Plan revision number: 0
Plan revision date: 6/24/2025

Underground Injection Control
Carbon Sequestration
Class VI Permit Application

QUALITY ASSURANCE AND SURVEILLANCE PLAN
40 CFR 146.90(k)
Section 8.11

NexGen Carbon Oklahoma, LLC
Vanguard CCS Hub

June 2025

8.9 QUALITY ASSURANCE AND SURVEILLANCE PLAN
40 CFR 146.90(k)

VANGUARD CCS HUB

Facility Information

Facility name: Vanguard CCS Hub
Vanguard I-1
Vanguard I-2
Vanguard I-3
Vanguard I-4
Vanguard I-5
Vanguard I-6
Vanguard I-8
Vanguard I-9
Vanguard I-10
Vanguard I-12

Facility contact: Marc Thomas, President & COO
600 Rockmead Drive, Suite 112
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(346) 576-8215
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Well locations: Osage County, Oklahoma

Vanguard I-1: Lat 36.633288°N, Lon -96.571029°W (NAD 83)
Vanguard I-2: Lat 36.660083°N, Lon -96.534652°W (NAD 83)
Vanguard I-3: Lat 36.664329°N, Lon -96.586951°W (NAD 83)
Vanguard I-4: Lat 36.710244°N, Lon -96.542370°W (NAD 83)
Vanguard I-5: Lat 36.744047°N, Lon -96.533843°W (NAD 83)
Vanguard I-6: Lat 36.724157°N, Lon -96.489526°W (NAD 83)
Vanguard I-8: Lat 36.823356°N, Lon -96.620496°W (NAD 83)
Vanguard I-9: Lat 36.849167°N, Lon -96.592912°W (NAD 83)
Vanguard I-10: Lat 36.893849°N, Lon -96.578026°W (NAD 83)
Vanguard I-12: Lat 36.785641°N, Lon -96.594085°W (NAD 83)

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ACRONYMS AND ABBREVIATIONS

2D	two-dimensional
°C	degrees Celsius
µS/cm	microseconds per centimeter
A	
AoR	area of review
ASTM	American Society for Testing and Materials
C	
CBL	cement bond log
CG	gas chromatography
CO_2	carbon dioxide
D	
DAS	distributed acoustic sensing
DTS	distributed temperature survey
DO	dissolved oxygen
E	
EPA	U.S. Environmental Protection Agency
M	
MFL	Magnetic flux leakage casing inspection tool
meq	milliequivalents
MIT	mechanical integrity testing
MVA	monitoring, verification, and accounting
N	
NACE	National Associated of Corrosion Engineers
P	
PISC	post-injection site care and closure
Project	Vanguard CCS Hub
PNL	pulsed neutron logging
Q	
QA	quality assurance
QASP	quality assurance and surveillance plan
QA/QC	quality assurance/quality control
QC	quality control
S	
SCADA	supervisory control and data acquisition
SOP	standard operating procedures
T	
TBD	to be determined
TDS	total dissolved solids
U	
UIC	Underground Injection Control
USDW	underground sources of drinking water
USIT	ultra sonic imager tool

TITLE AND APPROVAL SHEET

The Quality Assurance and Surveillance Plan will be finalized once the facility design is complete, encompassing all surface and subsurface systems, instrumentation specifications, sampling and laboratory methods, organizational roles, and document control procedures.

This QASP applies to all Vanguard CCS Hub wells: Vanguard I-1, I-2, I-3, I-4, I-5, I-6, I-8, I-9, I-10, and I-12.

By signing below, each party confirms their understanding of—and commitment to—adhering to the procedures detailed herein.

____

Signature Date
Marc Thomas
President and Chief Operating Officer

____

Signature Date

DISTRIBUTION LIST

The Vanguard CCS Hub (the "Project") participants, acting as key project managers (listed below), will receive the completed QASP and all future updates for the duration of the Project.

Marc Thomas | President and COO
NexGen Carbon Oklahoma, LLC
600 Rockmead Drive, Suite 112
Kingwood, TX 77339
marcthomas@nexgencarbonsolutions.com

8 TESTING AND MONITORING PLAN (CONT.)

8.11 Quality Assurance and Surveillance Plan

A. PROJECT MANAGEMENT

A.1 Project/Task Organization

A.1.a Key Individuals and Responsibilities

NexGen Project oversight for testing and monitoring will be the responsibility of NexGen Carbon Oklahoma, LLC's Project Managers, with execution carried out by the broader NexGen team. Monitoring activities are organized into five key areas:

-
- Groundwater well logging
- Annual mechanical integrity verification
- Continuous pressure and temperature surveillance
- Routine CO_2 stream composition analysis
- Time-lapse geophysical surveys

A.1.b Independence from Project Quality Assurance Manager and Data Gathering

The Testing and Monitoring Plan data is analyzed, processed, or witnessed by independent third parties outside the Project management structure.

A.1.c Quality Assurance Project Plan Responsibility

NexGen is responsible for maintaining and periodically distributing an official, approved Quality Assurance (QA) Project Plan. NexGen will periodically review this QASP and will consult with the U.S. Environmental Protection Agency (EPA) if changes to the plan are warranted.

A.1.d Organizational Chart for Key Project Personnel

The Project organizational structure is provided in **Figure 8.11.1**. NexGen will provide the Program Director a contact list of individuals fulfilling these roles.

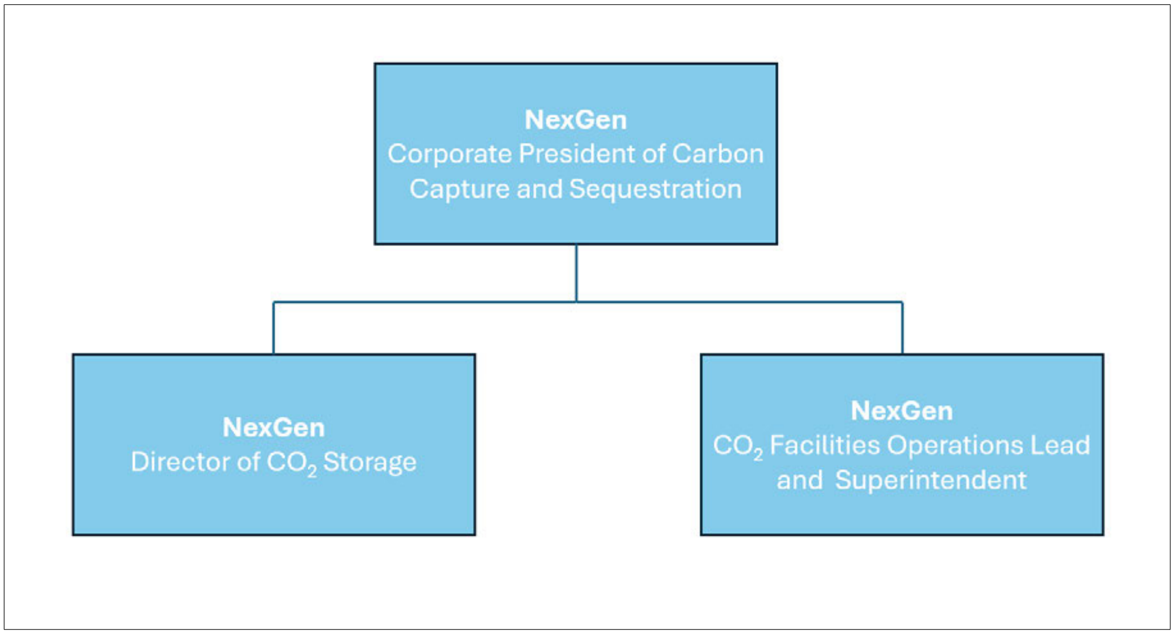

Figure 8.11.1—Project organization structure.

A.2 Project Definition/Background

A.2.a Rationale and Reasoning

NexGen proposes drilling and completing ten (10) carbon sequestration injection wells (Vanguard I-1, Vanguard I-2, Vanguard I-3, Vanguard I-4, Vanguard I-5, Vanguard I-6, Vanguard I-8, Vanguard I-9, Vanguard I-10 and Vanguard I-12), ten (10) above-zone monitoring wells (Vanguard AZM-1, Vanguard AZM-2, Vanguard AZM-3, Vanguard AZM-4, Vanguard AZM-5, Vanguard AZM-6, Vanguard AZM-8, Vanguard AZM-9, Vanguard AZM-10 and Vanguard AZM-12) and seven (7) in-zone monitoring wells (Vanguard IZM-1 through Vanguard IZM-7) for the safe sequestration of carbon dioxide at the Vanguard CCS Hub in Osage County, OK. The monitoring, verification, and accounting (MVA) program at the Vanguard CCS Hub is structured into three pillars: operational surveillance, verification activities, and environmental monitoring. Operational surveillance focuses on safe injection practices, real-time surveillance of reservoir behavior, and tracking the CO_2 plume's migration. The primary parameters to be monitored are:

- Anulus pressures in all ten (10) injection wells and all ten (10) in-zone monitoring wells. Tubing pressures in the injection wells will also be monitored.
- Injection zone pressure monitoring within all ten (10) injection wells
- Integrity of the confining zone
- Monitoring of the lowermost underground source of drinking water (USDW)

Additional monitoring parameters include injection rate, total volume injected, injection well temperature profiles and two-dimensional (2D) time-lapse seismic. The verification and environmental components inform NexGen if CO_2 leaks through the caprock and is released into the shallow subsurface or biosphere. At the wellbore, Pulsed Neutron Logging (PNL) as well as pressure and temperature monitoring are utilized across protected groundwater intervals and the confining zone. Two dimensional (2D) seismic will also be utilized to determine whether large amounts of CO_2 leakage is occurring, although this method has a time delay.

