A dynamic Health, Safety, Environment, and Service Quality philosophy permeates all of Halliburton’s work from the top management down. Our ethics, enforced throughout the company, state that every person is responsible not only for their own personal safety but that of the people who work around them. All employees are empowered with Stop Work Authority, compelling any unsafe work to cease until a resolution is created.

Comprehensive training and competency of all employees is enforced throughout the organization. Working safely and protecting the environment are conditions of employment, and are absolute requirements at all our work locations, as well as the communities in which we work. Compliance with applicable laws and regulations is mandatory.

Fifteen (15) innovative state-of-the-art research and development centers are located around the world. Three recent center openings are the Houston Technology Center, 2012, Singapore Manufacturing and Technology Center and Brazil Technology Center, 2013. These centers enable closer collaboration with the customer to deliver deepwater-specific answers to any challenges that may arise.

Flexibility and integration allows procurement and delivery of material and equipment to remote locations, enabling new frontiers or existing deepwater and Arctic regions to be developed where the oil and gas were previously unreachable.

Groundbreaking deepwater-specific solutions can help enable new reserves to be recoverable that were not previously accessible. These solutions maximize recovery in deeper, more complex, and more remote environments while minimizing nonproductive time without sacrificing safety, quality, or ecological responsibility.

- Comprehensive exploration solution portfolio that helps ensure quality reservoir characterization data is delivered, including coring, subsea testing, MWD/LWD, wireline and a host of other evaluation methods that carry on to the production phase of the lifecycle. This data returns high value the entire life of the asset.

- The award winning Enhanced Single-Trip Multizone (ESTMZ™) FracPac™ completion system is designed specifically for deepwater and ultra-deepwater to reliably deliver a high volume of proppant at a high flow rate in just one trip, thus stimulating more of the reservoir in less time. This increased efficiency can save 18 days on average, and reduces costs by approximately $22M for an average Gulf of Mexico Tertiary completion.

- The VersaFlex® Low Equivalent Circulating Density (ECD) expandable liner-hanger system is ideal for deepwater and mature assets. This system has trip-in speeds and circulation rates up to 90 percent better than standards liner-hanger systems, and a high torque rating to enable aggressive

Halliburton is committed to delivering safe, reliable, and efficient solutions that bring “bottom-line value” to the oil and gas stakeholder.
The last 15 years have seen incredible progress in our industry’s move into difficult and demanding environments in deep and ultra-deepwater and Arctic regions. From the Golden Triangle of the Gulf of Mexico, offshore Brazil and offshore West Africa, deepwater exploration and development has rapidly expanded to East Africa, the Mediterranean, India, and Australasia.

Dreams of drilling and producing in more than 10,000 feet of water are rapidly becoming realities. Nowhere is that more evident than in the Gulf of Mexico. Current projections foresee an increasing “boom” in the area, with activity growth approaching 26% this year and 19% in 2014, followed by continued, strong growth in the years that follow.

The outlook in the Arctic, where immense reservoirs are expected to yield higher than average recovery factors (EURs), is much the same. The higher EURs, plus ease of access compared to other unconventional regions, should sustain greater long term production in the area.

To fuel this growth, technology that only recently seemed the province of space exploration now regularly is loaded onto workboats headed to an increasing number of deepwater developments around the world, or trucked over hundreds of miles of ice roads to the northern reaches of the Arctic. But, as exciting and glamorous as these new operating environments are, the move into deep, ultra-deepwater and Arctic regions is based on solid industry tenets that have stood the test of time in our industry for decades. At its foundation are three distinct principles – we encounter a challenge, Halliburton collaborates with our customers to develop a solution, and we create value for our customers, ourselves and the global community.

At Halliburton, we welcome the challenges. More importantly, we are committed to collaborative solutions. We have assembled a team of dedicated professionals whose goals are safe and reliable operations, higher ultimate recovery delivery, lower development cost, and minimal environmental impact, all bound together in our commitment to innovation and delivery. Our adherence to these goals is illustrated daily in our global operations. We continually deliver reliable solutions in the most difficult environments, keeping our pledge to be there when you need us and where you need us, working with your team and the local culture to ensure value-added performance in a safe, sustainable manner.

These commitments manifest themselves in our solutions to challenges like minimizing non-productive time and eliminating reservoir uncertainties to maximize production over the full life cycle of a well. From the pre-spud meeting until the final barrel is produced, Halliburton is there for you, optimizing drilling activities, ensuring completion reliability, constantly monitoring the reservoir and participating in the crucial day-to-day planning and execution that drive enhanced performance in the field and profitability for the development. At the end of the day, these commitments drive high value – the value that allows us to constantly pursue the solutions that can provide a safe and secure energy future for all.
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Health, Safety, Environment and Service Quality Excellence

Effective health, safety, environmental, and service quality processes permeate Halliburton’s global business and provide the foundation that makes its broad range of services efficient, effective and safe.

Halliburton believes firmly that zero HSE incidents is an attainable goal company-wide and reaching that objective requires a methodical approach to continuous improvement of all HSE and SQ systems. Many of our geographic and product lines have demonstrated that zero HSE incidents is achievable over the past few years and our continuous improvement in injury rates and service quality is noticeable. The overriding mission is to make these examples of HSE excellence repeatable across all of business lines in all locations—all of the time.

The following principles guide Halliburton’s global operations, including deepwater and Arctic asset development:

- HSE incidents are preventable
- Leadership and management commitment are fundamental
- HSE performance is each individual’s responsibility
- Compliance with applicable laws and regulations is mandatory
- Working safely and protecting the environment are conditions of employment
- Stop any task or operation if a concern or question regarding an HSE risk exists

Halliburton’s deep-rooted HSE tenets place particular emphasis on continual training to instill a high level of competency in all its employees, as well provide all personnel full stop-work authorization should they recognize any unsafe activity. Specifically, Halliburton’s guiding HSE principals are:

- Ensure training and competency of the workforce. Halliburton HSE training gives employees the skills and knowledge to perform their jobs safely and competently. The training prepares the employees to recognize hazards, prioritize risk, assign controls to reduce risk to an acceptable level, and to understand internal and external reporting requirements. It also provides a basic knowledge of the applicable regulatory requirements and emergency response procedures. Also, workers are tested in various offshore jobs to meet certain competencies required for the specific job.

- Encourage employees to communicate and address risk. Employees are expected to observe each other’s HSE performance and to Stop Work when necessary. All employees or contractor personnel who observe an unsafe action or condition have an obligation to intervene by taking one or more of the following actions:
  - Communicate concerns directly to the persons involved
  - Correct the condition or situation
  - Relay the concern to the appropriate supervisor or customer representative
  - Stop Work (within the scope of responsibility) if clear and present danger exists.

Through careful analyses, five critical focus areas have been identified that present the biggest risk for HSE, process safety, and service quality incidents. When conducting operations in any of these areas, extra attention and absolute adherence to the processes are focused upon, particularly in deepwater and Arctic environments. Also, emphasis is put on weather conditions and the factor they play on human performance while working.

- Barriers – Physical measures (such as packers, plugs, BOP’s surface valves, drilling fluids or cement) that prevent unwanted gas or oil from flowing into the annulus from the formation and traveling to the surface.
- Hydrocarbons to the Surface – Flow of gas or oil to the surface such as well testing or well cleanup operations.
Deepwater Goes Global

Opportunities for deepwater development, once focused primarily on the Gulf of Mexico, Brazil and offshore Africa, now exist in a number of areas across the globe. From the Asia-Pacific to the Mediterranean, operators are gearing up to develop promising deepwater resources. This activity is reflected in the numbers for the last 10 years, in which: 1) deepwater wells have dominated reserves added per well; 2) they have led total volume of hydrocarbons discovered; and, 3) they have topped the value per BOE developed. And they have moved into deeper and deeper water, from an average water depth of a little more than 500 meters in 1982 to more than 1,500 meters in 2012. In this section, we take a brief review of the intense deepwater activity that is ongoing.

Meeting Brazil’s Deepwater Pre-salt Challenges

Oil and gas development offshore Brazil has always been daunting: ultra-deepwater, deep wells and long distances from shore. But in the face of these challenges, Halliburton has a lengthy record of success in optimizing deepwater drilling in Brazil’s Campos Basin and adjacent areas. With the discovery of highly productive formations under a layer of salt, deepwater drilling, evaluation, and completion in Brazil’s waters become even more complex.

Brazil’s offshore pre-salt reservoirs consist of a series of marine rocks up to 915 m thick, containing high quality oil with low acidity and low sulfur content, and located below a salt formation as thick as 2,000 m that serves as a reservoir seal. However, some of the reservoirs contain oil with a CO₂ content ranging from 2 to 12% which can cause corrosion conditions. These highly prospective formations cover almost 150,000 square km and may contain recoverable reserves of as much as 50 billion BOE.

Heterogeneous, hard microbialite carbonate reservoirs under the thick salt layer contain waxy oil (24-30°API, 80-240 GOR, gradational composition). Reservoir temperatures are as high as 260° F and pressures can reach 10,000 psi. Well depths can exceed 5,800 m TVD subsea. One of the biggest challenges now in Brazil is the pre-salt challenges that must be addressed. Halliburton specialists have defined some of the important pre-salt drilling fluids issues and solutions through high performance invert emulsion drilling systems and the holistic Low ECD suite discussed later in this booklet.
Impressive discoveries in the deep water of the US Gulf of Mexico have led to the development of impressive technology to develop these prolific finds. To fully exploit this resource requires innovative solutions to drilling, completion and production challenges posed by water depths to 3,050 m, thick salt layers, drilling depths to more than 9,100 m TVD subsea, reservoir pressures that can exceed 25,000 psi, and temperatures to 300°F (149°C).

An important target in the Gulf of Mexico is large, thick reservoirs of Lower Tertiary age stretching 300 miles across Federal waters offshore Texas, Louisiana and Mississippi that could ultimately yield 3-15 billion bbl of recoverable oil.

As well depths increase and subsurface conditions become more hostile, the challenge has been to develop new completion systems that are more cost effective. The ESTMZ™ system was specifically developed for the Lower Tertiary and offers additional benefits over conventional stacked multizone completion by reducing rig time, providing zonal isolation of the zone, providing customized stimulation for up to five zones. Without this technology, many operators would not have started developments in the Tertiary due to the poor economics.

Solutions for Africa’s Deep Water
In some ways, offshore West Africa deepwater reservoirs are similar to those of Brazil and the US Gulf of Mexico. But, West Africa deepwater exploration also presents some unique challenges, including unconsolidated sands, multiple producing zones, and variable water and gas flows in the reservoir.

East Africa countries are an emerging deepwater play offshore Africa seeing increased focus from several operators for exploration, drilling, evaluation and the installation of new facilities. While Mozambique began the East Africa activities, other countries up and down East Africa are in the investigation stage. Halliburton’s exploration solutions play a role in the East Africa deepwater arena to help acquire the right data for proper data analyses that influence final investment decisions.
Deepwater Goes Global

The primary deepwater exploration targets along the West African Transform Margin (Sierra Leone to Ghana) are turbidite fan sandstones in rotated fault block traps, stratigraphic traps, or combinations of the two.

In the Niger Delta and Lower Congo Basins, deepwater targets are thick, early Tertiary (Oligocene-Miocene) turbidite sands deposited in deepwater slope channel systems and basin-floor fans.

There is also renewed interest in the potential for a deepwater extension of the pre-salt play offshore Angola and Gabon. Most West Africa deep water discoveries have been in water depths from 305-2,000 m, but prospects exist in water depths to 3,000 m.

In deepwater wells offshore West Africa, Halliburton’s Intelligent Well Completion (IWC) (SmartWell®) system technology helps operators collect, transmit and analyze downhole data and remotely control selected reservoir zones.

Asia Pacific Draws Attention

A number of recent discoveries promise that significant deepwater petroleum resources exist in the Asia Pacific region. One of the many geological areas within the Asia Pacific petroleum theater with similar types of challenges is Malaysia. In Malaysia’s Sabah basin, the US Geological Survey has estimated mean undiscovered reserves are 4.3 billion bbl of oil and 26.4 Tcf of gas. The country’s Sarawak basin is also prospective. The shelf offshore northwest Borneo is dominated by thick middle Miocene–Holocene prograding shelf-slope sequences and complex slope topography of intra-slope basins and anticlinal structures. Promising discoveries have been made in the deep water of the northwest Sabah Basin in these Miocene channel and fan turbidites. Primary plays in the area involve multiple stacked sandstone reservoirs in structural traps formed in hanging-wall folds above toe-thrusts; most prospects are defined by four-way closure of the anticlines. Seismic imaging is severely affected by the presence of shallow gas hydrates and complex crestal faulting. The presence of shallow hazards—methane hydrates and over-pressure—create drilling risks. Real-time operations, reducing non-productive time and drilling optimization play as part of the significant solutions for the assets to be developed.

Arctic – Remains a Challenge

A complete section in the back of this booklet discusses the Arctic locations along with a few of the specific Arctic solutions Halliburton provides. Consult with the local Halliburton representative for specific Arctic solutions.

Innovation Delivery

Halliburton has significantly increased its technology investment. Over the past three years, several “state of the art” technology centers have opened worldwide, as shown here, with more on the way. This investment positions Halliburton closer to the customers, opening the door for better understanding their challenges and collaboration on in-depth solutions for deepwater and the Arctic markets. No matter where the client may be having a deepwater or Arctic challenge, Halliburton has the capability to deliver the innovation to solve the challenge.

Halliburton Houston Technology Center

Halliburton’s primary technology center in Houston continually attracts global clients seeking assistance in solving their specific challenges. The 215,000 sq ft (19,974 sq m) Houston Technology Center officially opened in 2012 and is now home to 550 innovators focusing on fluids and chemicals, sensor physics, rock mechanics, and electronics that are primarily driven into five product service line solutions’ deliveries as well as some integrated asset solutions.

The Houston Technology Center clearly reflects the critical importance of Health, Safety and Environmental excellence throughout Halliburton.
The building is rated LEED Silver, making it cutting edge in energy efficiency. Where required, the flooring of each room indicates the specific personal protection equipment (PPE) employees should use in that area. Cement flooring signals that workers should use eye protection and appropriate PPE. And the electrical dispersive floors help keep delicate electronics free of static buildup. Carpeted rooms mean no PPE is required.

The layout of the facility includes numerous huddle rooms and conference rooms which help foster an open office environment that encourages inter-disciplinary collaboration. While many of the eight primary areas house the very latest R&D tools, the Houston Technology Center is less about laboratory instruments and more about the solutions being developed and delivered to customers.

Halliburton Brazil Technology Center
In 2013, Halliburton opened its Brazil Technology Center at the Federal University of Rio de Janeiro (UFRJ) Technology Park, located at the do Fundao, Rio de Janeiro. The center provides a collaborative setting.
allowing Halliburton specialists to work closely with the country’s leading universities and customer research groups to establish a global center of expertise for deep water and mature fields, particularly those characteristic of Brazil. The 7,062 sq m (76,015 sq ft) technology center is located on three floors and includes specialized laboratories, a collaboration room, a testing area and conference and training centers.

**Halliburton Singapore Technology Center**

In 2014, Halliburton Completions Tools (HCT) will open a new Technology Center in Singapore, similar to the Carrollton Texas Technology Center that focuses on specific markets, such as mature fields and shale assets. The new center will complement the HCT Singapore manufacturing facility that opened in 2013. The combination of the technology and manufacturing center enhances Halliburton’s capacity to serve the Eastern Hemisphere and will enable the rapid delivery of solutions to area clients.

