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Integrated Services Achieves Multi-String Casing Exit and Re-Drill in Geothermal Well

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ABSTRACT

Tests and surveys on the Kapoho State-11RD, a geothermal well on the island of Hilo in Hawaii, indicated a shallow leak into the formation zone. Injection fluid was traveling through the current fractures from the re-drill to the original wellbore, creating interference problems with the production zone of another well. Re-drilling was considered, but the decision was made difficult by previous re-drilling and workovers to the well and the proximity of any new bore to the previous bores.

A coordinated research effort involving Baker Hughes Integrated Services and Puna Geothermal Venture revealed that the most economical procedure would be to relocate the target and kick-off point, sidetrack the well by performing a casing exit through the two casing strings to increase the separation from any previous wellbores, and then directional drill the hole to the designated target.

A window was milled in 17½ hr, including drilling 15 ft of formation below an extra-long whipstock ramp that was more than 19 ft long. The lighter-weight mill-cutting tool enabled the mills to stay on the ramp and avoided premature jumping off the ramp. Even though the T-95 grade casing usually requires several runs to mill a window through two strings, and drilling with a polycrystalline diamond compact (PDC) formation window mill also is difficult, the window was successfully milled. When running the drilling bottomhole assembly (BHA) through the window, no drag was encountered. The 7-in. casing was also run through without drag and then cemented.

The 5⅞-in. productive interval was drilled to the lease line stand off without encountering any significant production, and this entire interval was abandoned. A second window was milled several hundred feet above the first, through the same two strings of casing, using the same equipment and methods. This window was similarly successfully milled in 17½ hr. The 8½-in. hole was drilled and the 7-in. liner was run and cemented. The 5⅞-in. productive interval of this sidetrack was successful in encountering the top of production at 5,135 ft and was drilled to 6,872 ft, where pipe was inadvertently stuck in the hole. It was completed with 4.5-in. pre-perforated liner from 4,755 to 5,861 ft and a combination 7-in. and 5-in. alloy injection hang-down string from surface to 3,038 ft.

Job success was attributed to a team effort involving Ormat Technologies, Geothermal Resources Group and Baker Hughes Integrated Services. Coordination included the engineering, technical advice and field support services to achieve this task. This paper describes the well condition, the project plan, the equipment/materials used, and the procedure.

1. CASING EXIT TECHNOLOGY OVERVIEW

Prior to the progression of wellbore intervention technology, specifically at the advent of casing exit technology, improper trajectory of a cased wellbore into a reservoir necessitated that another well be drilled to potentially reach the intended "pay-zone". The capability to exit a well's main bore casing came from the need to reach a desired reservoir zone without drilling an additional main bore and well.

The primary methods of creating an exit in casing include section milling and window milling. As the name suggests, section milling involves milling away the complete circumference of a length of wellbore casing or liner at a predetermined well depth. The section milling method of exiting casing can be completed using available equipment such as section mills.

In a geothermal well, however, the formation behind the casing is usually abrasive, and when using a section mill, the carbide milling arms are prematurely depleted and require several runs to mill the window. Section milling through two strings of casing would require several runs and be very costly. The additional rotations per minute from the drill pipe tool joints contacting the casing while milling can cause excessive wear to the casing above the window. An advantage of the window milling method over the section milling method is that less cutting debris material must be circulated out of the well during the window milling, Guidry, Pleasants, and Sheehan (2010)

2. WELL BACKGROUND INFORMATION

The Kapoho State-11RD well, a geothermal well on the island of Hilo in Hawaii, previously underwent a re-drill and several workovers. The original 11¾-in. casing was set at a depth of 5,061 ft. It was plugged back with 195 ft^3 of cement at 4,652 ft, and a window was milled from 4,367 to 4,422 ft. This enabled an initial re-drill, with a 10⅝-in. hole that was drilled to 7,950 ft.

An obstruction in the well necessitated that this well be re-plugged, this time back to a depth of 6,430 ft. An 8⅝-in. slotted liner was hung from 4,192 ft to a depth of 6,405 ft, and then a 9⅝-in. liner was cemented from the surface to 3,200 ft, to seal off holes in the 11¾-in. casing. During a workover in 2006, a 6⅝-in. liner was cemented with latex cement from 4,028 to 4,752 ft.