A.2.b Reasons for Initiating the Project

The Project's objective is long-term, industrial-scale CO_2 storage in the Arbuckle Group to help lower atmospheric CO_2 levels. To confirm containment, a comprehensive MVA Plan has been designed. Under the Class VI Rule, operators must employ multiple monitoring techniques over the Project's lifespan to verify that:

- The injection well retains full mechanical integrity
- Fluid movement and pressure propagation remain inside the permit-defined boundaries
- There is no impact on underground sources of drinking water

Our monitoring suite includes annual mechanical integrity tests (MITs), routine injection-well performance evaluations, groundwater surveillance, and continuous mapping of the CO_2 plume and pressure front. This plan describes each measurement, the frequency and methodology for data collection, and the quality-assurance procedures that guarantee all results are reliable for decision-making throughout the Project.

A.3 Project/Task Description

A.3.a Summary of Work to be Performed

Table 8.11.1 provides a summary of the testing and monitoring tasks for the Project.

Table 8.11.2 provides details of the equipment that will be installed and used for monitoring.

Table 8.11.3 shows the geophysical monitoring tools and timelines.

Figure 8.11.2 depicts the Project area and the location of the ten (10) Vanguard injection wells their associated monitoring wells. The location and design of monitoring infrastructure is in progress and will iteratively be added to the map.

Table 8.11.1—Summary of testing and monitoring.

Activity	Location(s)	Method	Analytical Technique	Pre-Injection Baseline	Operation Period (20 years)	PISC Period (100 years)	Lab/ Custody	Purpose
Carbon Dioxide Stream Analysis	Upstream or downstream of the flowmeter	CO_2 sampling	Gas chromatography	Adequate to establish baseline	Continuous	N/A	Under review	Monitor injectate
Injection Rate and Volume	After compression	Coriolis mass flowmeter at the wellhead	Direct measurement	Adequate to establish baseline	Continuous	N/A	N/A	Monitor rate and volume
Injection Pressure	All ten (10) injection wells	Surface pressure gauge	Direct measurement	Adequate to establish baseline	Continuous	Under review	N/A	Monitor injection pressure
Annular Pressure	All ten (10) injection wells	Surface pressure gauge	Direct measurement	Adequate to establish baseline	Continuous	N/A	N/A	Monitor annular pressure
Annular Pressure	All ten (10) injection wells	Annulus pressure test	Direct measurement	Adequate to establish baseline	Once during construction; during workovers	N/A	N/A	Monitor annular pressure
Downhole Pressure/ Temperature	In-Zone All ten (10) injection wells, All ten (10) above-zone and all seven (7) in-zone monitoring wells.	Pressure/temperature gauge	Direct measurement	Adequate to establish baseline	Continuous	Continuous	N/A	Monitor reservoir in ten (10) injection wells; monitor above confining zone in ten (10) above-zone monitoring wells and in seven (7) in-zone monitoring wells
Pressure/Temperature	Above Confining Zone (All ten (10) above-zone	Fiber optic behind casing	Direct measurement	Adequate to establish baseline	Continuous	Continuous	N/A	Monitor above confining zone/USDWs in all ten (10) above-zone monitoring wells

Activity	Location(s)	Method	Analytical Technique	Pre-Injection Baseline	Operation Period (20 years)	PISC Period (100 years)	Lab/ Custody	Purpose
	monitoring wells)							
Corrosion Monitoring	All ten (10) injection wells	Corrosion coupons	ASTM International Method G1-03	1 time	Continuous	N/A	Under review	Monitor corrosion of materials
Mechanical Integrity	All ten (10) injection wells	Logging	Temperature log	1 time	Annually	Annually	N/A	Wellbore integrity
USDW Monitoring	All ten (10) injection wells	Logging	Pulsed neutron log	1 time	Annually	Annually	N/A	USDW saturations for CO_2 detection
Cement Evaluation	All ten (10) injection wells	Logging	USIT, Caliper Log, Magnetic Flux or equivalent	Adequate to establish baseline	Every 5 years	Every 5 years	N/A	Wellbore integrity
Pressure Fall Off Testing	All ten (10) injection wells	Pressure gauge	Direct measurement	1 time	Every 5 years	N/A	N/A	Wellbore integrity, reservoir monitoring
Near Surface USDW Monitoring	Ten (10) USDW wells on the same pad as the 10 above-zone monitoring wells	Direct sample	Chemical analysis	Adequate to establish baseline	Annually	Annually	Under review	Geochemical monitoring and CO_2 detection in utilized USDW(s)

Table 8.11.2—Instrumentation summary. T=Temperature; P=Pressure; F=Flow.

Monitoring Location	Instrument Type	Monitoring Target	Data Collection Location(s)	Explanation
CO_2 Facility	T, P, F	Surface	Discharge of high-pressure pumps	Monitoring the operation, equipment, and permit parameters
All seven (7) in-zone monitoring wells	T, P	Surface well head	Tubing	Monitoring operation, equipment, and permit parameters
			Annulus	
	P	Arbuckle Group	At the perforations, depth TBD	Monitoring operation, equipment, and permit parameters
All ten (10) injection wells.	T, P	Surface well head	Tubing	Monitoring operation, equipment, and permit parameters
			Annulus	
	P	Arbuckle Group	At the perforations, depth TBD	Monitoring operation, equipment, and permit parameters

T = Temperature gauge
P = Pressure gauge
F = Flow meter
TBD = To be determined

Table 8.11.3—Geophysical surveys.

Monitoring Activity	Well	Tool or Survey	Pre-Injection Baseline	Injection Phase Repeat Survey Interval	PISC Repeat Survey Interval	Description
Seismic	AoR	2D time-lapse seismic survey	Once	Once	Once	Monitor spatial extent of plume

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[redacted]

Figure 8.11.2—Map of the Project area and wells.

A.3.b Resource and Time Constraints

NexGen does not anticipate any additional resource or time constraints for the Testing and Monitoring Plan beyond Project funding levels and the proposed timeline outlined in **Figure 8.11.3**.

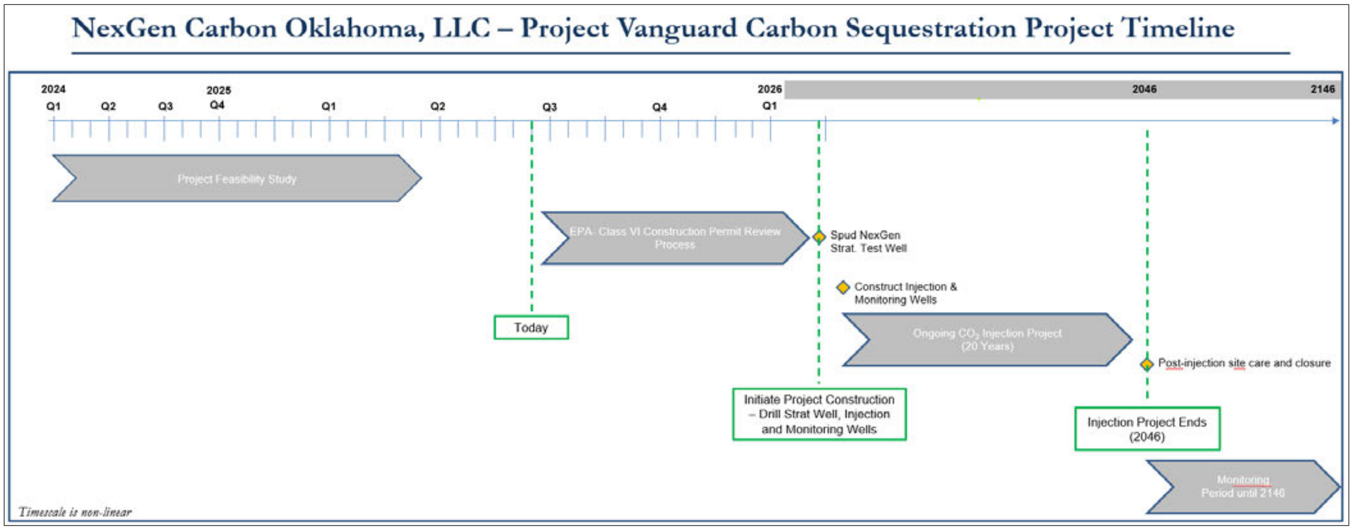


Figure 8.11.3—Anticipated timeframe for NexGen' proposed CO_2 sequestration project as part of the Vanguard CCS Hub.

