Over the last ten years, new technologies and field strategies have converged, enabling operators to give new life to old wells. Now, reviving production from declining fields has become a major activity for oil and gas companies, and one that requires more support to identify the right technical solutions. Optimizing well output and economics are the key goals of these production enhancement projects and service companies are actively participating in achieving these goals.

This growing demand has pressed companies in the service sector to diversify their skills and address a wider range of reservoir and production problems. It has also stimulated a flurry of technical creativity. For example, developments in the area of reentry drilling alone—coiled tubing drilling (CTD), slimhole measurements-while-drilling (MWD) systems and new completion technologies for multiple sidetrack boreholes—have produced a wealth of options for maximizing return on investment (ROI). But which approach offers the best solution; how should it be applied; and in which wells?

To help operators address these questions, service companies have reorganized to provide multiple integrated services.¹ With this broader outlook comes an extended range of capabilities, including identifying underperforming wells and recommending cost-effective interventions to increase well productivity and maximize net present value (NPV).²

With improved capabilities from new drilling technologies, a growing number of wells are candidates for reentry drilling—

Reentry Drilling Gives New Life to Aging Fields

A recent burst of technical creativity has produced an abundance of new ways to revitalize old fields and tap bypassed pockets of oil and gas. However, identifying the best solutions requires a team of experts with a broad range of skills that cross the traditional boundaries of petroleum engineering disciplines.

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DESC (Design and Evaluation Services for Clients), NODAL (production system analysis), PowerPak (steerable motors), RAPID (Reentry and Production Improvement Drilling), Slim 1, VIPER and VISPLEX are marks of Schlumberger. A-Z PackStock is a mark of Smith Drilling & Completions.
Making small fields economical. Innovative drilling techniques can improve asset value by tapping small pockets of oil. Using the latest downhole motor and geosteering technology, wells extending several kilometers from offshore platforms can be drilled, eliminating the need for additional structures. Multilateral wells that branch out from a main wellbore can access several areas of a field and eliminate the need for new wells.

Reentry systems. RAPID services cover the key elements of reentry and multilateral drilling, from pulling old completions to installing the new one and from drilling fluids to wireline logging.

short- or medium-radius sidetracks and multilaterals, drilled conventionally or with coiled tubing. This year, in the USA alone, more than 1500 reentry sidetracks will be drilled. By 1999, the number is expected to increase by 25%.3

Revisiting Existing Wellbores

Reentering wells to gain additional production is not new. Since the mid-1950s, oil companies have reentered old wells and drilled sidetracks to bypass formation damage or wellbore mechanical problems, and also to exploit new zones, saving the expense of drilling entirely new wells.4 Recent expansion of the reentry drilling market, however, owes much to improvements in drilling and completion technology.

Reentry drilling provides a means to reduce horizontal well costs. In addition to boosting well productivity, reentry drilling can also tap bypassed reserves (top right). Multiple lateral sidetracks can fan out from an existing wellbore for enhanced access to reservoirs (middle right). And smaller isolated pockets of oil and gas can be tapped by extended-reach wells or multilaterals (bottom right). Typically, a horizontal well will triple or quadruple productivity over a vertical well, and in some cases, much larger productivity improvements—up to 17-fold, or more—have been observed. Additionally, in zones with underlying water, overlying gas, or both, horizontal wells can significantly increase recoverable reserves.5

Today, service companies use various approaches to address the growing demand for reentry drilling. Baker Hughes INTEQ boosted its reentry drilling services with support from sister company Baker Oil Tools, and gained a reputation as a reentry specialist in the Gulf of Mexico. Within Schlumberger, RAPID Reentry And Production Improvement Drilling teams were created to address this fast-growing drilling option. Service under the RAPID umbrella draws on expertise in reservoir engineering, drilling, directional drilling, fluids engineering, petrophysics and completion engineering—the indispensable elements required to plan, drill and complete successful reentry laterals (above).

By-passed zone

OIl

WateR

Depleted zone

Improving net present value of old fields. Reentering wells and drilling horizontal laterals into bypassed zones can tap new reserves from existing wellbores.