**Value-Added Procurement and Logistics**

In large deepwater, ultra-deepwater or Arctic projects, procurement of the needed materials and delivery of the needed materials to the location in a timely matter is critical since additional time translates directly into unnecessary cost.

Strategically positioned in more than 110 countries, Halliburton’s supply chain infrastructure has the flexibility, resources and enterprise to deliver value-added products and services wherever and whenever they are required with unparalleled speed and reliability. Averaging in excess of 1.6 million moves every year, Halliburton’s Global Procurement and Logistics network comprises of high-caliber personnel, processes, and technology that work seamlessly with a keen focus on complying with all HSE regulations and guidelines.

Halliburton’s team of dedicated and experienced professionals shares the same goals and employs a consistent methodology at both ends of the acquisition chain. Each professional completes the Company’s Global Procurement or Logistics Educational Program to ensure competency.
Even where others have failed, Halliburton’s infrastructure helps ensure the secure and timely delivery of all goods and services needed, especially with respect to high-demand solutions, such as, drilling, formation evaluation, testing and completion equipment and services. The Global Procurement and Logistics network also provides specialized transportation and handling services for critical components, including oversized deliveries, time-sensitive material, bulk air or ocean charters, and the safe shipment of hazardous mechanical and chemical cargo, including radioactive materials.

**Heavy Emphasis on Local Content**

Within all its global operations, Halliburton actively seeks collaborative strategic relationships with local suppliers, with emphasis on equal opportunities for residents and small businesses. These win-win supplier relationships allow Halliburton to effectively manage the purchase of commodities on a global scale, thereby delivering long-term value to clients. Sourcing and supply are conducted within strict guidelines to ensure compliance with the local laws and internal control requirements. Halliburton adheres rigidly to the U.S. Foreign Practices Act, the U.K.’s Anti-Bribery Law, all applicable local regulations and “First World” ethics. These same standards also apply to third-parties, including freight forwarders and brokers.

**A Holistic Chain Streamlines the Process**

All of the individual steps in the supply chain are combined into a holistic system that links procurement and logistics with all the processes streamlined to ensure accurate and on-time delivery. This methodology allows the Global Logistics and Procurement organization to provide customers with the unparalleled speed, reliability and the visibility needed to enable better business decisions and greater efficiencies that can cut cost.
Exploration Infrastructure

The unknowns associated with an exploration project, particularly in virgin territory with zero infrastructure, make it difficult to justify the establishment of a permanent, full-scale service and supply facility. Halliburton addresses those limitations with a variety of portable facilities that can be set up quickly and equipped to deliver the maintenance and service required for the exploration program. The mobile set-ups even include capabilities to relay real-time data to the operator’s shore-base to expedite decision-making for the offshore well.

Cost-effective mobile maintenance systems available to accommodate temporary exploration and small developments in remote locations can include:

- Mud plants
- Cement bulk plants
- Multifunctional formation evaluation units
- Data acquisition laboratories
- Fluid testing labs
- Equipment maintenance and repair facilities
- Completion test facilities, including special API test facilities
- Production test facilities

Using these facilities, Halliburton successfully supports all exploration activities, including the provision of advanced reservoir characterization tools, reservoir-fluid sampling tools, production analyses and complete MWD/LWD, wireline and other evaluation technologies. Established processes determine the mobile facilities required. The process begins with

CASE HISTORY:
Dominant East Africa Position Begins With One-Well Set-Up

Halliburton responded to a client’s single-well Deepwater exploration opportunity in Tanzania, East Africa by being the first service provider to establish a local presence and infrastructure. The single-well opportunity mushroomed with Halliburton being the only service and equipment provider in position to deliver logistics and technical support for a first major deepwater gas discovery off Mozambique. With a number of operators having since made significant deepwater discoveries off Mozambique and Tanzania, and eyeing prospects offshore Kenya, Halliburton was the only provider locally established and capable of delivering the customized solutions to meet unique logistics challenges. Since that initial one-well project, Halliburton’s Pemba facility has grown to over 80 employees across several product service lines (PSL). Halliburton has established East Africa’s first fully equipped mud lab in Dar es Salaam, Tanzania with the capabilities to perform operational and quality analysis. Logistically, Halliburton has engaged local resources to meet the growing activity demands. By focusing on improving shipping times and solving importation issues, the time from order to delivery has been reduced from 160-180 days to the current average of 80-90 days. This has allowed better planning across all PSLs, enhancing service delivery to the growing client base.
selecting a site as close as possible to the location and proceeding through identifying the specific building requirements, preliminary setup, safety processes, risk management, preparations for operations and verification of operability. HSE and service quality audits are conducted throughout the process.

The selected site may be a floating drilling rig, offshore structure or a temporary onshore location. The goals of reliability, safety and efficiency are built into the equipment and best delivered by a service provider that designs and manufactures its own equipment and uses it on a daily basis.

Logistically, Halliburton has engaged local resources to meet the growing activity demands. By focusing on improving shipping times and negating importation problems, the time from order to delivery to get materials and equipment into East Africa has been reduced from 160-180 days to the current average of 80-90 days. This has allowed better planning across all PSLs, enhancing service delivery to the growing client base.

Owing to this high level of performance, Halliburton was recently named a finalist for the Africa Oil and Gas Supplier Awards 2013.

While meticulous planning is certainly imperative in any E&P venture, the pressures rise exponentially when designing a plan for high-cost and risk-intensive deepwater and Arctic developments.

Every Arctic or deepwater development program presents a series of planning and engineering challenges that must be systematically addressed with the utmost accuracy and speed. Accuracy is critical as the decisions translate into extremely high cost decisions that will affect the entire life cycle of the project. A thorough development plan begins with the seismic investigations in the initial basin exploration program, and continues to determine the geological model, the drilling operations and the development infrastructure to be built. Some of the most critical long-term decisions are made in these phases of a project.

Halliburton’s Landmark Software and Services has taken development planning to a new
Plan, Develop and Produce Arctic and Deepwater Developments with Speed and Accuracy

standard delivering the industry’s fastest and most accurate suite of software that gives geoscientists and engineers the data they need to make critical decisions, from determining whether a reservoir is commercial and, if so, how it should be developed. The objective is to provide a strategy that will incorporate the optimum reliability, safety and efficiency into the plan and deliver maximum bottom line value.

**New Tools Take Guesswork out of Planning**

In deepwater and Arctic field developments, the initial challenge for the operator is to quantify the volume, fluid properties and evaluate petroleum containment potential and emplacement patterns. Of course, in these environments ultra-accurate data produced quickly are paramount.

Landmark’s highly sophisticated DecisionSpace® family of planning software is unique in that it seamlessly allows results from one software to flow in and out of another software module. The final outcome is analysis that is more integrated resulting in a more optimized development plan delivered much faster than more conventional planning methodologies. Special features are built into the software, including the capability to modify for the specialized parameters needed for subsalt, deep water and Arctic conditions.

Within the suite, the Permedia™ Petroleum Systems software models basin-scale processes over geological time to help geoscientists evaluate source-rock potential, migration, reservoir trap and seal characteristics, and fluid-composition prediction, all with the aim of highlighting the “sweet spots.” The software includes a basin simulator to forward-model pressures and temperatures as input to the petroleum-migration simulator.

**Building Precise Geological Models Faster than Ever**

Historically, building the geological model critical for development decisions was a frustratingly slow exercise. Fault polygon digitizing and other conventional geological modeling were extremely time consuming, leaving development decisions hanging in the balance.

With its highly sophisticated DecisionSpace® Geology software, Landmark set the benchmark for expedient geological interpretation, mapping, and modeling. The modeling software improves traditional correlation and cross-sectioning tasks by leveraging industry-leading
Taking Mapping to the Reservoir

The geological map is only the first step and must be followed with an integrated reservoir and facility model to fulfill the holistic methodology of the entire asset development process.

The Nexus® Software optimized for the DecisionSpace environment provides solutions five times faster on average than other leading reservoir simulators, solving both surface and subsurface equations in a tightly coupled network model yielding more accurate results. The increased speed is a function of the unique volume balance formulation, which results in convergence with fewer iterations. A tightly coupled network model allows the surface and subsurface models to be solved simultaneously, leading to a faster and more accurate solution. What’s more, several reservoirs that might come from dissimilar earth model data sources can be combined into a common downstream model. This capacity is particularly beneficial in the typical multiple Arctic reservoirs tied into a common facility or deepwater development with a combination of platform and subsea wells. New reservoirs in these areas are more complex and multi-layered, but the Nexus model can handle these environments with no difficulties.

The Nexus model allows modifications to individual parts of the production chain and shows exactly how the change will affect the total asset performance. Performance is realized out of the box with minimal tuning required. Nexus differentiators include: volume balance formulation, compositional formulation, multi-reservoir coupling, surface facility modeling, tightly coupled fully implicit surface-sub-surface modeling, unstructured solver for faster computing, intelligent up scaling, direct access modeling, and parallel computing.

Individualized Well Planning

After the holistic asset has been planned, one of the major remaining challenges is to optimize individual well planning, as quickly as possible. Speed, however, must go hand-in-hand with design considerations, such as environmental impact, that must be taken into account. This is imperative for Arctic and deepwater developments.

DecisionSpace® Well Planning software helps asset teams reduce well-planning cycles by leveraging advanced automation techniques to quickly plan any combination of targets, pad or platform locations, and well trajectories for single wells, relief wells, and field development scenarios. The software is the latest advancement in well planning, allowing geoscientists, well planners, and drilling engineers to work collaboratively in a single application, and in the context of a shared-earth model. Algorithms optimize field development plans
based on user-specified cost parameters, risk and uncertainty, and degree of difficulty.

**Well Plans Recommend Rigs, Equipment**

Once the number of wells has been ascertained, the next challenge in the systematic approach is to decide how to deliver the individual wells as safely, efficiently and reliably as possible.

DecisionSpace Well Engineering software provides project-specific recommendations on the rig and other equipment to use, the proper string components, and the appropriate fluid properties and parameters to drill the targeted asset safely and efficiently.

The easy-to-use software matches rig, equipment and mud configurations for any deepwater or Arctic well type, including high-pressure/high-temperature, 3D directional profiles, horizontal, and extended reach.

**Special Focus on ERD, Horizontal Well Paths**

With the ever increasing number of ERD and horizontal Arctic and deepwater wells, operators need more data to properly land the well, especially for laterals being drilled off pads or platforms. For instance, drilling engineers require insight on the optimum geosteering that will help deliver maximum drainage and, in turn, reduce the costs and bring more value.

and determine if the wellbore is on target. Additionally, the software drives real-time updates to the 3D subsurface model, and drives powerful geosteering workflows.

Leveraging the dynamically updated subsurface model and the visual context of seismic data provides a unique “look-ahead” capability that enables team members to quickly determine the bit location and make operational adjustments to stay within the most productive zones.
Addressing Reservoir Uncertainties

Uncertainties exist in any reservoir, but acquiring thorough formation and reservoir data is especially critical to making exploration and development in deepwater and Arctic programs economical. For these projects, accurate and reliable downhole data is imperative to efficiently “right size” the development with respect to the subsurface, surface and infrastructure. Accurate insight from evaluation tools saves geophysicists, geologists and petrophysicists time in making decisions that can strongly impact the life-long productivity, HSE performance and the ultimate value of the asset.

Halliburton has assembled a holistic suite of advanced coring, testing, MWD/LWD and wireline-conveyed data acquisition innovations. Halliburton separates itself as the leader in data collection and interpretation for HP/HT, complex lithologies, the presalt and other equally extreme downhole applications with unparalleled accuracy and reliability between the data collection methods.

Delivering Value to Exploratory Assets

Perhaps more so than in any other E&P venture, the capture and analysis of comprehensive reservoir data is paramount for maximum exploitation of the pay zone in deepwater exploration prospects. This has spurred the development of highly-advanced descriptive tools and techniques, designed to yield a wealth of data for reservoir characterization. Technologies, applied individually or in combo, generate superbly accurate data, images and samples, which in combination with interpretative techniques, help the explorationist make the decisions necessary for maximum asset value.

Full, Clean and Cost Effective Coring Solutions

Analysis of unaltered, native-state cores is fundamental to the exploration process. However, the excessive vibration on the BHA when coring in hard and abrasive rock, coupled with extreme temperatures and pressures, have frustrated many in the ability to achieve 100% recovery of uncontaminated cores using previous technologies. Halliburton’s exploration suite extends to the industry’s most robust and efficient coring solution (RockStrong™ system), engineered with a superior design and core barrel drive mechanisms that makes it effective for all coring applications, including extreme hard rock and deep water. Halliburton coring systems also includes the proprietary Full Closure System (CFCS) which completely seals the

The Horizontal Well Correlation software can increase reservoir contact and improve the operational efficiency of horizontal drilling programs.

The Horizontal Well Correlation software correlates the predicted curve from offset wells and actual LWD/MWD data to create detailed inter-well XYZ control points. These control points fill the gaps between the offsets with new subsurface data, including dip variation, pinch-outs, or faults, which are interpreted in the well correlation.

The benefits of Landmark’s step change advancement in well and development planning comes to the forefront in wells and full-field developments that are delivered with optimum performance in reliability, HSE and efficiency and maximum bottom line value.
inner barrel and provides a coring system for Arctic and deepwater unconsolidated formations. The Hostile Rotary Sidewall Coring (HRSCT™) Tool was designed for retrieving undistorted cores in temperatures and pressures up to 400°F (204°C) and 25,000 psi, respectively. The HRSCT tool has demonstrated its capacity to acquire up to 30 high-quality 1½ in diameter core plugs in a single run – that are undistorted and easily analyzed, free of the micro-fractures typical of percussion cores.

**Solutions for Enhanced Reservoir Characterizations**

For both exploration and development, accurate characterization of reservoir rock and fluid properties is essential for gaining needed understanding of reservoir potential. These data sets provide the insight required to design a more efficient well that is landed perfectly and helps avoid the drilling hazards that can raise serious NPT and HSE issues.

Halliburton has an extensive portfolio of reservoir characterization technologies for deep water and equally critical applications. The portfolio ranges from the latest generation borehole seismic services, to advanced extreme HP/HT MWD/LWD sensors and sonic services, including azimuthal, ultrasonic LWD service and wireline.

**Three-pronged Solution for Defining the Presalt**

The emerging presalt basins of Brazil, West Africa and elsewhere bring unique challenges to reservoir characterization, largely due to the limitations of conventional seismic images to clearly delineate salt horizons.

Halliburton’s Borehole Seismic Services portfolio includes a new generation solution (3D Salt Proximity) that delivers high quality surveys that use X,Y and Z salt exit points to clearly define the salt flank in 3D space. Using 3-component downhole geophones, Halliburton’s 3D Salt Proximity refraction technology in tandem with advanced vertical seismic profile (VSP) software helps operators drill around salt formations.
The descriptive quality of 3D Salt Proximity surveys helps minimize the inevitable risks and costs of drilling a salt body. Salt flank delineation surveys also enhance asset value by helping operators locate attic oil deposits and guiding the directional drilling program toward hydrocarbon accumulations trapped up-dip from producing horizons and trapped against the salt.

**Meeting HP/HT MWD/LWD, Wireline Logging Challenges**

Deep water alone can make the acquisition of complete and reliable downhole data problematic, but add in the extreme temperatures and pressures and the difficulties/costs escalate considerably. Extreme HP/HT adversely impacts wireline and MWD/LWD tool reliability and performance. High temperatures damage tool electronics, affect sensor accuracy and precision, and can lead to premature tool failure if equipment is ill-designed for this service.