A.4 Quality Objectives and Criteria

A.4.a Performance/Measurement Criteria

This QASP provides confidence that the underground storage project is operating as planned and permitted; thus, the Project is not altering USDWs. Near-surface groundwater monitoring will be conducted during the pre-injection, injection, and post-injection phases of the Project in aquifer(s) identified as being the primary utilized aquifer(s) in the Project AoR. Minimum fluid analytical and field monitoring parameters for the near-surface aquifer are listed in **Table 8.11.4.** Analytical parameters for CO_2 stream monitoring, corrosion coupon assessment, and gauge specifications are shown in **Table 8.11.5** through **Table 8.11.8**.

Continuous CO_2 stream monitoring using a gas chromatograph will be monitoring for the following components:

- Carbon Dioxide
- Nitrogen
- Oxygen

Table 8.11.4—Summary of analytical and field parameters for fluid samples.

Parameters	Analytical Methods(1)	Detection Limit/Range	Typical Precisions	QC Requirements
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb, Se, and Tl	ICP-MS, EPA Method 6020	0.001 to 0.1 mg/L (analyte, dilution and matrix dependent)	±15%	Daily calibration; blanks, duplicates and matrix spikes at 10% or greater frequency
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010B	0.005 to 0.5 mg/L (analyte, dilution and matrix dependent)	±15%	Daily calibration; blanks, duplicates and matrix spikes at 10% or greater frequency
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography, EPA Method 300.0	0.02 to 0.13 mg/L (analyte, dilution and matrix dependent)	±15%	Daily calibration; blanks and duplicates at 10% or greater frequency
Dissolved CO_2	Coulometric titration, ASTM D513-11	25 mg/L	±15%	Duplicate measurement; standards at 10% or greater frequency
Total Dissolved Solids	Gravimetry; APHA 2540C	12 mg/L	±10%	Balance calibration, duplicate analysis
Alkalinity	APHA 2320B	4 mg/L	±3 mg/L	Duplicate analysis
pH (field)	EPA 150.3	2 to 12 pH units	±0.2 pH unit	User calibration per manufacturer recommendation
Specific conductance (field)	APHA 2510	0 to 200 mS/cm	±1% of reading	User calibration per manufacturer recommendation
Temperature (field)	Thermocouple	-5 to 50°C	±0.2°C	Factory calibration

Note 1: Once the laboratory is confirmed all analytical methods will meet or exceed the above, and an equivalent method may be employed with the prior approval of the UIC Program Director.

Table 8.11.5—Summary of analytical methods for characterizing the CO_2 stream (if lab-tested).

Parameters	Analytical Methods[(1)]	Detection Limit/Range	Typical Precisions	QC Requirements
Oxygen	ISBT 4.0 (GC/DID)	1 uL/L to 5,000 uL/L (ppm by volume)	±10% of reading	daily standard within 10% of calibration, secondary standard after calibration
Oxygen	GC/TCD	0.1% to 100%–	5 - 10% relative across the range, RT ±0.1 min	daily standard, duplicate analysis within 10% of duplicate sample
Nitrogen	ISBT 4.0 GC/DID	1 uL/L to 5,000 uL/L (ppm by volume)	±10% of reading	daily standard within 10% of calibration, secondary standard after calibration
Nitrogen	GC/TCD	0.1% to 100%–	5 - 10% relative across the range, RT ±0.1 min	daily standard, duplicate analysis, within 10% of duplicate sample
Carbon Monoxide	ISBT 5.0 Colorimetric	5 uL/L to 100 uL/L (ppm by volume)	±20% of reading	duplicate analysis
Carbon Monoxide	ISBT 4.0 (GC/DID)	1 uL/L to 5,000 uL/L (ppm by volume)	±10% of reading	daily standard within 10% of calibration, secondary standard after calibration
Oxides of Nitrogen	ISBT 7.0 Colorimetric	0.2 uL/L to 5 uL/L (ppm by volume)	±20% of reading	duplicate analysis
Total Hydrocarbons	ISBT 10.0 THA (FID)	1 uL/L to 10,000 uL/L (ppm by volume)	5–10% of reading relative across the range	daily blank, daily standard within 10% of calibration, secondary standard after calibration
Methane	ISBT 10.1 (GC/FID)	0.1 uL/L to 1,000 uL/L (ppm by volume)-dilution dependent	5–10% of reading relative across the range	daily blank, daily standard within 10% of calibration, secondary standard after calibration
Acetaldehyde	ISBT 11.0 (GC/FID)	0.1 uL/L to 100 uL/L (ppm by volume)-dilution dependent	5–10% of reading relative across the range	daily blank, daily standard within 10% of calibration, secondary standard after calibration
Sulfur Dioxide	ISBT 14.0 (GC/SCD)	0.01 uL/L to 50 uL/L (ppm by volume)-dilution dependent–	5–10% of reading relative across the range	daily blank, daily standard within 10% of calibration, secondary standard after calibration
Hydrogen Sulfide	ISBT 14.0 (GC/SCD)	0.01 uL/L to 50 uL/L (ppm by volume)-dilution dependent	5–10% of reading relative across the range	daily blank, daily standard within 10% of calibration, secondary standard after calibration

Parameters	Analytical Methods(1)	Detection Limit/Range	Typical Precisions	QC Requirements
Ethanol	ISBT 11.0 (GC/FID)	0.1 uL/L to 100 uL/L (ppm by volume)- dilution dependent	5–10% of reading relative across the range	daily blank, daily standard within 10% of calibration, secondary standard after calibration
CO_2 Purity	ISBT 2.0 Caustic absorption Zahm-Nagel	99.00% to 99.99%	±10% of reading	
CO_2 Purity	ALI method SAM 4.1 subtraction method (GC/DID)	1 ppm for each target analyte (analyte dependent–) - refer to Oxygen and Nitrogen analysis	5–10% relative across the range	duplicate analysis within 10% of each other

Note 1: An equivalent method may be employed with the prior approval of the UIC Program Director.

Table 8.11.6—Summary of analytical parameters for corrosion coupons.

Parameters	Analytical Methods(1)	Detection Limit/Range	Typical Precisions	QC Requirements
Mass	NACE RP0775-2005	0.005 mg	±2%	Annual Calibration of Measurement Scale (3rd Party / Vendor)
Thickness	NACE RP0775-2005	0.001 mm	±0.005 mm	Factory calibration

Note 1: Once the laboratory is confirmed all analytical methods will meet or exceed the above, and an equivalent method may be employed with the prior approval of the UIC Program Director

Table 8.11.7—Summary of measurement parameters for field gauges.

Parameters	Methods[1]	Detection Limit/Range	Typical Precisions	QC Requirements
Booster pump discharge pressure	ANSI Z540-1-1994	±0.001 psi / 0–3,000 psi	±0.01 psi	Annular Calibration of Instrumentation. (booster pump to injection tubing pressure (3rd party)
Injection tubing temperature	ANSI Z540-1-1994	±0.001°F / 0–500°F	±0.01°F	Annular Calibration of Instrumentation. (booster pump to injection tubing pressure (3rd party)
Annulus pressure	ANSI Z540-1-1994	±0.001 psi / 0–3,000 psi	±0.01 psi	Annular Calibration of Instrumentation. (booster pump to injection tubing pressure (3rd party)
Injection tubing pressure	ANSI Z540-1-1994	±0.001 psi / 0–3,000 psi	±0.01 psi	within 10% of duplicate sample
Injection mass flow rate	Under review	±0.1% of rate / 50,522–303,133 lbm/hr	±0.01 lbm/hr	Annual Calibration of Scale (3rd party)

Note 1: An equivalent method may be employed with the prior approval of the UIC Program Director.

Table 8.11.8—Actionable testing and monitoring outputs.

Activity or Parameter	Project Action Limit	Detection Limit	Anticipated Reading
External mechanical integrity (temperature log)	Action will be taken when there is a significant anomaly in the temperature profile	Under review	Under review
Internal mechanical integrity (magnetic flux leakage log, multi-arm caliper, USIT or equivalent)	Action will be taken when internal wellbore integrity shows significant signs of degradation	Under review	Under review
Surface and downhole pressure	Action will be taken when pressures are outside modeled/expected range	Under review	Under review
MIT—Pulse neutron logging	Action taken when PNL indicates CO_2 outside of pre-injection baseline range	±0.5 SIGM	TBD based on pre-injection baseline readings
2D seismic	Detect CO_2 outside the AoR	Dependent on fluid saturation, formation velocity and density	CO_2 plume migration similar to modeled outcome
Above-confining-zone pressure	Action will be taken when pressures are outside modeled/expected range	Under review	Under review

A.4.b Precision

Fluid sample data precision will be assessed by the collection and analysis of field blanks to test sampling procedures and matrix spikes to test lab procedures. Field blanks will be taken no less than once per sampling event to spot-check for sample bottle contamination. Laboratory assessment of analytical precision will be the responsibility of the individual laboratories per their standard operating procedures.