Optimizing Recovery

Multiple sidetracks for enhanced production. Additional drainholes (red) can fan out from existing wellbores or horizontal trunks and improve reservoir drainage.

Tapping Remote Structures

Making small fields economical. Innovative drilling techniques can improve asset value by tapping small pockets of oil. Using the latest downhole motor and geosteering technology, wells extending several kilometers from offshore platforms can be drilled, eliminating the need for additional structures. Multilateral wells that branch out from a main wellbore can access several areas of a field and eliminate the need for new wells.

2. Net present value is today's value of an asset accounting for all future expenditures and income.
The RAPID service was established in 1995 by a business development team in Sugar Land, Texas, USA (above). The lessons learned and the organizational support structure that has developed are now being duplicated in locations worldwide, tapping key specialized skills within all six Schlumberger Oilfield Services companies. In microcosm, the functions of the RAPID group reflect the state of the art in reentry drilling services today.

In some wells, production enhancement is best achieved without drilling. To address this need, a targeted effort on production enhancement was also initiated by Schlumberger. The front line of this effort is led by an integrated, cross-product-line team of engineers engaged in identification of candidate wells. This Production Enhancement Group, or PEG, is chiefly responsible for candidate recognition and

Optimizing production. Reservoirs can be classified by drainage volume (left). For each reservoir more than one well type—vertical, hydraulically fractured vertical, slanted, horizontal, hydraulically fractured horizontal, and multiple or stacked laterals—may be effective. Depending on permeability and reservoir characteristics, slanted and horizontal reentry drilling are two methods for improving production and recovery (center and right).
Water coning during production and breakthrough if perforations are too close to the oil-water contact. Reducing production rate decreases drawdown pressure and mitigates coning.

**Water Coning**

Water cresting

**Water Cresting**

Candidates for Reentry Drilling

Fracturing, reperforating, removing damage with acid, and recompletion are all widely used methods to increase production in existing wells, thereby improving the NPV of old fields. Now, reentry drilling is generating high interest for its potential to improve recovery from damaged or depleted zones, and tap new zones at lower cost.

So when should reentry drilling be used? Many times, traditional techniques may have already been tried unsuccessfully or may not be advisable. In older wells, reentry drilling is the best option when there is an identifiable reason for a slanted or horizontal well path (previous page, left). Reentry drilling from an existing wellbore is less expensive than a new well. And it has the advantage that borehole trajectory through the production zone is near the original wellbore where more is known about the reservoir from cores, logs, test measurements and production history.

When the existing wellbore passes through or near a gas cap or underlying aquifer, excess gas or water production usually develops. In the absence of a gas cap, a traditional strategy to delay bottom water breakthrough is to perforate near the top of the productive interval. However, the pressure gradient due to radial flow toward the well is often sufficient to draw water upward in the shape of a cone (above left). Once water reaches the deepest perforations, it may be preferentially produced because of higher mobility.

Even in the absence of a higher mobility contact, the strong bottom waterdrive can cause excess water production. Because horizontal wells drilled near the top of an oil zone and above the oil-water contact produce a linear pressure gradient normal to the well path, bottom water will rise in the shape of a crest instead of a cone (left). The advancing crest-shaped water front displaces more oil than a cone-shaped advance, which leads to greater recovery by virtue of flow geometry.

In formations where sand control is required, reentry laterals may avoid the need for expensive gravel-packed completions to improve production rates while minimizing sanding problems. Compared to vertical wells, horizontal wells allow the same or higher production rates at greatly reduced drawdown pressures.

Another reason for reentry drilling is to gain better access to layered reservoirs. If individual pay zones are thick enough to be targeted by horizontal wells, multiple stacked reentry laterals are a highly effective strategy. To balance productivity—barrels per day per unit of pressure drop—from reentry laterals, each drainhole can be drilled to an appropriate length inversely proportional to the flow capacity of that particular layer.

At less cost than stacked horizontal laterals, a slanted borehole boosts productivity of layered formations. By designing wellbore trajectory with more drilled length in less-productive layers, some conformance control—balanced productivity from individual zones—can be achieved. However, if early water breakthrough occurs in a high-productivity layer, the relative ease of shutting off production from one of the stacked laterals compared to shutting off production from a mid-length section of a slanted well may, in the long run, favor using a stacked lateral strategy.