Differentiating Halliburton is the development of high-temperature-rated downhole tools that enable the successful drilling and evaluation of deepwater wells. New tool designs and electronics provide greater control in extreme temperature reservoirs, thus reducing the uncertainties of “drilling blind.” This capability is allowing access to reservoirs previously considered uneconomic.

Halliburton’s one-of-a-kind suite of LWD and wireline-conveyed sonic and ultrasonic logging tools comprises the industry’s most advanced technologies for acquiring reliable data in the most extreme service conditions, often in one pass. Among the best-in-class innovations is the Hostile Wavesonic® wireline tool for the consistent delivery of reliable formation property measurements in temperatures up to 500°F and pressures of 30,000 psi.

The Hostile Wave Sonic™ (HWS™) tool, like the companion WaveSonic (WS™) tool, measures fast and slow shear wave travel times, P-wave slowness, compressive fluids in pore space and anisotropy. The Hostile Wave Sonic tool likewise calculates minimum and maximum stresses and field orientation. These measurements provide operators an inclusive characterization of formation properties in HP/HT wells, which conventional logging tools are unable to provide.

Fully compatible with all the tools in Halliburton’s HP/HT Hostile Logging (HEAT™) suite, the Hostile Wave Sonic tool can be incorporated in the same tool string for a single logging pass to reduce the trips required for complete formation evaluation. The all-inclusive logging portfolio also includes diverse LWD borehole imaging services to help identify structure dips, faults and fractures and otherwise help target the sweet spot.
The LWD suite includes the Sperry ADR™ Azimuthal Deep Resistivity sensor that provides fully compensated, multiple-depth resistivity measurement and petrophysical evaluation for both precise wellbore placement and more accurate petrophysical analysis. Sperry also offers the AFR™ Azimuthal Focused Resistivity Sensor that produces high-resolution resistivity images for identifying dip, fractures and borehole breakout.

The AFR sensor acquires data in up to 128 discrete, azimuthal sectors, or “bins” around the borehole. This fine delineation of the borehole wall translates into very high-resolution images that provides the customers accurate dip and fracture analysis.
# Table 1: State-of-the-Art Seismic, Logging and Reservoir Characterization Services BHT <350°F

<table>
<thead>
<tr>
<th>Tool</th>
<th>Wireline</th>
<th>LWD / SDL</th>
<th>How Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quad Combo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistivity</td>
<td>ACRt™ or DLL™, MSFL</td>
<td>ADR™, AFR™, EWR™</td>
<td>Fluid saturation, TOC</td>
</tr>
<tr>
<td>Spectral Density</td>
<td>SDL™</td>
<td>ALD™</td>
<td>Porosity, GIP</td>
</tr>
<tr>
<td>Dual-Spaced Neutron Porosity</td>
<td>DSN-II™</td>
<td>CTN™</td>
<td>Porosity, Gas Identification</td>
</tr>
<tr>
<td>Compensated Array Sonic</td>
<td>BSAT™</td>
<td>QBAT™, XBAT™</td>
<td>Sonic Data Acquisition</td>
</tr>
<tr>
<td>Spectral Natural Gamma Ray</td>
<td>CSNG™</td>
<td></td>
<td>Lithology Correlation</td>
</tr>
<tr>
<td>Natural Gamma Ray</td>
<td>NGR™</td>
<td>ABG™, DGR</td>
<td>Lithology, Clay Typing, Geosteering</td>
</tr>
<tr>
<td>Azimuthal Gamma w/ Inclination</td>
<td>ICT</td>
<td>GABI™</td>
<td>Lithology, Geosteering</td>
</tr>
<tr>
<td>6-arm Caliper</td>
<td></td>
<td>AcoutiCaliper™</td>
<td>Borehole Geometry, Log Correction</td>
</tr>
<tr>
<td>Elemental Analysis Tool</td>
<td>GEM</td>
<td>LaserStrat™, LithoSCAN™</td>
<td>Mineralogy, Clay Typing</td>
</tr>
<tr>
<td>Formation Pressures and Samples</td>
<td>RDT™</td>
<td>GeoTap*</td>
<td>Formation pressure and fluid sample analysis and extraction</td>
</tr>
<tr>
<td><strong>Advanced Logging Services</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3D Induction Resistivity</strong></td>
<td>Xaminer™ MCI</td>
<td></td>
<td>Measuring Resistivity Anisotropy and Formation Dips</td>
</tr>
<tr>
<td>Crossed-Monopole/Dipole Acoustic Tool</td>
<td>WaveSonic™</td>
<td>QBAT™</td>
<td>Porosity, Geomechanical Properties</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Stress-field Orientation (Anisotropy Analysis)</td>
</tr>
<tr>
<td>Azimuthal Acoustic Tool</td>
<td></td>
<td>XBAT™</td>
<td></td>
</tr>
<tr>
<td>Nuclear Magnetic Resonance T1 and T2 analysis</td>
<td>MRIL* Prime, MRIL-XL</td>
<td>MRIL*- WD</td>
<td>Porosity, and Free and Bound Water, Permeability, Fluid Typing</td>
</tr>
<tr>
<td>Borehole Imaging</td>
<td>XRMI™<em>, OMRI™</em>, CAST-1™</td>
<td>AFR™</td>
<td>Lithofacies, Dip, Fracture ID and evaluation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ADR™, ALD™</td>
<td></td>
</tr>
<tr>
<td>Pulsed Neutron</td>
<td>RMT-I™*, TMD-3D™</td>
<td></td>
<td>Mineralogy, Clay Typing, Hydrocarbon Saturation, Chi Modeling</td>
</tr>
<tr>
<td><strong>Vertical Well, BHT &lt;350°F</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sidewall Cores</td>
<td>RSCT™, HRSCT, SWC™</td>
<td></td>
<td>Mineralogy, Porosity, Permeability TOC, Kerogen Typing, Fluid Typing, Geomechanics, CST</td>
</tr>
<tr>
<td>Borehole Seismic Services</td>
<td>OMRI, XRMI, CAST-1</td>
<td></td>
<td>Reservoir Delineation, Fracture Evaluation, Reservoir Characterization</td>
</tr>
</tbody>
</table>
Table 2 – HP/HT Logging and Evaluation Services BHT >350°F

<table>
<thead>
<tr>
<th>Tool</th>
<th>Wireline</th>
<th>LWD</th>
<th>How Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hostile Triple Combo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma Ray</td>
<td>HNGR™</td>
<td>Quasar Pulse™</td>
<td>Lithology Correlation</td>
</tr>
<tr>
<td>Resistivity</td>
<td>HACRe™</td>
<td></td>
<td>Fluid Saturation, TOC</td>
</tr>
<tr>
<td>Spectral Density</td>
<td>HSDL”</td>
<td></td>
<td>Porosity, GIP</td>
</tr>
<tr>
<td>Dual-Spaced Neutron Caliper</td>
<td>HDSN™</td>
<td></td>
<td>Porosity, Gas Identification</td>
</tr>
<tr>
<td>HSFT-II</td>
<td>(included with density/neutron tools)</td>
<td></td>
<td>Borehole Geometry, Log Correction</td>
</tr>
<tr>
<td>Advanced Logging Services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossed Monopole/Dipole Sonic</td>
<td>Hostile WaveSonic™</td>
<td></td>
<td>Porosity, Geomechanical Properties</td>
</tr>
<tr>
<td>LaserStrat Chemostratigraphy</td>
<td></td>
<td></td>
<td>Mineralogy, Correlation</td>
</tr>
<tr>
<td>Additional Formation-Evaluation Services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sidewall Cores</td>
<td>HRSCT, SWC</td>
<td></td>
<td>Mineralogy, Porosity, Permeability, TOC, Kerogen Typing, Fluid Typing, Geomechanics, CST</td>
</tr>
<tr>
<td>Horizontal Open Hole, BHT &gt;350°F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same as for vertical well &gt; 350°F</td>
<td>HEAT™ Suite II”</td>
<td>Quasar Pulse™</td>
<td>Lithology Correlation</td>
</tr>
<tr>
<td>Horizontal Cased Hole, BHT &gt;350°F</td>
<td></td>
<td></td>
<td>Fluid Saturation, TOC</td>
</tr>
<tr>
<td>Advanced Services</td>
<td></td>
<td></td>
<td>Porosity, GIP</td>
</tr>
<tr>
<td>Pulsed Neutron</td>
<td>RMT-Elite™, TMD-3D™ Tool</td>
<td></td>
<td>Gas Identification</td>
</tr>
<tr>
<td>Crossed Dipole Acoustic Tool</td>
<td>Hostile WaveSonic™</td>
<td></td>
<td>Borehole Geometry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Log Correction</td>
</tr>
</tbody>
</table>

Halliburton constantly innovates to solve deepwater and ultra-deepwater challenges. Please consult with your local Halliburton Sperry Drilling representative regarding Extreme HT-200™ sensors rated to 392°F (200°C) and 25,000 psi (172.4 MPa); and Ultra HT-230™ sensors, rated to 446°F (230°C) and 25,000 psi (172.4 MPa) solution developments.
Keeping Sensors Intact
When the Heat’s On

When downhole temperatures increase so does the failure rate of conventional MWD and LWD sensors. Standard MWD/LWD sensors are unable to hold up under extreme temperatures, resulting in a replacement trip, not to mention serious doubts over the validity of any acquired data.

Sperry Drilling is widely identified as the pace-setter in developing MWD/LWD sensors that continue to acquire the highest quality data even in the face of downhole temperatures as high as 392°F (200°C). Designed to provide accurate and timely reservoir measurements while maximizing reservoir deliverability, Sperry’s full range of rugged SOLAR™ sensors withstand temperatures as high as 347°F (175°C) and pressures as high as 30,000 psi, depending on tool size and type.

The entire SOLAR suite of formation evaluation sensors, which includes directional, gamma, pressure, resistivity, neutron, density, sonic and formation pressure testing, were developed to ensure quality information is obtained throughout the well. The SOLAR sensors help ensure accurate directional data and steering capabilities through harsh conditions, delivering wireline-quality reservoir data for effective, economical reservoir characterization while drilling or stored for later retrieval.

In extreme environments with temperatures push 392°F (200°C), Sperry offers the unrivaled Quasar Pulse℠ service that combines extreme-HP/HT directional, gamma ray, PWD and vibration sensors in a single collar to accurately and quickly acquire the reservoir measurements necessary for precise and efficient wellbore placement. The Quasar Pulse service is the only M/LWD tool capable of consistently acquiring reliable data while drilling in temperatures up to 392°F and pressures of up to 25,000 psi (172 MPa).

The Quasar Pulse service has been run successfully on more than 35 deepwater and unconventional wells, 75% of which encountered temperatures higher than 347°F (175°C), well outside the capabilities of conventional tools. On one run, the Quasar Pulse tool handled sustained temperatures of 390°F (199°C) and continued to deliver accurate directional and gamma-ray data for well placement and formation evaluation.

The Quasar Pulse service contains an integrated telemetry system for data transmission of data to surface in real time. Data also is stored in downhole memory for later retrieval if desired.

The Quasar Pulse℠ service has been run successfully on more than 35 deepwater and unconventional wells, 75% of which encountered temperatures higher than 347°F (175°C), well outside the capabilities of conventional tools. On one run, the Quasar Pulse tool handled sustained temperatures of 390°F (199°C) and continued to deliver accurate directional and gamma-ray data for well placement and formation evaluation.

Tools to Help Enhance Completion Efficiency

Gathering all the reservoir data possible can avoid future problems that can arise from a completion that has not been designed to properly match specific reservoir fluid and rock properties.

An advanced suite of reservoir-specific LWD and wireline-conveyed sonic and other tools has been developed to help in completion design to maximize the bottom line value of the asset. The Sperry Drilling QBAT™ multipole LWD sonic tool delivers shear and compressional velocity measurements to determine porosity and rock properties, while also providing input to numerous advanced calculations, such as synthetic seismograms and wellbore stability analyses. The QBAT tool delivers monopole, dipole, and quadrupole reservoir measurements over a wide range of formation types and velocities. The QBAT sensor is less sensitive to drilling noise that can compromise acoustic measurements and delivers reliable high-temperature performance with a rating of 175°C (347°F).

The Sperry XBAT℠ azimuthal sonic and ultrasonic LWD service combines multipole transmitters, four azimuthal receiver arrays and a 4-pinger acoustic caliper, which in combo have raised the bar in velocity measurements. The sonic-caliper combination of XBAT tool helps
Addressing Reservoir Uncertainties

mitigate risk through pore pressure prediction and hole shape data for wellbore stability monitoring, while optimizing the position of the wellbore with synthetic seismograms that tie back to surface seismic data.

**Nuclear Magnetic Resonance Delivers Fluids Movement**

The solutions offering also includes a suite of Nuclear Magnetic Resonance (NMR) tools that provide accurate and timely measurements to maximize reservoir deliverability. The MRIL™-WD magnetic resonance imaging logging-while-drilling tool provides important reservoir fluid information, i.e. water saturation, mobility, etc, delivering wireline-quality reservoir data for efficient, reliable and value-added reservoir characterization. Wireline conveyance of NMR provides valuable reservoir information on production, depletion and waterflood.

**Safe and Reliable Subsea Testing Solutions**

A reliable subsea safety system is vital for deepwater well testing, as well as collecting completion data and providing invaluable data as to how to design the infrastructure that will last the entire field life. Reliable subsea tests that are conducted with the highest level of safety are imperative for determining system performance.

In deep water, serious weather conditions arise quickly and sometimes the need to disconnect from the drillship is paramount. Halliburton’s subsea safety testing system with the Dash™ Emergency Response Module (ERM) has near-instantaneous well shut-in and landing-string disconnect. Also, the testing equipment capability is essential when conducting well-testing operations from a...
dynamically positioned deepwater rig where water depths can reach 10,000 ft (3,048 m).

Unlike conventional “rapid response” systems that rely on downhole nitrogen accumulators and complicated electrical systems to hydraulically deliver tool functionality, Dash ERM simply uses stored energy developed within the marine riser. Completely passive during operations, the Dash ERM requires no complex downhole electronics to effect immediate activation. An electrical signal is simply sent from the surface through the umbilical to a single solenoid valve mounted within the Dash ERM.

The solenoid valve is energized to open and allows a small volume of accumulated fluid within a hydraulic hose to enter the tool and release a mechanical lock that allows the upper section of the landing string to move through the BOP stack and clear the lower marine riser package (LMRP).

The Dash ERM also provides real-time displays of wellbore temperature and pressure to accurately predict hydrate formation. In addition, the sophisticated ERM displays real-time fault monitoring of internal pressures, as well as continuity verifications of actuators post-deployment. The surface control module is mounted within the frame of the electrical reel units, helping reduce space requirements.

Halliburton’s subsea testing and evaluation solutions also include the wireline-deployed Armada® large-bore sample system and the Reservoir Description Tool (RDT™). These tools are used for accurate PVT and fluid sampling in extreme-HPHT deepwater exploration wells. Effective up to 400°F (204°C) and 20,000 psi, the Armada was developed to solve the risks and difficulties of obtaining accurate fluid sampling in cased holes. The RDT incorporates the very latest in microprocessor technology and best-in-class-pump control to deliver up to 15 clean and representative reservoir fluid samples and of up to 10 fluid and formation properties to be monitored during testing, including C1, C2, C3, C4-5, saturates, aromatics, resins, asphaltenes and GOR.

Exploration data is unrivalled in the value that it brings to the operator as major decisions are made early on. Accuracy of the data is paramount. Halliburton collects the reservoir and fluid data with accuracy and reliability across all the various reservoir characterization, fluid analyses, coring analyses, and formation evaluation sampling methods. This data helps ensure the long-time economic vitality of these cost-intensive E&P ventures.