A.4.c Bias

Laboratory assessment of analytical bias will be the responsibility of the individual laboratories per their standard operating procedures and analytical methodologies. For direct pressure or logging measurements, there is no bias.

A.4.d Representativeness

For fluid sampling, data representativeness expresses the degree to which data accurately and precisely represents a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. A sampling network was designed to provide data representative of site conditions. For analytical results of individual groundwater samples, representativeness will be estimated by ion and mass balances. Ion balances with ±10% error or less will be considered valid. Mass balance assessment will be used in cases where the ion balance is greater than ±10% to help determine the source of error. For a sample and its duplicate, if the relative percent difference is greater than 10%, the sample may be considered non-representative.

A.4.e Completeness

For fluid sampling, data completeness is a measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under normal conditions. It is anticipated that data completeness of 90% for fluid sampling will be acceptable to meet monitoring goals. For direct pressure and temperature measurements, it is expected that data will be recorded no less than 90% of the time.

A.4.f Comparability

Data comparability expresses the confidence with which one data set can be compared to another. The data sets to be generated by this Project will be very comparable to future data sets because of the use of standard methods and the level of quality assurance/quality control (QA/QC) effort. Direct pressure, temperature, and logging measurements will be directly comparable to previously obtained data.

A.4.g Method Sensitivity

Table 8.11.9 through **Table 8.11.15** provide additional details on gauge and surveillance logging specifications and sensitivities.

Table 8.11.9—Pressure and temperature—downhole gauge specifications.

Parameter	Value
Calibrated working pressure range	0–10,000 psia
Initial pressure accuracy	±0.02%
Pressure resolution	0.01 psi or better
Pressure drift stability	Under review
Calibrated working temperature range	25–125°C
Initial temperature accuracy	0.5°C
Temperature resolution	0.005°C
Temperature drift stability	Under review
Max temperature	200°C
Instrument calibration frequency	Under review

psi = Pounds per square inch
psia = Pounds per square inch (ambient)

Table 8.11.10—Representative surveillance logging tool specifications.

Parameter	Value
Logging speed	1,800 ft/hr
Vertical resolution	2.5 feet
Investigation	6 in.
Temperature rating	< 300°F
Pressure rating	< 15,000 psi

ft/hr = Feet per hour
psi = Pounds per square inch

Table 8.11.11—Pressure field gauge specifications.

Parameter	Value
Calibrated working pressure range	0–3,000 psi
Initial pressure accuracy	Under review
Pressure resolution	0.001 psi and 0.00001 mA
Pressure drift stability	Under review

mA = Milliamp
psi = Pounds per square inch

Table 8.11.12—Pressure field gauge—injection tubing pressure.

Parameter	Value
Calibrated working pressure range	0–3,000 psi
Initial pressure accuracy	Under review
Pressure resolution	0.001 psi and 0.00001 mA
Pressure drift stability	Under review

mA = Milliamp
psi = Pounds per square inch

Table 8.11.13—Pressure field gauge—annulus pressure.

Parameter	Value
Calibrated working pressure range	0–3,000 psi
Initial pressure accuracy	Under review
Pressure resolution	0.001 psi and 0.00001 mA
Pressure drift stability	Under review

mA = Milliamp
psi = Pounds per square inch

Table 8.11.14—Temperature field gauge—injection tubing temperature.

Parameter	Value
Calibrated working temperature range	0–500°F
Initial temperature accuracy	Under review
Temperature resolution	0.001°F and 0.0001 mA
Temperature drift stability	Under review

mA = Milliamp

Table 8.11.15—Mass flow rate field gauge—CO_2 mass flow rate.

Parameter	Value
Calibrated working flow rate range	Under review
Initial mass flow rate accuracy	Under review
Mass flow rate resolution	Under review
Mass flow rate drift stability	Under review

A.5 Specialized Training and Certifications

A.5.a Specialized Training and Certifications

The qualified service-company personnel will handle all geophysical surveys and wireline logging operations, adhering to the equipment manufacturer's and industry best-practice guidelines. Collected data will undergo processing and interpretation in line with established standards. Groundwater sampling will be performed by staff trained in the project's specific sampling protocols; no additional certifications are required. Upon request, NexGen will furnish the regulator with the laboratories' standard operating procedures (SOPs) for each analytical parameter. Laboratory technicians will receive training on the relevant SOPs, and their training records will be submitted as part of the semiannual compliance report.

A.5.b Training Provider and Responsibility

Training for personnel will be provided by the operator or by the subcontractor responsible for the data collection activity.

A.6 Documentation and Records

A.6.a Report Format and Package Information

A semi-annual report from NexGen to EPA will contain all required Project data, including testing and monitoring information as specified by the UIC Class VI Permit. Data will be provided in electronic or another format as required by the UIC Program Director.

A.6.b Other Project Documents, Records, and Electronic Files

Other documents, records, and electronic files such as well logs, test results, or other data will be provided as required by the UIC Program Director.

A.6.c Data Storage and Duration

NexGen or a designated contractor will maintain the required Project data as provided elsewhere in the permit.

A.6.d Quality Assurance and Surveillance Plan Distribution Responsibility

The NexGen Director of CO_2 Storage operations will be responsible for ensuring that all those on the distribution list will receive the most current copy of the approved QASP.

B. DATA GENERATION AND ACQUISITION

This section focuses on fluid sampling and does not address monitoring methods that do not gather physical samples (e.g., logging, seismic monitoring, and pressure/temperature monitoring).

During the pre-injection and injection phases, fluid sampling in the primary utilized near-surface USDW is planned to include an extensive set of chemical parameters to establish aqueous geochemical reference data. Parameters will include selected constituents that:

- Are the most responsive to interaction with CO_2 or brine
- Are needed for QC
- May be needed for geochemical modeling

The minimum set of parameters is provided in **Table 8.11.4**. After a sufficient baseline is established, the monitoring scope may shift to a subset of indicator parameters that are:

- The most responsive to interaction with CO_2 or brine
- Are needed for QC

Implementation of a reduced set of parameters would be performed in consultation with the EPA. All samples will be analyzed by a third-party laboratory. Dissolved CO_2 will be analyzed by methods consistent with Test Method B of ASTM D 513-06, Standard Test Methods for Total and Dissolved Carbon Dioxide in Water or equivalent.

B.1 *SAMPLING PROCESS DESIGN*

B.1.a Design Strategy

B.1.a.i. CO_2 Stream Monitoring Strategy

The CO_2 injection stream will be analyzed with sufficient frequency to yield data representative of its chemical and physical characteristics. The objective of this analysis is to evaluate the potential interactions of CO_2 and other constituents of the injectate with formation solids, fluids, or any components of the injection system. Testing will be conducted using gas chromatography analysis. This analysis will also test for constituents that include sulfur dioxide, hydrogen sulfide, nitrogen oxides, hydrocarbons, carbon monoxide, methane, water vapor, nitrogen, oxygen, mercury, and arsenic. The gas chromatography equipment will meet American Society for Testing and Materials (ASTM) testing standards.

B.1.a.ii. Corrosion Monitoring Strategy

A corrosion coupon system will be installed, and the coupons will be deployed upstream of the wellhead through which the injection stream passes. This monitoring method will detect any possible metal loss due to the chemical or electrochemical reactions that may result in loss of mass or thickness or pitting of injection well components. The coupons will be prepared, analyzed, installed, and QA/QC protocols will be implemented using the National Association of Corrosion Engineers (NACE) Standard Recommended Practice (RP)-0775 and ASTM Standards G1 and G4.

B.1.a.iii. Groundwater Monitoring Strategy

NexGen will use pulsed neutron (PNL) and temperature logging at Vanguard I-1 to Vanguard I-12 and temperature (fiber optic DTS) monitoring at Vanguard M-1 to Vanguard M-7 for early leakage detection in the USDWs above the Lower Mississippian Lime and Woodford Formation confining zones. Baseline pulsed neutron and temperature logs will be run to accurately characterize baseline or pre-injection conditions of the injection zone, confining zones, and all permeable zones above the confining zone in subsequent surveillance logging. With the planned monitoring frequencies, it is expected that baseline conditions can be documented, natural variability in conditions can be characterized, unintended brine or CO_2 leakage could be detected should it occur, and sufficient data will be collected to demonstrate that the effects of CO_2 injections are limited to the intended storage reservoir. Groundwater sampling and analysis from near-surface ground water monitoring well(s) will take place during baseline, injection and post-injection on an annual basis. To augment PNL and temperature logs, 2D seismic will provide indication of extent of plume(s) over the AoR.