Another re-drilling of the KS-11RD well was considered because injection fluid was traveling through the original well and interfering with the production zone of the nearby KS-5 well. A spinner survey performed in 2006 indicated that most of the injection fluid was entering the formation zone at 5,000 ft. Results from a nitrogen purge test in April 2008 revealed that the shallowest wellbore leak was at 4,835 ft.

2.1 Casing Exit and Re-Drill Plan

There was some risk that a re-drill of KS-11RD would result in unwanted fluid flow into the production of KS-5 from KS-11RD. However, this risk could be minimized by plugging the current wellbore with clay and cinders, and re-drilling KS-11RD from a point over 1,000 ft in vertical distance from the shoe and to the southeast, to a new target in the KS-5 production interval.

The most economical procedure was to relocate the target and sidetrack the well at 3,200 ft to minimize doglegs while directional drilling the hole to the designated target and increasing the wellbore separation in the productive interval. Performing a casing exit at this depth would save the customer the cost of preparing a new surface location well pad, pipelines to the plant, and wellhead equipment. The associated costs of drilling three hole intervals and three strings of casing and cementing also had to be considered.

The directional services team planned a well path map from the casing exit to the new target. The exit depth was determined to be 3,200 ft. At this location, the well had 9⅝-in. 54 lb/ft T-95 casing cemented inside 11¾-in. 65 lb/ft T-95 casing. This plan required milling a window through both casing strings and using a whipstock oriented to the desired target to avoid any casing couplers. (See Figure 3 for an exemplary test fixture used during a casing exit test of the improved casing exit milling system.)

2.2 Motor and Bit Details

For the 8½-in. hole section, a 6¾-in. medium-speed extra-high torque high-performance downhole motor was selected. This motor had a 5/6 lobe power section, 0.33 rev/gal ratio and 5,050 ft-lb of torque. The bit selected was an International Association of Drilling Contractors (IADC) Code 517. This bit had single energizer metal seal to provide long life in a high-RPM motor application. It was also equipped with extra stabilization and enhanced OD protection. The objective goal was to drill each hole section (8½-in. and 6½-in.) with one selected motor and drill bit.

The objectives were accomplished by meeting the directional needs and completing this 1,836-ft section with one motor and one bit. The 6-1/4-in. run took 63.5 hr with a 29.61 ROP. The IADC code 517 bit accumulated 892K revolutions on the bearing, which included drilling, reaming and hole cleaning.

For the 5-⅞-in. hole section, a medium-speed extra-high torque 4¾-in. motor was again selected with a 5/6 lobe power section, 1.03 rev/gal ratio and 2,600 ft-lb of torque. The 5-⅞-in. bit was an IADC Code 447. This bit had single energizer metal seals to support the high-RPM motor application. It was also equipped with enhanced leg protection.

Again, the hole section objectives were met, drilling 1,990 ft in 63 hr for a 31.7 ROP. The IADC Code 447 bit also accumulated 889K revolutions. Due to hole problems, this bit was lost in hole and never recovered. For this reason, its dull grade was not rated.

The KS-11RD3 was directionally drilled off an oriented whipstock. The whipstock was set and the milling BHA milled through a dual 9⅝-in. and 11¾-in. casing string. The 8½-in. directional hole was drilled to a depth of 4,909 ft. This re-drill was completed in 6¼-in. hole to a total depth of 6,872 ft. The objective goals were met, drilling each hole section (8½-in. and 6½-in.) with one selected motor and drill bit.

KS-11RD3 Puna Geothermal Ventures Parameter Sheet

IADC	Size	Motor RPM	Rotary RPM	Total RPM	Footage	Motor Bend	GPM	WOB	ROP	Hours	Krev's	Slide %	Rotate %	Dull Grade
517	8½	197	30	227	1836	1.3	597	30k	29.61	62	892	35%	65%	3, 3, WT, A, E, I, NO, HP
447	6¼	212	30	242	1999	1.5	206	13k	31.73	63	889	13%	87%	Lost In Hole

Point of interest data was aquired from Bit records and Baker Hughes INTEQ DDRs

8½ IADC 517 bit also used for reaming and cleaned the hole section for a total additional 24 hours this is reflected in total Krev's (1000 revolutions).

6¼ IADC 447 bit has no dull grade because the bit was lost in hole.