A slanted well can produce a marginal increase in productivity over a vertical well in laminated formations where beds are too thin for horizontal drilling. Often hydrocarbon zones are missed or not produced in original completions. Such intervals can be reperforated and a hydraulic fracture may significantly improve productivity. However, when the interval is thin, reentry drilling of a horizontal lateral will outperform a hydraulic fracture.

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8. Mobility is the ratio of permeability to viscosity. Low-gravity crude oils have high enough viscosity and hence, lower mobility than formation water.
In some reservoirs, stratigraphic compartmentalization due to depositional processes may account for bypassed hydrocarbons both vertically and horizontally. Facies with considerable contrasts in flow characteristics may serve as barriers or conduits. In some cases, reservoir sands may be too thin to be individually identified in a seismic section, but have sufficient areal extent to be visible in seismic amplitude maps for a given structural horizon. In such cases, horizontal wells may be an ideal strategy for producing thin formations and for extended reach into remote hydrocarbon sands.

A major application of horizontal wells has been in naturally fractured formations like the Austin Chalk in south Texas. When horizontal wells are drilled normal (perpendicular) to natural fracture planes, they provide an excellent plumbing system for enhancing production. Locating natural fractures and determining their orientation are crucial to getting the best well design in these formations. A horizontal well normal to natural fractures usually provides better productivity than a vertical well stimulated by hydraulic fracturing. Although natural fractures are usually vertical, shallower reservoirs and overpressured zones may have horizontal fractures open to flow. In these formations, vertical and slanted wells are reasonable choices. However, in overpressured deep formations, it may be advisable to prop the natural fractures open to avoid loss of productivity as production proceeds and pore pressure declines.

Elongated reservoirs can be the result of fluvial deposition or significant faulting. Both environments are natural candidates for horizontal drilling. In either case, there are apparent drilling strategies, depending on the objective for the well. For example, wellbores can be maintained in an elongated reservoir body, or directionally drilled to encounter as many different reservoir bodies as possible. The latter case implies drilling in a direction normal to the elongation, which, for a fluvial reservoir, means drilling perpendicular to the downhill direction at the time of deposition. Another approach might be multibranch wells, designed to target channels identified with borehole seismic measurements in the horizontal trunk well.

Another application for horizontal drilling deals with a special structural geometry called attic compartments. In these cases, steeply dipping beds may be in contact with an up-dip gas cap or down-dip aquifer. One strategy is to drill a horizontal well that passes through several beds, but stays sufficiently below up-dip gas or above down-dip water. Although this would seem to be an efficient approach, it suffers distinct disadvantages. Flow is commingled among layers, and gas or water breakthrough will interfere with production from other layers. A better strategy might be to drill multiple horizontal wells, each on strike and staying in a given bed. The advantage of this approach is that each well maintains an optimal distance from gas-oil or oil-water contacts, thus delaying multiphase production as long as possible. Each well can also be drilled to the optimal productive length within the formation.

Reentry Candidate Recognition in Action
The Western Siberian region in the former Soviet Union contains reservoirs that have been produced for 10 to 50 years using conventional vertical wells. Often a simple workover, such as reperforating, acid stimulation or hydraulic fracture treatment, significantly improves production. But in some cases, a better solution is to reenter existing wells and drill a horizontal lateral.

In September 1995, the RAPID team was approached to assist in choosing the best option for layered reservoirs with thick oil columns, where, typically, vertical wells penetrate the entire productive thickness. Reservoirs are then progressively drained from the bottom up, plugging back and abandoning depleted zones over time. Production from vertically isolated zones is never commingled in any well.