B.1.a.iv. Soil Sampling Strategy

NexGen does not have plans to monitor the soil within the area of review (AoR). If deemed necessary in the future by the UIC Program Director, NexGen will develop a Soil Monitoring Plan that will include sampling plans and station locations.

B.1.b Type and Number of Samples/Test Runs

Sampling activities are detailed in **Table 8.11.1**.

B.1.c Site/Sampling Locations

Table 8.11.16—Site sampling locations.

Well Name	Latitude*	Longitude*	PLSS
Vanguard I-1	36.633288	-96.571029	20-T25N-R7E
Vanguard I-2	36.660083	-96.534652	10-T25N-R7E
Vanguard I-3	36.664329	-96.586951	7-T25N-R7E
Vanguard I-4	36.710244	-96.542370	22-T26N-R7E
Vanguard I-5	36.744047	-96.533843	10-T26N-R7E
Vanguard I-6	36.724157	-96.489526	18-T26N-R8E
Vanguard I-8	36.823356	-96.620496	14-T27N-R6E
Vanguard I-9	36.849167	-96.592912	6-T27N-R7E
Vanguard I-10	36.893849	-96.578026	20-T28N-R7E
Vanguard I-12	36.785641	-96.594085	25-T27N-R6E
Vanguard IZM-1	36.608527	-96.593760	30-T25N-R7E
Vanguard IZM-2	36.690345	-96.407091	35-T26N-R8E
Vanguard IZM-3	36.693141	-96.605618	36-T26N-R6E
Vanguard IZM-4	36.767924	-96.486755	6-T26N-R8E
Vanguard IZM-5	36.817858	-96.660029	16-T27N-R6E
Vanguard IZM-6	36.858637	-96.548578	33-T28N-R7E
Vanguard IZM-7	36.926076	-96.548619	9-T28N-R7E

* NAD83

B.1.d Sampling Site Contingency

No problems of site accessibility are expected within the Project area. If inclement weather makes site access difficult, sampling schedules will be reviewed, and alternative dates may be selected that would still meet permit-related conditions.

B.1.e Activity Schedule

Sampling activities and frequency are detailed in **Table 8.11.1**.

B.1.f Critical/Informational Data

Detailed field and laboratory documentation will be taken during field sampling and analytical efforts. Documentation will be recorded in field and laboratory forms and notebooks. Critical information will include time and date of activity, person/s performing activity, location of activity (wellfield sampling) or instrument (lab analysis), field or laboratory instrument calibration data, field parameter values. For laboratory analyses, much of the critical data are generated during the analysis and provided to end users in digital and printed formats. Non-critical data may include appearance and odor of the sample, problems with well or sampling equipment, and weather conditions.

B.1.g Sources of Variability

Potential sources of variability related to monitoring activities include:

- Natural variation in fluid quality, formation pressure and temperature, and seismic activity
- Variation in fluid quality, formation pressure and temperature, and seismic activity due to Project operations

- Changes in instrument calibration during sampling or analytical activity
- Different staff collecting or analyzing samples
- Differences in environmental conditions during field sampling activities
- Changes in analytical data quality during life of Project
- Data entry errors related to maintaining Project database

Activities to eliminate, reduce, or reconcile variability related to monitoring activities include:

- Collecting long-term baseline data to observe and document natural variation in monitoring parameters
- Evaluating data in timely manner after collection to observe anomalies in data that can be addressed be resampled or reanalyzed
- Conducting statistical analysis of monitoring data to determine whether variability in a data set is the result of Project activities or natural variation
- Maintaining weather related data using on-site weather monitoring data or data collected near Project site (such as from local airports)
- Checking instrument calibration before, during and after sampling or sample analysis
- Thoroughly training staff,
- Conducting laboratory QA checks using third party reference materials, and/or blind and/or replicate sample checks
- Developing a systematic review process of data that can include sample-specific data quality checks (i.e., cation/anion balance for aqueous samples).

B.2 Sampling Methods

B.2.a Sampling Standard Operation Procedures

Laboratory SOPs have been developed by the service provider. All procedures for sampling shall be consistent with the U.S. Environmental Protection Agency (EPA) *Groundwater Sampling Guidelines for Superfund and RCRA Project Managers* (May 2002). **Table 8.11.17** summarizes stabilization criteria during well purging.

Table 8.11.17—Stabilization criteria of water quality parameters during fluid purging.

Field Parameter	Stabilization Criteria
pH	±0.2 units of measure
Temperature	±1°C
Specific Conductance	TBD
Dissolved	±10% of reading or 0.3 mg/L whichever is greater

B.2.b In-situ Monitoring

NexGen does not plan to perform in-situ monitoring of groundwater chemistry.

B.2.c Continuous Monitoring

NexGen will collect periodic pressure data (e.g., hourly to daily) from the injection wells and in-zone monitoring wells.

B.2.d Sample Homogenization, Composition, Filtration

To obtain a representative sample, each well will be purged at a flow rate between 10 and 50 gallons per minute (gpm). Samples will be collected within 24 hours of the well being purged. If a monitoring well does not supply adequate water for sampling, the condition of the well will be investigated, and it may be considered for replacement.

To ensure the collection of a representative sample, a series of water quality indicator measurements will be collected using a water quality meter prior to collecting an aliquot(s) for the analytical laboratory sample. Purging will continue until three successive measurements of the indicator parameters meet the stabilization criteria per **Table 8.9.17**.

Following indicator parameter stabilization, fluid samples collected for laboratory analysis will be obtained via direct capture of liquid from the sample port into clean, unused laboratory analytical method-specific containers.

B.2.e Sample Containers and Volumes

Sample collection devices for groundwater fluids will be carefully chosen to minimize the potential for altering the quality of the sample. Teflon and stainless steel are preferred materials, although polyvinyl chloride (PVC), high-density polyethylene (HDPE), and other similar materials are considered sufficient in some cases

Stream monitoring samples for CO_2 will be collected in a clean sample container rated for the appropriate collection pressure (i.e., mini cylinders or polybags provided by Airborne Labs International Inc. or a similar lab).

Assay for CO_2 Quarterly Gas Analysis:

- CO_2 Purity (v/v, [GC])
- Oxygen (O_2, ppm, v/v)
- Nitrogen (N_2, ppm, v/v)
- Carbon Monoxide (CO, ppm, v/v)
- Oxides of Nitrogen (NOx, ppm, v/v)
- Total Hydrocarbons (THC, ppm, v/v as CH_4)
- Methane (CH_4, ppm, v/v)
- Acetaldehyde (AA, ppm, v/v)
- Sulfur Dioxide (SO_2, ppm, v/v)
- Hydrogen Sulfide (H_2S ppm, v/v)
- Ethanol (ppm, v/v)

For fluid samples, all sample bottles will be new. Sample bottles and bags for analytes will be used as received (i.e. ready for use) from the vendor or contract analytical laboratory for the analyte of interest. A summary of sample containers is presented in **Table 8.11.18**.

Table 8.11.18—Summary of sample containers, preservation treatments, and holding times for groundwater samples.

Target Parameters	Volume/Container Material	Preservation Technique	Sample Holding Time
Cations: Ca, Fe, K, Mg, Na, Si, Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, Tl	250 ml/HDPE	Filtered, nitric acid, cool 4°C	60 days
Dissolved CO_2	2 × 60 ml/HDPE	Filtered, cool 4°C	14 days
Dissolved CO_2	60 ml/HDPE	Filtered, cool 4°C	14 days
Alkalinity, Anions (Br, Cl, F, NO3, SO_4)	500 ml/HDPE	Filtered, cool 4°C	45 days
Field Confirmation: Temperature, Dissolved Oxygen, Specific Conductance, pH	200 ml/glass jar	None	< 1 hour
Field Confirmation: Density	60 ml/HDPE	Filtered	< 1 hour

HDPE = High density polyethylene
mL = Milliliter

B.2.f Sample Preservation

Table 8.11.18 provides sample preservation techniques for collected fluid samples.

Sample preservation is not required or used for the CO_2 gas stream. Additional details of sampling requirements are shown in **Table 8.11.19**. Corrosion coupon sampling only requires that the coupons be physically separated (e.g., sleeves, baggies) during transportation to prevent physical abrasion.

Table 8.11.19—Summary of sample containers, preservation treatments, and holding times for CO_2 gas stream analysis.

Target Parameters	Volume/Container Material	Preservation Technique	Sample Holding Time (max)
CO_2 gas stream	(2) 2L MLB Polybags (1) 75 cc Mini Cylinder	Sample Storage Cabinets	5 business days

B.2.g Cleaning/Decontamination of Sampling Equipment

Equipment used for sampling and other activities associated with on-site work will be decontaminated before and after performance of a given activity. Decontamination procedures will vary depending on the material being decontaminated and manufacturer recommendations. At a minimum, decontamination will include external cleaning using a non-phosphate detergent, followed by a minimum of three rinse cycles using deionized water. All reusable field glassware will be cleaned with tap water to remove any loose dirt, washed in a diluted nitric acid solution, and rinsed three times with deionized water before use. Disposable items will be disposed of as solid waste in an approved, permitted client facility.