2.3 Drilling Fluid Details

The drilling fluid system used on the Puna KS-11RD2 and the 11RD3 was a Bentonite/Xanthan Gum mud system. This system was comprised of Wyoming bentonite, a complex polysaccharide and xanthan gum. The complex polysaccharide (BPac) used in conjunction with Wyoming bentonite and xanthan gum provided improved shear thinning characteristics. The API fluid loss was further controlled with a vinyl sulfonated copolymer (AMPS/AM), Perricone et al.,(1985). Micronized cellulose (MicroCell) was used as the primary lost circulation material (LCM). The LCM concentrations in the mud system ranged from 2% up to 5% by volume, depending on the severity of mud losses, Rickard et al., (2010). Additional MicroCell was used for sweeps to improve hole cleaning and to control seepage. The approximate formulation and fluid properties of the Bentonite/Xanthan Gum mud system are shown in Tables 1 and 2**.**

Product	Description	Function	Concentration (lb / bbl)
Gel	Bentonite	Viscosity and fluid loss control	10 to 17.5
BPac	Complex polysaccharide	Low shear rate viscosity and fluid loss control	0.4 to 0.75
Xanthan Gum	Biopolymer	Low shear rate viscosity	0.3 to 0.5
(AMPS/AM)	vinyl sulfonated copolymer	Viscosity and solids suspension	0.3 to 0.5
(MicroCell)	Micronized cellulose	Lost circulation and in sweeps for improved hole cleaning	2% up to 5% by volume

Table 1: Formulation of Bentonite/Xanthan Gum Mud System

Fluid Property (active mud system)	Range
Density, ppg	8.5 to 8.9
Funnel Viscosity, sec/qt	40 to 44
Plastic Viscosity, cP	8 to 14
Yield Point, lbf/100 ft^2	9 to 12
10 sec Gel Strength, lbf/100 ft^2	3 to 4
10 min Gel Strength, lbf/100 ft^2	5 to 7
API Filtrate, ml/30 min.	10 to 19
pH	7.5 to 9.0 (max of 11.5 from cement)
MBT, lb/bbl Bentonitic Equivalent	10 - 15

Table 2: Fluid Properties of Bentonite/Xanthan Gum Mud System

The well was drilled 4,745 ft and a drilling liner was run cemented. Then it was drilled to the standoff from the lease line without encountering any significant production zones. The well was plugged back again to just above the window and sidetracked through a second window that was just as successful as the first. A drilling liner was run and cemented from 2,824 to 4,873 ft.

When the target zone was reached on the KS-11RD3 well, a total loss of circulation occurred. Thereafter, water was used as the drilling fluid. The remaining mud was isolated on surface, conditioned with micronized cellulose, and used for sweeps to assist with hole cleaning and suspension of drilled cuttings. A sweep of approximately 20 bbl was pumped for every 15 ft of hole drilled, and more frequently when necessary. The water was fed directly into the pill tank and used for drilling. Partially-hydrolyzed polyacrylamide (PHPA) was added to the water to improve lubricity.

3. CASING EXIT AND RE-DRILL HISTORY

The re-drill plan would begin by filling the lower portion of the wellbore with cinders and clay. Cement would be placed on top of the sand and clay, and then a whipstock would be set on top of the cement. The well would be re-drilled with an 8½-in. bit to 5,000 ft and then 7-in. casing cemented in place to seal off any possible leakage to the old wellbores before drilling the productive interval.

3.1 Re-drilling History

Mobilization and rig-up occurred on October 29, 2009 and blowout prevention equipment (BOPE) was nippled up on KS-11. The 22CR alloy hang-down injection liner was pulled and laid down. Cleanout occurred through the 9⅝-in. and 11¾-in. casing and to 4,863 ft inside of the 8⅝-in. liner. The original wellbore was abandoned with sand and cement plugs. Cleaned out the top of cement to 3,194 ft and then pressure-tested the casing above the plug.

The whipstock was orientated and the anchor was set on the cement with the top of the ramp at 3,170 ft. The window was milled successfully to 3,202 ft in one trip. A second trip was made with a stiff milling assembly to extend the window. Then an 8½-in. hole was drilled with three LC plugs to 4,745 ft and a 7-in. drilling liner was run and cemented from 4,741 to 3,126 ft. No issues were encountered with the window or whipstock. A 5⅞-in. hole was drilled with no significant losses or productive intervals to the southeast corner of the lease.