The RDT tester and Oval Pad tandem comprises a surface area of 15.09 sq in. of flow area, significantly larger than other testers. The larger area delivers less differential pressure across the sand face during sampling and less stress on the formation at any given flow rate. The 25,000-psi Reservoir Description Tool (RDT) device and the Oil Mud Reservoir Imager (OMRI™) tool are available for Gulf of Mexico ultra-deepwater service.
Managing Risks to Optimize Safety, Efficiency, Reliability

The well-documented risks inherent to deep water, Arctic and similarly demanding applications require meticulous and proactive identification of all potential hazards, followed by the development of reactive measures to mitigate the impact of any incident that may occur.

Boots & Coots, a Halliburton Service, provides comprehensive solutions that help ensure the possible risks are identified and understood and pre-event contingency planning is established should the need arise. The Boots & Coots program for reducing the risks of the deepwater and Arctic operations follows a systematic strategy that includes:

- Hazard identification (HAZid)
- Hazard and Operability Study (HAZops)
- Emergency Response Plan
- Emergency Response Exercise
- Blowout Contingency Plan
- Relief Well Plan
- Safety Case
- Wellhead Audit

The components of the comprehensive Boots & Coots risk management solution are in line with the API RP-75 standard of US offshore Safety and Management Systems (SEMS) regulations.

The HAZid is a key element that provides a systematic process that breaks down the targeted project into component parts with each subjected to detailed analysis. This analysis precedes the HAZops that provides a structured and systematic examination of a planned or existing process or operation to identify and evaluate problems that may represent risks.

All the data assembled is used in the development of a project-specific emergency response plan, followed by emergency response exercises meant to realistically demonstrate that the risks have been mitigated to as low as reasonably practicable. Data provided by the respective operators also is incorporated into the Blowout Contingency and Relief Well Plans that are customized for each specific well.

A unique component of Boots & Coots integrated risk management solutions is a quantitative Wellhead Audit that evaluates five elements to help mitigate overall impediments to safe and efficient operations, including:

- Well data
- Wellhead condition
- Property Liability
- Impact liability
- Pressure/volume risks

Further details on the risk management approach for deepwater and Arctic operations are available from your local Halliburton Boots & Coots representative.
Reducing Drilling NPT

Given the daily spread costs of deepwater floaters that can run upwards of $1 million with consumables, avoiding any unplanned events that wastes valuable rig time that otherwise could be spent drilling new formation is a predominating criteria.

Besides the challenges of operating in extreme water depths, the subsurface of deepwater and ultra-deepwater wells holds distinctive drilling risks – high pressure, deeper horizons, low overburden and tight pore pressure-fracture gradients with narrow drilling windows – that must be considered and addressed early in the planning stage.

Befitting its holistic approach to well construction, Halliburton considers all aspects of the drilling process with an ultimate objective of eliminating NPT and delivering bottom line value to operators. From planning to execution, this multi-disciplinary approach considers all the variables that drive a safe and efficient drilling operation, including lithology, geomechanics, pressure, temperature and targeted depth. With innovations that include state-of-the-art rotary steerable systems and motors, advanced geosteering, high performance drill bits, environmentally friendly drilling fluids, and formation evaluation innovations.

Halliburton offers NPT-reducing solutions that deliver reliability, efficiency and HSE stewardship in the most challenging applications. These solutions reduce NPT and maximize the value of the cost-intensive deepwater, ultra-deepwater, and Arctic assets.

Planning NPT Out of the Well Plan

Failure to identify potential drilling hazards up front and plan accordingly not only reduces efficiencies throughout the process, but can seriously increase NPT and possibly threaten the ability to drill the well. The risks, for instance, begin in the top hole, which must be drilled riserless to compensate for the lack of overburden. Drilling the riserless section can generate shallow water flows that can cause erosion and even wellbore collapse. The risks magnify as the well deepens and the narrow drilling window comes into play.

Halliburton’s Landmark Software and Services takes deepwater well planning to a new dimension with the new DecisionSpace® Well Planning software. The design package considers the well from a reservoir perspective, combining automation and optimization technology to reduce well planning time up to 80%. Using the collaborative DecisionSpace 3D visualization environment, well design teams generate well trajectories, BHA designs and reservoir targets, using data to help conceive and evaluate development scenarios, and quickly respond to risks, or changes to scheduling or capital expenditure constraints. It also can be integrated with the Reservoir Real Time Operations data system, further optimizing drilling on an ongoing process.

Reliable Equipment for Turning to the Right Longer, Faster

A thorough well plan is only as good as the reliability of the equipment selected to execute without having to trip to replace a prematurely destroyed bit or motor. Running a bit that lacks the mechanical integrity to drill harder rock of deeper intervals can seriously restrict efficiency, but also elevates NPT risks. Halliburton’s response is a reliable and efficient suite of bit-motor combos and rotary steerable systems (RSS).

Halliburton Drill Bits & Services has augmented its fixed cutter drill bit line with the state-of-the-art MegaForce™ PDC bit, incorporating the latest generation cutter technology. The MegaForce™ bit is field proven in deepwater applications and contain all the latest material and cutter technologies to reduce bit erosion, extend bit life, improve hydraulics, and increase average ROP.

The efficiency of MegaForce bit to drill long intervals in a single BHA run is attributed largely to the state-of-the-art and continuously
Reducing Drilling NPT

improving SelectCutter™ PDC technology. In various hard-to-drill applications, the MegaForce-SelectCutter tandem has delivered field-record ROP and cumulative footage drilled with appreciable cost-per-foot reductions.

The step-change advancement in PDC cutter technology features individual cutting elements that stay sharper longer, allowing operators to drill more footage faster, even in highly abrasive formations. Owing to its reduced shank length, MegaForce bit reduces bit-to-bend distance by up to 14%, improving directional control and extending fatigue life in the connection.

**Advanced Steering for Reducing Downtime, Optimizing Efficiency**

In highly deviated and horizontal deepwater and Arctic wells, achieving the performance benefits of a drill bit with exceptional mechanical integrity and longevity depends largely on the steering mechanism designed to reach the target, quickly, safely and efficiently. The last thing operators need while drilling a deepwater or Arctic well, for instance, is unproductive time dealing with a stalled motor or, at worse, tripping to replace a motor with prematurely destroyed internal components.

Sperry Drilling services has developed a comprehensive portfolio of dependable high performance directional drilling innovations, including high torque motors and point-the-bit rotary steerable systems. Matched perfectly to the targeted lithology and designed well path, these steerable systems consistently maximize ROP while reducing NPT.

The SperryDrill® and GeoForce® XL and XLS series motors represent the most reliable and powerful motors in the market, delivering higher torque output and designed with a rugged mud-lubricated or sealed bearing assembly. Compared to a standard motor, the XL and XLS series motors deliver 80% more power, 65% higher torque load, 50% increase in operating differential pressure and a shorter bit-to-bend distance for improved build rates. The result is longer motor runs, fewer trips and increased rate of penetration.

Conventional directional drilling systems often encounter efficiency-restricting problems in extended reach and similarly complex well geometries, including orienting the tool face during sliding.

The advanced Geo-Pilot® XL RSS avoids the problems of conventional directional drilling assemblies. The Geo-Pilot XL sends more RPM to the bit, resulting in comparatively higher drilling rates while reducing stick-slip.

The Geo-Pilot® GXT RSS delivers a new level of drilling performance by integrating a GeoForce® motor power section between the rotary steerable system and the LWD system. Delivering increased horsepower and revolutions per minute directly to the bit, the Geo-Pilot GXT system overcomes challenging formations while reducing the occurrence of stick-slip. The system provides the ability to achieve higher penetration rates while minimizing casing wear by decoupling the bit speed from the drill string speed.
The Sperry suite of RSS innovations also includes the revolutionary Geo-Pilot® Dirigo system, which gives operators all the benefits of point-the-bit rotary steerable drilling, with higher build rates previously possible only with conventional mud motors. Being able to provide consistent high build rates in large hole and soft formations often encountered in deepwater and Arctic formations, allows more flexibility in designing wellbore trajectories, with the ability to achieve higher inclinations earlier in the well, such as those required in subsea or drilling pads. The sail angle for extended reach drilling (ERD) also can be reduced. Improving ERD capabilities, the RSS is driving access to reserves from existing platforms and reducing development costs. The variable deflection point-the-bit RSS provides maximum ROP while at the same time delivers gun-barrel hole quality, reducing torque and drag associated with challenging profiles. This capacity enhances project economics particularly in the high cost deepwater applications. The reduced profile of the RSS helps improve hole cleaning and tripping efficiency. The shorter tool allows movement of LWD sensors closer to the bit for improved and faster formation evaluation, critical for ERD applications.

Like any component of the drilling process, the higher temperatures and harder rock of many contemporary deepwater wells can shorten the operational life of conventional drilling systems, increasing the NPT risks.

CASE STUDY: Geo-Pilot Dirigo RSS Sets Build-Rate Standard Off Angola

An operator drilling an extended reach deepwater exploration well off Angola in 1,428 m (4,685 ft) of water wanted to drill the 12 ¾-in. section from shoe-to-shoe in one run and do so using a rotary steerable system. The plan called for building angle in a very soft unconsolidated formation at 6°/30 m immediately below the 13 ¾-in shoe, reaching up to 86° prior to hitting the geological target where angle would be dropped to 46° at TD. A Geo-Pilot Dirigo 9600 series RSS system was matched with an HDBS 12 ¾-in PDC bit; the BHA also comprised a penta-combo MWD/LWD suite that included a GeoTap formation pressure tester. The assembly drilled the entire section in 132.25 circulating hours at an average ROP of 20 m/hr (66 ft/hr), achieving up to 7.25°/30 m dogleg - the best RSS build rate to date in the block.

CASE STUDY: Turbodrill Helps Cut 12 Rig Days in Brazil Presalt Exploration Well

After average ROP dropped to 1.1 m/hr (3.7 ft/hr), the operator pulled the RSS from a presalt exploration well in 1,943 m (6,375 ft) of water offshore Brazil. An alternative solution to the previous PDC bit-RSS assembly was required that would deliver faster drilling rates in the very hard formation while also maintaining excellent directional control. Sperry recommended running a 9 5⁄8-in T245 Turbopower™ turbodrill turbine with 1° bent housing and an impregnated bit in the 12 ¾-in intermediate section. The turbodrill went on to drill 552 m (1,811 ft) from 4,512 to 5,064 m (14,803 to 16,614 ft) while building a hold inclination from 14.6 to 37° and Continued on next page
Reducing Drilling NPT

CASE STUDY CONTINUED: Turbodrill Helps Cut 12 Rig Days in Brazil Pre-salt Exploration Well

Simultaneously changing azimuth from 326 to 303°. Despite a poor performing rig compensator, the tool face remained steady and in the 266 m (873 ft) sliding mode, the Turbodrill assembly achieved a sliding mode average ROP of 3 m/hr (9.7 ft/hr). The Turbopower Turbodrill delivered rotating mode average ROP of 3.2 m/hr (10.4 ft/hr) over 286 m (938 ft). The Turbodrill efficiently drilled the hard rock without compromising steerability or hole quality. The exceptional performance saved 12 days rig time, encouraging the operator to use the Turbodrill assembly in the next section.

Solutions for Reducing Mud Losses

Studies have shown that a main culprit to NPT in deepwater wells is wellbore instability brought on by severe losses. Consequently, drilling new formation efficiently with zero NPT or HSE impact begins with a properly formulated and maintained drilling fluid system incorporating the highest degree of fluid loss control. In the ever-changing temperatures and pressures of deep water, it is imperative the mud system maintain stable properties. The challenge is magnified in ERD and horizontal wells drilled in deeper horizons, requiring an even higher fluid loss control and sag resistance.

One of the problems with maintaining fluid properties is that downhole conditions can change repeatedly, and with only two mud checks typically taken each twelve hours, decisions all-too-often were based on rheology that may not reflect the real-time fluid condition. The lack of up-to-the-minute rheological data can make it extremely difficult to optimize the fluid loss control properties of the active mud system.

Baroid has taken a major step in enhancing the timeliness of drilling fluid modifications with the fully automated Real Time Density Viscosity (RTDV) technology that measures fluid density and rheology in real time. The compact RTDV is installed near the mud tanks and uses automated sensors to continually collect data on fluid properties. The subsequent measurements are then recorded and archived with Halliburton’s InSite® data acquisition software with the data displayed just as the measurements are made and transmitted to a real-time shore-based operations center for immediate evaluation by off-location personnel serving as expert advisors.

Baroid has long been recognized as an industry leader in developing synthetic-based drilling fluids that provide the highest level of efficiencies within regulatory HSE requirements. Formulating and maintaining excellent fluid loss control must be balanced with the HSE requirements of any mud system used in the severely limited to “zero” discharge deepwater environment. An optimum high performance drilling fluid is one that reduces losses, meets strict discharge requirements, reduces waste disposal costs and prevents potential bottlenecks.

SPE 137999

The ACCOLADE® and companion ENCORE® synthetic-based muds (SBM) consistently reduce overall well costs in deepwater wells, while complying with low-toxicity environmental regulations worldwide. These SBM are formulated with an ester-internal olefin (IO)-blend comprising a combination of fully biodegradable esters – recognized as the least toxic base fluid available.

Complementing their environmental fitness, the organophilic clay-free fragile gel ACCOLADE (up to 300°F BHT) and ENCORE (>300°F BHT) drilling fluids are customized to meet specific formation characteristics and targets, ensuring the delivery of exceptional value-added performance. The systems provide operators a fluid that maintains stable viscosities through a wide range of temperatures and pressures and are highly resistant to contaminants and sustains exceptional rheologies in low equivalent circulating densities (ECD) environments often encountered in deepwater and Arctic formations. A case study on page 32 demonstrates how the drilling fluids optimize Brazil pre-salt drilling.

Serious risks also lie in the deepwater riserless drilling section, which requires higher weight muds to provide the hydrostatic density necessary to avoid shallow water flows. Most rigs, however, do not have the storage capacity for high volumes of the more than 10 lb/gal riserless mud required.

**CASE STUDY:**

ACCOLADE Synthetic Based Mud Cuts $1 million in Lower Tertiary Well

The operator selected the ACCOLADE drilling fluid for its demanding Lower Tertiary well in the Deepwater Gulf of Mexico, where temperatures typically can vary widely. The primary objective was to drill the well, programmed for a 56° deviation, as quickly and safely as possible with a maximum allowable flow rate, minimal ECD, and maintain excellent hole cleaning conditions. The constant rheological profile of the ACCOLADE SBM allowed Sperry Drilling to pump a maximum flow rate and reduce by 21 days the programmed time for drilling, directional work, tripping, logging and running casing, reducing costs by more than $1 million.