CO_2 gas stream sampling containers will be either disposed of or decontaminated by the analytical lab.

No sampling equipment will be utilized with the corrosion coupons or annual field gauge calibrations.

B.2.h Support Facilities

The following instruments are required to collect fluid samples: air compressor, vacuum pump, generator, multi-electrode water quality sonde, analytical meters (e.g., pH, specific conductance). Field activities are usually completed in field vehicles and portable laboratory trailers located on site.

Sampling tubing, connectors and valves required to sample the CO_2 gas stream. These will be supplied by the analytical lab providing the sampling containers. Sampling will occur within the existing CO_2 compression building.

Similarly, corrosion coupons will be removed from the CO_2 injection line within the existing CO_2 compression building.

Field gauges will be removed from the injection and monitoring wells utilizing existing standard industry tools and equipment. Deployment and retrieval of well gauges will be performed using procedures and equipment recommended by the vendor, subcontractor, or is standard per industry practice.

B.2.i Corrective Action, Personnel, and Documentation

The sampling and analysis service providers will be responsible for testing instruments and equipment and preforming corrective action on defective equipment. Corrective action taken on equipment will be documented.

B.3 Sample Handling and Custody

Sample holding times (**Table 8.11.18** and **Table 8.11.19**) are consistent with those described in US EPA (1974), American Public Health Association (APHA, 2005), Wood (1976), and ASTM Method D6517-00 (2005). After collection, samples will be placed in ice chests in the field and maintained thereafter at approximately 4 degrees Celsius (°C) until analysis. The samples will be maintained at their preservation temperature and sent to the designated laboratory within 24 hours. Analysis of the samples will be completed within the holding time listed in (**Table 8.11.18** and **Table 8.11.19**). As appropriate, alternative sample containers and preservation techniques approved by the Program Director will be used to meet analytical requirements.

B.3.a Maximum Hold Time/Time Before Retrieval

Refer to **Table 8.11.18** and **Table 8.11.19** for sample holding times.

B.3.b Sample Transportation

The samples will be maintained at their preservation temperature and sent to the designated laboratory within 24 hours. During transportation, precautions will be implemented to ensure that sample integrity is not affected by extreme temperatures and/or excessive vibration.

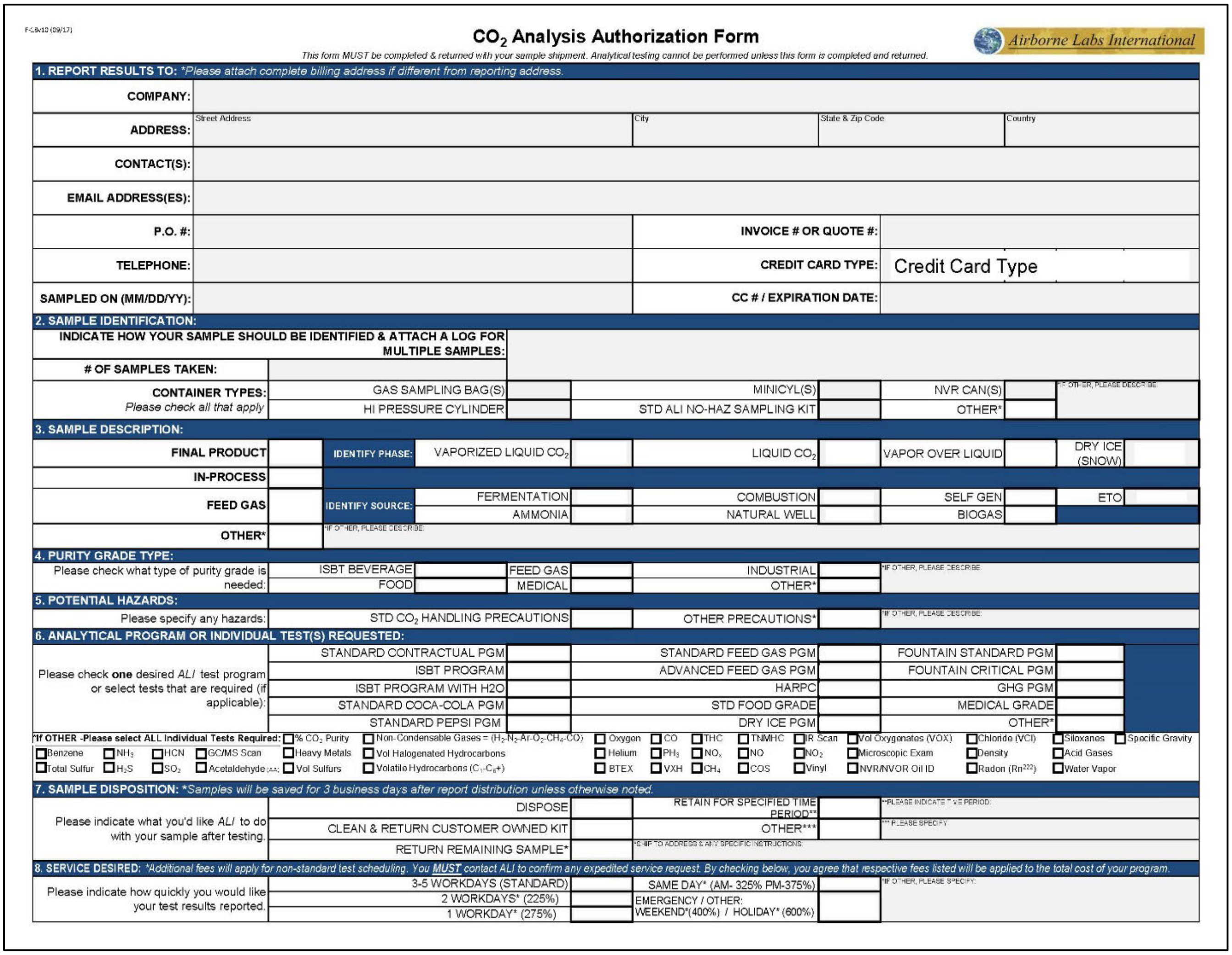
Upon arrival at the service provider, the samples will be reviewed to ensure the following:

- The sample arrived intact without container leakage or breakage.
- Chain of custody documentation and sample labels agree
- Confirmation that the sample was preserved correctly.

B.3.c Sample Documentation

Field notes will be recorded on all Lyons fluid sample collections. These notes will be retained and archived as reference. The sample documentation is the responsibility of fluid sampling personnel.

An analysis authorization form shall be provided with each CO_2 gas stream sample provided for analysis as shown by the example in **Figure 8.11.4**.



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CO_2 Analysis Authorization Form

Airborne Labs International

This form MUST be completed & returned with your sample shipment. Analytical testing cannot be performed unless this form is completed and returned.

1. REPORT RESULTS TO: **Please attach complete billing address if different from reporting address.*

COMPANY:
ADDRESS: Street Address | City | State & Zip Code | Country
CONTACT(S):
EMAIL ADDRESS(ES):
P.O. #: | INVOICE # OR QUOTE #:
TELEPHONE: | CREDIT CARD TYPE: Credit Card Type
SAMPLED ON (MM/DD/YY): | CC # / EXPIRATION DATE:

2. SAMPLE IDENTIFICATION:

INDICATE HOW YOUR SAMPLE SHOULD BE IDENTIFIED & ATTACH A LOG FOR MULTIPLE SAMPLES:
OF SAMPLES TAKEN:
CONTAINER TYPES: *Please check all that apply* — GAS SAMPLING BAG(S) | MINICYL(S) | NVR CAN(S) | HI PRESSURE CYLINDER | STD ALI NO-HAZ SAMPLING KIT | OTHER* | *IF OTHER, PLEASE DESCRIBE:

3. SAMPLE DESCRIPTION:

FINAL PRODUCT | IDENTIFY PHASE: VAPORIZED LIQUID CO_2 | LIQUID CO_2 | VAPOR OVER LIQUID | DRY ICE (SNOW)
IN-PROCESS
FEED GAS | IDENTIFY SOURCE: FERMENTATION | COMBUSTION | SELF GEN | ETO | AMMONIA | NATURAL WELL | BIOGAS
OTHER* | *IF OTHER, PLEASE DESCRIBE:

4. PURITY GRADE TYPE:

Please check what type of purity grade is needed: ISBT BEVERAGE | FEED GAS | INDUSTRIAL | FOOD | MEDICAL | OTHER* | *IF OTHER, PLEASE DESCRIBE:

5. POTENTIAL HAZARDS:

Please specify any hazards: STD CO_2 HANDLING PRECAUTIONS | OTHER PRECAUTIONS* | *IF OTHER, PLEASE DESCRIBE:

