Open-Hole Wireline Services

Resistivity

ACRt™ Array Compensated Resistivity Tool System

The ACRt™ array compensated resistivity tool system represents the latest thinking in conventional array induction technology. Every aspect of mechanical, electrical, software, and signal processing design has been optimized to yield array induction measurements with unparalleled accuracy, stability, and dynamic range.

The ACRt system is an asymmetric design that consists of a single transmitter operating at three frequencies and six receiver antennas with spacings from 6 to 80 in. A simple and robust skin effect method utilizes only the in-phase components of the received signals at all three frequencies. Each tool is individually characterized for thermal drift during manufacture. This characterization, in concert with sonde-mounted temperature sensors, provides the basis of a proprietary and highly accurate temperature compensation method. Real-time borehole corrections are usually derived from a caliper source and a sonde-mounted mud cell. When the caliper input is absent (e.g. downlogging), borehole corrections are derived from the short-spaced induction receiver data alone. The final step in the processing chain, 2D software focusing, produces five radial curves with matched vertical resolution and with radial focal depths of 10, 20, 30, 60, and 90 in. The ACRt sonde includes an integrated SP sensor.

Applications

- Accurate measures of formation resistivity at varying depths of investigation for enhanced estimates of $R_t$, $R_{xo}$, and $D_i$
- Quantitative assessment of $S_{np}$, $S_{xo}$, and moveable water volumes
- Qualitative assessment of permeability and rock quality
- Array induction measurements are available in formations with resistivities from 0.2 to 2000 ohm-m and in water, air, or oil-filled boreholes
- Analysis of finely-bedded formations

Real-time 10-20-30-60-90 in. radial curves from the ACRt™ system are displayed in track 2. Good sensitivity to shallow invasion is in evidence in the zones 10290 and 10385. $RT$, $RXO$, $DI$ and the graphical invasion map are available in real time.
Features

- State of the art processing scheme features:
  - 2D software focusing produce five resolution-matched radial curves with radial focal depths of 10, 20, 30, 60 and 90 in.
  - Real-time inversion for \( R_t \), \( R_{xo} \), \( D_i \), and invasion “map”
  - Proprietary thermal correction scheme
  - Three frequency skin effect correction
  - Real-time borehole corrections with or without caliper inputs
  - Resolution-match filters of 1, 2 and 4 ft

- Optimized receiver antenna spacings provide improved sensitivity to shallow and mid-range mud filtrate invasion depths along with excellent deep response for \( R_t \)

- Receiver coil spacings closely approximate computed radial curve depths, which results in fundamentally stable processing

- Short array length reduces dependency on “speed correction” when encountering moderate overpulls

- Environmental ratings of 350°F and 20,000 psi

- Logging speeds up to 6,000 ft/hr

ACRt™ Array Compensated Resistivity Tool Specifications

<table>
<thead>
<tr>
<th>Length ft (m)</th>
<th>Minimum Borehole Diameter in. (mm)</th>
<th>Maximum Borehole Diameter in. (mm)</th>
<th>Operating Pressure Rating psi (bar)</th>
<th>Operating Temperature Rating °F (°C)</th>
<th>Weight lb (kg)</th>
<th>Maximum Logging Speed ft/hr (m/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.5 (5.9)</td>
<td>4.75 (121)</td>
<td>12.25 (311)</td>
<td>20,000 (1400)</td>
<td>350 (177)</td>
<td>308 (140)</td>
<td>6,000 (1830)</td>
</tr>
</tbody>
</table>
HRAI™ High Resolution Array Induction Tool

The HRAI™ high resolution array induction tool represents a significant engineering advance over the HRI™ high resolution induction tool. The HRAI tool leverages the proven features of the HRI tool “three-coil” receiver configuration while providing induction measurements with six radial focal depths. The sonde is a symmetrical design, with five upper and five lower receivers positioned around a center-mounted transmitter. Raw conductivity data is collected at two frequencies, 8 and 32 kHz, and the receiver antennas are spaced from 17 to 78 in.

A new speed correction algorithm implemented in the logging software enhances the accuracy of HRAI tool coil array data even during large overpulls in sticky boreholes. Long transmitter-receiver spacing and optimized array processing help to significantly reduce the effects of washouts, rugosity, and tool eccentricity.

Applications
- Accurate measures of formation resistivity at varying depths of investigation for enhanced estimates of $R_t$, $R_{xo}$, and $D_i$
- Quantitative assessment of $S_w$, $S_{xo}$, and moveable water volumes
- Qualitative assessment of permeability and rock quality
- Array induction measurements are available in formations with resistivities from 0.2 to 2,000 ohm-m and in water, air, or oil-filled boreholes
- Analysis of finely-bedded formations

Features
- Real-time 2D software focusing achieves an optimum balance of vertical resolution, radial focusing, and symmetry of response
- Resolution-matched radial curves are computed with radial focal depths of 10, 20, 30, 60, 90 and 120 in.
- Each resistivity comes with a 1-ft, 2-ft, and 4-ft vertical resolution
- Real-time $R_t$, $R_{xo}$, and $D_i$ curves and an invasion “map” are available
- Real-time borehole corrections facilitated by a sonde-mounted mud resistivity sensor
- Advanced “speed correction” algorithm for correcting array data for over-pulls in sticky boreholes
- Vertical resolution-matched elemental measurements
- High logging speeds up to 6,000 ft/hour are possible

HRAI™ High Resolution Array Induction Tool Specifications

<table>
<thead>
<tr>
<th>Description</th>
<th>Logging Speed ft/hr (m)</th>
<th>Length ft (m)</th>
<th>Minimum Borehole Diameter in. (cm)</th>
<th>Operating Pressure psi (bar)</th>
<th>Operating Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOGIQ</td>
<td>6,000 (1830)</td>
<td>25.43 (7.75)</td>
<td>4.5 (11.43)</td>
<td>20,000 (1400)</td>
<td>350 (177)</td>
<td>400 (181)</td>
</tr>
<tr>
<td>DIT</td>
<td>6,000 (1830)</td>
<td>35 (10.67)</td>
<td>4.5 (11.43)</td>
<td>20,000 (1400)</td>
<td>300 (150)</td>
<td>598 (266.5)</td>
</tr>
</tbody>
</table>

Real-time answer products of HRAI™ tool: an invasion map in Track 4, $R_t$ and $R_{xo}$ in Track 3, and Track 2 shows the 2-ft resolution radial resistivity curves.
**HRI™ High Resolution Induction Tool**

The HRI™ high resolution induction tool is an electrical wireline tool that belongs to the induction logging family of tools. It records apparent conductivity of the subsurface formations. Data processing converts the measured conductivity into resistivity. The HRI tool works well in boreholes drilled with water, air, or oil. Standard HRI tool presentation includes deep and medium resistivities derived from the raw conductivities. In conductive muds, a digitally focused resistivity log (DFL) and SP measurements are available.

**Applications**
- Reliable \( R_i \) in resistivity environments from 0.2 to 2,000 ohm-m provides improved estimates of water saturation
- Quantitative moveable hydrocarbon volumetric analysis and radial fluid distribution around the borehole when DFL is available
- High vertical resolution deep, medium conductivities and DFL logs enhance analysis in finely laminated reservoirs
- Distinguishes between conductive water-bearing and hydrocarbon-bearing formations
- Provides estimate of invasion diameter and \( R_{xo} \)

**Features**
- Sonde architecture consists of four transmitters and one receiver. The transmitter operates at 20 kHz
- The single receiver is a “three-coil” configuration for enhanced vertical resolution
- The tool measures both \( R \) and \( X \) components of the conductivities. \( X \) signals are used for skin effect correction
- The signal processing chain includes corrections for formation skin and shoulder bed effects to produce the deep (HDRS) and medium (HMRS) resistivities
- The DFL provides a shallow focused resistivity measurement with a radial investigation of 15 in. The vertical resolution of the DFL closely matches that of the HRI tool induction curves
- A 1-ft vertical resolution improves estimates of \( S_w \) and the hydrocarbon reserves in thinly laminated pays

![Standard HRI™ log example showing deep and medium resistivities (Track 2) computed by correcting the raw conductivity data for skin, shoulder bed, and borehole effects.](image)

**HRI™ High Resolution Induction Tool Specifications**

<table>
<thead>
<tr>
<th></th>
<th>Length (ft)</th>
<th>Diameter (in.)</th>
<th>Operating Pressure (psi)</th>
<th>Operating Temperature (°F)</th>
<th>Weight (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>33.3</td>
<td>3.63</td>
<td>20,000</td>
<td>350</td>
<td>455</td>
</tr>
<tr>
<td>(10.2)</td>
<td>(92.2)</td>
<td></td>
<td>(137.9)</td>
<td>(176.7)</td>
<td>(206.4)</td>
</tr>
</tbody>
</table>

Open-Hole Wireline Services
DLL™ Dual Laterolog Service

Halliburton’s proven DLL™ dual laterolog service provides a reliable means of measuring formation resistivity in conductive borehole fluids and/or where large contrasts exist between the formation and mud resistivities. The DLL service operates by focusing currents into the formation to produce a deep resistivity measurement (LLd) and a shallow resistivity measurement (LLs). The MSFL™ micro-spherically focused log is usually run in combination to provide a third shallow resistivity measurement. Together, these three measurements provide the resistivity profile around the borehole and permit the computation of $R_i$ in presence of invasion.

Applications
- Provides accurate, high resolution shallow (LLs) and deep (LLd) resistivity measurements in high $R_i/R_m$ conditions (>100) or when formation resistivity exceeds the limits for conventional induction tools (> 2,000 ohm-m)
- Quantitative assessment of $S_w$
- When run with the MSFL log, provides estimates of $R_o$, $R_{xo}$ and diameter of invasion
- Quantitative assessment of moveable water saturations ($S_{xo}$) and moveable hydrocarbon volumes
- Acquires improved formation resistivity measurements in saline borehole fluids and in high $R_i/R_m$ (>100) contrast logging conditions or when formation resistivity exceeds the limits of induction tools (>2000 ohm-m)
- Provides MSFL measurements to help delineate thin beds and provide estimates of $R_{xo}$
- Offers qualitative indication of permeable zones and estimating invasion diameters (when run with the MSFL tool)

Features
- Rugged sonde construction and state-of-the-art electronics provide for accurate measurements of formation resistivity up to 40,000 ohm-m
- Dual electrode arrays and an automatic current-focusing technique
- The fundamental vertical resolution is 24 in. for both measurements which facilitates reservoir description of thinly bedded formations

DLL™ log example from a carbonate-evaporite sequence showing deep and medium laterolog curves presented along with the shallow MSFL™ log.

DLL™ Dual Laterolog Service Specifications

<table>
<thead>
<tr>
<th>Length (ft)</th>
<th>Diameter (in.)</th>
<th>Maximum Pressure (psi)</th>
<th>Maximum Temperature (°F)</th>
<th>Weight (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33.9</td>
<td>3.63</td>
<td>20,000</td>
<td>350</td>
<td>460</td>
</tr>
<tr>
<td>(10.3)</td>
<td>(92.2)</td>
<td>(137.0)</td>
<td>(176.7)</td>
<td>(208.7)</td>
</tr>
</tbody>
</table>
**MSFL™ Micro-Spherically Focused Log and Microlog (ML)**

The MSFL™ micro-spherically focused log and microlog (ML) tool is a pad-type version of the spherically focused log (SFL) that was developed to eliminate borehole effects and achieve superior shallow resistivity measurements with high vertical resolution. Included with the MSFL tool is a ML sensor. The ML recorded 2-in. normal and 1.5-in. lateral resistivity measurements. The MSFL and ML tools are combined into one tool which can be run as a standalone service or in combination. The pads are arranged on opposing, powered caliper arms which provide accurate measures of borehole size.

**Applications**

- The MSFL tool provides measurements of $R_{xo}$ in all types of conductive mud systems. $R_{xo}$ is used quantitatively in computing $S_{xo}$ and moveable water volumes
- The ML tool is sensitive to the presence of mudcake and provides a qualitative indication of formation permeability
- Evaluation of thinly bedded sand/shale sequences
- Two powered caliper arms provide reliable estimates of borehole size

**Features**

- The MSFL tool records resistivity with a vertical resolution of 8 in. and a depth of investigation of 3 in.
- The ML tool records resistivity with a vertical resolution of 2 in. and a depth of investigation of 1 in.
- Both the MSFL and ML tools, by virtue of being pad-type devices, offer measurements relatively free of environmental effects. This makes them particularly well suited for operations in highly conductive (salt-saturated) mud systems
- Non-rubber versions of the MSFL and ML tools are available that provide superior resistance to gas absorption and better durability and run life over older rubber pad versions
- The tool can be run independently or in combination with other logging tools. When run in combination, the MSFL/ML tool can be placed anywhere in the toolstring

---

### MSFL™ Micro-Spherically Focused Log and Microlog (ML) Specifications

<table>
<thead>
<tr>
<th>Tool</th>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSFL™ Tool</td>
<td>10.2 (3.1)</td>
<td>5 (127)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>214 (96.4)</td>
</tr>
<tr>
<td>ML with HFDT™ Assembly</td>
<td>27.5 (8.4)</td>
<td>5 (127)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>720 (326.6)</td>
</tr>
<tr>
<td>ML with SDLT™ Assembly</td>
<td>18.6 (5.7)</td>
<td>4.5 (114.3)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>475 (215.5)</td>
</tr>
</tbody>
</table>

1 Weight, length, and diameter apply to the HFDT/Microlog assembly.
2 Weight, length, and diameter apply to the SDLT/Microlog assembly.
**HFDT™ High Frequency Dielectric Tool**

The HFDT™ high frequency dielectric tool is a pad-type electric logging tool used primarily in the determination of flushed-zone water saturation ($S_{xo}$). The HFDT tool transmits a continuous 1,000 MHz electromagnetic wave into the formation and measures the propagated wave amplitude and phase with respect to the transmitted signal. The principle measurement objectives are to determine the complex dielectric constant of the formation. Depth of investigation ranges from 1 cm to about 10 cm.

**Applications**

- Provides reliable $R_{xo}$ measurements for determining flushed-zone water saturation ($S_{xo}$) and moveable hydrocarbon volumes
- Determining irreducible water saturation ($S_{wirr}$) in oil-based muds
- Evaluation of thinly bedded sand/shale sequences
- Determination of the cementation exponent ($m$) when combined with other micro-resistivity logs

**Features**

- Absolute and differential dielectric measurements are recorded, resulting in less sensitivity to borehole rugosity
- Uniquely measures both the incident and reflected phase and amplitude signal
- Phase-shift and attenuation measurements from three receivers for increased accuracy
- Automatic gain control permits good log quality across a wide range of formation resistivity
- Extendable pad sensor reduces borehole rugosity effects.
- An accelerometer curve and composite profiles of resistivity and dielectric curves give indications of irregular tool motion, mudcake buildup, and pad lift-off
- Independent deployment of the pad and backup arm permit optimal alignment with other tools in the toolstring for more effective combination logging
- Works in fresh, salt-saturated, and oil-based mud systems, freshwater and most saltwater formations, and in formations where water salinity is highly variable or unknown

**HFDT™ High Frequency Dielectric Tool Specifications**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (ft/m)</td>
<td>27.5 (8.4)</td>
</tr>
<tr>
<td>Diameter (in/mm)</td>
<td>4.75 (120.7)</td>
</tr>
<tr>
<td>Maximum Pressure (psi/Mpa)</td>
<td>20,000 (137.9)</td>
</tr>
<tr>
<td>Maximum Temperature (°F/°C)</td>
<td>320 (160)</td>
</tr>
<tr>
<td>Weight (lb/kg)</td>
<td>720 (326.6)</td>
</tr>
</tbody>
</table>

*HFDT™ log computed on a sandstone matrix. Hydrocarbons are indicated when dielectric porosity $F_{PHI}$ falls below density/neutron porosity. In the above example, the high frequency dielectric clearly shows that the zones from 46 ft to 83 ft and 91 ft to 99 ft are hydrocarbon bearing while the zone from 132 ft to 142 ft is water filled.*
Imaging

EMI™ Electrical Micro Imaging Service

The EMI™ Electrical Micro Imaging service provides highly detailed, core-like images of the formations encountered by the borehole. These images are produced by measuring and mapping formation micro-resistivity with each of the 150 pad-mounted button electrodes on six independent arms. The current of each button is recorded as a curve and sampled every 0.1-in. (120 samples/ft). These current variations are then converted to color or gray-scaled images. Conventional dipmeter information is embedded into the image data and is available for standard SED™ tool answer products. A navigation package is included in the EMI tool to provide accurate information on tool position and orientation within the borehole.