### Candidate Recognition Analysis

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<th>C</th>
<th>D</th>
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<td>12</td>
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<td>5</td>
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### Production rate, m³/d

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<td>22</td>
<td>23</td>
<td>38</td>
<td>37</td>
<td>69</td>
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<tr>
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<td>63</td>
<td>56</td>
<td>59</td>
<td>58</td>
<td>99</td>
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<td>86</td>
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<td>Horizontal well, forecast</td>
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<td>95</td>
<td>169</td>
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<td>236</td>
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### Production ratios

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<th>C</th>
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<tr>
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<td>4.1</td>
<td>4.1</td>
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<tr>
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<td>2.5</td>
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<td>18</td>
<td>13</td>
<td>13</td>
<td>10</td>
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</table>
To accommodate this request, a questionnaire was designed to collect data from several reservoirs. Six wells were selected that appeared to be particularly promising. For each of the six cases, productivity improvement expected from a horizontal lateral was calculated (see “Evaluating Productivity Improvement,” right). Because vertical wells had been drilled through the entire productive oil column, shallow zones were damaged during drilling as mud weight was increased to reach total depth. The sensitivity to skin damage was investigated to compare production rate improvements that could be achieved from a vertical workover, hydraulic fracture and horizontal lateral.

To evaluate the potential productivity improvement from a horizontal well reentry, a lateral drainhole length of 750 ft [229 m] was assumed for all cases. An ideal target skin of unity in the lateral was assumed for productivity comparisons (previous page). Only horizontal wells calculated to be twice as productive as fracture-stimulated vertical wells were considered as candidates for lateral reentry.

The most favorable production enhancement plan called for medium-radius drilling with VISPLEX drilling fluid, and completion of the lateral section with a predrilled liner.9 Proof of the validity of this approach will come from results of the drilling program, scheduled to begin later this year.

An interesting application for reentry drilling in difficult structures occurred in north Texas, where, the operator, TRIO, was drilling vertical wells through mound-shaped reefs. The reefs are seen on 3D seismic surveys, but hydrocarbons have migrated into traps, caused by dolomitization, which cannot be identified by seismic surveys. Wells are usually drilled into the center of the reefs, but this is somewhat of a hit-or-miss proposition.

In the Gulf of Mexico, there are many clean sands with high permeabilities—often in excess of 1000 md—but completion designs must provide sand control. A typical example illustrates the use of reentry drilling under these conditions.

A previously drilled well path was deviated at about 35˚ through the productive sand and hydraulically fractured for stimulation and sand control. The post-treatment well test indicated a high skin of 40 and a permeability of about 180 md. Because the reservoir contained two approximately 40-ft [12-m] thick, clean sands separated by a shale bed, the question was whether to design a slanted reentry well or two stacked laterals.

Since the design was for a reentry well, lateral diameter was limited to 6 in. [15 cm]. The lateral completion called for a prepacked screen and gravel pack for sand control, leaving the internal flow diameter at just under 2 in. [5 cm]. A NODAL sensitivity study for this case shows two families of curves (above). The green curves show the effect of lowering surface pressure on vertical flow performance. The steep climb at high rates suggests, to experienced reservoir engineers, that larger tubing would allow higher flow rates. However, the cost of replacing tubing was prohibitive. The blue curves show sensitivity of the inflow performance relationship (IPR) to slanted or horizontal wellbore length. Because of friction-induced pressure drop in the small internal flow diameter, the IPR curves converge for longer tunnel lengths, and there is little productivity gain between drilling a 1200-ft [366-m] and a 2400-ft [732-m] hole. The red curve is the total productivity of two 300-ft [91-m] stacked laterals, one in each layer. Because of the shorter length, and therefore less frictional resistance, the two stacked short (300-ft) laterals should outperform one long (2400-ft) slanted well.

This illustrates the impact of tubing diameter on reentry laterals in high-permeability formations. Since drilling horizontal or slanted wells increases production rates, frictional pressure drop in the tubing or lateral can limit production potential. In this case, another solution could be to plan to produce the lateral or laterals at a lower drawdown pressure. This solution could avoid the need for expensive sand control measures—prepack screen or gravel pack. Net present value analysis, accounting for the costs of various options and coupled with production forecasts for each design, can provide a way to select the optimal solution.