This wellbore was plugged back and abandoned with cement to above the top of the window and a second whipstock was oriented and set on cement at 3,053 ft with the top of the ramp at 3,029 ft. Again, the window was successfully milled in one trip to 3,073 ft. The window was again extended with a stiff milling assembly. Then an 8½-in. hole was drilled to the northeast with 5 LC cement plugs and a 7-in. drilling liner was run and cemented from 4,873 to 2,824 ft. The 5⅞-in. hole was drilled to the first major loss zone (4,909 ft) with mud and then drilled blind with sweeps to keep the hole clean to the top of the production interval at 5,135 ft. Drilling continued until the assembly became stuck at 6,872 ft and was eventually abandoned in place.

A 4½-in. pre-perforated liner was run, utilizing a drill-in system and set from 5,861 to 4,755 ft and a combination 5-in., 23CR and 7-in., 22CR hang-down injection liner was run and hung from surface to 3,038 ft. Again, the hole was drilled with no issues encountered with the window or whipstock. The BOPE was nippled down and the rig moved off on December 19, 2009. Therefore, two targets were explored for production in less than two months. The normal time to complete a grassroots well is three months. Significant savings were realized.

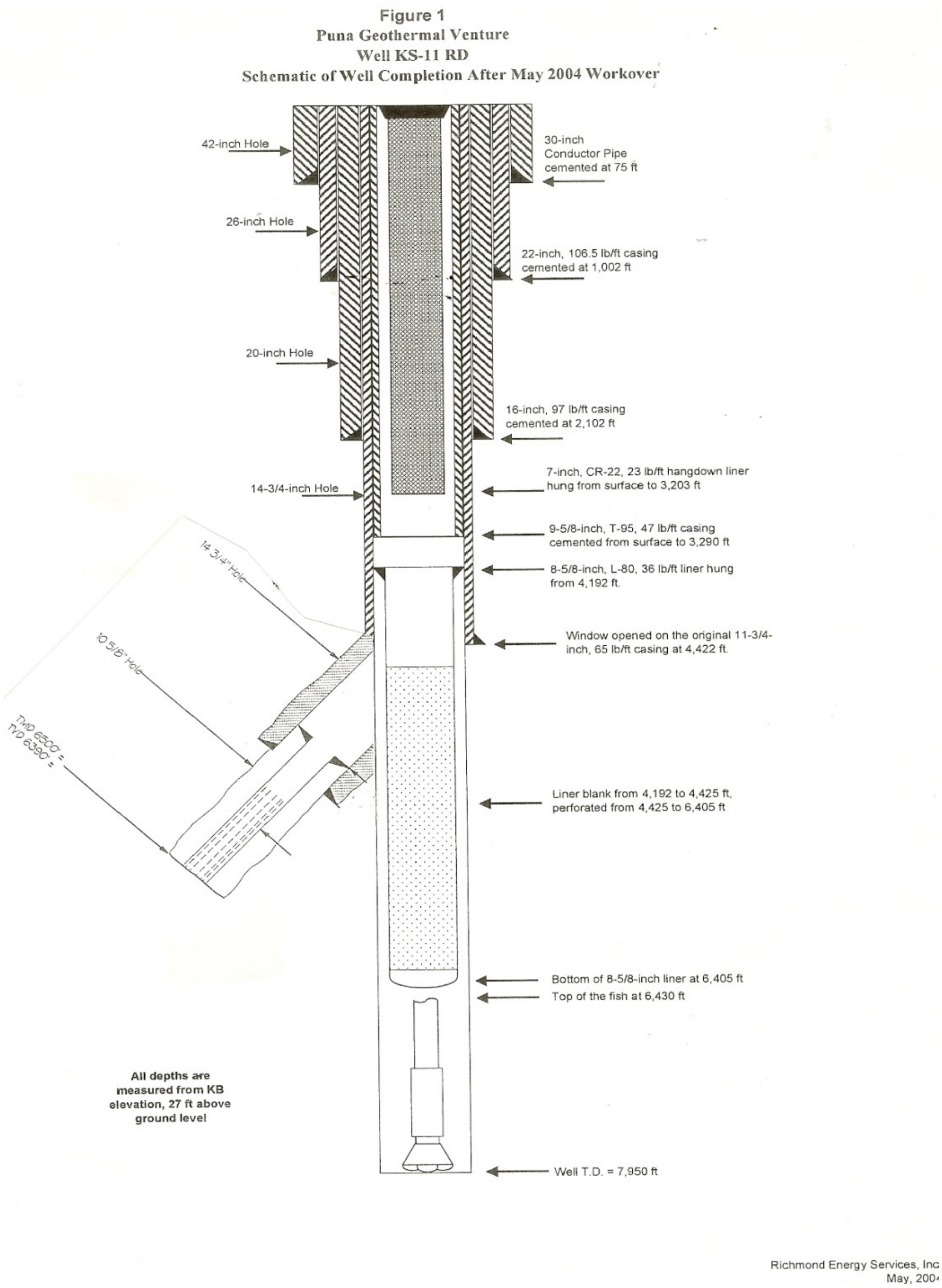

Figure 1: Schematic of well completion after May 2004 workover

3.2 Casing Exit Equipment and Materials

- Whipstock anchor
- Whipstock
- 8½-in. PDC formation window mill

- 8½-in. (special design) lower watermelon mill
- 8½-in. flat bottom mill

3.3 Well History

Displaced plug, 34 barrels of 13.5 ppg lead cement through diffuser at 3,910 ft. The cement in place at 00:30 hrs. The 5 stands were pulled out, circulated and waited on cement. Tagged cement at 3,524 ft. Tripped for slick 8½-in. bit BHA. Circulated to cool hole and waited on the replacement casing collar locator (CCL) tools and pulled out of hole. The wireline equipment was rigged up to run CCL log. The CCL tool was repaired and ran the CCL log from 3,500 ft, through 11¾-in. and 