Consistent, direct pad contact with the borehole wall is essential to obtaining high quality borehole image data. By virtue of independent arm linkages and pad articulation, optimum pad contact can be maintained with a minimum of pad pressure even in rugose, washed-out, or non-circular boreholes. This results in accurate, sharp images, more complete borehole coverage, and a reduced dependence on corrections for irregular tool motion effects (speed corrections). In addition, the EMI service uses six independent arms, making it possible to acquire quality image data in non-optimal hole conditions.

Applications

- Provides a variety of real-time and post-processing 2D and 3D image products to evaluate geological, petrophysical, and borehole properties
- Offers detailed structural, stratigraphic, and sedimentological analysis for optimized offset well placement, completion tactics, and hydrocarbon depletion efficiency
- Allows thin bed delineation and improved net pay estimations
- Quantifies rock textures and electro-facies
- Permits 2D and 3D borehole geometry and breakout presentations from 6 caliper measurements as well as characterization and evaluation of secondary porosity
- Identifies orientation and connectivity of fracture systems

Features

Electric borehole technology has the capability of resolving features impossible to resolve using conventional logging tools. Small fractures, vugs, bedding planes, depositional features, thin beds, and rock texture changes provide significant insights that can impact reservoir exploration and development.

Associated Answer Products

- SHIVA™ program
- AutoDip™ service
- TrendSetter™ service
- Texture-profile
- Manual dip picking
- Image interpretation

Static (Track 2) and dynamic (Track 5) enhancement of an EMI™ borehole image showing a sand-shale sequence and the computed dips (Track 4) of the sedimentary strata. Vertical fractures (drilling artifacts) are also seen in the enhanced images. High resolution data can provide insight into the texture of the formation and reveal details conventional logs cannot.
Soft sediment deformation and slumping are captured on the electric image. The AutoDip™ program does a good job of capturing the dip reversals and handling the high angle dips.

Fine structural and stratigraphic details of a thinly bedded reservoir are captured in this borehole image. The automatically picked dips do an excellent job of capturing dip trend details. There are over 100 dips selected in this 13-ft interval. Hand picking would be tedious, time consuming, and perhaps discretionary.

Structural and stratigraphic dips are well represented in this example. Slumping above the base of the sand (3295) is evident and current bedding above give evidence of the depositional environment.

### EMI™ Electrical Micro Imaging Service Specifications

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Length (ft/m)</th>
<th>Diameter (minimum) (in/mm)</th>
<th>Maximum Pressure (psi/Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight (lb/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMI™ Tool Only</td>
<td>24 (7.3)</td>
<td>5 (127.0)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>496 (225)</td>
</tr>
<tr>
<td>EMI Toolstring</td>
<td>41 (12.5)</td>
<td>5 (127.0)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>N/A</td>
</tr>
</tbody>
</table>
XRMI™ X-Tended Range Micro Imager Tool

This new electrical wireline borehole imaging tool is designed to obtain superior quality images even in high \( R_t:R_m \) environments. The expanded operating range of the XRMI™ X-tended range micro imager tool over conventional electrical imaging tools is achieved through its new, state-of-the-art 32 bit digital signal acquisition architecture combined with a large increase in available power for the excitation current (EMEX).

As a result, the signal to noise ratio of the raw measurements is improved by a factor of up to five, and the dynamic range is expanded by a factor of up to three. The resulting images offer superior fidelity even in highly resistive formations (\( R_t > 2000 \text{ ohm} \cdot \text{m} \)) or relatively salty borehole fluids (\( R_m < 0.1 \text{ ohm} \cdot \text{m} \)).

Besides the new electronics, the mandrel architecture derived from Halliburton's highly successful EMI™ imaging tool greatly helps the XRMI tool generate superior quality borehole images. Pads mounted on six independently articulated arms help maintain pad contact in rugose, washed-out, elliptical, or highly deviated boreholes. Further, high sampling rate (120 samples/ft) and adequate borehole coverage (67% in 8.5 in. holes) help obtain high resolution pictures of the borehole walls.

Applications

- Shows bedding dips that help rationalize the choice of next drilling location
- Chooses the sidewall core zones, formation testing zones, and perforation intervals accurately by integrating images with other open-hole logs
- Computes accurate high resolution net-to-gross
- Optimizes offset well placement by evaluating structural and stratigraphic features and bedding orientation
- Provides more accurate net-to-gross estimations in laminated shaly sands and carbonates by delineating thin beds and laminations
- Rationalizes well stimulation and formation testing decisions by characterizing the secondary porosity (e.g. fractures and vugs) in reservoirs
- Optimizes drilling efficiency by evaluating and orienting borehole breakout
- Optimizes the completion tactics and reservoir management by providing characterization of rock texture and electro-facies

High resolution XRMI™ images showing the micro-textural geological details in the fabric of a limestone section in a test well from Permian Basin, West Texas: (a) vugular open porosity; (b) open natural fractures; and (c) stylolites. The \( R_t:R_m \) ratio exceeds 100,000 in this borehole.
An XRMI™ formation evaluation answer product generated by Halliburton’s proprietary software WXforecast. The first image track shows the static equalized image and the second image track exhibits the texture-enhanced high resolution image produced by the application texture-pro. Central dip-track shows the results of Auto-Dip™ service. The sharp change in the dip azimuths from west to east is interpreted to be due to slump faulting. The base of the channel sand is also a scoured surface.

### XRMI™ X-Tended Range Micro Imager Tool Specifications

<table>
<thead>
<tr>
<th>Length</th>
<th>Maximum OD</th>
<th>Minimum Hole Size</th>
<th>Maximum Hole Size</th>
<th>Maximum Pressure</th>
<th>Maximum Temperature</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft (m)</td>
<td>in. (cm)</td>
<td>in. (cm)</td>
<td>in. (cm)</td>
<td>psi (KPa)</td>
<td>°F (°C)</td>
<td>lb (kg)</td>
</tr>
<tr>
<td>24.18 (7.37)</td>
<td>5 (12.7)</td>
<td>6 (15.240)</td>
<td>21 (53.34)</td>
<td>20,000 (137,895)</td>
<td>350 (176.7)</td>
<td>496 (225)</td>
</tr>
</tbody>
</table>

Borehole coverage is 67% in 8.5 in. hole.
OMRI™ Oil-Based Micro-Imager Tool

The latest addition to Halliburton’s borehole imaging solutions is the OMRI™ tool for use in oil-based muds. The OMRI tool generates crisp, high-resolution digital images of the wellbore down to 1 in. of vertical resolution, instead of 1 ft of vertical resolution that is available with conventional logging tools. The extra resolution makes thin bed pay and other important features clearly visible.

An advanced pad sensor generates six resistivity measurements per pad, each with a vertical resolution of 1 in. and a depth of investigation of about 3 in. Data is collected at 120 samples per foot with a proprietary signal acquisition scheme optimized for rugose hole conditions. The pads are mounted on six independent caliper arms which yield true assessments of borehole shape and stress, useful in frac jobs and completion designs. The sensor pads are mounted on the caliper arms with unique two-axis of articulation. This facilitates improved pad contact, and thus improved images, in less than ideal borehole conditions. This combination of features provides unparalleled image fidelity over the widest possible range of logging conditions.

Applications

- High vertical resolution pay zone volumetrics (both fluids and minerals)
- Pay zone detection (in extreme thin bed / “low contrast” pay zones)
- Structural and stratigraphic dips
- Sedimentary features and textures
- Net-to-gross sand counts
- Identification of faults and unconformities
- Evaluation of sedimentary sequences and flow units
- Lithologic unit thickness
- Secondary porosity evaluation
- Sequence stratigraphy analysis
- Borehole stresses analysis
Features

- Identifies important reservoir characteristics, such as structural and stratigraphic dips, sedimentary geometry and texture, borehole stresses, and lithologic unit thickness
- Recognizes features beyond resolution of conventional logs, including permeability barriers, sand attributes, clasts, vugs, and more
- Quantifies important reservoir characteristics such as lithology, porosity, water saturation, permeability, fluid profile, and flow potential when integrated with other logs and well information
- Provides detailed, accurate pictures of the reservoir that answer key geological and petrophysical questions
- Identifies thin bed pay that cannot be seen with conventional logs, particularly in geologically younger, unconsolidated formations
- Helps increase success rate in multi-well developments by answering questions about sedimentology and structural and stratigraphic analysis, which serve to enhance reservoir management decision making
- Optimizes design of completion programs in order to be more efficient and cost effective

OMRITM Oil-Based Micro-Imager Tool Specifications

<table>
<thead>
<tr>
<th>Length ft (m)</th>
<th>Maximum OD in. (cm)</th>
<th>Maximum Pressure psi (Kpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Minimum Hole in. (cm)</th>
<th>Maximum Hole in. (cm)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.54 (8.39)</td>
<td>5.5 (13.97)</td>
<td>20,000 (137 895)</td>
<td>350 (176.7)</td>
<td>6.5 (16.5)</td>
<td>16 (40.6)</td>
<td>760 (344.73)</td>
</tr>
</tbody>
</table>

Borehole Conditions

<table>
<thead>
<tr>
<th>Range of Mudcake Thickness</th>
<th>Mudcake Resistivity</th>
<th>Recommended Logging Speed*</th>
<th>Tool Positioning</th>
<th>Borehole Fluids</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.25 in.</td>
<td>&gt; 10,000 ohm-m</td>
<td>High Data Rate: 30 ft/min (9.1 m/min)</td>
<td>Low Data Rate: 20 ft/min (6.1 m/min)</td>
<td>Centralized: Salt:</td>
</tr>
</tbody>
</table>

*Slower logging speed may be required for low resistivity environments or poor borehole conditions.
CAST-V™ Circumferential Acoustic Scanning Tool-Visualization

The CAST-V™ circumferential acoustic scanning tool-visualization is an ultrasonic tool that provides high-resolution images in both fresh and oil-based drilling fluids. The tool’s interchangeable head rotates a full 360° and contains a high-frequency acoustic transducer to provide a full 360° profile of the borehole. A second acoustic transducer is mounted in the scanner housing and is used to measure characteristics of the borehole fluid. A directional sub is provided to orient images to either the high side of the hole or to north. The image mode, run primarily in open hole, consists of 200 points horizontally by 40 samples/ft vertically. The CAST-V tool is designed to operate in conjunction with other DITS™ tools but must be run centralized in fluid filled boreholes.

Applications
- Provides complete borehole imaging for accurate, precise formation evaluation
- Detailed structural, stratigraphic, and sedimentological analyses for optimized offset well placement, completion design, and hydrocarbon depletion efficiency
- Thin bed delineation and improved net pay estimations
- 2D and 3D borehole geometry and breakout presentations from acoustic caliper measurements

Features
- Resolves features impossible to resolve using conventional logging tools. Small fractures, vugs, bedding planes, depositional features, thin beds, and rock texture changes provide significant insights that can impact reservoir exploration and development
- Real-time fluid cell measures both borehole fluid transit time and fluid impedance. The fluid transit time is used to correct the internal radius measurements made from the scanner head while the acoustic impedance measurement is used as a quality control monitor

CAST-V™ Circumferential Acoustic Scanning Tool-Visualization Specifications

<table>
<thead>
<tr>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.9 (5.5)</td>
<td>3.63 (92.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>316 (143.3)</td>
</tr>
</tbody>
</table>

Associated Answer Products
- Manual dip-picking
- Image interpretation

CAST-V™ tool open-hole fractures example—3D projection with perspective view. Borehole breakout (in direction of minimum stress) normal to strike of fractures.
The SED™ six arm dipmeter is an electric logging tool that provides data used to compute formation dip. It provides six formation micro-resistivity measurements, tool orientation data, and six caliper curves. The six micro-resistivity measurements are taken at 60° increments around the borehole. This data is then correlated to identify bedding and other features in the formation.

**Applications**
- Evaluate magnitude and direction of structural and stratigraphic dip events for offset well placement, reservoir modeling, and reservoir management decisions
- Improved evaluation of thinly laminated sand/shale sequences
- Fracture detection
- Directional data to provide TVD, drift surveys, and bottomhole location
- Caliper data as input to 2D and 3D borehole profile plots as well as integrated borehole volumetrics

**Features**
- High resolution micro-resistivity measurements sampled at 0.1-in.
- Independent arm linkage and swiveled pads provide optimum pad contact with a minimum of pad force
- Tri-axial accelerometers and three magnetometers are employed to compute borehole drift, azimuth, and corrections for tool rotation and irregular motion
- Available oil-based mud pads for acquiring dip logs in non-conductive drilling fluids
- Six independent caliper measurements describe borehole washout and breakout in precise detail

**Associated Answer Products**
- SHIVA™ program – standard analysis package to correlate raw micro-resistivity data and evaluate it for planar structural or sedimentological features. Results presented as vector (tadpole) plots. Available at the wellsite as well as in the computing centers
- Omnidip – module of SHIVA program uses the tool's high sampling density to identify nonplanar surfaces and describe current bedding characteristics and other nonplanar sedimentary structures
- Resmapa – borehole imaging program that interpolates between the six micro-resistivity curves to produce a color oriented image of structural and sedimentological features

**SED™ Six Arm Dipmeter Specifications**

<table>
<thead>
<tr>
<th></th>
<th>Length</th>
<th>Diameter</th>
<th>Maximum Pressure</th>
<th>Maximum Temperature</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ft (m)</td>
<td>in. (mm)</td>
<td>psi (Mpa)</td>
<td>°F (°C)</td>
<td>lb (kg)</td>
</tr>
<tr>
<td>Length</td>
<td>22.3</td>
<td>4.5</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>470</td>
</tr>
<tr>
<td>Diameter</td>
<td>(6.8)</td>
<td>(114.3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Standard processed SED™ log showing the raw resistivity data and results of dip analysis.*
Nuclear

SDL™ Spectral Density Log

The SDL™ spectral density log provides superior formation bulk density and borehole compensated photoelectric factor (Pe) measurements.

Applications

• Determination of formation porosity
• Identification of formation lithology regardless of formation fluid type
• Indication of gas when used in combination with a neutron log

Features

• Delineation of thinly bedded formations using the unfiltered Pe curve
• Field engineers perform precise calibration and wellsite checks
• Curves indicating data quality are displayed on a computer screen in real-time and are recorded on the log
• Advanced correction algorithm is applied to density data
• Rigid tungsten pad incorporates a 1.5-curie cesium-137 source and two high-efficiency scintillation detectors designed to maintain high gamma counts
• Rugged construction and advanced gain stabilization help maintain measurement integrity under varying temperature conditions
• Combiable with a complete family of tools that operates under the DITS™ digital interactive telemetry system

Typical Field Output of the SDL™ Tool

Mineral Identification Plot
Associated Answer Products

- The wellsite answer product is apparent bulk density of the formation and borehole compensated photoelectric factor
- Bulk density or density porosity data is used with other open-hole sensors as input to Halliburton's mineralogy, open-hole, and cased-hole saturation analysis to provide a complete formation evaluation product. These include:
  - ULTRA™ multi-mineral evaluation program
  - CORAL™ complex lithology analysis
  - LARA™ laminated reservoir analysis
  - SASHA™ shaly sand analysis

### SDL™ Spectral Density Log Specifications

<table>
<thead>
<tr>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.3 (5.9)</td>
<td>4.5 (114.3)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>420 (190.5)</td>
</tr>
</tbody>
</table>
DSN™ Dual-Spaced Neutron Tool

The DSN™ dual-spaced neutron tool is a thermal neutron tool designed to measure formation porosity from neutron-nuclei interactions. Neutron porosity logs provide total fluid information for use with resistivity logs and/or pulsed neutron logs in determining formation water saturation. They can be combined with density logs to provide an indication of formation gas saturation and also with density and/or sonic logs to provide indications of formation lithology. In open holes, the DSN tool is usually combined with the SDLT™ spectral density logging tool and the NGRT™ natural gamma ray tool. In cased holes, the DSN tool is usually combined with the NGRT tool and DITS™ casing collar locator.