**CASE STUDY:**

ENCORE Eliminates Wiper Trip, Saves $1.2 Million

The operator of a Mississippi Canyon well in the Deepwater Gulf of Mexico planned to evaluate the formation, run casing, requiring a fluid solution that would avoid having to run a wiper trip in the S-shaped hole at a more than 6125 m (20,095 ft) TD. A maximum 12.6 lb/gal ENCORE SBM was used to drill to casing depth at 4984 m (16,352 ft) MD where the well was wireline-logged for 94 hrs, after which the liner was run to bottom and cemented with full returns while not requiring a wiper trip. The ENCORE SBM proceeded to drill the entire 9½- in interval, which logged for 101 hrs and the 75⁄8-in. liner was run to bottom and cemented successfully, also without a wiper trip. The fluid system was credited with cutting 24 hrs of rig time for an estimated bottom-line saving of $1.2 million.
The pre-salt of Deepwater Brazil comprises halite and anhydrite with layers of carnallite and tachydrate, which bring distinctive drilling challenges. Brazil’s salt has low mechanical strength and becomes semi-plastic at 220°F (104°C) and plastic at 400°F (204°C). An important consideration, especially when formulating the drilling fluid system, is the tendency of the salt to creep, or flow, either vertically or horizontally with the creep rates varying widely from the top to bottom of the interval. Consequently, it was critical that torque and drag be monitored closely. After carefully defining the most important pre-salt drilling fluids issues, Baroid developed a multi-pronged solution to customize the high performance synthetic-based fluid system to optimize well construction for the pre-salt drilling:

- **Lost circulation.** To increase the hoop stress around the wellbore to cut losses, the system was designed to achieve low gel-breaking pressure, reduced ECD and minimal cold water rheology effect.
- **ECD management:** The hydraulics-related conditions were modeled in the plan and monitored in real time while drilling.
- **Cold water rheology:** Running the high-performance invert emulsion drilling fluid reduced the downhole pressure loss and high ECD ramifications of cold water.
- **Wellbore stability.** For drilling the pre-salt layers containing anhydrite, modifying the system with strong emulsion and salinity properties and constant monitoring of cuttings integrity maintained wellbore stability.
- **Barite sag.** As an organophilic clay-free system, the drilling fluid did not require the increased clay concentrations typically used for suspension, which tended to elevate rheology and ECD, resulting in sag. Thus, circulating/conditioning of the fluid was no longer necessary.
- **Hole cleaning.** Drill solids were monitored continuously to ensure the cuttings bed remained below 3% and the open hole circulating pressure did not exceed the fracture gradient.
- **ROP.** Running a drilling fluid with low colloidal solid content based on polymers and surfactants helped increase the drilling rates.
- **Stuck pipe.** Stuck pipe risks were reduced in the salt layers by displacing with seawater pills and operating a drilling jar.
- **Shallow hazards.** Large volumes of high density fluids helped prevent flows and achieve hole stability.
- **Lubricity.** The drilling fluid was formulated with excellent lubrication properties to prevent high torque and drag, and vibration while drilling the salt and carbonate layer.
- **High temperature.** Customizing the mud with excellent rheological properties maintained stability in the high temperatures and pressures.

In addition, for the presalt, the high performance invert emulsion drilling fluid was formulated to resist contaminants, avoid formation damage, mitigate corrosion, enhance well control and help control hydrates while drilling.
A key component of Baroid Surface Solutions™ is the easy-to-install and operate OTF Mixer that effectively blends high-weight mud and seawater at rates up to 2,000 gpm, providing even mixing with consistent fluid properties, and relaxing on-board storage requirements for the deepwater riserless section.

Mitigating Hazards, Optimizing Efficiencies While Drilling

The challenges of successfully drilling a deepwater well are compounded with drilling hazards that can dramatically increase NPT and reduce overall efficiency. Excessive equipment-damaging, performance-restricting vibration, especially in highly deviated and long lateral wells, along with the heightened risk of wellbore collisions, and drilling into unforeseen dips and faults can severely increase NPT rates.

An advanced portfolio of while-drilling (PWD, MWD, LWD) innovations has helped mitigate many of the hazards in deepwater wells. State-of-the-art tools have been developed to help eliminate the risk of inter-wellbore communication to help precisely land the well as quickly and efficiently as possible. New generation technologies help reduce the impact of excessive vibration while a full suite of LWD borehole imaging technologies help pinpoint the sweet spot and point the Geo-Pilot RSS to the optimum location.

Solutions for Avoiding Wellbore Collisions

Typically, especially in multi-well locations, wireline gyro was used to orient the pipe and survey the well, which is time consuming and raises a host of HSE issues. The time lapse between gyro shots also means the downhole tool is being steered without real-time orientation, increasing the potentially catastrophic risks of drilling into a nearby well.

Sperry Drilling addressed the collision risks with the Evader® MWD gyro while-drilling service that consistently provides faster, safer and more accurate drilling in the presence of adjacent or nearby wellbores. The Evader service optimizes orientation, eliminating the costly and risky use of wireline gyros to orient or steer the drilling assemblies, while affecting accurate wellbore guidance to avoid collisions and deliver precise trajectory placement. Especially important in high latitude locations such as the Arctic, the Evader sensors are

**SPE/IADC 163485**

Hernando Jerez, Rafael Dias, and Jim Tilley, Halliburton, “Offshore West Africa Deepwater ERD: Drilling Optimization Case History,” presented at 2013 SPE / IADC Drilling Conference and Exhibition, March 5-7, Amsterdam, The Netherlands
not affected by magnetic interference, which also allows them to be run closer to the bit in the MWD string, eliminating the need for non-magnetic spacing collars. The modular design allows it to be placed anywhere in the drill collar and it may be run with either positive pulse or negative pulse telemetry systems.

**Real-Time Pressure Measurements Cut NPT**

Owing to ever-changing temperatures and pressures in deepwater wells, optimizing mud densities and managing equivalent circulating densities (ECD) are constant challenges. Acquiring real-time formation pressure while drilling is invaluable to the overall efficiency and safety of the drilling process, and plays a key role in minimizing NPT risks.

Sophisticated PWD formation pressure innovations provide operators the critical real-time data required to fully optimize deepwater well construction and help with making cost-effective decisions. The capacity to collect while-drilling formation pressure data can reduce the time and costs of wireline testing as well as the risks of well control issues.

An integral component of the Sperry PWD solutions suite is the advanced GeoTap® formation pressure tester sensor that provides early recognition of potential lost-circulation zones, influx situations or well control issues. Today, the ability to test formation properties in real time, while drilling, helps guide the well to the most productive reservoir sweet spots in the first attempt, while avoiding geohazards, faults, or salt lenses. Since the GeoTap formation pressure tester measures absolute pressure gradients to determine the position of the wellbore relative to fluid contacts in the reservoir, its value is magnified in deepwater exploration projects, where typically wellbore position uncertainties are greater than the actual geometrical dimensions of the reservoir. Moreover, the timeliness of while-drilling measurements ensures the data acquisition while the borehole is stable and not contaminated by mud filtrate invasion. Accordingly, real-time measurements contribute to lower rig costs by significantly reducing the time required for pressure data collection.

More importantly, GeoTap tester is an essential component in safe drilling. In the event of changing pore pressures, real-time pressure data allows the drilling crew to take immediate action to maintain well control. Early on, Halliburton recognized the importance of this capability, which is pronounced in the imperceptible pressure regimes within the subsalt and presalt drilling environments of deepwater Gulf of Mexico and Brazil, respectively, where the structure and stratigraphy of salt bodies are difficult to interpret from seismic imagery. The

The GeoTap® formation pressure tester helps drillers detect potential well control issues prior to them becoming an issue.
technology has advanced to the point that many deepwater operators run the GeoTap tester as an integral part of the standard deepwater BHA particularly on subsalt exploration wells and provides dual goals of defining the reservoir as well as reducing the non-productive time objectives and helps ensure safe drilling.

**Drilling Optimization**

The more efficient the drilling the less time and money spent getting the operation back on a productive track. Excessive shock on the drillstring, annular pressures that are outside the wellbore boundaries, and drilling with mud weight higher than the optimum density window and a non-direct drilled pathway to the reservoir sweet spot are some of the problems that can elevate NPT.

The ADT® Optimization Service considers three of the most important areas for drilling optimization, with the overriding objective to improve drilling performance and, hence, lower NPT and achieve maximum value. With the ADT service, Sperry experts consider drillstring integrity, hydraulics and wellbore integrity that can increase efficiency and decrease NPT.

After the three-component analysis, the Sperry specialist provides project-specific solutions to optimize drilling rates, improve operational efficiency, and minimize the impact of unplanned events. The Model, Measure and Optimize process leverages Sperry Drilling’s specialized software, surface and downhole measurements to achieve the desired objectives.

**CASE STUDY:**

**ADT Solution Delivers Long GoM Salt Run Under Ultra-High Pressures**

The 16,887-ft (5,147 m) salt body in a Gulf of Mexico well in 4,132 ft (1,259 m) of water was expected to encounter pressures higher than 30,000 psi. The operator required an MWD/LWD combo that could drill at least 60% of the salt section in one run and mitigate vibration without compromising ROP. The Sperry ADT Applied Drilling Technology optimization services incorporated all pre-planning data into the MaxBHA™ modeling software to identify the critical RPM and weight-on-bit parameters, along with torque and drag analysis. The real-time surveying and logging data provided by the AGR (azimuthal gamma ray), EWR-M5™ resistivity, PWD and directional survey sensors allowed the section to be drilled with a 16 ½-in bit to 10,685 m MD (35,055 ft) in a single run, despite up to 32,433 psi internal pressure. Average ROP in the interval ranged from 80 to 100 ft/hr (24 to 30.5 m/hr).

**LWD Solutions for Optimizing Drilling, Targeting the Pay Zone**

In deep water, inadequate formation data not only can increase drilling problems, but can frustrate development plans going forward.

Sperry’s M5™ Integrated LWD Services combines five state-of-the-art solutions that provide formation evaluation answers from resistivity and azimuthal gamma ray sensors, as well as drilling optimization answers from vibration and pressure sensors. These fully digital sensors are bundled together in one short, integrated collar, reducing the number of connections and yielding a significantly more reliable design. The service includes the third-generation Sperry EWR-M5™ resistivity sensor, as well as azimuthal gamma ray, mud resistivity and temperature, PWD and dynamic motion sensor measurements.

The dual-challenge for operators in highly cost-intensive deepwater wells is reducing NPT while efficiently landing the well for maximum reservoir exposure. Unidentified faults, dips and other deformities in the geological structure can make that challenge even more daunting.

As part of its borehole imaging services, Sperry offers the latest advancements in LWD resistivity sensors (ADR™, AFR™, ALD™) that provide operators deeper insight into their reservoir geology to optimize well placement,
Reducing Drilling NPT

The ADR sensor, in tandem with the StrataSteer® 3D geosteering service, provides fully compensated, multiple-depth resistivity measurement, petrophysical evaluation and stratigraphic navigation solution in one package. The deeper readings improve reaction time, increasing drilling speed and decreasing drill out risks.

The AFR™ (azimuthal focused resistivity) sensor provides high-resolution borehole images while drilling that deepens insight into the reservoir. Coupling the visualization of AFR sensor data with the StrataSteer geosteering model facilitates precise and efficient positioning of the well within the sweet spot. In addition, the sensor improves interpretations with accurate resistivity values in highly conductive muds and high formation resistivities and elevates the confidence of real-time decisions with at-bit measurements that provide early alerts of changes in fluid properties and lithology. Some complex geologies require supplementary data to achieve greater insight into reservoir properties and characteristics. The AFR azimuthal focused resistivity sensor delivers four additional types of data in fractured and otherwise complex formations, including:

- Omni-directional, laterolog type resistivity data
- Azimuthal laterolog type resistivity data
- Electrical images of the formation
- At bit resistivity (ABR) measurements.

Developed specifically for use in electrically conductive muds, the AFR sensor complements the EWR and other propagation type sensors. The AFR at-bit resistivity measurement uses the BHA below the sensor as a measurement electrode. Consequently, the AFR measurement is particularly useful for detecting conductive beds as they are penetrated by the bit.

Also, the Azimuthal Lithodensity Tool (ALD™) measures formation density, lithology and provides borehole images for geosteering, determination of structural dip, and borehole stability applications.

CASE STUDY: Sperry Suite Cut Costs by $30 Million in Risk-Laden Well

The Deepwater well off Mexico was fraught with risks, beginning with highly faulted upper sections with the serious risk of total drilling fluid losses and stuck pipe with the strong probability of washouts and cave-ins. High pressures in the producing formation also would make it difficult to control the well in the 6-in hole. Compounding the difficulties was the presence of H₂S. Sperry provided an optimized drilling solution that included a Geo-Pilot RSS, a GeoForce® motor, an advanced PDC bit, as well as an MWD/LWD and PWD package to continuously monitor pressures and ECD while drilling. The integrated solution helped the operator drill the well trouble-free, reducing drilling time by 121 days and cutting more than $30 million in drilling cost.
Managing the Low ECD Challenge

The narrow margin between fracture gradient and pore pressures intrinsic of deep water, Arctic, pre-salt and the depleted zones in mature assets generate low Equivalent Circulating Densities (ECD). Uncontrolled low ECD can increase the risks of fracturing pressure-sensitive formations and induce lost circulation that can raise the risks of wellbore instability, pack-offs, stuck pipe, well control issues, formation damage and even the inability to complete the well. The problems are especially magnified when circulating mud, running casing or liners and cementing in high-angle extended reach and horizontal well geometries.

Halliburton’s holistic Low ECD Solution can deliver safe, reliable and efficient solutions that help maximize the value of your asset by:

- Maintaining well control, while avoiding formation damage
- Reducing NPT, while improving well integrity
- Improving efficiency and cost-effectiveness.
- Tapping into the reservoir safely

ECD must remain between the pore pressure and the fracture gradient to avoid issues, maintain safe drilling, and successfully drill difficult sections. This profile shows a depleted zone, where pressure is significantly lower than surrounding formations.

Managing Fluid Properties to Resist Sag, Control ECD

Many of the solutions to low ECD margins begin with the drilling fluids. In these environments, unstable fluid rheologies may lead to NPT and threaten the project success.

For drilling narrow fracture gradient / pore pressure margins, Halliburton Baroid offers an engineered mud system formulated to reliably and cost-effectively address low ECD conditions. The BaraECD™ high-performance invert emulsion drilling fluid is designed to maintain ECD control in narrow drilling window intervals. The exceptional rheological profile drilling fluid delivers low viscosity to minimize ECD, while providing superb and customized suspension properties to optimize hole cleaning and resist barite sag, even during prolonged static periods.

CASE HISTORY: Low-ECD Fluid Solution Avoids Losses in Depleted GOM Zone

At 5182 m (17,000 ft), the slim-hole high-angle Gulf of Mexico well encountered a depleted and permeable zone that was being drilled at 3,000-psi overbalance, elevating the risks of lost circulation, stuck pipe and well control issues. The slim hole diameter raised the risks of elevated ECD, which could not be tolerated given the 14.8 lb/gal fracture gradient and 13.7 lb/gal surface mud density. Halliburton responded with its BaraECD Low ECD fluid solution that allowed the operator to successfully reach bottom without HSE issues, indications of sag, mud losses or stuck pipe while drilling, tripping, logging or running casing. A safe ECD window was maintained below the safe 4.8 lb/gal operating window.
Managing the Low ECD Challenge

The BaraECD system uses the very latest emulsion and polymer technology to maintain superb rheology and robust, yet fragile gels and can be customized to deliver ECD control based on temperature requirements, environmental restrictions and logistic limitations.

In addition, before a low ECD fluid is delivered to the wellsite, it is run through Baroid’s Hydraulic Shearing Unit that helps produce a drilling fluid system with significantly higher levels of stability, yield point and low shear rheology without relying on rig pumps or rig time.

**Reducing Stuck Pipe Issues During the Running Liner Deployment**

Excessive pressure drops across the liner top in tight margins can dramatically hinder the efficiency, long-term reliability, safety and ease of running liner hangers.

A key component of the holistic expandable liner hanger solution includes the VersaFlex® Low ECD system that specifically handles low-pressure formations and narrow fracture gradients. Independent field analysis routinely verifies the capacity of the system to reduce pressure drop across the liner top during circulation and cementing in the well construction design process. Due to an outer diameter (OD) smaller than industry-standard, the VersaFlex Low ECD system reduces pressures within a wide range of mud densities. The resulting increase in the bypass area promotes faster trip-in speeds. This enhanced flow-rate helps optimize the cementing process, especially when integrating its reciprocation and rotation capability, thus increasing cement integrity.