9. VISPLEX mud (containing a mixed-metal hydroxide) is a high shear-thinning (thixotropic) drilling fluid, primarily used for milling windows in casing, which is also used as a drilling and a drill-in fluid. The mudcake produced is easily removed from the formation.
Well performance analysis. In RAPID reservoir analysis, selecting a production improvement plan begins with well performance matching. In this example, the well inflow performance relationship (IPR)—wellhead pressure versus flow rate—includes several tubing uptake curves. Flow rate can be significantly increased by changing to larger diameter tubing.

After a dry-hole vertical well was drilled, Anadrill was approached to plan a sidetrack from the vertical well, building angle quickly to laterally traverse the reef and increase the chance of intersecting areas of vugs—large spaces in the formation—that hold oil. The well had been drilled with a 7½-in. vertical hole through the reef, but because of the small areal size of the structure, only a maximum 500-ft [152-m] horizontal displacement was available for a lateral borehole. It is difficult to get a long- or medium-radius sidetrack turned in such a short distance and it is also a challenge to kick off with a small-diameter bit inside such a large open hole.

The proposed solution was unique. The hole was plugged with cement to about 100 ft [30 m] above the planned kickoff point (KOP). A smaller, 6¾-in. pilot hole was drilled to the KOP with a 4¾-in. bottomhole assembly (BHA). Then a 6½-in. bit was placed on the BHA with a 4½-in., 3°-bend motor. The smaller bit was used to prevent damage to the cement pilot hole while running in to the KOP with the bent motor. The BHA drilled the curved section at a rate of 27°/100 ft and found hydrocarbons at about 62° inclination. The reentry sidetrack turned a $230,000 vertical dry hole into a well that produced 200 BOPD. Sidetrack cost, including completion, was about $140,000.

Another example comes from a major oil company in Houston, Texas, that asked the RAPID team for horizontal drilling recommendations in the difficult conditions of a south Texas gas field. The reservoir was depleted to 300 psi [2070 kPa] at a depth of 10,000 ft [3048 m]. Even drilling with air would result in severe overbalance conditions that could damage the reservoir. Although coiled tubing drilling was the only practical drilling technique, anticipated production would not justify the cost of this option.

The RAPID team examined well conditions and field performance, and discovered that the 15-year-old completion design used in the 80 producing wells of this field contained a flow restriction that limited production rates. Well performance analysis indicated that reengineered completions using larger tubing would double production rates (left). The implemented solution cost 95% less than horizontal drilling with coiled tubing and was immediately available for every producing well in the field. Gas production from wells worked over according to this recommendation doubled from about 1 to 2 MMscf/D.

Reentry Drilling Systems
When reentry drilling is the optimal solution, one of the first decisions is to choose between conventional and coiled tubing drilling (CTD). Through-tubing reentry and underbalanced CTD is an economical solution for drilling and workover operations on rigless platforms. Underbalanced drilling minimizes formation damage and increases drilling penetration rates.

The majority of older wells will be reentered by conventional drilling with long-radius—greater than 500-ft [152-m]—or medium-radius—200- to 500-ft [61- to 153-m]—sidetracks. However, there is a major trend toward reentry drilling with short-radius—40- to 100-ft [12- to 30-m]—drilling. Short-radius sidetracks require articulated drilling systems, which are highly effective in competent formations that can be completed without liners or other completion hardware. Short-radius drilling techniques, whether by conventional means or with coiled tubing, allow drillers to turn well trajectories in a much shorter distance than was previously possible. This allows kicking off below well hardware, if required, or drilling a curve and lateral section completely within a reservoir to avoid problems with overlying formations.

Multilateral drilling, an increasingly popular drilling strategy in new wells, uses multiple horizontal sidetracks from a primary trunk in a parent well. This technique can make small fields economical and reduce the number of wells needed to drain a reservoir. Fewer wellheads significantly reduce the cost of subsea completions and tie-back operations. The multilateral geometry can be simple opposing laterals in the same horizontal formation for better penetration, or stacked laterals to gain access, in multilayered reservoirs for example, to formations at different depths. A multilateral pattern can be used in the same horizon to drain larger...
reservoir areas through parallel laterals or as angled laterals in a fan-shaped pattern.