The DSN tool consists of an instrument section housing the electronics, two He3 detectors, and a source sub housing an americium-beryllium source which generates fast neutrons that penetrate the formation at an initial energy of 4.6 MeV. Thermal neutron tools are not as limited by the spacing and depth of investigation problems associated with epithermal neutron tools. Since thermal neutrons are detected, count rates are much higher than for epithermal neutrons. However, thermal neutron detectors are more sensitive to lithology and are affected by borehole and formation salinity. The dual detector method is used to compensate for these environmental effects.

Applications
- Gas detection
- Porosity
- Lithology

Features
- Detector array contains two helium proportional counters
- Optimized detector spacing, advanced calibration methods, and greater counting rates
- Faster log runs
- Delineation of thin-bed formations with enhanced vertical resolution (EVR) available in real-time or in post-processing
- A combination of logging tools can be run to identify lithology, reveal gas zones, and calculate shale volumes

In this DSN™ log example, the subject well was logged twice. The resulting near/far ratio curves and the calculated porosity curves are overlaid to illustrate the high repeatability of DSN tool porosity measurements.
Associated Answer Products

- Wellsite answer product is the neutron porosity NPHI
- Neutron porosity data is also used with other open-hole sensors as input to Halliburton’s mineralogy, open-hole, and cased-hole saturation analysis to provide a complete formation evaluation product. These include:
  - ULTRA™ multi-mineral evaluation program
  - CORAL™ complex lithology analysis
  - LARA™ laminated reservoir analysis
  - SASHA™ shaly sand analysis

### DSN™ Dual-Spaced Neutron Tool Specifications

<table>
<thead>
<tr>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.25 (3.1)</td>
<td>3.63 (92.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>196</td>
</tr>
</tbody>
</table>
DSEN™ Dual-Spaced Epithermal Neutron Log Tool

The DSEN™ dual-spaced epithermal neutron log tool is a subsurface logging tool that provides a measurement of epithermal neutron porosity. It is used primarily in air-filled wells or in fluid-filled wells where shales and/or formation salinity adversely affect thermal neutron measurements. In open boreholes, the DSEN tool is usually combined with the SDLT™ spectral density logging tool and the NGRT™ natural gamma ray tool.

Applications

- Neutron porosity measurements in water or gas filled boreholes
- Gas detection in the formation or in filled wellbores when combined with density measurements
- Porosity curve measurements that are less affected by thermal neutron absorbers in shale, such as boron and gadolinium

Features

- Less affected by formation water salinity
- Combinable with other tools
- Optimized dual neutron detector design combines two-detector responses for enhanced accuracy
- Uses a steady-state neutron generating source (radioactive americium-beryllium, AmBe) and two epithermal neutron detectors to investigate formation porosity
- Provides reliable porosity measurements even in air, gas, and foam-filled boreholes
- Provides consistent, repeatable data over entire porosity range
- Requires minimum corrections in high-temperature environments, such as steamfloods and high-porosity formations

Associated Answer Products

- Epithermal neutron porosity (wellsite)
- Neutron porosity data is also used with other open-hole sensors as input to Halliburton’s mineralogy, open-hole, and cased-hole saturation analysis to provide a complete formation evaluation product. These include:
  - ULTRA™ multi-mineral evaluation program
  - CORAL™ complex lithology analysis
  - LARA™ laminated reservoir analysis
  - SASHA™ shaly sand analysis

DSEN™ log computed assuming a limestone matrix. The bottom of the well is liquid filled. From x534 to the top, the well is air filled. Formation gas is indicated when the density porosity becomes greater than the neutron porosity. This log reveals good gas zones from x586 to x427.

DSEN™ Dual-Spaced Epithermal Neutron Log Tool Specifications

<table>
<thead>
<tr>
<th>Length (ft (m))</th>
<th>Diameter (in. (mm))</th>
<th>Maximum Pressure (psi (Mpa))</th>
<th>Maximum Temperature (°F (°C))</th>
<th>Weight (lb (kg))</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.25 (2.2)</td>
<td>3.63 (92.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>170 (77.1)</td>
</tr>
</tbody>
</table>
CSNG™ Compensated Spectral Natural Gamma Ray

The CSNG™ compensated spectral natural gamma ray tool measures the gamma ray spectrum from 0 to 3,000 keV. The tool uses full-spectrum processing to provide precise and accurate logs of potassium, uranium, and thorium concentrations. Measurement precision curves and tool diagnostics help validate logging data quality.

The CNSG tool’s unique stabilizer system differentiates it from the competition by compensating for temperature related drift in the gamma ray energy gain and offset conversion. The full-spectrum processing performs additional refinement of the energy calibration and compensates for variations in detector resolution.

Another unique feature of the CSNG tool is its ability to provide real-time outputs corrected for the borehole environment and converted to standard conditions (8.625-in. borehole, freshwater in borehole, no casing, and tool eccentered).

Estimates of borehole potassium concentration and photoelectric absorption made during the log are helpful to confirm real-time corrections or to apply corrections in a re-computation mode. Also, removal of borehole potassium signal produces accurate total gamma ray and elemental yields in potassium muds.

Applications
• Detection of producible zones
• Determine clay types, volumes, and cation exchange capacity using elemental concentration data and CLAMS™ clay and matrix analysis post-processing analysis

Features
• Measures and records energy of individual gamma rays
• Elemental yield calculations are insensitive to photoelectric absorption in barite muds or other high-Z materials
• Filtering technique improves the statistical precision of the elemental yields
• Forms a spectrum of gamma energies indicating the number of gamma rays recorded at each energy level
• 0 to 3 MeV spectrum facilitates determination of potassium, uranium, and thorium weight concentrations in the formation
• Reduced cross-correlation among elemental yields

Associated Answer Products
• Output from the CSNG spectral processing includes total gamma ray and elemental concentrations of potassium, uranium, and thorium
• Clay typing, volumes, and cation exchange capacity can be compared using CLAMS analysis software
LOGIQ® CSNG™ Compensated Spectral Natural Gamma Ray Specifications

<table>
<thead>
<tr>
<th>Housing</th>
<th>Makeup Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure* psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium</td>
<td>14.9 (4.5)</td>
<td>3.625 (92.1)</td>
<td>14,000 (96.5)</td>
<td>350 (176.7)</td>
<td>271 (122.9)</td>
</tr>
<tr>
<td>Low Z</td>
<td>12.9 (3.9)</td>
<td>3.625 (92.1)</td>
<td>8,000 (55.2)</td>
<td>275 (135)</td>
<td>260 (117.9)</td>
</tr>
</tbody>
</table>

*Please refer to the CSNG Pressure Rating Chart below.
Acoustics

**BSAT Borehole Compensated Sonic Array Tool**

Halliburton’s BSAT service integrates two monopole transmitters with an array of five receivers. This tool configuration provides borehole compensation of the P-wave measurement. The full waveform data is digitally recorded for each receiver, thus permitting advanced data analysis and quality control for waveform amplitude, slowness, and arrival time in both open-hole and cased-hole applications.

The BSAT tool is over 12 ft shorter than many other acoustic logging tools. While not compromising data quality, the reduction in tool length helps speed up rig-up and rig-down times, especially when lubricator and pressure control equipment are required.

The P-wave slowness is obtained using a robust waveform cross correlation coherency process which utilizes the waveform data from the entire receiver array. The process evaluates many attributes of the waveform data before selecting, in real time, the acoustic velocities of the formation.

The BSAT tool can also be used for 3-ft to 5-ft CBL-VDL measurements and can be run in combination with any IQ tool services.

**Applications**

- P-wave slowness used for sonic porosity determination
- Time-to-depth correlation
- Synthetic seismograms
- Identification of pore pressure changes
- 3-ft to 5-ft CBL-VDL measurement
- Instantaneous waveform attributes

**Features**

- Waveforms can be recorded at high logging speeds
- The P-wave slowness is obtained using a robust waveform cross correlation semblance process
- Downhole digitization helps eliminate the transmission noise and improve signal-to-noise ratio. Compression technique allows high uplink data transfer rate

- Can be used as CBL tool in combination with any LOGIQ® cased-hole services

---

**BSAT Borehole Compensated Sonic Array Tool Specifications**

<table>
<thead>
<tr>
<th>Length (ft)</th>
<th>Diameter (in.)</th>
<th>Maximum Pressure (psi)</th>
<th>Maximum Temperature (°F)</th>
<th>Weight (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.83</td>
<td>3.63</td>
<td>20,000</td>
<td>350</td>
<td>318</td>
</tr>
<tr>
<td>(4.82)</td>
<td>(92.2)</td>
<td>(137.9)</td>
<td>(176.7)</td>
<td>(144.4)</td>
</tr>
</tbody>
</table>

---

Gamma ray, VpVs, and caliper presented in Track 1. Compressional and refracted shear are presented in Track 2. Semblance with compressive and shear slowness overlaid on the semblance image are presented in Track 3.
WaveSonic® Tool

The WaveSonic® crossed dipole sonic tool provides simultaneous monopole, XX dipole, and YY dipole sonic measurements. The dipole flexural wave propagation allows for the measurement of shear wave slowness in virtually all formation conditions. The compressional P-wave slowness, refracted shear wave slowness, and Stoneley wave properties are obtained from the monopole data. The shear wave slowness in two orthogonal directions can be obtained in real-time from the XX and YY dipole data. The WaveSonic tool is combinable with all standard open and cased-hole tool services. The WaveSonic tool requires a liquid filled borehole and can be used in freshwater, saltwater, or oil-based mud systems. The robust mechanical design of this tool allows for drillpipe conveyed logging, and it is not limited to the bottom of the toolstring. A hostile WaveSonic version is available for high-temperature and high-pressure applications.

The shear wave slowness in the XX and YY directions and the monopole P-wave slowness are the basic well site deliverables. The tool has 32 broadband receivers, arranged in eight rings of four receivers, to provide high-quality waveform data. The tool provides 96 waveforms (32 monopole, 32 YY dipole, and 32 XX dipole) for each firing cycle, which are recorded by the surface system. The fast and slow shear wave travel times are obtained with advanced waveform processing methods in Halliburton’s reservoir evaluation services centers, strategically located throughout the world.

From the fast and slow shear wave travel times, and their orientation in the formation, the minimum and maximum principal stresses and stress field orientation can be obtained by combining oriented slowness data with overburden and analysis, wellbore stability, and production enhancement treatment design.

Natural gamma ray and caliper are presented in Track 1. Semblance quality data is presented in the depth track. The dipole X travel time, dipole Y travel time, and monopole P-wave travel time are presented in Track 2. Monopole semblance with the compressive wave slowness overlaid on the semblance image are presented in Track 3. The dipole X semblance with the XX shear wave slowness overlaid on the semblance image are presented in Track 4. The dipole Y semblance with the YY shear wave slowness overlaid on the semblance image are presented in Track 5.
Sonic anisotropy analysis provides the fast and slow shear wave travel times as a simultaneous solution of 64 waveforms (32 XX and 32 YY). Anisotropy and its orientation can be used to determine the minimum horizontal stress and the orientation of natural fractures. The sonic attributes of slowness, amplitude, and frequency content can be used for identification of fractures and compressive fluids and to measure various geomechanical properties. The fast and slow shear wave travel times and their orientation, combined with P-wave slowness, allows for better 3D seismic analysis.

**Applications**
- Determine fast and slow wave travel times and orientation in the formation
- Calculate minimum and maximum principal stresses and stress field orientation
- Porosity estimation
- Fracture identification
- Permeability (mobility) estimation
- AVO calibration
- Synthetic seismogram

**Features**
- Programmable-frequency sources to minimize effects of near-wellbore alteration
- Broadband eight-level, quad receiver array for high-quality waveform data
- All 96 waveforms for each set of transmitter firings are recorded at the surface for advanced waveform processing techniques
- Combinable with all open-hole tools, including MRIL® and RDT™ tools and services

**Associated Answer Products**
- Shear slowness anisotropy analysis
- RockXpert2™ sand production and fracture strength analysis
- FracXpert™ fracture stimulation zoning analysis pore pressure data information is vital for geo-mechanical
- Instantaneous waveform attributes
- Stoneley derived permeability
- Stoneley reflection analysis
- Formation stress, borehole stability, and sanding potential

**WaveSonic® Tool Specification**

<table>
<thead>
<tr>
<th></th>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>34.0 (10.3)</td>
<td>3.63 (92.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>520 (236.3)</td>
</tr>
</tbody>
</table>

**Hostile WaveSonic® Tool Specification**

<table>
<thead>
<tr>
<th>Tool Version</th>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 kpsi Tool</td>
<td>40.9 (12.4)</td>
<td>3.13 (79.4)</td>
<td>20,000 (137.9)</td>
<td>500 (260.0)</td>
<td>595 (269.9)</td>
</tr>
<tr>
<td>30 kpsi Tool</td>
<td>40.9 (12.4)</td>
<td>3.13 (79.4)</td>
<td>30,000 (206.8)</td>
<td>500 (260.0)</td>
<td>720 (326.6)</td>
</tr>
</tbody>
</table>
**FWS™ Full Wave Sonic Tool**

The FWS™ tool provides compressional wave, refracted shear wave, and Stoneley wave properties of downhole formations for a wide range of petrophysical, geological, and geophysical applications. To minimize the number of logging trips required for complete formation evaluation, the FWS tool is compatible with all DITS™ logging tool strings. A liquid-filled borehole is required for sonic logging and can be used in fresh, salt, or oil-based mud systems.

The long transmitter-to-receiver offset allows for the acquisition of borehole sonic data beyond the effects of any near-wellbore altered region. This long offset also allows for the acquisition of high-quality sonic data in enlarged boreholes where critical angle effects would affect sonic tools with short transmitter-to-receiver offsets.

The information obtained from the FWS tool is plotted in three separate log presentations:

- **Slowness presentation** – compressional slowness and refracted shear slowness, velocity ratio, and time-depth integration of the compressional and shear travel times, and other logging data such as gamma ray and caliper
- **Quality presentation** – indicators which establish confidence levels for the slowness processing, including compressional slowness and semblance coherency and refracted shear and semblance quality gain curves for each receiver
- **Waveform presentation** – waveforms from all four receivers can be presented. Gain curves reflecting the gain applied to the waveform by the automatic gain control (AGC) circuit, and correlation curves, including gamma ray and caliper information

The FWS tool can be run in the cased-hole environment to obtain sonic properties through casing. Acoustic coupling of the pipe-to-formation is required for cased-hole applications.