The VersaFlex Low ECD system also carries an improved operating envelope without inner diameter (ID) restrictions.

The high-torque rating of the VersaFlex Low ECD system permits aggressive reaming and drill-in capabilities, which are especially beneficial in sloughing formations, swelling clays, and cave-ins.

**CASE HISTORY:**

**BaraECD™ Fluid System Eliminates Squeeze, Saves $1 Million**

Baroid used the BaraECD fluid system in a Deepwater Gulf of Mexico well to allow the production string to be run and cemented, while avoiding excessive losses that would require a squeeze in the liner top. Owing to the 11.6 lb/gal equivalent sand pressure and surface mud density of 15.0 lb/gal, the pressure difference across the sand was 3,786 psi. The drilling fluid allowed the operator to successfully run the production liner with full cement coverage, thus avoiding a squeeze and saving an estimated $1 million in rig time.

**SPE 143814**

“Large-Bore Expandable Liner Hangers Significantly Improve Operational Cost in a Deepwater Gulf of Mexico Well,” M. Johnson and K. Ardoin, Halliburton, and B. Bullard, ENI, presented at 2011 Brasil Offshore, June 14-17, Macaé, Brazil

The VersaFlex® Low ECD system can provide nearly twice the annular flow area, thereby allowing for increased flow rates.
Reducing Surge During Casing Run In
Pressure surges restrict the operational efficiency of running casing through low ECD zones, reducing running speed and potentially damaging the formation.

Halliburton developed the SuperFill™ Surge Reduction System specifically to help manage surge pressures and enhance run-in efficiencies.

The SuperFill™ Surge Reduction System
Halliburton developed the SuperFill™ Surge Reduction System specifically to help manage surge pressures and enhance run-in efficiencies.

The SuperFill suite works seamlessly to provide reliable casing auto-fill to minimize the surge and swab effects and maximize the running speed into the well.

Complementing the surge reduction system is the Protech CRB® Centralizers, that help minimize blade embedment into the formation while running in. The low friction coefficient helps minimize the drag forces between the casing and the formation to enable smoother casing or liner running operations. The modular blade design increases the flow area to reduce the frictional pressure drop across each centralizer and, in turn, reduce pressure on the formation minimizing Low ECD damaging effects.

The Protech CRB® Centralizers are key components of the SuperFill surge reduction system.
Ensuring Long-Term Well Integrity

The investment required of a deepwater or Arctic development mandates optimal reservoir drainage, often up to 30 years or longer.

To help operators achieve long life long reliability and realize maximum asset value, Halliburton employs a holistic strategy for wellbore integrity assurance with a portfolio of solutions employed systematically during planning and continuing to production.

**Engineering Integrity Up-Front**

A cement design matched for specific wellbore characteristics and downhole conditions is critical to maintaining integrity.

Halliburton’s iCem® service was developed to do just that. The predictive-analysis software, which is based on computational fluid dynamics and finite element analysis, consistently delivers independently verified simulations of the slurry during placement. Simulations that once took days to develop and execute can now be completed in two to three hours.

Using iCem service, Halliburton evaluates the effects of variable changes, including mud displacement, slurry properties, casing/pipe movement, centralization, fluid volumes, pump rates, and temperature/pressure differentials. Three-dimensional models simulate fluid-flow interaction and displacement phenomena, while prognostic models evaluate stresses in the cement. The iCem service provides predictive input on material selection and volumes that help achieve long-term wellbore integrity.

The iFacts™ laboratory management system provides engineers immediate access to collective data from thousands of fluid tests. Data centralization promotes information sharing and collaboration among the global technical professionals for the optimization of spacers, flushes, and cement slurries for specific formations.

**Well Integrity Provided from Design, Cement Slurry and Equipment**

As wells age, the cement sheath is subjected to stresses from formation and pressure changes. Upon investigating the root cause of potential damage, Halliburton developed the three-tier WellLife® III cementing service, comprising iCem service for modeling, analysis and cementing operations design; ElastiCem® and LifeCem™ cement systems and Swellpacker® isolation systems based on proprietary Swell Technology systems. This trio works synergistically to preserve cement integrity, while reducing or eliminating costly remediation.

**Safety and Reliably Executing Cementing Operations**

For any offshore operation, especially deep water and Arctic, safety and reliability are fundamental to the success of the cementing process.

Developed to support cementing and liner operations, the Commander™ 1000 cement head is designed to surface launch balls or darts to operate subsea plugs. When used with wireless remote control (WRC), the cement head can eliminate the need for personnel in the derrick or red zone safety area during pumping.

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SPE 157280


SPE 141005

The Commander™ 1000 cement head is well suited for offshore well construction, including the pre-salt, low ECD, extended salt formations or any application requiring heavier casing and work strings.

Compliant with all Lloyds and DNV regulations, the cementing head enables cement plugs to be loaded offshore and in a basket without breaking the tool apart, thus allowing ultra-efficient pumping of the cement, reducing rig time, in a safer environment.

**Reducing Drag and Heavy Load**

Running casing to setting depth in highly deviated wells can prove extremely problematic as drag forces often exceed those for running the casing. The result can be slow casing run-ins or inability to land at the desired depth.

Halliburton’s response is the Buoyancy-Assisted Casing Equipment (BACE™), recognized as a major breakthrough in flotation technology. Used in conjunction with Super Seal™ II floating equipment, BACE traps fluids or air at the lower end of the string, effectively reducing the casing weight. The reduced weight lowers drag forces, significantly extending the potential running depth and minimizing buckling or sticking risks.

**Late Life Well Integrity**

Casing leaks or micro-annuli can occur over the life of a well and remediation usually is costly and challenging, especially in very narrow annuli or micron-sized fissures.

Halliburton’s WellLock® resin system readily penetrates and blocks small casing leaks, micro-annuli, or gravel packs without requiring acid cleanups. The system comprises excellent mechanical properties with high ductility and compressive strengths up to 18,000 psi, capable of withstanding pressure differentials up to 100 times more than required within the wellbore.

**CASE HISTORY:**

**WellLock® Resin Blocks Leaks in Gulf of Mexico P&A**

The presence of bubbles after the initial casing cut during decommissioning of a Gulf of Mexico well prevented continuation with conventional P&A methods. Pressure could not be held on the cement plug, which raised concerns over having the bubble stream channel through the cement. The WellLock resin system was used in a squeeze, effectively stopping the annular leak and allowing a 15 m (50-ft) resin plug to be set and the permanent abandonment completed.
Ensuring Long-Term Well Integrity

Reducing Completion NPT

No activity can have more of a damaging effect on productivity than failing to efficiently remove all drilling fluid and other contaminants during the wellbore cleanup.

The appropriately named CleanWell® system offers a mechanical solution for pre-completion wellbore cleaning. CleanWell system employs a number of cleanup innovations, including the Vac Tech® educator system, Vali Tech® mechanical filter, and Mag Tech® magnet to remove more metal debris than competitive systems, often in single runs.

CASE STUDY:
Single-trip Drill-out, Clean-up Cuts $1.5 Million in Gulf of Mexico

The CleanWell® system was used to drill out and cleanout a Deepwater Gulf of Mexico well in a single trip, establishing depth at 5,730 m (18,799 ft) and displacing mud with brine. The job included drilling out more than 34 m (110 ft) of cement and washing/reaming 396 m (1,298 ft). The system recovered 165 lb of debris in the initial run, while a subsequent crown plug and post-perforation cleanout run recovered more than 280 lb of debris - four times that of conventional systems. The CleanWell system saved two days rig time and at least $1.5 million.

Wellbore Cleanup Assures Well Production Reliability

Delivering a usable wellbore safely, efficiently and with zero NPT means little if the completion fails or otherwise restricts optimum production. The weight placed on designing and maintaining a reliable and fully-functional completion intensifies with the multiple zones being completed to produce deeper horizons, such as the Lower Tertiary Wilcox formation of the Gulf of Mexico. For these ultra-deep and HP/HT multi-zone reservoirs, superb zonal isolation control, equipment reliability and minimizing remediation trips are critical to maximizing asset value.

Halliburton long ago recognized the opportunities for innovative solutions to reduce rig and intervention costs for efficient completions in these demanding environments. Through collaboration with numerous operators, Halliburton addressed the NPT and completion efficiency issues, and developed an all-inclusive suite of a new solution comprised of technologies and processes. These advancements are combined synergistically in a holistic strategy to reduce the NPT-inducing and production-restricting issues that can affect the completion and the production.

CASE STUDY:
West Africa Operator Cleans Up, Saves $1.6 Million

The CleanWell system was employed for a single-trip drill out, cleanout and displacement for a Deepwater well, where the operator needed a safe cost-effective method to remove debris and establish total depth of 3,467 m (11,375 ft). The system established the desired depth in a single run, cleaning both the well and BOP, performing the negative pressure test to ensure integrity and displacing the mud with brine while drilling through cement stringers. More than 90 lb of debris was removed, mitigating any well control issues or completion remediation runs, saving the operator approximately $1.6 million in rig and fluid costs.
Cutting Trips, Optimizing Isolation in Multi-Zone Completions

Historically, installing frac-pack, multi-zone completions not only increased rig days considerably, but once production commenced, operators faced the tremendous challenge of maintaining complete and reliable zonal isolation throughout the life of the well. Obviously, for instance, multiple-zone completions heighten the risks of sand production that if uncontrolled can result in hardware erosion, sand bridging and otherwise restrict production and increase NPT for remediation.

Halliburton has revolutionized multi-zone deepwater completions with its technologically advanced and NPT-reducing Enhanced Single-Trip Multizone (ESTMZ™) Frac System, engineered specifically for the distinctive challenges of deep and ultra-deepwater reservoirs. This ground-breaking innovation allows single work string deployment of a frac pack completion that provides unmatched isolation and efficient separation of long reservoir intervals to optimize fracturing design. In addition, ESTMZ system gives operators a cost-effective solution for accessing marginal reservoir intervals that typically would be bypassed as uneconomical.

The ESTMZ system consistently demonstrates its capacity to save up to three work string trips per zone in a typical Gulf of Mexico Tertiary Completion. Compounding the palpable savings...
Reducing Completion NPT

Halliburton has successfully deployed nearly 20 ESTMZ systems worldwide, from the Gulf of Mexico to the Asia Pacific region.

for the completion itself, deployment on a single string likewise reduces the costs of the deepwater rig as well as the stimulation vessel mobilization and demobilization.

The ESTMZ system offers other distinguishing advantages that further contribute to optimum reliability, reduced NPT, and increased and sustained production, including:

- Exceptional pre and post-treatment formation isolation with access to each zone provided with the frac circulation sleeve and optional production sleeve.
- The system’s full 10,000-psi differential pressure rating increases the operating envelope for deeper wells and facilitates optimum frac designs.
- The industry’s highest ratings for frac pumping (45 bbl/min) and proppant volume (750,000 lb/interval) provide opportunities to optimize frac designs for individual reservoir intervals.
- Offers the industry’s largest 10K ID system, which maximizes stimulation rates, reverse flow and production rates while being fully compatible with SmartWell* zonal flow control equipment.

CASE STUDY: ESTMZ System Cuts $22 Million from Three-Well Lower Tertiary Completions

A major operator chose the ESTMZ Frac System for a three-well completion in the Lower Tertiary of the Deepwater Gulf of Mexico. Compared to the plan, the ESTMZ system reduced on average 18 days the time required to complete each well, for a cost savings of approximately $22 million. While none of the wells have yet been put on production, the first well tested in excess of 13,000 BOPD. Contributing to the success of the three-well completions were wellbore assurance initiatives that combined all the critical operations, including wellbore cleanout, completion services, pumping and fluids.

Solutions to Help Reduce Completion Interventions

Most deepwater completions are designed to facilitate interventions for a number of post-treatment activities. Any activity that can be carried out without requiring a high-cost subsea intervention reduces precious rig time and helps enhance the overall economic profile of the asset.

SPE 116245


The revolutionary Enhanced Single-Trip Multizone (ESTMZ) Frac System delivers complete zonal isolation in a single work string deployment. The 4 1/4-in. system ID for 9 5/8-in. casing also provides comparatively larger flow area for maximum frac and production rates.
Remote Open Close Technology

Intelligent Completions

- No Dedicated Personnel Required
- Extensive Run History
- Run Open or Closed
- Remotely Operated Time-after-time

Features & Benefits

- Dramatically reducing rig-time and associated risks.
- The eRED valve, an intervention is eliminated from the operation as a downhole barrier or flow control device. With each use of the eRED® valve, an intervention is eliminated from the operation as a downhole barrier or flow control device. It is deployed below either a lock or bridge plug and can be used repeatedly to open and close by remote command.
- There are no connections to surface and no interventions are required to operate or communicate with the valve.
- Long Battery Life

Overview

Saves time and helps reduce risk by removing interventions from well operations. It reduces the number of operations personnel - saving costs and helping reduce risk. Halliburton Red Spider eRED®-FB computer controlled full-bore barrier valve provides the necessary barrier without the need for any follow-up intervention run. Permanently deployed as part of the tubing string, the innovative eRED-FB valve can be opened and closed repeatedly by remote command. This unique downhole barrier technology, operates on a closed-loop hydraulic circuit powered and controlled by the integrated electronics. The unit requires no surface connections, and more importantly, eliminates the significant HSE risks and interventional costs in mechanically deploying and retrieving each plug required for the pressure testing exercise.

At the foundation of this integrated NPT-reducing strategy is the delivery of optimized efficiency, reliability and HSE superiority to maximize the bottom line value of these premium assets.

Close-up of the 4.250 inch eRED® Valve Flow Port (2.25-5.96 inch).

Delivering a usable wellbore safely, efficiently and with zero NPT means little if the completion fails or otherwise restricts optimum production. An ill-designed completion with hardware lacking the mechanical integrity to handle the flow rates or reservoir characteristics can severely impact the economic performance of the asset.

The AccessConnect Enterprise allows multi-access workflow and leverages multi-disciplinary expert resources to create and publish best practice workflows.
The stakes rise considerably in deeper, hotter and multi-formation completions, where complete zonal isolation, hardware dependability and effective stimulation are essentials.

Halliburton’s holistic solutions for a deepwater completion considers every variable that drives an effective and long-functioning completion, from wellbore clean-up to sustaining production once online. Reliability is engineered into the design of the completion, using the very latest planning technologies. In execution, reliability is ensured with completion hardware carrying the highest mechanical integrity ratings, a full suite of high-performance and non-damaging fracturing fluids and new-generation technology for keeping sand production and excessive water-gas cut to a minimum.

All this and more is supported by the industry’s largest and newest generation fleet of stimulation vessels, strategically placed to quickly deliver fracturing, acidizing and sand control treatments anywhere and anytime in the world.

As part of its “intelligent” approach to completions, Halliburton relies on the industry’s most advanced design innovations, taking all variables into consideration to reduce the uncertainties and deliver maximum value. Landmark’s one-of-a-kind AssetConnect™ Enterprise distributed technical workflow automation software is the foundation of this strategy for designing deepwater completions. AssetConnect considers all aspects of well construction, deepwater fracturing and completion operations, including the critical path time line, and overall well costs, to create multiple customized completion scenarios.

The capacity to enable distributed execution with centralized model management ensures consistency and the complete automation of the multi-disciplinary workflows. This new-generation approach incorporates all the elements within the asset’s value chain, from the reservoir through production. The result is a more thorough, efficient and cost-effective completion designed solely to optimize value.