Reentry Well Engineering
Preparing a well for reentry drilling can involve a range of services from supplying the workover rig, pulling the old completion and cement squeezing old perforations to fishing debris from wells and cased-hole logging for corrosion and formation evaluation. Depending on well design and conditions, there are several possible reentry scenarios ranging from kicking off in open hole or cased-hole sidetracks using a whipstock to cut a window through the side of the casing—window milling—to cutting a complete section out of the casing or liner—section milling.11

To provide efficient section milling and window opening capabilities, Schlumberger formed an alliance with Smith Drilling & Completions. This partnership allows the RAPID group to provide worldwide sidetracking services, including permanent and retrievable whipstocks, and milling systems.12 Complete engineering and technical support come from Smith specialists, but crosstraining allows Anadroll drillers to run Smith equipment.

Sidetracking out of casing begins with a gyro survey of the existing hole to precisely determine location of the casing. A correlation log pinpoints the target formation. Using these data, kickoff depth and position of the milled section are chosen. A cement-bond log shows whether there is good cement behind the proposed milled section. If not, an underreamer is run between milling and plug-setting operations to clean up bad cement and enlarge the borehole.13

For section milling, about 60 ft [18 m] of casing is milled if the kickoff is to be steered magnetically out of a vertical well (above). The milled length of casing can be reduced if a gyro is used to steer the BHA. A competent cement plug is then set across the milled section. To avoid magnetic interference, the plug is dressed with a bit to the kickoff point 20 ft [6 m] from the lower casing stub. The disadvantages of section milling are that it requires a secure cement plug for proper sidetracking, and there is a risk of not

Section milling. A specialized bottomhole assembly cuts through the casing and into the cement at a chosen depth (A). Cutter blades extend from the tool when needed and retract for tripping. Length of the milled section depends on several factors—nominal ID and casing coupling diameter, bit diameter, and bent housing motor angle (B). After milling (C), cement is placed across the open interval and new hole is drilled by kicking off of this plug (D). When milling is complete, the lower section of the original well is permanently isolated from the sidetrack (E).
Window milling. Operations to cut an opening out of the casing begin by running and orienting a retrievable whipstock, which is used to guide mills in the lateral direction (A). After the whipstock anchor is set, the attaching pin is sheared and a starter mill initiates the window cut a few inches into the casing (B). The window mill does the bulk of the milling, and is run together with string, or watermelon, mills that open up and smooth out the new opening through the casing wall (C). Once milling is completed, lateral drilling can start (D). The whipstock is used to guide BHA's and completion equipment into the lateral sidetrack (E). After the lateral is completed, the whipstock can be removed to allow access to lower formations (F and G).
being able to reenter the lower casing stub after drilling the lateral. Drilling penetration rates are often limited by the ability to clean cuttings from the well, and once the wellbore turns horizontal, cuttings removal is even more difficult. Modern milling tools are designed to create small, nonclogging cuttings that are easily removed from the well. Polymer muds are more effective for milling than clay-base muds. Oil-base muds are not recommended for milling operations.

An alternative to section milling is to cut a window in the casing. This requires setting an oriented whipstock and milling an opening in the casing (previous page). After the whipstock is set in position, the bolt connecting the starter mill to the whipstock is sheared. Then rotation is started and carbide tips on the nose of the starter mill cut into the casing wall. In the next stage, a window is cut into the casing using a window-milling bit, which is forced into the casing and the formation by the angle on the whipstock face. The window is enlarged or polished using the window mill and one or more watermelon mills run directly below the drill collars.

Section milling offers several advantages over window milling. It can eliminate the need for gyroscopic orientation, moves the kickoff depth closer to the target for a given curve radius and requires only one milling operation. Window milling, on the other hand, uses a whipstock that provides a positive sidetracking mechanism, but requires several gyro runs to orient both the whipstock and drilling assembly. Cutting a window also requires multiple milling operations and a shallower kickoff depth due to the ratheole needed for the subsequent drilling assemblies.

Whichever system is used, once entry to the formation is gained, there are more choices to be made. Besides standard medium-radius drilling, several recently introduced options for reentry drilling systems can make well reentries more cost-effective. Short-radius drilling, coiled tubing drilling, and multilaterals are each candidates for thorough cost-benefit analysis (right).