**Applications**

- Identify wave properties of downhole formations
- Acquisition of borehole sonic data

---

The natural gamma ray, X-X caliper, Y-Y caliper, P-wave travel time and P-wave semblance quality are presented in Track 1. The monopole waveform data is presented in Track 2 in the MicroSeismogram™ format (X-Z) and in an X-Y waveform presentation in Track 3.
Features

- Long transmitter-to-receiver offsets and 1 ft receiver-to-receiver spacings
- Detection of signals at all receivers for each transmitter pulse ensures constant source characteristics
- Automatic gain control of each receiver preserves signal amplitude
- Downhole digitizing helps eliminate transmission noise and allows broadband frequency response
- Low-frequency response allows detection of low frequency Stoneley waves and multiple $\Delta t$ measurements per depth interval
- Continuous uninterrupted recording of full waveform signals
- Records various types of information including tool data, quality curves, and final results
- Operator-selectable multiple modes of tool operation, digitally recorded waveform data, and improved porosity estimates using both $\Delta t_c$ and $\Delta t_s$

- Lithology identification by means of velocity ratio, $\Delta t_s/\Delta t_c$, and location of gas zones, even in poor hole conditions and cased holes
- Indication of permeability variations with depth from Stoneley wave attenuation and slowness
- Detection of naturally fractured zones, determination of rock elastic constants, and estimation of formation strength and least horizontal stress
- Prediction of vertical extent of hydraulic fractures
- Improved vertical resolution for detection of thinner beds (Beds as thin as 3 in. can be identified with the $t$ curves)
- Calculates sonic porosity from P-wave slowness and can determine secondary porosity by combining sonic porosity with neutron and density porosity data
- Time-to-depth correlation for seismic correlation
- Combining sonic slowness data with formation density data is the required input information needed for synthetic seismograms

### FWS™ Full Wave Sonic Tool Specifications

<table>
<thead>
<tr>
<th>Length f.t (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.6 (8.7)</td>
<td>3.625 (92.1)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>460 (208.7)</td>
</tr>
</tbody>
</table>
NMR

MRIL-XL™ and MRIL®-Prime Magnetic Resonance Image Logging Tools

The MRIL-XL™ tool is the latest family member of Halliburton’s wireline NMR logging tools. Both the MRIL-XL and MRIL®-Prime should be considered the first choices for primary formation evaluation in open holes.

NMR logging answers the four basic, critical questions all well operators must answer to understand the economics of a newly drilled prospect:

- Has the well penetrated reservoir rock? (What is the total and effective porosity in a complex lithology environment?)
- What types of fluids (hydrocarbons) are present in the reservoir and how are they distributed?
- What is the ability of the reservoir to produce these hydrocarbons, i.e. will they flow in this type of formation? (What is the permeability?)
- Will there be associated water production (BVI/FFI)?

The MRIL-XL and MRIL-Prime tools utilize the very same principles as medical MRI by directly measuring the magnetic resonance of hydrogen atoms in fluids. Amplitude of the measured signals gives porosity, whereas the actual signature carries information on rock properties and fluid characteristics.

Applications

The MRIL® tools are used in open-hole logging programs to:

- Obtain minerology-independent measurements of porosity. The MRIL tools truly measure the amount of fluid in the pore space and do not measure rock matrix. Unlike density, neutron, or sonic porosity devices, which require accurate matrix and fluid-density or Δt-matrix and Δt fluid to compute porosity, the MRIL tools are uniquely a minerology-independent porosity tool(s), yielding clay-bound water porosity, irreducible porosity (i.e. volume of bound fluid), free-fluid porosity, and total porosity
- Provide a permeability profile along the well. (Note that standard perm values are not calibrated; this requires integration with core data.)
- Provide fluid-typing (gas-oil-water), find fluid contacts, identify changes in oil viscosity
- Identify low-resistivity and/or low-contrast pay zones
Features
As an eccentered NMR tool, the MRIL-XL™ signal penetration into the formation is effectively increased in large boreholes, and the effects of drilling mud are eliminated. MRIL-XL service is available with a standard 6-in. sonde to accommodate holes sizes from 7.875-in. to >12.25-in. and is especially effective in large deviated boreholes. MRIL®-Prime is available in two sizes (slim sonde has 4.875-in. OD and standard sonde has 6-in. OD) to accommodate hole sizes from 5.875-in. to 12.25-in. Both MRIL services may be operated at up to 9 RF-frequencies—allowing data acquisition to be fast and efficient.

- Each frequency creates an independent volume of fluids in the formation, which allows the tool to log considerably faster than any single frequency NMR tool
- Both MRIL services can acquire simultaneous T₁ and T₂ logs and all MRIL services have maximum temperature ratings of 350°F
- Through-wire and switching sub adapters offer ultimate combinability with other Halliburton tools and competitor tools
- Compatible with drillpipe or tubing conveyed type logging systems in highly deviated wells
- Accurately measures porosity in mixed mineralogy reservoirs
- Improves completion success in low-permeability reservoirs
- Identifies pay zones in laminated, fine-grained sand, and shale formations
- Increases access to reserves by providing complete and accurate analyses of low resistivity/low-contrast intervals
- Identifies zones of water-free production
- Multi-frequency capability allows operators to acquire much more accurate data by combining the measurements made in each volume (at each different frequency)
- Only product to allow combining of different measurements probing different NMR properties of the fluids and formation in one single pass—a major step forward in fluid identification and quantification
- Has successfully pioneered the discovery of oil in zones which triple-combo has traditionally bypassed, leading to increased production of reserves and some spectacular discoveries in even mature production areas

These huge amounts of reservoir information from a single device are extremely valuable for optimizing stimulation and completion programs, thereby optimizing the productivity of each well drilled.

Associated Answer Products
- MRIAN™ MRI analysis – an integrated analysis which incorporates MRIL porosity from T₁ and/or T₂ plus resistivity data in the dual-water model
- TDA™ time domain analysis – a MRIL only fluids and porosity analysis derived from analysis of the raw NMR echo train data only
- DTW dual wait time analysis – an analysis of hydrocarbon type or types found within each reservoir. Obtained by operating the MRIL service using a short and long Tₚ (wait time, such as 1s and 12s) in a single logging pass
- DTE dual echo time analysis – an analysis of hydrocarbon or other fluids within each reservoir. Obtained by operating the MRIL service using two different Tₑ (inter-echo spacing, such as a short Tₑ of 1.2ms and a longer Tₑ of 6ms or longer)

MRIL®-Prime Magnetic Resonance Image Logging Tool Specifications

<table>
<thead>
<tr>
<th>Sonde in.</th>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>52.9 (16.1)</td>
<td>6.00 (152.4)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>1,475 (669.1)</td>
</tr>
<tr>
<td>4.875</td>
<td>50.4 (15.4)</td>
<td>4.875 (123.8)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>1,275 (578.3)</td>
</tr>
</tbody>
</table>

MRIL-XL™ Service Specifications

<table>
<thead>
<tr>
<th>Sonde in.</th>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>45.7 (13.49)</td>
<td>6.00 (152.4)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>1,600 (726)</td>
</tr>
</tbody>
</table>
Halliburton’s patented MRILab® service is another breakthrough development of nuclear magnetic resonance imaging technology for oil and gas operators. The service provides laboratory-quality fluids measurements at reservoir conditions in real time by directly measuring the magnetic resonance parameter $T_1$. Because contaminates mixed with crude oil modulate the $T_1$ response, these measurements can be interpreted to determine when a clean sample can be taken and saved in Halliburton’s RDT™ reservoir description tool sample chambers. This ability to provide downhole laboratory-quality fluid measurements makes the MRILab service an integral component of the RDT tool.

The MRILab service allows operators to measure relaxation times on reservoir fluids in-situ at true reservoir conditions—an important industry first. The measured $T_1$, $T_2$, and the self-diffusion coefficient ($D$) of the reservoir fluids tie directly into important fluid characteristics such as viscosity and apparent Hydrogen Index. This makes the MRILab service approach superior to traditional reservoir fluid sample processing that involves transferring samples uphole at the wellsite for conventional laboratory analysis. These measurements are significant for completion and reservoir engineering as well as for reservoir understanding, and they are available at the wellsite immediately where they will have the most value.

Features

- Identifies connate oil vs. oil-based mud filtrate differentiation
- Provides accurate fluid data for MRIL® log interpretation either wireline or LWD
- Measures hydrocarbon viscosity in-situ
- Complements MRIL logging service and extends the application of MRI technology in reservoir fluids determination
- Can be conveyed on wireline or drillpipe
- Measures the magnetic resonance properties of reservoir fluids as the RDT pumps from the reservoir into the borehole or sample chamber
- Measures $T_1$ of fluid in the flowline while pumping with the RDT
- Measures $T_2$ and diffusivity of stagnant fluid in the flowline

MRILab® service is a modular component to the RDT™ reservoir description tool, providing real-time fluid analysis while pumping out to determine optimal time to obtain the cleanest samples possible.
Available immediately at vastly reduced cost compared to conventional laboratory measurement. Surface laboratory PVT analysis is both expensive and can take weeks or months to produce results. The actual task of collecting a reasonably uncontaminated reservoir fluid sample can require significant rig time. And during that time the clock is running on the well operators’ and other contractors’ time, rental equipment, and personnel costs. It is not uncommon for physical drillstem tests for viscosity and other key fluid properties to cost the operator hundreds of thousands of dollars when all the expenses are calculated.

More accurate measurements of native oil than other methods. Since the MRILab® measurements occur downhole on in-place and unaltered reservoir fluids, there is no direct human manipulation and no opportunity for the errors that can occur in surface lab work. The well operator can have confidence in the viscosity oil characterization measurement results on the native oil in place in the reservoir.

Results are available in real-time at the rigsite or by remote viewing. Viscosity and oil characterization are important attributes usable for making completion decisions.

Producing this information right away at the rigsite makes MRILab data infinitely more valuable than surface lab data that may be delayed for over a month. Similarly, the MRILab tool is equipped with real-time telemetry capability that makes the results of the measurements viewable remotely over a secure connection between client and the tool.

Health, Safety, and Environmental
The ability to analyze the filtrate contamination level of reservoir fluids in real-time allows one to minimize the volume of fluid that is pumped from the formation into the wellbore before securing the fluid into the sample chamber. Further, real-time analysis of the reservoir fluids may reduce the number of samples that are required, thus eliminating the need for transfer and transport of hazardous fluid samples.

MRILab® Service Specifications

<table>
<thead>
<tr>
<th>Length (ft) (m)</th>
<th>Diameter (in.) (mm)</th>
<th>Maximum Pressure (psi) (Mpa)</th>
<th>Maximum Temperature (°F) (°C)</th>
<th>Weight (lb) (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 (4.3)</td>
<td>4.75 (120.7)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>400 (181.4)</td>
</tr>
</tbody>
</table>
Borehole Geophysics

Wellbore Seismic

High Resolution Seismic Imaging—(Near Offset VSP, Fixed Offset VSP, Walkaways, 3D VSP, Salt Proximity Surveys, Microseismic Surveys)

Halliburton provides high-resolution images in the vicinity of the borehole using a number of different techniques depending on the objectives and the geologic environment. The techniques include vertical incidence vertical seismic profiles (VIVSP) in deviated wells, salt proximity surveys, tomographic velocity analysis, fixed offset VSP surveys (FOVSP), 2D walkaway surveys, 3D VSP, and ExactFrac® or microseismic surveys.

Halliburton is an industry leader in providing advanced source and downhole array technologies for borehole seismic. Halliburton's expertise serves to benefit operators with reduced rig time and improved data quality. Advanced source and receiver technology is crucial towards obtaining a more accurate and comprehensive geological picture of your well, field, or reservoir.

Halliburton can offer custom built solutions for client's seismic imaging field needs. For survey planning, we use the most advanced 3D wavefront modeling software available, GeoTomo's VECON software.

Multi-component arrays can be mobilized downhole to more accurately record true amplitude information of both compressional and shear waves.

Compressional and shear images can be used in conjunction for lithology and fluid identification. Surveys can be repeated for time-lapse 4D views of fluid movements.

Downhole seismic tools can also be used to passively listen to the reservoir and to map fluid movements, fault reactivation, or active fracture monitoring.

A full array of tools is available for analyzing high resolution seismic data for reservoir imaging. Halliburton offers advanced pre-processing, including multi-component wavefield separation and final imaging using pre-stack depth migration (PSDM).

High Resolution Seismic Imaging Features
- Generation of high-resolution multiple free images
- Mapping of steep structures (such as salt flanks)
- Detailed velocity cubes in areas of laterally changing velocity (shallow gas, permafrost, salt, etc.)
- Map structure, stratigraphy, lithology, and fluids with higher resolution and confidence than can be obtained with surface seismic
- Improve a poor data quality area or overcome no-data areas

High Resolution Seismic Imaging Applications
- Profiling salt dome flanks
- Detecting natural fractures
- Enhanced seismic velocity analysis
- Primary seismic reflector identification
- Porosity and permeability estimation
- Anisotropy determination
- AVO analysis
- Determine height, length, and width of well frac or stimulation process

Associated Answer Products
- Vertical incidence VSP
- Synthetic seismogram
- FWS™ full wave sonic processing
- ExactFrac® services
Reservoir Geophysics

Long Array Multi-Component Acquisition Tools
Halliburton offers survey planning, data acquisition, and data processing using multi-component long seismic arrays. Each tool combines advanced-source technology with industry leading multi-component and anisotropic migration software for a complete package of advanced custom designed reservoir imaging systems. Systems include the GeoChain™ VSP downhole receiver array.

GeoChain VSP Downhole Receiver Array
The GeoChain vertical seismic profile (VSP) array is designed for large borehole imaging surveys and can be used in open and cased holes with standard seven-conductor cable even in deep and hostile environments.

GeoChain VSP Receiver Array Features
- Based on the proven ASR-1 downhole geophone
- Can be used in wells up to 25,000 psi and with hole sizes from 3.5-in. to 22-in.
- Unique ACS™ active cooling system allows continuous operation up to 356°F (180°C)
- Up to 42 satellites can be used in the array with a maximum tool spacing of 200 ft
- All satellite locking arms open and close simultaneously, and the entire string can lock into a 9.625-in. well in only 30 seconds
- Can be run in the following configurations:

<table>
<thead>
<tr>
<th>No. of Tools</th>
<th>Sample Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1/2 ms</td>
</tr>
<tr>
<td>10</td>
<td>1 ms</td>
</tr>
<tr>
<td>21</td>
<td>2 ms</td>
</tr>
<tr>
<td>26</td>
<td>2.5 ms</td>
</tr>
<tr>
<td>32</td>
<td>3 ms</td>
</tr>
<tr>
<td>42</td>
<td>4 ms</td>
</tr>
</tbody>
</table>

Associated Answer Products
- 3D VSP imaging
- 2D VSP imaging
- Interwell imaging
- ExactFrac® (microseismic) services

Synthetic Seismic and Sonic Log Calibration

The synthetic seismogram obtains an accurate tie between well logs measured in depth and the surface seismic image measured in two-way time. Correlation between logs and seismic is important to verify interpreted horizons and to help determine the true phase of the surface seismic (important for advanced lithologic and fluid interpretations from seismic data).

An accurate synthetic depends on sonic log calibration using data from a vertical seismic profile (VSP) or check shot survey. This calibration is necessary for a number of reasons such as:
- Sonic log and surface seismic are measured at different frequencies (dispersion)
- Sonic log and surface seismic can measure different rock and fluid volumes (fluid differences, invaded zones, damaged borehole, non-vertical ray paths, etc.)

Calibration of the sonic log includes an analysis of the data to determine the cause of the differences (drift) between the sonic and the check shots.

Depending on the cause of the drift, different methods of correction are used. The corrected sonic log is converted to interval velocity. Acoustic impedance is calculated using the corrected velocity log and the bulk density. Changes in acoustic impedance are used to create a reflection coefficient log, which is subsequently convolved with a desired wavelet to create a synthetic seismic trace.

Recording of a shear sonic log or calculation of a synthetic shear log allows calculation of a 2D synthetic to analyze or predict AVO effects on the surface seismic. Perturbation of the rock parameters also allows study of the effects of fluid and lithology changes on the seismic character.

Synthetic Seismic Features
- Helps promote accurate tie between well logs and surface seismic including phase determination
- Allows identification of multiples on the surface seismic
- Allows study of fluid and lithology effects on the seismic character

Associated Answer Products
- Vertical incidence VSP
- High resolution seismic imaging (walkaway, fixed offset, 3D VSP, salt proximity, AVO Studies)
- FWS™ full wave sonic processing
Vertical Incidence Vertical Seismic Profiling (VIVSP) Analysis

The VIVSP analysis is a downhole seismic survey with the surface source positioned vertically above the geophones anchored in the well. In a vertical well, it is known as a zero offset VSP (ZOVSP) with the source positioned in a single location near the wellhead. In highly deviated wells, the source is moved along with the downhole geophone tool to keep the source vertically positioned above the geophone tool at each level.