The suite includes the multi-phase QuikLook® software, an advanced 3-D, four-component, non-isothermal numerical reservoir simulator. The simulator helps design effective well treatments, including fracturing, conformance and sand control and is even designed to predict production from complex wells and reservoirs.
Reliable Zonal Isolation Solutions

Over time, high differential pressures, formation shifts and similar events can weaken packer sealing, not only increasing NPT, but jeopardizing the integrity of the zonal isolation network.

The robust Swellpacker® isolation system makes it the ideal option for the unique challenges of deepwater multi-zone completions. Compared to conventional packer systems, Swellpacker systems provides a simpler, safer and much more stable solution for complete and long-term zonal isolation. Swellpacker systems demonstrate their capacity to cut rig time and reduce costs, all the while delivering absolute isolation of producing zones. In some open hole completions, Swellpacker systems may even eliminate cementing and perforating altogether.

Well-suited to cased or open hole completions, Swellpacker systems is based on the swelling properties of rubber in hydrocarbons and/or water. Swelling up to 200%, it effectively seals the annulus around the pipe and achieves unprecedented zonal isolation.

Once deployed, the rubber retains its flexibility, allowing the Swellpacker system to adapt to shifts in the formation over time and retain seal integrity.

A bonded-to-pipe product, the Swellpacker system can be delivered with element length via a unique cable feed-through option that enables passage of single or multiple control lines and flat packs for downhole monitoring, chemical injection and the SmartWell completion system.
Controlled Unwanted Water and Gas via Inflow Control Solutions

Multiple-zone completions, especially in unconsolidated reservoirs, heighten the risks of sand production, as well as increased water and gas cuts that if unrestrained can severely impact completion functionality. Sand production specifically often erodes hardware and causes sand bridging and other problems that can restrict production and increase NPT.

Halliburton bolstered its completions portfolio with the advanced EquiFlow® Automatic Inflow Control Device (AICD). Typically installed in tandem with the PoroMax® or other premium sand control screens, the EquiFlow AICD dramatically minimizes the production of water and gas at breakthrough.

To maximize oil production, EquiFlow AICD employs groundbreaking dynamic fluid technology to differentiate between fluids flowing through the device. The reservoir fluid flows from the formation, through the sand screen, and into the flow chamber, where it continues through one or more tubes.

Fluid Solutions for Safe Fracturing of HP/HT Reservoirs

The enormous challenges of deep water and ultra-deepwater extend to pre-production fracturing stimulation, requiring considerably higher bottomhole treatment pressure. Conventional fracturing fluids, however, are unable to provide the required pressure without exceeding the safety limit ratings of the rig’s surface treatment equipment or downhole tubulars. Whether the pressure-generated failures occur on the surface or downhole, the result is increased HSE risks and costs.

Halliburton addressed those risks with high-density fracturing stimulation fluid systems (DeepQuest® and DeepQuest® HT) formulated specifically to safely and efficiently fracture HPHT reservoirs. These high-density systems allow fracture stimulation of HPHT reservoirs without exceeding the safety limits of treating equipment or tubulars or compromising the optimum fracture treatment design.

The DeepQuest HT service reduces surface treating pressure without the costs of...
higher-pressure equipment. The DeepQuest HT fluid system is effective in bottomhole temperatures up to 375°F (191°C) and provides improved performance with treating pressures higher than 15,000 psi. The weighted system takes advantage of gravity and is an ideal option when the availability of 20,000 psi fracturing equipment is limited.

SeaQuest® HT service is an advanced proprietary fluid system that enhances performance, while promoting more flexible service delivery. Designed for seawater mixing, SeaQuest® proprietary fluid mixing technology allows for simple on-the-fly rheology modifications with on-line quality control to assure desired fluid properties are being maintained.

Engineering a completion that clears the way for full and sustainable production is one more example of Halliburton’s commitment to deliver the highest reliability, safety and efficiency to produce maximum asset value.

helps reduce delays caused by the stimulation vessel scheduling issues that occur often when freshwater-based fluid systems are used. The complementary InstaVis™ mixing system helps reduce and even eliminate the NPT traditionally associated with preparing the frac fluid. The proprietary fluid mixing technology allows for simple on-the-fly rheology modifications with on-line quality control to assure desired fluid properties are being maintained.

Engineering a completion that clears the way for full and sustainable production is one more example of Halliburton’s commitment to deliver the highest reliability, safety and efficiency to produce maximum asset value.

Sustainable Production

Hand-in-hand with designing and maintaining a reliable and high performance completion is the challenge of sustaining production and ideally, extending the life of the production asset. Key elements in meeting that challenge is to have the capacity to remove formation damage and monitor production.

Removing Formation Damage

For stimulating high temperature carbonate or mixed carbonate/sandstone reservoirs, the environmentally benign KelaStim™ chelant-based stimulation service provides a non-acid method for increasing production. The KelaStim fracturing fluid reduces the risk of rock deconsolidation that can occur with high-strength HCl acid stimulation fluids. KelaStim provides reliable fracturing stimulation in higher than 300°F bottom hole static temperature.

New Age Real-Time Monitoring Solution

Historically, real-time monitoring of downhole conditions and determining actual oil and gas volumes being produced required high-cost intervention.

Pinnacle, a Halliburton service, has capitalized on its leadership position in fiber optic sensing technology with FiberWatch® well monitoring and reservoir management service that requires zero intervention.
Flow Assurance

The distinctive deepwater build-up of production-restricting hydrocarbon solids, namely asphaltene, wax, and hydrates, has made flow assurance one of the most intensely investigated disciplines ever since operators first ventured into deeper waters. Hydrates, which form in cold deepwater temperatures and high pressures, are especially problematic, as they not only can plug the production line, but also the BOP stack, choke and kill lines, raising serious well control issues.

Multi-Chem, a Halliburton service, has been a key player in preventing and removing obstructions for the free flow of hydrocarbons, and maintaining the overall integrity of the production system, including the subsea pipeline network. From analysis to deployment of innovative chemical remedies, highly experienced Multi-Chem deepwater technical teams provide meticulously engineered and cost-effective solutions that keep deepwater production flowing.

Addressing the Risks Pre-production

Of course, the ideal and less costly approach to mitigating problems is identifying the risks during planning and developing contingencies. Issues that can undermine maximum hydrocarbon flow are certainly no exception.

Well before first oil or gas hits the sales lines, Multi-Chem engineers analyze the specific flow assurance parameters and model flow through the production system. Based on the analysis, the Multi-Chem flow assurance specialists provide the operator process and procedure reviews, as well as recommendations and assistance in field design to help resolve potential flow assurance risks and develop the best mitigation solutions for the targeted asset.

Much of the analytical work is undertaken at Multi-Chem’s global R&D technology center, which houses some of the most sophisticated analytical tools in the industry, including cross polarized microscopy (CPM), differential scanning calorimetry (DSC), high-pressure cells rated to 14,600 psi, among others.

The Multi-Chem analytical tool set also includes the first and only purpose-built rocking cells for testing low-dosage hydrate inhibitors (LDHI). These ultra-advanced cells are designed to withstand H₂S gas to effectively replicate the conditions of a client’s actual deepwater or Arctic production system. Specifically, these one-of-a-kind analytical rocking cells and specialized procedures offer:

- Fully automated protocols
- Proprietary seal and center-ported design with double sapphire windows.
• Proximity sensors, P/T transducers and CP and CV capability with pressure rated to 3,000 psi.
• 18 total cells, 12 of which are H₂S compatible

The results and recommendations developed better simulate the conditions in a deepwater or Arctic operator’s sour reservoir and provide safe and optimized solutions, without any damage to the production system equipment.

Chemical Solutions to Revive Steady Flow
Extricating hydrate plugs, getting rid of wax deposits or otherwise dealing with any naturally occurring solid obstacle once they have built foolproof. When it comes to hydrate plugs, however, complete remediation is imperative to prevent potentially catastrophic HSE issues.

Multi-Chem is an industry leader in chemical solutions that are well documented highly effective. The suite of Low Dosage Hydrate Inhibitors (LDHI) includes multiple and continuous applications with Kinetic (KHI) and Anti-Agglomerate (AA) inhibitors employed in site-specific applications. The unique LDHI has been shown to extend production beyond that of conventional methanol or glycol-based thermodynamic inhibitor treatments. In addition, they provide faster start-up time and the low dosage required reduces transportation and equipment costs.

The Multi-Chem chemical solutions package also includes new generation:
• Scale inhibitors and removers
• Paraffin and asphaltene inhibitors, dispersants and solvents
• Foam Assisted lift to resolve liquid loading issues
• Biocides, corrosion inhibitors, sequestering agents, as well as the AcroClear™ and traditional line of H₂S scavengers
• Full water treatment solutions

Post-deployment, Multi-Chem deepwater experts monitor system data and flowline performance.
Flow Assurance

**CASE STUDY: LDHI Prevents Hydrates in Gulf of Mexico 20-Mile Tieback**

The 20-mi tieback flowline in 1,463 m (4,800 ft) of water in the Gulf of Mexico encountered hydrate formation that methanol along was unable to resolve. After rocking cell tests, Multi-Chem recommended a specially formulated low-dosage hydrate inhibitor (LDHI) that would control hydrates at the 60% produced water cut of the production. Treatment with the anti-agglomerate technology combined with methanol supplementation allowed the operator to continue to produce the well at the high water cut, effectively controlling hydrates and increasing the production life.

**CASE STUDY: Production Restored on Paraffin-Blocked Flow Line**

After losing production when an inter-field flow line became plugged with paraffin, the operator spent nearly $8 million in unsuccessful attempts to completely remove the plug. Multi-Chem suggested the best option was paraffin dispersant blended into seawater at a 5% concentration and pumped into the line. The 5% MX 3-1450 mixed in seawater was pumped in and the line cleaned completely with a chemical expenditure of less than $20,000.

**CASE STUDY: Defoamer Clears Separators, Restores Production**

Foaming issues were causing the IP and LP separators to experience liquid carry over, raising the risks of damage to the gas compressor downstream of the separators. Multi-Chem recommended a 30 ppm treatment of DF-7190 oil-based, silicone defoamer. The foaming issues virtually were eliminated following a treatment of 22 ppm and the separation system has since operated for eight months problem-free.

**CASE STUDY: Multi-Chem Water Solution Assures Compliance**

Owing to high oil and grease levels in overboard water, the platform operator faced the risk of regulatory non-compliance and potential downtime. Multi-Chem stepped in with a cost-effective chemical solution that ensured the discharge water remained in compliance. By optimizing the chemical program and treatment rates, the oil and grease content dropped to around 12 ppm, well within regulatory standards.

**CASE STUDY: LDHi Prevents Hydrates in Gulf of Mexico 20-Mile Tieback**

Subsea flowlines, especially the scores of tiebacks laid to connect with primary production facilities, can ill-afford hydrate, paraffin wax or other deposits that block steady production. The ultimate economic ramifications are particularly glaring with the tiebacks used for producing otherwise marginal reservoirs.

Halliburton Pipeline & Process Services’ heat-driven SureTherm™ service was developed solely to treat deposits, such as paraffin wax or hydrate, to return blocked subsea flowlines to full production. The services...
uses a proprietary time-delayed exothermic chemical technology to generate sufficient heat that consistently restores flow without requiring mechanical scrapers in a reduced ID or restricted pipeline. The treatment can be applied either during production flow or during shutdown.

The SureTherm technology provides a cost-effective alternative to conventional solvents, which are unable to remove significant quantities of paraffin in the low internal temperature environment of subsea pipelines. The service can be applied singularly or synergistically with the highly effective Paragon™ paraffin solvent.

The SureTherm™ service enables precise control of the timing of the exothermic reaction so that heat is generated when and where it will be most effective.

Halliburton has established early and firm presence in nearly all the world’s active Arctic basins.
The world’s Arctic basins have been christened the next frontier for giant hydrocarbon discoveries. The latest US Geological Survey (USGS) assessment places undiscovered and technically recoverable oil and gas reserves of more than 412 billion barrels of oil equivalent (BOE), largely concentrated offshore the northernmost regions of North America, Asia and Europe.

Accessing those enormous reserves, however, requires overcoming incomparably daunting challenges, not the least of which are tremendously remote locations with limited or zero infrastructure, prevailing temperatures that can drop to below -50°F, 120- mph winds, highly restrictive working conditions, ever-intensifying environmental security and, of course, extremely high costs.

The obstacles certainly do not end on the surface. Downhole, limited regional reservoir information, narrow pore pressure-fracture gradients that generate low Equivalent Circulating Densities (ECD), heightened risk of wellbore collisions, and protection of an extremely fragile permafrost combine to place tremendous pressure on the exploration and drilling teams.

Having established a first-mover position in nearly all the world’s emerging and more established Arctic drilling and production areas, Halliburton brings an unequaled wealth of resources, experience and expertise to these mega-challenging environments. For Arctic operators, this means access to the industry’s most comprehensive and responsive supply chain network, the very latest in reservoir characterization and drilling innovations, technologies designed specifically to protect the permafrost and state-of-the-art drilling waste management.

Applied seamlessly, all this translates into unrivaled reliability, HSE stewardship and efficiencies to help operators optimize the bottom line value of these demanding assets.

**Cutting Risks With Real-Time Shore-Based Monitoring**

The remoteness and restricted working conditions of Arctic locations require that on-site personnel requirements be minimized wherever possible.

Halliburton has helped reduce the risks, while elevating the speed, efficiency and reliability of the asset decision-making exercise, with implementation of its shore-based Real Time Reservoir Solutions (RTRS) at Arctic offshore exploration and development operations.

Incorporating a revolutionary network of powerful computers, satellites and other monitoring technologies, the RTRS bridges the distance between personnel and downhole data, in real time. Using RTRS, Halliburton and client experts can collaborate, share knowledge and solve well problems almost instantly from anywhere in the world. Well-matched for Arctic operations, the RTRS reduces HSE risks and helps maximize economic recovery with the delivery of timely and reliable data necessary to optimize investment decisions. In fact, multiple Arctic regions have teamed up previously to save drilling costs. In some cases, drillers stationed in Norway drilled wells offshore and monitored both Norway and Alaska rigs during their twelve hour shifts. At the end of the 12 hour shift, the drilling monitoring shifted to drillers in Alaska who monitored the Alaska-Norway wells, saving costs for both operations.
Reliable Supply Chain

Having bottlenecks in the supply chain that could put a project on hold is always unacceptable, but even more so for remote Arctic drilling and production operations. The long lead times and hard-to-access locations require a supply chain infrastructure that is fully prepared and organized to perfection to deliver on time.

Operating one of the world’s most comprehensive, responsive, flexible and value-added supply chain networks, Halliburton consistently meets and often exceeds the on-time delivery schedules required of E&P operations in the Arctic environment. Even for the most advanced and in-demand reservoir characterization, geosteering and equally sophisticated technologies, Halliburton routinely provides what Arctic operators require, when and where they are needed.

Halliburton’s Arctic infrastructure set-up includes equipment and portable facilities that are completely winterized for the glacial environment and buttressed to withstand near-hurricane wind speeds. The suite of portable modular facilities fashioned specifically for Arctic conditions is ideal for minimizing the environment impact. In addition, Halliburton offers mobile and multi-functional formation evaluation facilities, data acquisition laboratories, and tool maintenance and repair workshops that are readily available for Arctic operations anywhere in the world.