Short-RADIUS Systems

Short-radius wells are drilled to avoid traversing problem formations that would otherwise require a liner to isolate, or because wells must be kicked off below hardware, such as an external casing shoe. In some formations, the kickoff and lateral can be kept entirely in the pay zone, avoiding shale beds and reducing the risk of stuck pipe (above).


A roadmap for the driller. Before reentry drilling begins, a detailed plan is designed. At the Schlumberger Sugar Land District in Texas, Catherine Ortiz, a Drilling Planning Center engineer, reviews a trilateral plan with Steve Thurston, a well planning engineer, before her crew leaves for a job scheduled to start within 24 hours.
The curved section is drilled with a specifically designed short-radius system. The short-radius BHA consists of a drill bit, articulated motor, flexible nonmagnetic drill collar housing and MWD systems. High-strength drillpipe is run immediately above the BHA for easy passage through the curved section. Drillstring in the vertical well section usually contains standard drillpipe.

The curvature of borehole drilled by a conventional—long- or medium-radius—downhole motor is defined by three points of contact between the BHA and borehole wall—generally the drill bit, the near-bit stabilizer and the first stabilizer above the motor. On a short-radius system, however, the three points of contact have to be positioned below the motor knuckle joint. Articulations are needed to allow the motor to pass around sharp bends and have no effect on angle build rate. They also allow rotary drilling. Both roller cone or polycrystalline diamond (PDC) bits can be used at the operator’s discretion to handle different formation characteristics.

The Anadroll short-radius drilling system uses a 4-ft [1.2-m] rigid motor section with a surface-adjustable standoff as the third point of contact to control radius of curvature (below). This system maintains continuous contact with the borehole, allowing predictable build rates and easy control of the horizontal section. This also avoids the need to prepare different motors for each section of the well. Directional control is monitored with a Slim 1 retrievable MWD system that includes a gamma ray measurement for geological correlations. This MWD tool was designed to communicate with the surface through mud-pulse telemetry during angle-build drilling to a 40-ft minimum radius of curvature. The directional sensor has been placed in the lowest position, directly above the motor power section, for enhanced trajectory control.

One recent example of production enhancement through short-radius drilling took place in OXY’s Alturitas field, 30 miles [48 km] west of Lake Maracaibo, Venezuela (left). The target Marcelina reservoir lies below a coal stringer that is difficult to drill at any inclination other than vertical, which made horizontal drilling uneconomical.
until short-radius drilling technology became available.

Alturitas 22 was producing 300 BOPD [47 m³/d], so the objective was to increase production by drilling a horizontal lateral using the Anadrill short-radius drilling system. The plan was to set a retrievable whipstock in the 9½-in. casing, mill a window, drill the curve and lateral, and then place the well on production. The retrievable whipstock allows the original completion to be reentered, if necessary, or more laterals to be added at a later date.

An A-Z PackStock was set at 10,895 ft [3321 m] and a 20-ft [6-m] window, including about 9 ft [3 m] of formation, was milled using a gel mud to improve removal of cuttings. Inclination at 10,915 ft [3327 m] was 3°. The mud system was changed to oil-base and the BHA was replaced with an Anadrill short-radius drilling system. In another 84 ft [26 m] of drilling, 90° inclination was achieved, placing the lateral well within the target depth of 10,988 to 11,003 ft [3349 to 3354 m] (above right).

Drilling continued horizontally through the reservoir, which consisted of a series of sandstone layers. The horizontal lateral was allowed to angle upward from the lowermost layer, crossing all the sandstone members for about half the lateral length. The wellbore was then steered downward again, staying within the pay. Drilling was stopped after the well path had descended back through the entire sand sequence—a horizontal distance of 1933 ft [589 m] from the kickoff point.

Success of this project can be measured by current production and cost. The lateral was left as an openhole completion flowing 2000 BOPD [318 m³/d]—nearly a sevenfold improvement in production rate over the original vertical well.