VIVSP analysis is useful for facilitating more accurate time-depth correlation between your well logs and your surface seismic. It is also useful for determining the phase of your surface seismic and for identifying multiples.

VIVSP data provides an indispensable bridge between sonic log data and surface seismic data. In areas where it is difficult to obtain a good tie between the synthetic and the surface seismic, the VIVSP can be helpful to identify and resolve the differences.

VIVSP is also very useful for predicting lithology, fluids, and pore pressure ahead of the bit. Velocity trends that are useful for predicting pore pressure are calibrated at the well.

VIVSP data is typically higher frequency than the surface seismic and can be used to better understand the reflectivity seen in the surface seismic.

VIVSP data can be useful for computing the dip of the reflecting horizons in the vicinity of the borehole.

This can be used to confirm dips seen on dipmeter tools and help project these dips away from the well.

In deviated wells, the VIVSP also delivers a high resolution 2D image beneath the wellbore. This image is typically higher frequency than the surface seismic, multiple free, and tied directly to the wellbore in depth.

Halliburton uses advanced proprietary software to handle VSPs in the most demanding geologic environments (advanced editing, multi-component wavefield separation, interpolation, deconvolution, and migration tools).

VSP software and processing can be used in the field, in a computing center linked to the wellsite, or in the client offices for special projects.

VSP acquisition teams utilize customized energy sources and the most advanced seismic tools available to record high-quality seismic data. The rugged, computerized logging systems precisely position the geophone tool in the well, properly synchronize the energy sources, and accurately transfer the measured data to the surface. The data obtained from VSPs provide extremely important information for enhancing and supplementing surface seismic data.

VIVSP Features

- Allows detailed analysis of the downgoing and upgoing wavefield
- Real seismic trace rather than synthetic for log seismic correlation
- Provides detailed velocity analysis

VSP Applications

- Direct correlation between surface seismic data and logs recorded in depth
- Calibrate wireline sonic data for correlating synthetic seismograms with conventional seismograms
- Mapping geologic structure in the vicinity of the wellbore
- Predict stratigraphy, lithology, and structure ahead of the drill bit to help save drilling time and costs
- Improve poor data-quality area or overcome no-data area
- Helps profile salt dome flanks
- Helps detect natural fractures
- Aids seismic identification of lithology
- Prospect delineation
- Enhanced seismic velocity analysis
- Primary seismic reflector identification
- Analyze multiple patterns
- Deconvolution operator for surface seismic data processing
- Porosity and permeability estimation
- 2D and 3D stratigraphic and structural imaging
- Helps locate overthrust granite/sediment interface
- AVO analysis

Associated Answer Products

- Synthetic seismogram
- High resolution seismic imaging (walkaway, fixed offset, ocean bottom cable, salt proximity, AVO studies)
- FWS™ full wave sonic processing
**ExactFrac® Services**

Halliburton eases frac modeling concerns by taking a full-service approach to logging, offering both dipole sonic and borehole seismic services. To give engineers the answers they require, our microseismic techniques provide real-time assessments of fracturing processes using two wells:

- A stimulation well where actual frac jobs are under way
- A monitor well equipped with a downhole geophone tool array with multiple sensors

These microseismic techniques provide accurate information on the length, height, and distance of the frac being generated in the formation and can dramatically optimize the placement of future wells.

**ExactFrac Services Features**

- Allows operators to optimize drilling program in field
- Improves later frac jobs (only zone you need to frac)
- Minimizes uncertainty in your fracturing program
Sampling

**RDT™ Reservoir Description Tool**

RDT™ reservoir description tool is a modular, combinable formation tester and fluid-sampling tool. The RDT tool provides accurate pressure measurements. High-quality clean and representative formation fluid samples are collected, along with a broad range of valuable reservoir data. This is accomplished through:

- Pressure-gradient testing
- Permeability anisotropy testing
- Formation fluid properties monitoring
- Zero Shock™ pressure/volume/temperature (PVT) sampling

The RDT Zero Shock PVT sampling method eliminates unanticipated fluid expansion and pressure shocks during pumping and sampling through its advanced digital control feedback system, which maintains a constant flowrate throughout the sampling process. Two closely spaced probes are standard, providing redundant packer seals and probes. In-situ PVT bubblepoint testing is performed while pumping to determine the ideal sampling pressure for oil-bearing reservoirs. Sample chambers are filled against hydrostatic pressure and additional pump pressure can be applied to maintain the sample in the single-phase condition while retrieving reservoir fluid to surface.

Bubblepoint, compressibility, density, and resistivity are fluid properties which are monitored while pumping. In addition, spherical mobility, horizontal mobility, and anisotropy are monitored. When the MRILab® section is added, additional fluid properties including Hydrogen Index (HI), T₁ and T₂ distributions, log mean T₁, viscosity index, and capacitance are also monitored. Because these properties are monitored real-time, operators are able to identify the optimum point at which to divert fluid flow and collect samples.

**Applications**

- Identify depleted and overpressured zones
- Assess reservoir fluid types and contacts
- Collect uncontaminated, representative, PVT-quality reservoir fluid samples
- Determine reservoir fluid PVT behavior
- Determine formation permeability and anisotropy
- Assess reservoir compartmentalization

**Features**

- The 100 cc pre-test chamber allows for rate- or pressure-controlled fluid entry to ensure accurate bubblepoint and PVT analyses. The large volume chamber also allows multiple pretests per pad set without releasing the pad from the borehole wall
- Dual probe configuration provides improved horizontal and vertical permeability estimates due to probe proximity
- Determine real-time horizontal and vertical mobilities while sampling or pre-testing
- Dual probe configuration provides high reliability and redundancy with multiple quartz and strain gauge pressure measurements
- Fluid type identification and contamination monitoring is used to discriminate between filtrate and formation fluid and to determine the optimal time to collect a fluid sample. Each multichamber section includes three 1,000 cc PVT sample chambers
- Multiple fluid property sensor outputs are combined to yield reliable hydrocarbon/fluid typing even in oil- or synthetic-based mud
- Powerful pump reduces cleanup time, contamination level, and saves rig time
- Three flow control pump-out sections, configured for 4,000; 6,000; and 8,000 psi pump pressure provide extended range pressure sampling capabilities in highly depleted or overbalanced conditions
- Zero Shock™ flowrate control ensures sample integrity
Pressure Testing and Zero Shock™ Sampling

Low Mobility and Laminated Pressure Testing and Zero Shock™ Sampling

Mini-DST and VIT Pressure Testing and Zero Shock™ Sampling with Straddle Packer
DPS Dual Probe Section
The DPS section deploys two independent probe/pad assemblies against the borehole wall for pressure drawdown/buildup analysis and pumping formation fluid. The DPS is designed to detect horizontal mobility ($k_h/\mu$), permeability ($k_h$), and anisotropy ($k_v/k_h$) over an extended range of operation. The DPS pressure testing flowrate is precisely controlled with the advanced digital control feedback system, thus achieving steady-state pressure quickly and reducing required testing time. By running two dual probe sections in tandem, the RDT™ tool is used to determine the pressure between the probes and profile permeability and anisotropy. This further enables an extended depth of investigation and detection of permeability barriers.

Features
- Design redundancy – two flow paths
- Operational efficiency
- Different pad configurations
- Closely spaced – enhanced permeability
- Probe shut-in valve – reduced flowline storage volume
- Faster buildup times – tight zones
- Resistivity fluid ID sensor
- Drawdown rate control 0.1 to 15 cc/sec
- Drawdown volume control 0.1 to 100 cc

Oval Pad
Carbonate rocks, thinly bedded sands, and naturally fractured reservoirs can exhibit a very challenging logging environment when pressure testing and fluid sampling are required. The challenge is due to, at least, reservoir heterogeneity and the difficulty of sealing the probes in these reservoirs. The RDT utilizes a proprietary oval pad section (OPS) to help overcome all of these challenges. The oval pad spans a 9-in. vertical section of the borehole, giving it the sealing advantages of a straddle packer but still maintaining the operational flexibility of a probe. In particular, the oval pad design ensures an effective seal for the probe during formation testing and fluid sampling in the presence of vuggy and/or fractured carbonate rocks. In addition to the increased vertical sealing area, the oval shape can reduce the sampling time due to a focusing effect the pad has on near-wellbore flow. Simulations show that when the complete testing system performance is considered, the oval pad reduces pumping times compared to a standard probe and in some cases a straddle packer.

Straddle Packer
The straddle packer section (SPS) offers advantages over probes in low permeability applications as well as heterogeneous environments. SPS incorporates a dual port design which offers unique benefits in non-horizontal wells when a density contrast exists between the drilling mud contaminant and reservoir fluids. The lighter fluid segregates towards the top of the packed-off interval. After initially pumping through both inlet ports and detecting reservoir fluid, one available option is to close the bottom port to flow only the lighter fluid through the top probe. Proper manipulation of the dual ports and taking advantage of naturally occurring fluid segregation of the fluids contained in the packed-off interval provides cleaner samples faster than samples attainable with only a single port tool. In carbonates, thinly bedded sands, and naturally fractured reservoirs, most of the production occurs from small features. Such features make sampling and reservoir characterization difficult with a probe. The probe is more likely to be placed in a location that is characteristic of the rock matrix, which usually results in a tight test. The SPS isolates a 1 m interval, which is normally ample to characterize heterogeneous rock. The primary advantage of an SPS is its ability to cover a vertical interval where a probe is a pinpoint evaluation by comparison.

FPS Flow-Control Pump-Out Section Features
- High pump rates-less contamination
- Faster pump-out times-reduced rig time
- Pump up or down (four-way valve)
- Multiple pump capability and flexible location in string
- Sampling flowrate – real-time control
- Outlet gauge controls sample filling
- Interchangeable pump pistons enable 4,000; 6,000; or 8,000 psi pumps
- Instantaneous control (0.004 to 1.1 gpm)
- Flowrate feedback control
- Single phase samples

QGS Quartz Gauge Section
The quartz pressure transducer features 14.7 - 20,000 psi calibration at 350°F. Resolution is 0.02 psi with accuracy to ± [1 psi + 0.01% reading]. This sensor is just 0.75-in. OD × 2.25-in. long. Other properties include a low mass, which means shorter time to thermal stability and fast temperature compensation.
The MRILab® section measures in-situ reservoir fluid relaxation time at true reservoir conditions. The measured $T_1$, $T_2$, and the self-diffusion coefficient (D) of the reservoir fluids tie directly into important fluid characteristics such as viscosity index, fluid type, and contamination cleanup during pump-out.

**MRILab® Section**

**MCS Multi Chamber Section**

The MCS contains motorized chamber valves with three 1,000 cc sample chambers. The chambers are detachable, transportable, and approved by the US department of transportation (DOT) and national association of corrosion engineers (NACE). Single phase nitrogen-charged sample chambers are available. Nitrogen-charged sample chambers maintain the fluid sample at higher pressure than standard chambers while the fluid is cooled and retrieved to the surface. Nitrogen charged sample volume is approximately 550 cc at surface conditions.

**Sampling Tools Specifications**

<table>
<thead>
<tr>
<th>Module</th>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Minimum Hole Size in. (mm)</th>
<th>Maximum Hole Size in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVS</td>
<td>2.3 (0.7)</td>
<td>4.75 (120.7)</td>
<td>6 (152.4)</td>
<td>18 (457.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>75 (34.0)</td>
</tr>
<tr>
<td>QGS</td>
<td>4.2 (1.3)</td>
<td>4.75 (120.7)</td>
<td>6 (152.4)</td>
<td>18 (457.2)</td>
<td>17,000 (117.2)</td>
<td>350 (176.7)</td>
<td>102 (46.3)</td>
</tr>
<tr>
<td>DPS</td>
<td>10.6 (3.2)</td>
<td>4.75 (120.7)</td>
<td>6 (152.4)</td>
<td>18 (457.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>385 (174.6)</td>
</tr>
<tr>
<td>OPS</td>
<td>10.6</td>
<td>4.75 (120.7)</td>
<td>6 (152.4)</td>
<td>17.5 (444.5)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>385 (174.6)</td>
</tr>
<tr>
<td></td>
<td>6-in. Pad</td>
<td>5.6 @ Pad (142.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPS</td>
<td>8.8 (2.7)</td>
<td>4.75 (120.7)</td>
<td>6 (152.4)</td>
<td>18 (457.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>296 (134.3)</td>
</tr>
<tr>
<td>FPS</td>
<td>12.0 (3.7)</td>
<td>4.75 (120.7)</td>
<td>6 (152.4)</td>
<td>18 (457.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>450 (204.1)</td>
</tr>
<tr>
<td>MCS</td>
<td>8.9 (2.7)</td>
<td>4.75 (120.7)</td>
<td>6 (152.4)</td>
<td>18 (457.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>290 (131.5)</td>
</tr>
<tr>
<td>PTS</td>
<td>7.0 (2.1)</td>
<td>4.75 (120.7)</td>
<td>6 (152.4)</td>
<td>18 (457.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>211 (95.7)</td>
</tr>
<tr>
<td>MRILab®</td>
<td>14.0 (4.3)</td>
<td>4.75 (120.7)</td>
<td>6 (152.4)</td>
<td>18 (457.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>450 (204.1)</td>
</tr>
<tr>
<td>SPS</td>
<td>18.6 (5.7)</td>
<td>4.75 (120.7)</td>
<td>6 (152.4)</td>
<td>12.25 (311.1)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>858 (389.2)</td>
</tr>
</tbody>
</table>

**CVS Chamber Valve Section**

The CVS contains motorized sample chamber shut-in valves, an expulsion valve, and a check valve which prevents backflush. The MCS carries up to two standard 2-3/4 gallon SFTT™ sample chambers typically used for large volume, non-PVT, water sampling.

**Associated Answer Products**

- PTA pressure transient analysis
- In-situ real-time bubble point
- Advanced analysis from Applied Formation Evaluation Centers
The SFT-IV™ sequential formation tester IV tool is used for gathering the quality formation data required to evaluate reservoir potential and plan well completions and is part of our comprehensive line of wireline formation testing services. This service includes a full suite of open-hole test tools designed to allow the best possible test in any formation under any condition.

**Features**

- Surface controlled pre-test volumes (0 to 20 cc)
- Multiple drawdown without pad resetting
- Variable rate drawdown (0.1 to 0.33 cc/sec)
- Backflushing of pre-test volume (0 to 20 cc)
- Variable hydraulic pad seating pressure
- Optional precision quartz gauge (14.7 to 12,000 ±1.0 psi accuracy)
- All parameters necessary for a successful test—accuracy, adaptability, speed, and reliability—are designed into the test tool
- Pre-test does not start until the operator gives the command, allowing:
  - Verification of padset before starting pre-test
  - Evaluation of mudcake properties from padset data
- Proprietary quartz transducer technology allows better response to pressure changes
- Temperature compensation crystal, attached to the pressure crystal, provides improved temperature compensation and pressure measurement accuracy
- Crystal size and special construction features permit reliable transducer operation—even under harsh borehole conditions

### SFT-IV™ Sequential Formation Tester IV Tool Specifications

<table>
<thead>
<tr>
<th></th>
<th>Length $^1$ (ft/m)</th>
<th>Diameter $^2$ (in./mm)</th>
<th>Maximum Pressure (psi/Mpa)</th>
<th>Maximum Temperature ($^\circ$F/$^\circ$C)</th>
<th>Weight (lb/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17.8 (5.4)</td>
<td>5.5 (139.7)</td>
<td>12,000 (82.7)</td>
<td>350 (176.7)</td>
<td>Varies</td>
</tr>
</tbody>
</table>

$^1$ Without sample chambers.
$^2$ Standard configuration.

Various chamber configurations are available for specific applications or formation conditions. Check with your local Halliburton representative for further information. The 2.75 gal (10.4 L) chambers are H$_2$S compatible.
SFTT™ Sequential Formation Test Tool

The SFTT™ sequential formation test tool measures wellbore and formation fluid pressure at any point in the well with a petroquartz pressure transducer. The SFTT tool can also collect representative formation fluid samples for up to two test depths in one trip into the well.

