnetic field intensity number. These numbers are collected at various depths during a ranging run and an interpretive model is used to provide the distance and direction to the target well; a vector. This vector is given to Boots and Coots who can determine a well plan to the next ranging depth.

WellSpot™ tool (WS) – A magnetic ranging tool that provides highside data to the target well using magnetometers and accelerometers. Provides Highside, Apparent North to Target, Intensity, Earth magnetic field data, inclination and magnetic azimuth data.

Radial Gradient Ranging Tool (RGR) – This is a WellSpot tool with two sets of magnetometers. This allows for the collection of direct distance to target numbers when the signal intensity is strong enough. This is extremely accurate when the wells are very close together; around 8 ft or less. Sometimes direct distance data occurs at greater distances but is not as accurate.

Highside to target (HSTg) – This is an angle from the highside of the drilling well (the perpendicular pointing opposite gravity to the direction of the drilling well) to the target well. 0° highside means the target is dead ahead or above the drilling well. 180° highside means the target is behind or below drilling well. A highside of -90° means the target is to the left and +90° is to the right of the drilling well.

Normalized Intensity – The strength of the magnetic field from the target measured in micro amps per meter per amp or uA/m/A. Data is acquired at stations in the well like a seismic tool. The tool must be absolutely still. Current is injected into the formation via the transmitter or electrode. This current is never the same value from station to station (depth to depth). To make a graph that is easy to read the current is "normalized" at each depth so that intensity readings on the graph are based upon 1 amp or current. For example at 6000 ft. we inject 4 amps of current and get a reading of 1200 ua/m. This is then divided by 4 to get 1200/4 = 300 uA/m/A. At 5900 ft. we injected 5 amps and the intensity recorded was 1500 uA/m, on the graph the reading would be 1500/5 = 300 uA/m/A.

Apparent North to Target (ANTg) – This is used when trying to range to a vertical well. At low inclinations (< 3°) azimuth and highside start to become undefined. Think of ANTg as Highside to target except pointing towards Magnetic North, but not quite.

Total Cross Axis Magnetic Field – This is the measurement of the earth's magnetic field in the plane perpendicular to the WellSpot™ tool. It is a way to see magnetic perturbations from the target well.

Distance to Target – This is an actual measurement from the center of the RGR tool to the center of the targets tubular. This is very accurate when we are within a few feet of the target well. This is what allows us to mill and re-enter target wells.

Call Box – This is the uncertainty determined by the Vector Magnetics engineer of the answer provide to Boots and Coots. Magnetic ranging relies on interpretive modeling to determine the vector to the target. There is a level of uncertainty to that answer. As the strength of the magnetic field increases the accuracy of the data improves and the call box becomes smaller.

CML tool – Continuous Magnetic Logging tool is a means of collecting Passive magnetic data while moving the wireline. It is useful when there is a magnetic field present on a target well and provides information about the depth of packers and can also be used to provide a vector to the target if the signal strength from the target is sufficient.

Ranging BHA – By using gap subs to isolate the electricity coming from the transmitter away from the receiver and the wireline data can be acquired behind the BHA. The WellSpot™ tool needs to be in non-mag drill collars.

Target well shifts – These are numbers reported each run stating how much the target well had to be shifted from its original position (usually 0.0 ft. N and 0.0 ft. E) to have the interpretive model fit the ranging data. Sometimes just shifting the well is not enough for the model to fit the data and one of the surveys has to be modified. The majority of the time it is the target well survey that is modified.

Horizontal plane distance and direction – This is the tie from the drilling well to the target well stating where the target is located. This is the same as moving the position of the target well on a two dimensional map.

Weighted sleeves – Bearing bronze cylinders that can be screwed together to create a non-magnetic weighted assembly to help the WellSpot tool descend inclined wells.

Combo-Tool – Combination of the WS – CML and Gyro/Data tool. This allows three different tools to acquired data on a single trip in the well. Usually separate passes are required over the interval of interest.

For Additional Information and Inquiries Please Contact

Alan Gosse
Operations Leader – Proximity Ranging & Interception
Alan.Gosse@halliburton.com
Cell: 405.464.1244

Ryan Zallas
Service Coordinator – Proximity Ranging & Interception
Ryan.Zallas@halliburton.com
Cell: 281.467.4805