9⅝-in. casing to 2,900 ft. Ran in hole with cement diffuser to 3,524 ft. The plug # 4 was displaced, 37 barrels of 13.5 ppg lead slurry, CIP 23:20 hrs. Pulled 6 stands and circulated pipe clean. Ran in hole to the top of cement at 3,144 ft. The cement was cleaned out to 3,194 ft. Tested casing and blowout prevention equipment successfully. Pulled out of hole and tested blind rams, successfully. Rigged up and ran CCL to correlate collar depths.

Made up whipstock and milling assembly. Ran in hole and oriented whipstock with gyro. Set anchor at 3,194 ft with top of whipstock at 3,170 ft. Milled window out of (9⅝-in. and 11¾-in.) casing from 3,168 ft to 3,171 ft. Milled window off of whipstock out of (9⅝-in. and 11¾-in.) casing from 3,169 to 3,202 ft pumping high-viscosity sweeps every 5 ft (total milling time 17½ hrs.) tripped to change milling assembly. Mills gauge okay.

3.4 BHAs

BHA 1

- 9⅝-in. anchor
- 9⅝-in. whipstock with a ramp of 19.7 ft
- 8½-in. PDC formation window mill (Reference Figure 2)
- 8½-in. lower watermelon mill dressed with special carbide
- UBHO NC50 box
- HWDP NC50 box
- X-O 4½ XH box

Figure 2: Exemplary used PDC formation window mills

Reamed out window and made three passes - no drag, window good, trip out for drilling BHA.(1 hr. reaming time)

BHA 2

- Mill 4½ Regular
- X-O 4½ XH box
- X-O NC50 box

- NC50 lower watermelon mill
- NC50 upper watermelon mill
- X-O 4½ XH box
- DC (6) 4½ XH box
- X-O (1) NC50 box
- Jars NC50 box
- HWDP NC50 box

3.5 Window Cutting System

The one-trip window cutting system, with the carbide window mill or PDC formation window mill, provides a means to efficiently exit casing and provides a window through which it is suitable to run a drilling BHA, liners, and completion equipment. The complete window is normally accomplished in one round-trip with drillpipe. In one trip, the starting cut is made, the window milled, and a pilot hole is drilled for the subsequent drilling.

3.5.1 Retrievable Bottom Set Anchor

The retrievable bottom set anchor is used to anchor a whipstock in place in the wellbore.