CASE STUDY: Meticulous Planning Keeps Alaska Project on Course

Supplies an extremely remote development operated from a man-made island in far north Alaska was challenged with limited ice-road and barge support access. Twice during the year, 'break-up' and 'freeze' essentially renders the island cut off from supply for several months. Logistics planning prior to and during these periods must be carefully managed to assure effective ongoing operations year-round. Halliburton continuously maintained an effective supply stream throughout the project, allowing the small footprint operation to keep adequate stock. No stock-out incidents were encountered during the entire program.

Improving Reservoir Understanding

One of the shortcomings in Arctic development planning is the comparative lack of regional reservoir understanding. Without a reasonably accurate estimation of potential reserves, designing the well construction and completion programs are burdened with uncertainties.

Halliburton brings its extensive portfolio of MWD/LWD and wireline-conveyed reservoir characterization and sampling innovations to bear in helping operators gain deeper understanding of their Arctic asset. New-generation technologies, such as the Sperry GeoTap® LWD formation tester, the Reservoir Description Tool (RDT™) and the DynaLink® telemetry system and others have helped operators amass extensive data to aid in their critical investment decisions.

Tackling the Unique Demands of Pad ERD Drilling

To reduce the environmental footprint, operators typically construct Arctic wells from onshore pads or near-shore man-made islands. Extended reach and multi-well pad drilling increases the risks of inter-wellbore communication, requiring meticulous focus on ensuring the well is landed perfectly. To compound the difficulties, the narrow pore pressure-fracture gradients innate to Arctic formations can lead to barite sag, low ECD and other serious drilling impediments in the
Meeting the Challenges of the Arctic Environment

Ultra-ERD wells required to tap offshore reserves.

Technologies and practices introduced to help optimize the drilling efficiency and HSE performance of Arctic wells include a new generation rotary steerable system, Managed Pressure Drilling (MPD) and the use of an environmentally friendly low ECD drilling fluid.

Sperry Drilling has reduced the potential for wellbore collision in high build-rate wells with the Geo-Pilot® Dirigo rotary steerable system (RSS). Capitalizing on recent RSS advancements, the Geo-Pilot® Dirigo has demonstrated its capacity to achieve high angle wells in both small and larger hole diameters, as well as soft formations.

Owing to novel geometry, the variable deflection point-the-bit RSS system avoids drag and stick-slip in high-speed drilling, maintaining excellent hole quality while maximizing ROP.

Raising the Bar in Efficient, HSE-Focused Drilling

While at the foundation of any drilling program, balancing drilling efficiency with the highest level of HSE stewardship is especially paramount in the Arctic. Owing to its vast experience in the Arctic environment, Halliburton provides operators solutions that deliver exceptional drilling efficiency in tandem with protection of on-site personnel and the sensitive ecosystem.

Halliburton Baroid offers high-performance water-based drilling fluid systems (BOREMAX™, BaraECD) that combine superb and cost-effective drilling rates with the inherent HSE benefits of aqueous-based muds.

The award-winning BOREMAX fresh water-based drilling fluid has consistently exhibited exceptional performance in the harshest downhole conditions, including zones with high differential pressures requiring mud weights up to 17.5 lb/gal. BOREMAX is simple to maintain without the need for dispersants or caustic materials and consistently demonstrates dilution rates three to four times lower than conventional water-based muds. The system also has shown enhanced solids control efficiency, even when drilling in highly reactive clays.

Meeting Arctic Environment Regulation Requirements: Zero Discharge Directive

Rigid adherence to zero discharge is a universal mandate throughout the world’s Arctic E&P theaters. This means that operators require the most advanced technologies and practices to make certain zero drilling waste makes its way into the pristine ecosystem.

CASE STUDY:
BOREMAX Drilling Fluid Cuts Drilling Time by a Third in Far Russia

The operator of an Arctic development in far north Russia needed to overcome the low ROP and high NPT resulting from overloading of the solids control equipment and flowline plugging. As an alternative to the standard KCl muds that had been used, the operator chose the non-dispersed BOREMAX drilling fluid, which was used to drill the troublesome interval in a third of the time with minimal NPT attributed to flow line plugging.
Halliburton has assembled a wide range of state-of-the-art drilling waste management systems and methodologies that consistently meet and exceed strictly enforced zero discharge regulations. Drilling waste management solutions comprise a wide range of customized solids control equipment and waste treatment packages that can include mobile vertical cuttings dryer and centrifuge combinations, high performance XTRA-FLO® shaker screens, thermal processing systems, the ENVIRO-FLOC® mud dewatering system and the SupaVac™ SV 400 cuttings collection and pumping system, among others.

All the solutions come together within the Baroid Total Fluids ManagementSM (TFM) service that identifies the waste-related costs of a specific project and develops appropriate solutions.

One of the most efficient solutions is found in cuttings injection, which if planned, executed and monitored correctly is considered the most effective and permanent drilling waste management process available. With its Full Circle® cuttings injection system, Halliburton has developed an integrated solution that begins with feasibility studies of a prospective waste injection well and continues with the highly engineered design and execution of a cuttings and spent fluid injection process, which also includes continual post-injection monitoring.

CASE STUDY: Total Fluid Management® Service Best Practices Cuts Alaska Waste Costs, Footprint

An operator on Alaska’s North Slope spent more than $15 million in one year to dispose of drilling waste. The Baroid Total Fluids Management service stepped in and introduced a long-term strategy to improve the efficiencies throughout the well planning and drilling process. The service specialist assigned to each rig evaluated the primary sources of waste-related costs and developed a sweeping strategy that considered all aspects of the well construction operation, from drilling fluid selection and continuing all the way through to waste processing techniques. The end result was a per-well savings up to $50,000 in waste management costs with full compliance.

CASE STUDY: FullCircle® System Delivers High-Volume CRI in Ultra-ERD Wells

The Sakhalin Island operator faced tremendous challenges in processing and disposing of enormous volumes of cuttings and fluid wastes generated from extended reach wells more than 5 miles (8 km) offshore and located in an extremely sensitive marine ecosystem. Halliburton specially designed an integrated FullCircle cuttings re-injection system that was designed to process up to 50 tons/hour of drilling waste. Throughout its operation, the FullCircle process more than kept up with the generated waste volume with minimal NPT, while delivering minimal environmental impact.

Keeping the Permafrost Isolated and Unharmed

Effective annular isolation is critical to prevent heat from the drilling operation from melting or otherwise damaging the sensitive permafrost that can be up to 610 m (2,000 ft) thick.

Halliburton is one of the few companies to offer environmentally friendly cementing solutions (ArcticCem™, Permafrost E*) engineered specifically to provide annular insulation that fully protects the permafrost. ArcticCem cements, part of the application-specific Tuned Cementing Solutions™, are formulated to set up in temperatures well below the range of conventional cements. Accordingly, it provides superior insulation that protects the permafrost.
Permafrost E is a special blend of cementing materials formulated specifically for setting conductor pipe in extremely cold conditions. This environmentally sound solution provides superior thermal protection in formation temperatures as low as 15°F (-9.4°C). Typically, it is used in areas where washouts, fractures and ice lenses are encountered. The low-temperature hydration capacity of Permafrost E allows rapid compressive-strength development in subfreezing conditions.

**Durable ESP Solutions to Sustain Production**

At some point, most wells will require some form of artificial lift to keep production flowing at value-added rates. Reversing production declines from an Arctic well usually means installing an electrical submersible pump (ESP), where the primary objective and challenge is to install it on the wellhead once and never has to pull it because of a failure.

Halliburton offers the industry’s most robust and high performing suite of ESPs, motors, and protectors, engineered, manufactured and tested to deliver unmatched service life. Unlike conventional ESPs, Halliburton’s pumping units are differentiated by their capacity to handle gas, including overall multiphase flow. When conditions warrant, the ESP offering includes accessories to increase resistance to abrasion and corrosion, and extra high-torque shafts are available for all models.

Optional instrumentation allows for remote monitoring and transmittal of all well and ESP performance data to the surface control box. This capacity means equipment operation can be maintained at peak efficiency and, in turn, optimize and extend well performance.

From designing a reliable fit-for-purpose completion, deploying industry-leading solutions and ensuring production continues unabated, Halliburton is the one company committed to seamlessly integrate the highest measure of reliability, HSE performance and efficiency, all with the primary objective of delivering optimum bottom line value to your deepwater and Arctic investments.

**Biocide-free Water Flooding Remedy for Older Producers**

Bacteria growth over time has caused severe water flooding of many mature Arctic producing wells that, if untreated, could generate hydrogen sulfide (H₂S) production. Historically, the only remediation was in the form of high-dosage biocide treatments that could carry a number of environment considerations.

Halliburton has addressed those concerns with its award-winning CleanStream® ultraviolet light bacteria control process. The UV light technology provides an on-the-fly solution that significantly reduces the volume of biocides needed to control bacteria. Overall the use of the ultraviolet solution can significantly reduce the use of larger quantities of biocides which can be costly from logistics and quantity standpoints. CleanStream service is a new technology first originated in the unconventional shale operations but it is now beginning to be utilized in offshore waterflood operations and is a high candidate to reduce biocides in waterflood operations in the Arctic.
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<td>ММП (многолетнемерзлые породы)</td>
</tr>
<tr>
<td>Permeability</td>
<td>проницаемость</td>
</tr>
<tr>
<td>Plugs</td>
<td>пробки</td>
</tr>
<tr>
<td>Porosity</td>
<td>пористость</td>
</tr>
<tr>
<td>PP (Pore Pressure)</td>
<td>поровое давление</td>
</tr>
<tr>
<td>R&amp;D (Research &amp; Development)</td>
<td>Исследования и разработки</td>
</tr>
<tr>
<td>Real-Time Monitoring</td>
<td>наблюдение в режиме реального времени</td>
</tr>
<tr>
<td>Reservoir Formation</td>
<td>продуктивный пласт</td>
</tr>
<tr>
<td>Resin</td>
<td>смола</td>
</tr>
<tr>
<td>Rig</td>
<td>буровая</td>
</tr>
<tr>
<td>Sand Control</td>
<td>ограничение выноса песка</td>
</tr>
<tr>
<td>Stimulation Vessels</td>
<td>сосуды/ёмкости для стимуляции</td>
</tr>
<tr>
<td>Submersible</td>
<td>погружной</td>
</tr>
<tr>
<td>SW (Water Saturation)</td>
<td>водорастворимость</td>
</tr>
<tr>
<td>Swellable Packers</td>
<td>набухаемые пакеры</td>
</tr>
<tr>
<td>Tubing</td>
<td>НКТ</td>
</tr>
<tr>
<td>Unconventional</td>
<td>нетрадиционный</td>
</tr>
<tr>
<td>Under Balance</td>
<td>недостаток</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Вязкость</td>
</tr>
<tr>
<td>Water Disposal</td>
<td>сброс воды</td>
</tr>
<tr>
<td>Water Management</td>
<td>ограничение водопритока</td>
</tr>
<tr>
<td>WD (Water Depth)</td>
<td>глубина воды</td>
</tr>
<tr>
<td>Well Heads</td>
<td>колонная головка, фонтанная арматура</td>
</tr>
<tr>
<td>Well Testing</td>
<td>испытание скважины</td>
</tr>
<tr>
<td>Wellbore Damage</td>
<td>повреждение ствола скважины</td>
</tr>
<tr>
<td>Winterization</td>
<td>подготовка к зимней эксплуатации</td>
</tr>
</tbody>
</table>
### УСКОРЕНИЕ

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Фут в секунду в квадрате (ft/s²)</td>
<td>метр в секунду в квадрате</td>
</tr>
<tr>
<td>Дюйм в секунду в квадрате (in/s²)</td>
<td>метр в секунду в квадрате</td>
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</tbody>
</table>

### УГОЛ

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Градус (угла)</td>
<td>Радиан (rad)</td>
</tr>
</tbody>
</table>

### ПЛОЩАДЬ

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Акр (США, геодезический)</td>
<td>Метр в квадрате (m²)</td>
</tr>
</tbody>
</table>

### ВРАЩАЮЩИЙ МОМЕНТ

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Дина-сантиметр (dyne • cm)</td>
<td>Ньютон-метр (N.m)</td>
</tr>
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### ЭЛЕКТРИЧЕСТВО И МАГНЕТИЗМ

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Абампер (abampere)</td>
<td>Ампер (A)</td>
</tr>
<tr>
<td>Абкулон (abcoulomb)</td>
<td>Кулон (C)</td>
</tr>
</tbody>
</table>

### ЭНЕРГИЯ (ВКЛЮЧАЯ РАБОТУ)

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Международная британская тепловая единица (BTU)</td>
<td>Джоуль (J)</td>
</tr>
<tr>
<td>Калория</td>
<td>Джоуль (J)</td>
</tr>
<tr>
<td>Фут-фунт (ft • lbf)</td>
<td>Джоуль (J)</td>
</tr>
<tr>
<td>Килокалория (международная система)</td>
<td>Джоуль (J)</td>
</tr>
</tbody>
</table>

### ЭНЕРГИЯ ПРОХОДЯЩАЯ ЧЕРЕЗ ЕДИНИЦУ ПЛОЩАДИ В ЕДИНИЦУ ВРЕМЕНИ

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Термохимическая британская тепловая единица на квадратный фут секунду (Btu/ft²•s)</td>
<td>Ватт на квадратный метр (W/m²)</td>
</tr>
</tbody>
</table>

### СИЛА

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Килограмм-силы</td>
<td>Ньютон (N)</td>
</tr>
<tr>
<td>фунт-сила на фут (lb/ft)</td>
<td>Ньютон на метр (N/m)</td>
</tr>
</tbody>
</table>

### ТЕПЛОПРОВОДНОСТЬ

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Международная британская тепловая единица-фут в час на квадратный фут на градус Фаренгейта (Btu (International Table) •ft/h • ft² • °F (k, thermal conductivity))</td>
<td>Ватт на метр на кельвин (W/m • K)</td>
</tr>
<tr>
<td>Термохимическая британская тепловая единица-фут в час на квадратный фут на градус Фаренгейта</td>
<td>Ватт на метр на кельвин (W/m • K)</td>
</tr>
<tr>
<td>Международная британская тепловая единица на квадратный фут (Btu/ft²)</td>
<td>Джоуль на квадратный метр (J/m²)</td>
</tr>
<tr>
<td>Международная калория на грамм на градус Цельсия</td>
<td>Джоуль на килограмм на кельвин (J/kg • K)</td>
</tr>
</tbody>
</table>

### ДЛИНА

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Фут</td>
<td>Метр (m)</td>
</tr>
<tr>
<td>Дюйм</td>
<td>Метр (m)</td>
</tr>
<tr>
<td>Международная миля</td>
<td>Метр (m)</td>
</tr>
<tr>
<td>Ярд</td>
<td>Метр (m)</td>
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</tbody>
</table>

### МАССА

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Унция</td>
<td>Килограмм (kg)</td>
</tr>
<tr>
<td>Тонна</td>
<td>Килограмм (kg)</td>
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</table>

### МАССА НА ЕДИНИЦУ ПЛОЩАДИ

<table>
<thead>
<tr>
<th>Единица</th>
<th>Транслитерация</th>
</tr>
</thead>
<tbody>
<tr>
<td>Фунт на квадратный фут (lb/ft²)</td>
<td>Килограмм на квадратный метр (kg/m²)</td>
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</table>

### МАССА НА ЕДИНИЦУ ДЛИНЫ

<table>
<thead>
<tr>
<th>Единица</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Фунт на фут (lb/ft)</td>
<td>Килограмм на метр (kg/m)</td>
</tr>
<tr>
<td>Фунт на дюйм (lb/in)</td>
<td>Килограмм на метр (kg/m)</td>
</tr>
</tbody>
</table>
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