The following measurements are available for monitoring and recording at the surface system:

- Hydrostatic (mud column) and formation pressures
- Continuous recording of time so significant events during the test can be timed for computations
- Pre-test volumes
- Petroquartz pressures
- Petroquartz pressure sample rate
- Petroquartz transducer temperature

Features

- Variable pre-test volumes (5 to 10 cc)
- Drawdown rates (0.5 to 2 cc/sec)
- Drawdown after padset established
- Adaptable to H₂S
- Standard precision quartz gauge
- Determine reservoir pressure
- Identify gas and oil reservoir boundaries
- Monitor reservoir intercommunication
- Indicate areas of pressure depletion
- Estimate formation permeability by pressure/time curve correlation
- Determine chemical concentrations and reservoir fluid properties through laboratory analysis of retrieved formation samples
- Measure flow and shut-in pressures vs. time

SFTT™ Sequential Formation Test Tool Specifications

<table>
<thead>
<tr>
<th>Tool</th>
<th>Length (ft)</th>
<th>Diameter (in.)</th>
<th>Maximum Pressure (psi)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFTT™-B</td>
<td>22.1 (6.7)</td>
<td>6.5 (165.1)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>675 (306.2)</td>
</tr>
<tr>
<td>SFTT-C</td>
<td>18.9 (5.8)</td>
<td>6.5 (165.1)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>525 (238.1)</td>
</tr>
</tbody>
</table>

The SFTT™ tool features ruggedized construction for measuring precise formation and wellbore-hydrostatic pressure readings. The SFTT tool can also collect reservoir fluid samples in two separate chambers for analysis of fluid properties with standard 2.75-gal chambers and optional 1.0, 5.0, and 8.0 gal chambers.

The advanced Halliburton quartz gauge is standard and can measure pressures with an accuracy of ± (1.0 psi + 0.01% of the reading); resolution is 0.01 psi and a repeatability of 1.0 psi.

The sequential formation test tool is also available for hostile environments. For more information, reference the HSFT™ hostile sequential formation tester tool on page 56.
**RSCT™ Rotary Sidewall Coring Tool**

The RSCT™ tool diamond-drills cores perpendicular to the borehole wall with continuous monitoring of the coring process. After gamma ray depth positioning, a backup shoe is extended to decentralize and hold the tool securely against the formation. A diamond bit rotating at 2,000 rpm cuts a 0.9375-in. OD, 1.75-in. long sample from the formation. Surface control of weight-on-bit optimizes drilling.

After the sample has been cut, a slight vertical movement of the bit breaks the core sample from the formation. The bit containing the sample is then withdrawn into the tool and the core is punched into a receiver tube. An indicator reveals both the existence and length of the sample. The tool is then ready for the next selected core point.

The RSCT tool is used to obtain core samples in consolidated formations. A tubular shaped drill bit with diamond cutting edges is used to drill the core. The core is recovered as a cylindrical shaped plug of the formation.

The system operates independently from other systems on the logging truck or skid. The only input required is a source of AC voltage. A recording device is necessary for recording gamma ray correlation data.

The downhole tool is controlled from the surface by use of the control panel.

**Applications**

Rotary core samples collected by the RSCT tool can be used to provide:

- More accurate readings of porosity and permeability that reduce reservoir analysis variables. Microfractures in core samples taken with percussion tools cause false readings of porosity and permeability
- Information useful in fine-tuning MRIL® data
- Reliable data for rock mechanical analysis necessary for hydraulic fracturing design, wellbore stability analysis, and sand potential prediction
**Features**

- Allows 30 or more cores to be taken in one run
- Can be run on Toolpusher™ service or coiled tubing to acquire cores in deviated, extended reach, and horizontal wells
- A core length indicator takes the guesswork out of core recovery
- Stand-alone tools can be run on third-party logging units
- Originally designed to recover cores in hard rock formations inaccessible with percussion tools, the RSCT™ tool can be used with equal success in soft rock formations

- Gamma ray tool positioning provides accurate core point location
- Core samples are undistorted with consistent cylindrical geometry which allows a wide range of petrophysical testing and analysis
- Allows for evaluation of pre-existing formation damage by providing core samples free of distortions caused by percussion tools
- HRSCT™ hostile rotary sidewall coring tool available for use in hostile environments

**RSCT™ Rotary Sidewall Coring Tool Specifications**

<table>
<thead>
<tr>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.1 (5.5)</td>
<td>4.87 (123.7)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>275 (124.7)</td>
</tr>
</tbody>
</table>
SWC™ Side Wall Coring Tool

The SWC™ side wall coring tool allows geologists to take a sample of a prospective formation traversed by the borehole. These sidewall core samples can improve log analysis, help to identify a rock’s type and origin, and can be used to determine the exact location of gas and oil, gas and water, or oil and water contacts within a reservoir. In some cases, sidewall cores can even discover productive reservoirs not evident on logs.

The SWC tool consists of a propelling explosive material and hollow core barrels housed in the body of the gun. The tool is lowered to a predetermined depth and fired, one shot at a time. The barrels containing the core samples are then retrieved by means of a cable attaching the barrels to the gun.

The SWC tool utilizes a single cable running through and in-between the barrel back and barrel. The two ends of the cable are secured to the side rails of the gun, helping to reduce the number of broken cables. In addition, release rings adapted to the top of the barrel control entry depth and velocity and provide flexibility during the coring process.

Applications
- Clay typing
- Fluid saturation estimation
- Matrix makeup
- Grain size and cementing agents
- Paleonthological data
- API oil gravity
- Gas and oil presence

Porosity and permeability estimations can also be made using sidewall core analysis. However, these estimates should never be used to extensively evaluate porosity or permeability since there is a high probability that the core structure has been altered by the impact of the core barrel into the formation.

Features
- Area specific – can shoot 24 to 144 cores on a single trip into the well
- Depth correlation via gamma ray or SP application
- Sampling can be done at any time before casing is run
- Allows sampling of very soft formations
- Permits positive verification of formation type indicated by the other open-hole logs

SWC™ Side Wall Coring Tool Specifications

<table>
<thead>
<tr>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7 (2.4)</td>
<td>4.5 (114.3)</td>
<td>20,000 (137.9)</td>
<td>400 (204.4)</td>
<td>215 (97.5)</td>
</tr>
</tbody>
</table>
**HRSCT™ Hostile Rotary Side Wall Coring Tool**

The HRSCT™ hostile rotary sidewall coring tool provides a new approach for acquiring multiple sidewall core samples from an earth formation and special means for storing and identifying individual samples in multiple tubes for wireline operation. This apparatus is specifically designed with high efficiency to provide high-speed bit rotation combined with high torque for best drilling performance.

The coring tool apparatus consist of control/power electronics and includes a hydraulic valve section, motor drive section, and the mandrel section. The descriptions of each section are as follows.

### Hydraulic Valve Section

This section incorporates multiple solenoid valves for independent control of the tool functions such as, setting tool, tilting bit box, bit rotation, drilling/bit advance control, and core storage. The main feature of this section is the bit advance control mechanism which is based on applying bit weight and receiving positive feedback from the bit torque for the active control system. Small incremental increase and decrease in bit weight are possible to provide for smooth drilling without the risk of bit stalling.

### Motor Drive Section

This section consists of an electric motor with a small pump at one end, for providing hydraulic pressure for all the auxiliary functions. The other end of the motor is connected to a clutch mechanism used for engaging and disengaging the bit on demand. The output of the clutch is directly coupled to the bit box through a flexible steel drive shaft. The main feature of this drive system is that by eliminating the hydraulic pumps and motors, high drive train efficiencies of as much as 80% is possible without sacrificing performance. The clutch mechanism can also be adjusted to slip at the torque rating of the electric motor to eliminate motor/bit stalling while drilling.

### Mandrel Section

This section incorporates a bit box movable by actuators for tilting, advance/retract, bit break, and storage functions. The bit box incorporates several sets of bevel and spur gears to translate the direction of the rotation of the flexible shaft into normal direction to the axis of the wellbore. Finally, multiple core separator tubes are positioned in a carousel manner. The carousel rotates on demand from the hydraulic power section after depositing a core to place a washer for positive identification. The carousel stores up to sixty 2.12-in. cores that would otherwise be length prohibitive if a single tube is used. During the coring operation, the mandrel is secured to the borehole using two powerful backup pistons instead of a single backup arm. The backup pistons are sized so that minor slippage that could cause mandrel movement can be eliminated. This reduces the possibility of lodging and sticking the bit in the formation.

### Features

- High temperature AC motor drives the bit for:
  - Full power across entire temperature range
  - Minimum post-job re-fit time
- Software control offers “cruise control” option
- Surplus power:
  - 1500 rpm with 22-in.-lb torque for fast drill times
- Excellent coring capacity:
  - 60 cores 2.12-in. L × 1.0 diameter
- Fail-safe retract includes bit-box and backup pistons
- Combinable
- Sensor coring record includes:
  - ROP, bit torque, and RPMs
  - Drilled core length
  - Recovered core length

### HRSCT™ Hostile Rotary Side Wall Coring Tool Specifications

<table>
<thead>
<tr>
<th>Maximum Temperature °F</th>
<th>Maximum Pressure psi</th>
<th>Push Pull Tension lb</th>
<th>Push Pull Compression lb</th>
<th>Maximum OD in.</th>
<th>Length ft</th>
<th>Minimum / Maximum Hole in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>20,000</td>
<td>100,000</td>
<td>50,000</td>
<td>4.75 nominal 5.125 at standoffs</td>
<td>30</td>
<td>6.25 - 12</td>
</tr>
</tbody>
</table>
Hostile—Slimhole Formation Evaluation

HEAT™ Hostile Environment Applications Tool Suite

The HEAT™ hostile environment applications tools suite comprises six logging instruments—a cablehead-tension load cell and associated centralizer, decentralizer, flex-joint, and telemetry assemblies. Each HEAT tool contains an internal temperature sensor that provides quality control data related to operational characteristics and tool electronics. Such information is usually critical only in very hot well conditions—in particular, when temperatures over a prolonged period are near the 500°F limit of the toolstring.

The following are tools in the HEAT suite:
- HDIL™ Hostile Dual Induction Log (see page 5)
- HEDL™ Hostile Environment Dual Laterolog
- HFWS™ Hostile Full Wave Sonic Tool
- HSDL™ Hostile Spectral Density Tool
- HDSN™ Hostile Dual-Spaced Neutron Tool
- HNGR™ Hostile Natural Gamma Ray Tool
- HSFT™ Hostile Slim Formation Tester Tool

Features
- HEAT suite tools are digital and smaller than standard logging tools—2.75-in. to 3.5-in. OD for HEAT suite versus 3.625-in. to 4.5-in. OD for standard tools
- The HEAT sonic, neutron, and gamma ray tools can all operate in open and cased holes
- Built to handle the severe conditions encountered in deep and hot hydrocarbon-bearing formations
- Can be combined in almost any configuration to suit the borehole geometry and formation evaluation requirements of each job
HEDL™ Hostile Environment Dual Laterolog Tool

The HEDL™ hostile environment dual laterolog tool is a wireline-deployed formation resistivity device designed for extreme borehole temperatures and pressures. It is the tool of choice when those resistivities routinely exceed 100 ohm-m, especially in highly conductive muds.

The HEDL tool is combinable with other hostile environment tools, e.g. the density and neutron tools to permit simultaneous resistivity/porosity measurements in the reservoirs. The tool is designed to be run with the HETS™ hostile environment telemetry sub and must be located immediately below the HETS sub and a 2.75-in. diameter isolation sub. From top to bottom, the HEDL tool assembly consists of:

- A flaked electronic assembly
- An upper toroid sub
- An alpha sub
- A lower toroid sub

Features

- 2.75-in. diameter permits slimhole and through drill-pipe logging of high-temperature/high-pressure wells
- Performs two resistivity/porosity measurements: a deep laterolog (LLd) and a shallow laterolog (LLs) resistivity measurement
- Calibrated using three external resistor networks that simulate relatively low, medium, and high resistivities
- Under conditions of high R_t and low R_m and at temperatures higher than 350°F, the HEDL tool provides the basic formation resistivity data to aid formation evaluation

![Typical HEDL™ log recorded in highly resistive carbonate formations](image)

HEDL™ Hostile Environment Dual Laterolog Tool Specifications

<table>
<thead>
<tr>
<th></th>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21 (6.4)</td>
<td>2.75 (69.9)</td>
<td>25,000 (172.4)</td>
<td>450 (232.2)</td>
<td>300 (136.1)</td>
</tr>
</tbody>
</table>
HFWS™ Hostile Full Wave Sonic Tool

The HFWS™ hostile full wave sonic tool is a 2.75-in. acoustic velocity logging tool that is a part of the HEAT™ suite hostile environment applications tool toolstring. The HFWS tool, along with all of the HEAT suite sensors, have a pressure rating of 25,000 psi (172,400 kPa). The HEAT suite logging tools are designed for continuous operation of six hours at 500°F (260°C).

The HFWS tool, like the larger in diameter (3.625-in.) FWS™ full wave sonic tool, provides compressional wave, refracted shear wave, and Stoneley wave properties of downhole formations for a wide range of petrophysical, geological, and geophysical applications. To minimize the number of logging trips required for complete formation evaluation, the HFWS tool is compatible with all HEAT suite logging toolstrings. A liquid filled borehole is required for sonic logging, and can be used in fresh, salt, or oil-based mud systems.

The HFWS tool can be compared to having two sonic tools within the same toolstring—a long-spaced sonic tool for traditional full waveform open-hole sonic logging, and located within the transmitter-to-receiver offset, a cement bond tool that utilizes the second transmitter and two receivers. The upper transmitter and the lower four receivers array are utilized for FWS full wave sonic logging. The lower (second) transmitter and the upper two receivers are utilized for cement bond logging and short, offset compressional wave travel time. The long transmitter-to-receiver offset allows for the acquisition of borehole sonic data beyond the effects of any near-wellbore altered region. The long offset also allows for the acquisition of high-quality sonic data in enlarged boreholes where critical angle effects would affect sonic tools with short transmitter-to-receiver offsets.

Applications

- Full waveform open-hole sonic logging
- Cement bond logging
- Acquisition of borehole sonic data

The natural gamma ray, X-X caliper, Y-Y caliper, P-wave travel time and P-wave semblance quality are presented in Track 1. The monopole waveform data is presented in Track 2 in the MicroSeisogram™ format (X-Z) and in an X-Y waveform presentation in Track 3.
Features

- Advanced system design and software processing with long transmitter-to-receiver offsets and 1/2 ft receiver-to-receiver spacings
- Detection of signals at all receivers for each transmitter pulse to promote constant source characteristics
- Automatic gain control of each receiver helps preserve signal amplitude
- Downhole digitizing helps eliminate transmission noise and allows broadband frequency response
- Low-frequency response allows detection of low frequency Stoneley waves and multiple Δt measurements per depth interval
- Facilitates continuous uninterrupted recording of full waveform signals
- Ability to record various types of information including tool data, quality curves, and final results
- Operator-selectable multiple modes of tool operation, digitally recorded waveform data, and improved porosity estimates using both Δt₁ and Δt₅
- Facilitates lithology identification by means of velocity ratio, Δt₅/Δt₁, and location of gas zones, even in poor hole conditions and cased holes
- Indication of permeability variations with depth from Stoneley wave attenuation and Δt
- Detection of naturally fractured zones, determination of rock elastic constants, and estimation of formation strength and least horizontal stress
- Prediction of vertical extent of hydraulic fractures using the RockXpert2™ analysis package
- Improved vertical resolution for detection of thinner beds (Beds as thin as 3-in. can be identified with the t curves)
- Time-to-depth correlation for seismic correlation
- Combining sonic slowness data with formation density data are the required input information for synthetic seismograms

HFWS™ Hostile Full Wave Sonic Tool Specifications

<table>
<thead>
<tr>
<th>Length* (ft (m))</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature** °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.2 (9.2)</td>
<td>2.75 (69.9)</td>
<td>25,000 (172.4)</td>
<td>500 (260)</td>
<td>340 (154.2)</td>
</tr>
</tbody>
</table>

*Add 3.50 ft (1.1 m) for each in-line centralizer (usually two).
** 6 hour

Gamma ray and caliper are presented in Track 1, compressional wave travel time (DTC) is presented in Track 4, and the P-wave semblance quality is presented in Track 3.