3.5.2 PDC Formation Window Mill

- PDCs capable of milling steel and formation
- Engineered by the world leaders in casing exits and drill bits
- Cuts hard formation casing exits in one trip
- Mills window and drills an extended rathole in one trip
- Allows directional drilling to begin immediately after casing exit
- Balanced spiral set cutter arrangement for smoother, cleaner cuts
- High set carbide cutters protect PDCs while starting the exit
- Aggressive all cutter center design allows for maximum penetration rates in formation
- Watercourses guide drilling fluid flow to efficiently cool and clean cutter elements

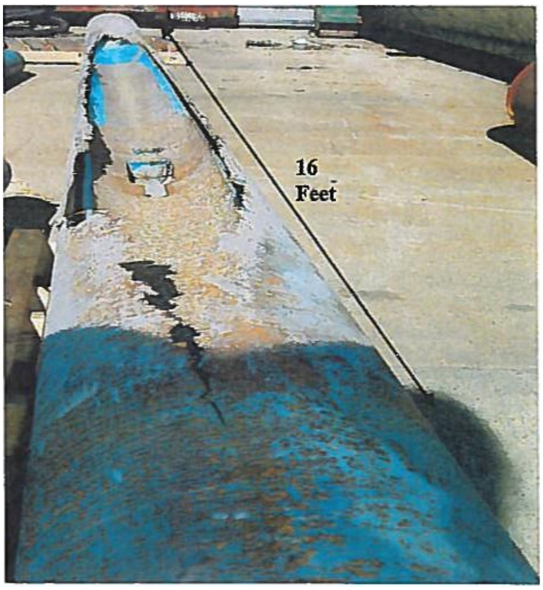

Figure 3: Exemplary test fixture used during casing exit test of the improved casing exit milling system

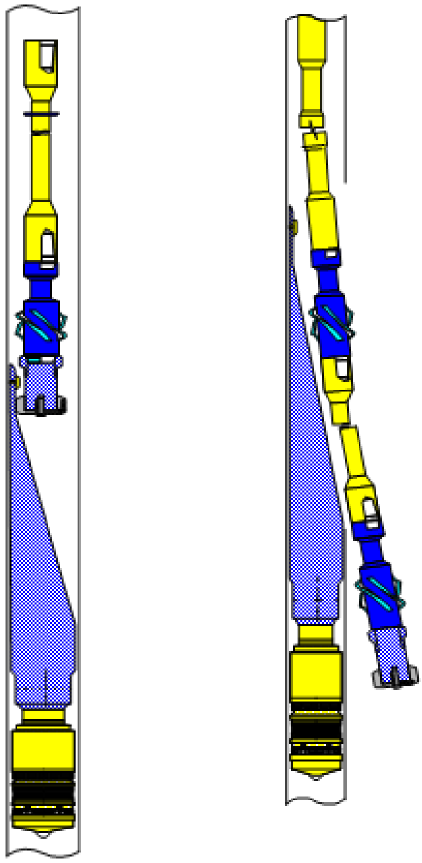

Figure 4: Milling BHAs, whipstocks, and anchors

3.5.3 Improved Casing Exit Milling System Design

When performing a casing exit, the technology includes tool strings comprised of mills with cutting structures for traversing anchored whipstocks to create elliptically shaped windows. Successful casing exit operations involve generating windows sufficiently long for easy passage of subsequently run directional drilling BHAs and creating full-gauge ratholes that deviate from the exited casing and allow passage of the casing liner through the window for completion of the well. Maintaining sufficient restraining forces on the bottom-most mill is important to keep it tracking on the face of the whipstock for the full length of the ramp. Proper restraining forces prevent an early whipstock ramp departure and help generate a long window.

3.6 Results

The window was milled in 17½ hr, including drilling 15 ft of formation below the extra-long whipstock ramp that was 19.7 ft long. Mill cutting design enhanced ROP with lighter drill weight required, keeping mills on ramp to avoid jumping off ramp prematurely. The casing was T-95 grade, which is typically very difficult to mill. It usually takes several runs to mill a window through two strings, and the formation is very difficult to drill with a PDC formation window mill. The hole was drilled successfully with no drag when running drilling BHA through window. The 7-in. casing was run and cemented with no drag while going through.

4. CONCLUSION

Job success was attributed to a team effort. Geothermal Resource Group and Baker Hughes (Integrated Services) worked as a team, contributing engineering, technical advice and field support services to achieve this task.

4.1 Special Acknowledgement

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