6. ANALYTICAL PROGRAM OR INDIVIDUAL TEST(S) REQUESTED:

Please check **one** desired *ALI* test program or select tests that are required (if applicable):
STANDARD CONTRACTUAL PGM | STANDARD FEED GAS PGM | FOUNTAIN STANDARD PGM
ISBT PROGRAM | ADVANCED FEED GAS PGM | FOUNTAIN CRITICAL PGM
ISBT PROGRAM WITH H2O | HARPC | GHG PGM
STANDARD COCA-COLA PGM | STD FOOD GRADE | MEDICAL GRADE
STANDARD PEPSI PGM | DRY ICE PGM | OTHER*

*If OTHER -Please select ALL Individual Tests Required: ☐% CO_2 Purity ☐Non-Condensable Gases = (H_2-N_2-Ar-O_2-CH_4-CO) ☐Oxygen ☐CO ☐THC ☐TNMHC ☐IR Scan ☐Vol Oxygenates (VOX) ☐Chloride (VCl) ☐Siloxanes ☐Specific Gravity
☐Benzene ☐NH_3 ☐HCN ☐GC/MS Scan ☐Heavy Metals ☐Vol Halogenated Hydrocarbons ☐Helium ☐PH_3 ☐NO_x ☐NO ☐NO_2 ☐Microscopic Exam ☐Density ☐Acid Gases
☐Total Sulfur ☐H_2S ☐SO_2 ☐Acetaldehyde (AA) ☐Vol Sulfurs ☐Volatile Hydrocarbons (C_1-C_6+) ☐BTEX ☐VXH ☐CH_4 ☐COS ☐Vinyl ☐NVR/NVOR Oil ID ☐Radon (Rn^{222}) ☐Water Vapor

7. SAMPLE DISPOSITION: **Samples will be saved for 3 business days after report distribution unless otherwise noted.*

Please indicate what you'd like *ALI* to do with your sample after testing.
DISPOSE | RETAIN FOR SPECIFIED TIME PERIOD** | **PLEASE INDICATE TIME PERIOD:
CLEAN & RETURN CUSTOMER OWNED KIT | OTHER*** | *** PLEASE SPECIFY
RETURN REMAINING SAMPLE* | *SHIP TO ADDRESS & ANY SPECIFIC INSTRUCTIONS:

8. SERVICE DESIRED: **Additional fees will apply for non-standard test scheduling. You MUST contact ALI to confirm any expedited service request. By checking below, you agree that respective fees listed will be applied to the total cost of your program.*

Please indicate how quickly you would like your test results reported.
3-5 WORKDAYS (STANDARD) | SAME DAY* (AM- 325% PM-375%) | *IF OTHER, PLEASE SPECIFY:
2 WORKDAYS* (225%) | EMERGENCY / OTHER: WEEKEND*(400%) / HOLIDAY* (600%)
1 WORKDAY* (275%)

Figure 8.11.4—Example of CO_2 gas stream analysis authorization form.[1]

B.3.d Sample Identification

Samples will be identified with the sampling location, date, sample identification, sampler, and sample type.

B.3.e Sample Chain-of-Custody

An analysis authorization form for CO_2 stream analyses will accompany the samples to the lab at which point a chain-of-custody accompanies the sample through their processes.

NexGen will provide the program administrator with a sample chain-of-custody once the third-party contractor is selected. An example chain-of-custody form is provided in **Figure 8.11.5**. Copies of the form will be provided to the person/lab receiving the samples as well as the person/lab transferring the samples. These forms will be retained and archived to allow simplified tracking of sample status. The chain-of-custody form and record keeping is the responsibility of fluid sampling personnel.

[1] www.airbornelabs.com/images/editor/files/co2-analysis-authorization-form.pdf

Chain of Custody Record					
Project No.		**Project Title**			**Organization** **Contact** **Address**
Shipping Container No.					
Field Samplers:	*print*		*signature*		
Date	**Time**	**Site/Location**	**Sample Type**	**Sample ID**	**Remarks**
Relinquished by (*print and signature*):		Received by (*print and signature*):			**Comments**

Chain of Custody Record					
Project No.		**Project Title**			**Organization**
Laboratory/Plant: ____					
Sample Number	Number of Container	Sample Description			
Person responsible for samples			Time:		Date:
Sample Number	Relinquished By:	Received By:	Time:	Date:	Reason for change in custody

Figure 8.11.5—Example chain of custody form.[2]

[2] https://www3.epa.gov/ttnamti1/files/ambient/pm25/qa/vol2sec08.pdf

B.4 Analytical Methods

B.4.a Analytical Standard Operational Procedures (SOP)

See **Table 8.11.4** and **Table 8.11.5** for details on Analytical SOPs. The selected laboratory will use standard EPA laboratory analytical methods to quantify the concentration of anions, cations, dissolved CO_2, total dissolved solids (TDS), water density, alkalinity, pH, specific conductive, and temperature. Laboratory QC procedures are inherent to the analysis methodology. The laboratory is responsible for documenting and maintaining compliance with these measures in accordance with industry standards and state licensing. If other water quality objectives are required, NexGen will coordinate with the designated analytical laboratory prior to the sample event to evaluate the appropriate laboratory procedures and sample equipment necessary to fulfill the Project objectives.

B.4.b Equipment/Instrumentation Needed

Equipment and instrumentation is specified in the individual analytical methods referenced in **Table 8.11.4** and **Table 8.11.5**.

B.4.c Method Performance Criteria

Non-standard method performance criteria are not anticipated for this Project.

B.4.d Analytical Failure

Each laboratory conducting analyses in **Table 8.11.4** and **Table 8.11.5** will be responsible for appropriately addressing analytical failure according to their individual SOPs.

B.4.e Sample Disposal

Each laboratory conducting analyses will be responsible for appropriate sample disposal according to their individual SOPs.

B.4.f Laboratory Turnaround

NexGen will request analytics turn-around times to meet all permitted reporting requirements with the understanding that laboratory turnaround will vary by laboratory, but generally turnaround of verified analytical results within 1 month will be suitable for Project needs.

B.4.g Method Validation for Non-Standard Methods

Non-standard methods are not anticipated for this Project. Should non-standard methods be required or proposed in the future, the injection program administrator will be consulted on additional appropriate actions to be taken.

B.5 Quality Control

B.5.a Quality Control Activities

B.5.a.i. Field Blanks

For fluid sampling, a field blank will be collected and analyzed for the inorganic analytes in **Table 8.11.4** and **Table 8.11.5**.

at a frequency of 10% or greater. Field blanks will be exposed to the same field and transport conditions as the groundwater samples. The field blanks will be utilized for deep groundwater sampling and analyzed for the inorganic analytes at a frequency of 10% or greater in **Table 8.11.4** and **Table 8.11.5**. Field blanks will be used to detect contamination resulting from the collection and transportation process.

B.5.a.ii. Duplicates

Duplicate fluid samples will be collected in separate containers from the primary samples and processed separately. Duplicate samples will be used to assess sample heterogeneity and analytical precision. Duplicate samples will be collected at a frequency of one duplicate per 20 sample sets per sampling event.

B.5.b Exceeding Control Limits

If the sample analytical results exceed control limits (i.e., ion balances > ±10%), further examination of the analytical results will be achieved by evaluating the ratio of the measured TDS to the calculated TDS (i.e., mass balance) per APHA. The method indicates which ion analyses should be considered suspect based on the mass balance ratio. Suspect ion analyses will be reviewed in the context of historical data and interlaboratory results, if available. Suspect ion analyses will be brought to the attention of the analytical laboratory for confirmation and/or reanalysis. The ion balance will be recalculated, and if the error is still not resolved, suspect data are identified and may be given less importance in data interpretation.

B.5.c Calculating Applicable Quality Control Statistics

B.5.c.i. Charge Balance

The analytical results will be evaluated to determine correctness of analyses based on anion-cation charge balance calculation. Because all potable waters are electrically neutral, the chemical analyses should yield equally negative and positive ionic activity. The anion-cation charge balance will be calculated using the formula in **Equation 8.11.1**:

Equation 8.11.1—Formula for anion-cation charge balance.

$$\%\ \text{difference} = 100 \times \frac{\Sigma_{\text{cations}} - \Sigma_{\text{anions}}}{\Sigma_{\text{cations}} + \Sigma_{\text{anions}}}$$

Where the sums of the ions are represented in milliequivalents (meq) per liter and the criteria for acceptable charge balance is ±10%.

B.5.c.ii. Mass Balance

The ratio of the measured TDS to the calculated TDS will be calculated in instances where the charge balance acceptance criteria are exceeded using the formula shown in **Equation 8.11.2**.

Equation 8.11.2—Ratio of measured vs. calculated TDS.

$$1.0 < \frac{\text{measured TDS}}{\text{calculated TDS}} < 1.2$$

where the anticipated values are between 1.0 and 1.2.