This is a hard rock example. Natural gamma ray, caliper, and VpVs are presented in Track 1. The P-wave travel time and the refracted shear wave travel time are presented in Track 2. The semblance quality is presented in an image format in Track 3 for the P-wave and refracted shear wave.
HSDL™ Hostile Spectral Density Log

The HSDL™ hostile spectral density log is a section of the HEAT™ suite system. It is available with the source-detector pad either as a bottom-only in-line configuration (2.75-in. tool OD) or as a powered, extendable configuration (3.5-in. tool OD). It is fully combinable with all other HEAT suite tools.

The HSDL log measures formation density, photoelectric factor (a lithology indicator), and borehole diameter. It measures formation density by emitting gamma rays into the formation and recording the energy of gamma rays reflected by the formation to the two detectors in the tool. The HSDL log measures borehole diameter with a spring-loaded caliper arm that opens and closes as the tool is pulled through changes in hole diameter.

Additionally, as for all Halliburton’s HEAT suite services, the HSDL log provides reliable data in temperatures up to 500°F and pressures as high as 25,000 psi that are encountered in hot hydrocarbon bearing formations.

**Applications**

- Determination of formation porosity
- Identification of formation lithology regardless of formation fluid type
- Indication of gas when used in combination with a neutron log

**Features**

- More precise delineation of thinly bedded formations using the unfiltered Pe curve
- Curves indicating data quality are displayed on a computer screen in real-time and recorded on the log
- Advanced correction algorithm is applied to density data in real-time
- Rigid tungsten pad incorporates a 1.5-curie cesium-137 source and two high-efficiency scintillation detectors designed to maintain high gamma counts
- Rugged construction and advanced gain stabilization help maintain measurement integrity under varying temperature conditions
- Combinable with a complete family of tools that operates under the DITS™ digital interface telemetry system
- Extensively characterized in test pits with a full set of correction charts available
- 2.75-in. OD for use in slimholes makes it possible to design a through-formation evaluation program for holes as small as 3.5-in.
- Uses a new 4D technique to account for the density and photoelectric absorption of the formation and mudcake without assuming any correlation between these variables. Besides yielding a superior density, these calculations provide information for compensating the Pe measurement and computing useful quality indicators such as the two component density correction.
Associated Answer Products

- The wellsite answer product is formation density and Pe
- Density data is also used with open-hole sensors as input to Halliburton’s mineralogy, open-hole, and cased-hole saturation analysis to provide a complete formation evaluation product. These include:
  - ULTRA™ multi-mineral evaluation program
  - CORAL™ complex lithology analysis
  - LARA™ laminated reservoir analysis
  - SASHA™ shaly sand analysis

HSDL™ Hostile Spectral Density Log Specifications

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Length ft (m)</th>
<th>Diameter (minimum) in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-Line Pad</td>
<td>13.8* (4.2)</td>
<td>2.75 (69.9)</td>
<td>25,000 (172.4)</td>
<td>500 (260)</td>
<td>176 (79.8)</td>
</tr>
<tr>
<td>Extendable Pad</td>
<td>23.8 (7.3)</td>
<td>3.50 (89.9)</td>
<td>25,000 (172.4)</td>
<td>500 (260)</td>
<td>456 (206.8)</td>
</tr>
</tbody>
</table>

*Usually run with the HPDC-A—if so add 3.8 ft (1.2 m)
**6 hour
**HDSN™ Hostile Dual-Spaced Neutron Tool**

The HDSN™ hostile dual-spaced neutron tool is a section of the HEAT™ suite system. The HDSN tool consists of combinable, high-quality, small-diameter tools capable of comprehensive formation evaluation in harsh environments.

**Applications**
- Provides a neutron porosity log, i.e. the porosity of the formation as indicated by the detection of neutron radiation induced in the formation by the tool.
- Investigates formation lithology, using a steady state, neutron-generating source of radioactive americium-beryllium (AmBe) and two thermal neutron detectors. Neutrons emitted from the source are slowed and scattered by the surrounding media, and the resulting neutron field is sampled at two locations. The neutron flux is converted to electrical signals for logging.

**Features**
- Can be deployed in both open and cased-hole wells.
- Commonly run with the powered decentralizer to provide HDSN tool eccentricing and to furnish a continuous standoff measurement that helps improve porosity calculations, especially over rugose intervals.
- Uses caliper data from the decentralizer to correct porosity for hole size.
- Extensively characterized in test pits with a full set of correction charts available.
- Temperature and pressure ratings of 500°F (for 6 hours) and 25,000 psi, respectively to handle severe conditions encountered in deep and hot hydrocarbon-bearing formations.
- Specially designed He3 detectors minimize the effects of elevated temperature on observed count rates and computed porosity.
- 2.75-in. OD for use in slimholes.
- Small OD to design a through formation evaluation program for holes as small as 3.5 in.
- Combinable in almost any configuration to suit borehole geometry and provide appropriate formation evaluation information.

**Typical Field Output of the HDSN™ Tool**
Associated Answer Products

- The wellsite answer product is the neutron porosity NPHI
- Neutron porosity data is also used with other open-hole sensors as input to Halliburton's mineralogy, open-hole, and cased-hole saturation analysis to provide a complete formation evaluation product. These include:
  - ULTRA™ multi-mineral evaluation program
  - CORAL™ complex lithology analysis
  - LARA™ laminated reservoir analysis
  - SASHA™ shaly sand analysis

### HDSN™ Hostile Dual-Spaced Neutron Tool Specifications

<table>
<thead>
<tr>
<th>Length*</th>
<th>Diameter</th>
<th>Maximum Pressure</th>
<th>Maximum Temperature**</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft (m)</td>
<td>in. (mm)</td>
<td>psi (Mpa)</td>
<td>°F (°C)</td>
<td>lb (kg)</td>
</tr>
<tr>
<td>15.3 (4.6)</td>
<td>2.75 (69.9)</td>
<td>25,000 (172.4)</td>
<td>500 (260)</td>
<td>179 (81)</td>
</tr>
</tbody>
</table>

*The length and weight include the HGNI instrument section, which is required to run the HDSN™ tool. Add 7.04 ft (2.1 m) when run with the in-line, bowspring decentralizer.

**6 hour
**HNGR™ Hostile Natural Gamma Ray Tool**

The HNGR™ hostile natural gamma ray tool is a section of the HEAT™ suite system. Along with the HGNI™ tool, the HNGR tool can be run alone or with any other hostile service in either an open or cased-hole.

The HNGR tool is used to record naturally occurring gamma radiation. Gamma ray measurements are used for geologic correlation, depth control, and computing shale and clay volumes. Shale volume data can then be applied to correct the apparent porosities indicated by the acoustic, neutron, and density logs.

When wellbore conditions are not favorable for a definitive SP response, a gamma ray curve is recorded in its place.

**Applications**
- Record natural gamma radiation

**Features**
- Commonly run with the powered decentralizer to press the toolstring along the borehole wall and to furnish a continuous standoff measurement
- Temperature and pressure ratings of 500°F (for 6 hours) and 25,000 psi, respectively to handle severe conditions encountered in deep and hot hydrocarbon-bearing formations
- 2.75-in. OD for use in slimholes makes it possible to design through-formation evaluation programs for holes as small as 3.5-in.
- Combinable in almost any configuration to suit borehole geometry and provide appropriate formation evaluation information calibration and wellsite checks
- Curves indicating data quality are displayed on a computer screen in real-time and recorded on the log

### HNGR™ Hostile Natural Gamma Ray Tool Specifications

<table>
<thead>
<tr>
<th></th>
<th>Length* ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature** °F (°C)</th>
<th>Weight* lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.6 (3.5)</td>
<td>2.75 (69.9)</td>
<td>25,000 (172.4)</td>
<td>500 (260)</td>
<td>146 (66.2)</td>
<td></td>
</tr>
</tbody>
</table>

*The length and weight include the HGNI™ instrument section, which is required to run the HNGR™ tool.
**6 hour
HSFT™ Hostile Sequential Formation Tester Tool

The 3.125-in. OD HSFT™ tool is capable of formation testing in conditions where conventional tools cannot. The HSFT tool can be run in holes as slim as 4-in. and at temperatures and pressures up to 400°F and 25,000 psi.

The HSFT tool can take an unlimited number of pressure tests and up to two fluid samples per trip in the well. Formation pressures are determined using a high resolution, high temperature quartz gauge.

The HSFT tool is fully combinable with the HEAT™ suite toolstring, allowing open-hole data acquisition and formation testing in the same trip in the well.

Features

- Maximum tool OD 3-1/8 in. tool design includes self-contained standoffs, reducing the contact area between the tool and the borehole wall and minimizing the chance of differential sticking, especially in difficult hole conditions and depleted reservoirs
- Designed for wellbore diameters as small as 4 in.
- With optional backup shoe, pad can extend to 12.25 in.
- Sampling flowrate controlled by air or fluid cushions
- Two 1-gal sample chambers available
- Tool, reinforced pad design, and quartz gauge proven reliable to 400°F
- Backup strain gauge provides redundancy
- Low flowline volume reduces storage resulting in faster pressure tests in low mobility reservoirs, often encountered in high-pressure, high-temperature (HPHT) wells
- Self-cleaning sand screen design prevents snorkel plugging
- Extends pressure and temperature range over conventional testers
- Combinable with HEAT suite resistivity, sonic, and porosity logs to increase rig time savings
- Low power consumption electronics reduces internal heat generation and extends tool operating time

Real-time plot of HSFT™ tool data provides test monitoring and a drawdown mobility estimate.

Real-time HSFT™ tool analysis plot identifies flow regime and aids operator in determining when to terminate test, resulting in saved rig time.

Buildup analysis performed on HSFT™ tool data

HSFT™ Hostile Sequential Formation Tester Tool Specifications

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length* (ft)</td>
<td>28.0 (8.5)</td>
</tr>
<tr>
<td>Diameter (in.)</td>
<td>3.125 (79.4)</td>
</tr>
<tr>
<td>Maximum Pressure (psi)</td>
<td>25,000 (172.4)</td>
</tr>
<tr>
<td>Maximum Temperature (°F)</td>
<td>400 (204.4)</td>
</tr>
<tr>
<td>Weight (lb)</td>
<td>525 (231.8)</td>
</tr>
</tbody>
</table>

*HSFT™ tool only; does not include HPSU or sample chambers. Minimum toolstring length for pressures only, including gamma and telemetry sub 55 ft (16.8 m) HPSU length: 8.33 ft (2.5 m); weight 120 lb (54.4 kg); OD: 2.75 in. (69.9 mm).
Auxiliary Services

Multi-Conductor LockJar® System

The multi-conductor LockJar® system minimizes the risk of unproductive rig time in logging operations.

The benefits of using wireline instruments to log oil and gas wells can diminish quickly if the logging string becomes stuck in the wellbore while tripping. Now, with multi-conductor LockJar wireline technology available from Halliburton, that risk can be dramatically reduced.

Unlike previous jars, the LockJar system arrives at the wellsite ready to run. Logging crews can be trained to use the tool in minutes, so a jar service technician is not required on location. There is even a hydraulic time delay that allows the crew to pull the toolstring through a tight spot without activating the tool.

The new LockJar system can be adjusted right at the wellsite to begin metering the jar with a pull from the surface of 1,700 to 4,000 lb. It can function reliably in reservoir temperatures up to 400°F and at pressures as high as 22,500 psi. However, those specifications can be easily increased because the tool is pressure balanced.

Features

- Mechanical lock helps prevent inadvertent triggering during logging operations
- Hydraulic time delay allows actuation at any load above the mechanical lock setting and is not sensitive to pressure or temperature
- Balanced pressure increases the hydrostatic pressure rating by providing compensation to prevent collapsing
- Protected seal and impact surfaces enhance downhole reliability by minimizing friction from borehole fluids and problems associated with debris
- All internal parts, including the jar mechanism and conductive path, are sealed and segregated from the wellbore
- Permits operators to free-fall wireline in regions where persistent sticking problems have dictated the need for drillpipe-conveyed logging operations
- System ready to run upon arrival

*LockJar is a registered trademark of Evans Engineering, Inc.
Operation

In a typical open-hole logging string, the LockJar® system is placed immediately above the logging or formation testing tools. To augment the force with which the weight is thrown up hole after the jar is activated, it is mated with an enhancer. It has been demonstrated in the lab that the LockJar tool’s impulse is more than twice as powerful with up to five times more duration when the enhancer is added to the jar.

The LockJar tool is usually run in the string in the following order from the cable head down: enhancer, cable mode and telemetry sub-assemblies, and the jar. In combination, they create as large a mass as possible to help the jar release stuck logging tools. The enhancer stores energy in Belleville springs which propel the hammer into an anvil upon activation of the jar which generates the impact and impulse that are directed down towards the stuck point.

Borehole Conditions

- Borehole fluids: salt, fresh, oil, and air
- Tool positioning: centralized

Multi-Conductor LockJar® System Specifications

<table>
<thead>
<tr>
<th>Length (ft)</th>
<th>Maximum OD (in.)</th>
<th>Minimum Hole Size (in.)</th>
<th>Maximum Hole Size (in.)</th>
<th>Maximum Pressure (psi)</th>
<th>Maximum Temperature (°F)</th>
<th>Weight (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.4 (3.49**)</td>
<td>3.625 (9.20)</td>
<td>4.0 (10.16)</td>
<td>N/A*</td>
<td>20,000 (137 895)</td>
<td>400 (204)</td>
<td>365 (165***)</td>
</tr>
</tbody>
</table>

*Tool not restricted on maximum hole size

**Length of enhancer is 10.1 ft (3.07 m); combination jar and enhancer is 21.5 ft. (6.56 m).

***Weight of the enhancer is 290 lb (131.5 kg).
**RWCH™ Releaseable Wireline Cable Head**

The RWCH™ tool has an electrically activated wireline release system as opposed to the tension activated release system of conventional cable heads. Tension activated heads require a safety factor to avoid premature release of the wireline. This safety factor keeps you from utilizing the full safe load on the wireline when trying to free stuck tools from the borehole. The RWCH tool allows you to utilize this extra tension to free stuck tools. This additional tension has proven very successful at freeing stuck tools and avoiding fishing operations. This extra pull also allows you to safely run heavy toolstrings in deep wells.

The RWCH tool can reduce the costs of obtaining wireline logs in areas that are prone to tool sticking. It has reduced the incidence of fishing for stuck tools in problem areas, saving customers expensive and risky fishing jobs.

**Features**

- Allows for greater pulling of stuck tools at any depth and in any conditions
- Able to support heavy toolstrings by utilizing the full strength of the wireline, regardless of depth
- Electrically controlled release from the surface
- Contains a conventional 2.3125-in. fishing neck
- Includes a special sub designed to allow easy rigup and rig-down
- Allows the maximum pull to be applied at any depth in the well regardless of the total depth if the backup weak point is not used
- Allows the release to be aborted as long as the fusible alloy has not reached melting temperature

**RWCH™ Operation**

**RWCH™ Releaseable Wireline Cable Head Specifications**

<table>
<thead>
<tr>
<th>Length (ft (m))</th>
<th>Diameter (in. (mm))</th>
<th>Maximum Pressure (psi (Mpa))</th>
<th>Maximum Temperature (°F (°C))</th>
<th>Weight (lb (kg))</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3 (1.9)</td>
<td>3.63 (92.2)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>135 (61.2)</td>
</tr>
</tbody>
</table>
Toolpusher™ Logging (TPL) Service

Today’s search for oil and gas is heavily influenced by the rapid growth of technology. New tools and equipment are being built, new production and recovery methods are being tested, and new exploration techniques are being developed. Drilling programs are becoming increasingly complex and many wells now commonly include highly deviated or horizontal sections. In these cases, obtaining quality formation evaluation data with conventional wireline methods may be impossible or impractical at best—severely restricting the options available to the operator.