Coiled Tubing Systems
One of the newer technologies developed for the reentry market is coiled tubing drilling (right). This approach is attractive...
when drilling rig mobilization costs are prohibitive. The most successful application of CTD is through-tubing reentry combined with underbalanced drilling. Coiled tubing allows more precise control of low downhole hydrostatic pressure. Not having to pull production tubing and kill the well makes this technology attractive.¹⁹

New coiled tubing directional BHAs provide improved directional control and efficiency. One such system, called VIPER technology, is a wireline-powered BHA that includes a downhole orienting tool for directional control and MWD system for directional measurements. Both are operated from surface via wireline-supplied power and signals. Without the wireline, signal transmission is impossible in underbalanced drilling environments where foamed, aerated or nitrogenated mud is used. The wireline system also increases the data transmission rate by several orders of magnitude over mud-pulse systems, allowing surface control of sensors.

Another VIPER system benefit is improved coiled tubing drilling efficiency. The electric motor in the orienting tool offers higher torque, as well as accurate and uninterrupted directional control. Continuous slow rotation of the motor drills a smoother borehole profile, allowing longer-reach drilling by reducing friction and dogleg curves. The ability to continuously monitor downhole pressure during drilling, tripping and circulating ensures accurate maintenance of underbalanced conditions.

Multilateral Systems

Multilateral drilling places more than one drainhole into one or more hydrocarbon intervals (above left). Improved recovery and reduced well construction costs, through reuse of the parent borehole and surface equipment, make multilaterals an attractive option. The cost of preparing an existing well is the same regardless of how many laterals are drilled. Multilaterals, therefore, cost less per lateral than single lateral wells.²⁰ Slot management is improved, and the expense of drilling additional parent wellbores is eliminated.²¹ Additional reservoirs can be tapped by drainholes that could not have been
drilled previously, and production rates per wellhead can be much greater.

The most basic multilateral application is openhole, or barefoot, completions in competent carbonates like the south Texas Austin Chalk (previous page, bottom). Anadrill has drilled more than 50 such wells to date. Lateral drainholes intersect natural fractures, increasing production from a single well. Inability to perform workovers, however, is a drawback. These are essentially throw-away wells with commingled flow and no chance of turning off water production.

Completing Multilateral Wells

In general, three completion options are available for reentry multilateral wells (left). Wells can be left open as in the Austin Chalk, cased and perforated, or completed with some variation of a production screen.

Soft formations that produce from matrix permeability require normal completions, such as slotted liners and gravel packs in each branch, connected mechanically to the main wellbore trunk. This connection has to be pressure-tight to maintain zone isolation. Furthermore, when different reservoir types are produced through the same multilateral well, selective accessibility to each lateral may be necessary throughout the life of the well. Complete control of each drainhole is essential to avoid jeopardizing production of the entire multilateral system when one drain is depleted or produces excessive water or gas.

Today, most lateral connections are built downhole and rely on good cement to provide a seal and isolation. Schlumberger is developing hardware systems that allow separate completions for each branch of the well. These systems include surface-built junctions that can extend into any portion of the well—vertical or horizontal—and each branch can be easily and selectively accessed. With such systems, there are no reductions in internal diameter in the trunk, which allows lateral branches to be drilled in any sequence, and allows standard tubing and packer completion strings to be run. An outlet port will support a liner hanger and packer, making it possible to run any type of standard completion in the lateral, and enabling good sand control practices, isolation and flow control.

The Outlook

An explosion of new technologies coupled with a collapsing of conventional boundaries between different oilfield services has given operating companies the widest possible range of solutions to increase recovery in aging fields. A comprehensive toolbox for production optimization through reentry drilling and completion can be provided by groups like the RAPID team. The potential value of these services is dramatic. Thousands of wells have been drilled and completed conventionally. Using reentry techniques to increase production from just a fraction of these wells will be equivalent to discovering several giant new fields.

—RCH, JMK, AM


21. On offshore wells, a slot is a space that accommodates one wellhead in a template secured to the ocean floor. A template has a limited number of slots, which cannot be changed once the template is installed. If one well waters out or is dry, that slot is already used up. Reentry drilling, however, gives new life to the slot because it allows bypassing unproductive zones with a new drainhole.