The Toolpusher™ logging (TPL) service provides an innovative solution to this significant problem. TPL service utilizes drillpipe to effectively transport conventional electric wireline logging tools to the zone of interest. This method eliminates many of the problems associated with conveying tools through highly deviated or horizontal sections of the well. It also helps eliminate problems caused by:

- Wireline key seating
- Differential sticking of tools or wireline
- Swelling formations
- Heavy muds
- Doglegs
- Cuttings bridging off the wellbore

The TPL service has successfully logged thousands of highly deviated and horizontal wells, including:

- Wells with temperatures over 400°F (204°C)
- Depths exceeding 24,000 ft (7315 m)
- Logged intervals over 10,000 ft (3048 m)

The Toolpusher latch assembly has been deployed and latched at angles of up to 97° with a maximum logged angle of over 104°. Average job time at 12,000 ft is 16 to 18 hours.

Toolpusher service is designed to run both standard and modified wireline logging tools. The quick change, attached to the top of the logging toolstring, is attached to the bottom of a connector sub. Then the connector sub is attached to the drillpipe. The connector sub, available in three diameters, has slots cut through it so circulation can be accomplished at any time during a logging operation.
Toolpusher™ service requires a variety of specialty subs and hardware. Among the subs are the downhole tension device, multiconductor swivel adapter, and offset, alignment, flex, knuckle, and pad locator subs. Some of the specialty hardware includes the rig floor display, spinning stand-offs, stiffening collars, hole finders, bullnoses, protective sleeves, and standoffs. The lists of equipment can get quite extensive. Each piece is utilized for special situations and the variety makes Toolpusher service a very versatile and adaptable system. Many toolstrings have unique hardware to assist in getting the best possible data.

Toolpusher service was the first drillpipe conveyed logging system introduced in the field. It has a very long track record and has proven to be very reliable. Unlike our competitors, Toolpusher allows the customer to circulate at any time during the operation. The side-entry sub (SES) has a larger through-bore than the competition, which allows fishing operations to proceed as normal without restriction.

Applications
- Conventional open-hole and cased-hole logging
- Formation testing and coring
- Vertical seismic profiling
- Ultrasonic and electrical imaging
- Cement and casing evaluation

Features
- Control of pull off tension allows the operator to pull test to check the mechanical latch
- No metal around female electrical connection reduces the possibility of shorting
- Female wet connect is floating and spring loaded, eliminating the movement of the connection and reducing noise
- New wiper glands to clean the male probe removes conductive films from the pin
- Multiple o-ring seal after the connection is made to effectively seal the connection
- Spring loaded sleeve protects downhole parts before latching
- Male probe completely covered after latching to help seal out invading fluids
- Employs conventional high-resolution wireline tools to provide formation data with quality equal to that of wireline-conveyed logs. Conventional rig tripping procedures are used to mechanically position logging tools in the zone of interest
- Formation data is available in real-time at the wellsite. Also, zones of interest can be relogged by lowering the blocks
- Rig up on the drillpipe rather than multiple runs with conventional wireline can save time. Prior planning with your Halliburton representative can determine which method is more economical
- Provides mud circulation throughout the operation. This reduces the risk of tools getting stuck and minimizes further hole deterioration

### Toolpusher™ Logging (TPL) Service Specifications

<table>
<thead>
<tr>
<th>Tool Section</th>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side-Entry Sub SES</td>
<td>*</td>
<td>*</td>
<td>20,000 (137.9)</td>
<td>400 (204)</td>
<td>*</td>
</tr>
<tr>
<td>Positive Latch/Unlatch Quick Change Assembly</td>
<td>*</td>
<td>3.625 (92.1)</td>
<td>20,000 (137.9)</td>
<td>400 (204)</td>
<td>*</td>
</tr>
<tr>
<td>7-Conductor Pump Down Head **</td>
<td>**</td>
<td>2.0 or 2.25 (50 or 57.1)</td>
<td>20,000 (137.9)</td>
<td>400 (204)</td>
<td>**</td>
</tr>
<tr>
<td>Multi Conductor Swivel Assembly</td>
<td>3.02 (0.9)</td>
<td>3.625 (92.1)</td>
<td>20,000 (137.9)</td>
<td>400 (204)</td>
<td>70 (31.8)</td>
</tr>
<tr>
<td>DITS™ Downhole Tension Device</td>
<td>3.78 (1.2)</td>
<td>3.625 (92.1)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>96 (43.5)</td>
</tr>
<tr>
<td>DITS Single Knuckle Joint</td>
<td>5 (1.5)</td>
<td>3.625 (92.1)</td>
<td>20,000 (137.9)</td>
<td>400 (204)</td>
<td>50 (22.7)</td>
</tr>
<tr>
<td>DITS Flex Joint</td>
<td>5.64 (1.7)</td>
<td>3.625 (92.1)</td>
<td>20,000 (137.9)</td>
<td>400 (204)</td>
<td>140 (63.5)</td>
</tr>
<tr>
<td>DITS Double Knuckle Joint</td>
<td>5 (1.5)</td>
<td>3.625 (92.1)</td>
<td>20,000 (137.9)</td>
<td>400 (204)</td>
<td>75 (34)</td>
</tr>
</tbody>
</table>

* Size selection is based on casing size and drillpipe size and type.
** Length and weight are variable depending upon the latching conditions.
CTL™ Coiled Tubing Logging

As the only major service company that designs, manufactures, and operates its own coiled tubing equipment, Halliburton incorporates important input from field personnel and customers into designing features that are strategically directed toward the most effective possible job performance. Deploying logging tools on coiled tubing is one of the more innovative uses of Halliburton coiled tubing. Installing logging cable inside the coiled tubing allows tools to be deployed into highly deviated wells and permits a variety of remedial functions.

CTL logging differentiates itself from drillpipe conveyed logging by offering:
- Continuous circulation capabilities
- Pressure control while moving pipe
- Electrical connections made at the surface to eliminate wet latches
- Tolerance for high mud solids content
- Relogging of any interval, eliminating multiple latch runs
- Constant speed logging capability

Applications
- Cement bond logging in highly deviated wells
- Production logging to determine water entry points in highly deviated wells
- Open-hole logging in deviated air-drilled wells that need pressure control
- Single-trip underbalanced perforating with long gunstrings
- Setting plugs and packers in deviated wells with pinpoint depth control

Features
- Purpose-built coiled tubing cableheads
  - Shear pin release
  - Flow-release
- High pressure surface termination assemblies
  - Standard integral plumbing
  - DNV certified
- Self-contained unit, requires no rig
- Can continuously pump fluids into well while moving pipe
- Land or offshore system designs
- No workover rig required when using coiled tubing
- Reduced potential damage to formation
- Can be and is typically used on live wells (no kill fluids introduced into well)
- Acts as tool transport medium for deviated and horizontal wells
- Advanced data acquisition system to monitor key job parameters on tubing management

Coiled Tubing Cablehead Specifications

<table>
<thead>
<tr>
<th>Tool OD</th>
<th>1.50 in. (38.1 mm)</th>
<th>2.00 in. (50.8 mm)</th>
<th>2.50 in. (63.5 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coiled Tubing Size</td>
<td>1.00 to 1.50-in. (25.4 to 38.1 mm)</td>
<td>1.50-in. and above (38.1 mm and above)</td>
<td>1.50-in. and above (38.1 mm and above)</td>
</tr>
<tr>
<td>Top Connection</td>
<td>Roll-on or OECO “A” Box</td>
<td>Roll-on or OECO “A” Box</td>
<td>OECO “A” Box or AMMT Box</td>
</tr>
<tr>
<td>Bottom Connection</td>
<td>1-3/16-in. (30.2 mm) 12 UN Type “A” Pin</td>
<td>1-3/16-in. (30.2 mm) 12 UN Type “A” Pin or 3-5/8-in. (92.1 mm) DITS™ Tool</td>
<td>1-3/16-in. (30.2 mm) 12 UN Type “A” Pin</td>
</tr>
<tr>
<td>Fishing Neck Size</td>
<td>1.0-in. (25.4 mm) External</td>
<td>1.375-in. (34.9 mm) External</td>
<td>1.812-in. (46.0 mm) Internal</td>
</tr>
<tr>
<td>Emergency Release Force Range</td>
<td>3,200 to 10,000 lb (1,451.5 to 4,538 kg)</td>
<td>5,000 to 30,000 lb (2,268 to 13,608 kg)</td>
<td>Flow-release in conjunction with shear pins</td>
</tr>
<tr>
<td>Logging Cable</td>
<td>7/32-in (5.6 mm) or 5/16-in. (7.9 mm) monoconductor</td>
<td>5/16-in. (7.9 mm) monoconductor or 3/8-in. (9.5 mm), 7/16-in. (11.1 mm), 0.457-in. (11.6 mm), or 15/32-in. (11.9 mm) multiconductor</td>
<td>7/32-in (5.6 mm) or 5/16-in. (7.9 mm) monoconductor or 3/8-in. (9.5 mm), 7/16-in. (11.1 mm), 0.457-in. (11.6 mm), or 15/32-in. (11.9 mm) multiconductor</td>
</tr>
</tbody>
</table>
BHPT™ Borehole Properties Tool

The BHPT™ borehole properties tool is a DITS™ tools compatible electric logging tool, which provides signals used to determine characteristics of wellbore fluids. The primary outputs of a BHPT log are pressure, temperature, and borehole fluid resistivity. This information has long been requested by our clients and now is available during the first logging pass in a newly drilled well.

The BHPT tool is normally run in conjunction with other logging services but may also be used as a stand-alone logging tool requiring the use of a telemetry sub. Open-hole, cased-hole, and drillpipe conveyed logging environments will accommodate the BHPT tool and two external diameters are available. The open-hole version is standard 3.625-in. and a smaller 3.375-in. version may be necessary in heavy 4.5-in. casing and slimhole applications.

Downhole pressure and temperature readings can assist clients in blowout prevention, mud weight corrections, determining formation fracture pressures, thief-zone identification, determining wellbore fluid pressure gradients in deviated holes, thermal gradient calculation, bottomhole temperature, and detection of dynamic fluid environments within the wellbore, including location of gas entry points in air-drilled wells.

The resistivity sensor provides accurate, real-time information about mud resistivity at any depth and temperature in the wellbore. This information is required during water saturation calculations. The Rₘ data may be used in invasion diameter calculations and also to identify abnormal induction and laterolog readings caused by borehole fluid effects. In cased-hole environments, the resistivity sensor can locate fluid levels and contact depth of static oil and water.

Pre- and post-job maintenance requires flushing the pressure entry port to remove mud debris and create a pressure buffer to the sensor. Calibrations involve coefficient entry and internal resistor network readings.

The BHPT tool can be used at any location in the logging stack depending on the data acquisition depth priorities with the exception that it must be run below the telemetry sub.

The BHPT tool is available in two diameter sizes: a 3.375-in. tool and a 3.625-in. tool. The 3.625-in. BHPT tool is used specifically in open-hole applications. The smaller diameter 3.375-in. tool is used in cased-hole wells (with heavy 4.25-in. casing), and in slimhole applications.
Features
- Outputs real-time pressure, temperature, and mud resistivity data in the case that no similar measurements are taken in the toolstring configuration
- Aids in blowout prevention
- Makes mud-weight corrections
- Determines formation fracture pressures
- Identifies thief zone
- Determines wellbore fluid-pressure gradients in deviated holes
- Determines thermal-gradient calculation
- Determines bottomhole temperature
- Detects dynamic fluid environments within the wellbore, which also includes locating gas entry points in air-drilled wells

The resistivity sensor provides accurate, real-time downhole temperature and mud resistivity information at any depth. This resistivity measurement can be used to:
- Make water saturation calculations
- Make invasion diameter calculations
- Identify abnormal induction and laterolog measurements (caused by borehole fluid effects)
- Locate fluid levels and contact depth of static oil and water in cased-hole wells

Associated Answer Products
- Absolute pressure and differential pressure
- Absolute temperature and differential temperature
- Mud resistivity

BHPT™ Borehole Properties Tool Specifications

<table>
<thead>
<tr>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.02 (1.5)</td>
<td>3.375 (85.7)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>95 (43.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cased-Hole</td>
</tr>
<tr>
<td>5.02 (1.5)</td>
<td>3.625 (92.1)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>107 (48.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Open-Hole</td>
</tr>
</tbody>
</table>
**FIAC™ Four Independent Arm Caliper Tool**

The FIAC™ four independent arm caliper tool is a four-arm caliper which provides information on the borehole geometry of the wellbore. Unlike other X-Y caliper services, the FIAC tool has four independent caliper measurements.

The FIAC tool, run as a separate or combined service, provides an accurate measurement of the borehole diameter in four orthogonal directions with respect to the tool body. This survey is useful in calculating cement volume, selecting packer seats for formation sampling, and identifying and locating washouts and bridges in the borehole, as well as identify borehole ovality.

Borehole size may range from 3.625-in. diameter to 22-in. diameter. The caliper arms are mounted at 90° angles to each other and provide a continuous X-Y (borehole axis is Z) borehole measurement. This tool is combinable with any other DITS™ standard tools.

When the FIAC tool is combined with the SDDT™ navigation package, the borehole geometry information is oriented with respect to both magnetic north and the high-side of the wellbore. The borehole azimuth, borehole deviation, and relative bearing of the X and Y caliper data are presented in a continuous log presentation. This allows the correlation of the borehole geometry with the drilling process, such as correlation of the long axis of the borehole to the high-side/low-side of the well. The FIAC tool differs from the competition by providing four independent caliper measurements, whereas with types of other four arm calipers, the X-X and Y-Y arms are paired together to provide only two diameter measurements.

A borehole geometry presentation is created by combining the FIAC™ and SDDT™ data. Orientation data from the SDDT navigation tool is presented in Track 1, the deviation and hole azimuth are presented as text values every 50 ft and as continuous curves. The averaged X and Y calipers are presented in the depth track. The two independent X-X calipers are presented in Track 2 along with a bit size data. The two independent Y-Y calipers are presented in Track 3 along with the bit size data. This presentation illustrates an oval borehole with the long axis of the borehole aligned with the high-side/low-side of the deviated well. The short axis of the borehole is smaller than bit size, indicating the presence of mudcake.
Features

- Four independent caliper measurements to provide needed borehole geometry data
- Combined with a navigation package the borehole geometry profile can be oriented with respect to magnetic north as well as to the high side of deviated or horizontal wells
- Borehole geometry information can be used to monitor hole size and shape with wellbore deviation and azimuth for basic geo-mechanical analysis

- Helps optimize drilling and mud systems by the evaluation of borehole geometry along with mud weight and type, bit type, and ROP
- More accurate borehole volume and annular volume determinations for the required cement volume
- Identification of packer seats for sampling and testing

<table>
<thead>
<tr>
<th>FIAC™ Four Independent Arm Caliper Tool Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length ft (m)</strong></td>
</tr>
<tr>
<td>13.9 (4.2)</td>
</tr>
</tbody>
</table>
SDDT™ Stand-Alone DITS™ Directional Tool

The SDDT™ stand-alone DITS™ directional tool is a full navigational package that consists of three orthogonal fluxgate accelerometers and three orthogonal magnetometers.

Features
An enormous amount of data is acquired while logging. The SDDT tool transmits this data to the surface unit via Halliburton’s proven DITS™ digital interactive telemetry system.

The SDDT tool provides accurate information to help determine tool position, motion, direction, and orientation within the borehole.

SDDT™ Stand-Alone DITS™ Directional Tool Specifications

<table>
<thead>
<tr>
<th></th>
<th>Length ft (m)</th>
<th>Diameter in. (mm)</th>
<th>Maximum Pressure psi (Mpa)</th>
<th>Maximum Temperature °F (°C)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12.5 (3.8)</td>
<td>3.63 (92.9)</td>
<td>20,000 (137.9)</td>
<td>350 (176.7)</td>
<td>240 (108.9)</td>
</tr>
</tbody>
</table>