B.5.c.iii. Outliers

It is essential to determine statistical outliers prior to the statistical evaluation of fluid samples. NexGen will use the EPA's Unified Guidance (March 2009) as a basis for the selection of recommended statistical methods to identify outliers in fluid chemistry data sets as appropriate. These techniques include Probability Plots, Box Plots, Dixon's test, and Rosner's test. The EPA-1989 outlier test may also be used as another screening tool to identify potential outliers.

B.6 Instrument/Equipment Testing, Inspection, and Maintenance

Logging tool equipment will be maintained as per wireline industry best practices (see **APPENDIX B—Schlumberger Wireline Log Quality Control Reference Manual**). For fluid sampling, field equipment will be maintained, factory serviced, and factory calibrated per the manufacturer's recommendations. Spare parts that may be needed during sampling will be included in supplies on-hand during field sampling. For all laboratory equipment, testing, inspection, and maintenance will be the responsibility of the analytical laboratory per standard practice, method-specific protocol, or NELAP requirements.

B.7 Instrument/Equipment Calibration and Frequency

B.7.a Calibration and Frequency of Calibration

Pressure/temperature gauge calibration information is located in **Table 8.11.9** through **Table 8.11.15**.

Logging tool calibration will be at the discretion of the service company providing the equipment, following standard industry practices noted in **APPENDIX B**. Calibration frequency will be determined by standard industry practices.

For fluid sampling, sondes used to determine field parameters (e.g., pH, temperature, specific conductance, dissolved oxygen) are calibrated according to manufacturer recommendations and equipment manuals (Hach, 2006) each day before sample collection begins. Recalibration is performed if any components yield atypical values or fail to stabilize during sampling.

B.7.b Calibration Methodology

Logging tool calibration methodology will follow standard industry practices in Appendix B.

For fluid sampling, standards used for calibration are typically 7 and 10 for pH, a potassium chloride solution yielding a value of 1,413 microseimens per centimeter (µS/cm) at 25°C for specific conductance, and a 100% dissolved oxygen (DO) solution for DO. Calibration is performed for the pH meters per manufacturer's specifications using a 2-point calibration bounding the range of the sample. For coulometry, sodium carbonate standards (typically yielding a concentration of 4,000 mg CO_2/L) are routinely analyzed to evaluate instruments.

B.7.c Calibration Resolution and Documentation

Logging tool calibration resolution and documentation will follow standard industry practices in **APPENDIX B**.

B.8 Inspection/Acceptance for Supplies and Consumables

B.8.a Supplies, Consumables, and Responsibilities

Supplies and consumables for field and laboratory operations will be procured, inspected, and accepted as required from vendors approved by NexGen or the respective subcontractor responsible for the data collection activity. Acquisition of supplies and consumables related to groundwater analyses will be the responsibility of the laboratory per established standard methodology or operating procedures.

B.9 Non-Direct Measurements

B.9.a Data Sources

Pulsed neutron logging for CO_2 saturation monitoring of the Arbuckle Group injection zone, Woodford Formation confining zone, and the Sundance Formation, the first permeable interval above the upper confining zone, and all other relevant zones.

The in-zone pressure gauges in Vanguard I-1 to Vanguard I-12 will be used to gather pressure data for in-zone pressure monitoring.

B.9.b Relevance to Project

PNL will be run to detect CO_2 leaking from the injection zone.

In-zone pressure monitoring, data will be used in numerical modeling to predict plume and pressure front behavior as well as confirm the plume stage within the AoR.

B.9.c Acceptance Criteria

Following standard industry practices will ensure that the gathered pulsed neutron log data will be used for accurate monitoring.

B.9.d Resources/Facilities Needed

Under review by selected third-party contractor and laboratory within ASTM recommended guidelines.

B.9.e Validity Limits and Operating Conditions

Under review by selected third-party contractor and laboratory within ASTM recommended guidelines.

B.10 Data Management

B.10.a Data Management Scheme

NexGen will maintain the required Project data as provided elsewhere in the permit. Data will be backed up on hard drive media or held on secure servers.

B.10.b Record-Keeping and Tracking Practices

All records and gathered data will be securely held and properly labeled for auditing purposes.

B.10.c Data Handling Equipment/Procedures

All infrastructure used to store data will be properly maintained and operated according to proper industry standard techniques. The NexGen SCADA-like system and vendor data acquisition systems will interface; therefore, all subsequent data will be stored on a secure server.

B.10.d Responsibility

The primary Project managers will be responsible for ensuring proper data management is maintained.

B.10.e Data Archival and Retrieval

Under review—all data will be held by NexGen.

B.10.f Hardware and Software Configurations

All NexGen and vendor hardware and software configurations will be appropriately interfaced.

B.10.g Checklists and Forms

Checklists and forms will be procured and generated as necessary.

C. ASSESSMENT AND OVERSIGHT

C.1 Assessments and Response Actions

C.1.a Activities to be Conducted

Please refer to **Table 8.11.1** for a work summary and schedule and frequency of fluid sample collections. After completion of sample analysis, results will be reviewed for QC criteria. If the data quality fails to meet the criteria set samples will be reanalyzed, if still within holding time criteria. If the holding time has passed, additional samples may be collected, or sample results may be excluded from data evaluations and interpretations. Evaluation for data consistency will be performed according to procedures described in the USEPA 2009 Unified Guidance (USEPA, 2009).

C.1.b Responsibility for Conducting Assessments

Companies collecting data are in charge of conducting their own internal reviews.

C.1.c Assessment Reporting

All assessment information should be reported to the individual organization's project manager outlined in *Section A.1.a—Key Individuals and Responsibilities*.

C.1.d Corrective Action

Corrective action that only affects an individual organization's data collection duty will be addressed, verified, and documented within the organization and communicated to other stakeholders as necessary.

Corrective actions that involve multiple organizations will be addressed by all stakeholders involved and communicated to other members on the distribution list for the QASP. NexGen will coordinate all corrective actions and assessments that involve multiple organizations.

C.2 Reports to Management

C.2.a QA Status Reports

NexGen does not plan to send QA status reports.

D. DATA VALIDATION AND USABILITY

D.1 Data Review, Verification, and Validation

D.1.a Criteria for Accepting, Rejecting, or Qualifying Data

Data validation will include a review of the sample collection process, sample units, sample holding times, and a comparison and review of the appropriate duplicate, or blank QC/QA results. Results will be catalogued and periodically reviewed and compared to previous data. Analytical results will be reported on a frequency based on the approved UIC permit conditions. Data in these reports will be presented in a variety of formats as appropriate to characterize water quality and identify any changes with time.

D.2 Verification and Validation Methods

D.2.a Data Verification and Validation Processes

See *Sections D.1.a* and *B.5* for information related to NexGen data verification and validation process.

D.2.b Data Verification and Validation Responsibility

NexGen or a contractor approved by NexGen will verify and validate data.

D.2.c Issue Resolution Process and Responsibility

NexGen or a project manager approved by NexGen will oversee the data review process and take the appropriate actions to resolve any issues that may arise.

D.2.d Checklist, Forms, and Calculations

NexGen will generate checklists, forms and calculations designed to meet all permit requirements.

D.3 Reconciliation with User Requirements

D.3.a Evaluation of Data Uncertainty

Software will be employed to determine data consistency.

D.3.b Data Limitations Reporting

NexGen or project managers approved by NexGen will be responsible for making sure that all reported data is presented with the appropriate data-use limitations.

REFERENCES

American Public Health Association (APHA), 2005, *Standard methods for the examination of water and wastewater*, 21st edition: American Public Health Association, Washington, DC.

American Society for Testing and Materials (ASTM), 2005, Method D6517-00 (reapproved 2005), *Standard guide for field preservation of groundwater samples*: ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA.

Hach Company, 2006, *Hydrolab DS5X, DS5, and MS5 water quality multiprobes user manual*, February 2006: Hach Company, 73 p.

U.S. Environmental Protection Agency (US EPA), 1974, *Methods for chemical analysis of water and wastes*: U.S. Environmental Protection Agency, Cincinnati, OH, EPA-625/6-74-003a.

U.S. Environmental Protection Agency (US EPA), 2002, *Groundwater sampling guidelines for Superfund and RCRA project managers*: Washington, DC, EPA 542-S-02-001, 49 p.

Wood, W.W., 1976, *Guidelines for collection and field analysis of groundwater samples for selected unstable constituents*, in *U.S. Geological Survey, Techniques for Water Resources Investigations*, chapter D-2, 24 p.

APPENDIX A—DTS, DOWN-HOLE PRESSURE GAUGE INFORMATION AND SCHLUMBERGER PULSED NEUTRON, CEMENT BOND, MAGNETIC FLUX LEAKAGE LOGGING TOOLS.

8.12 Digital Pulsed Neutron Logging (PNL) Tool

Schlumberger

Digital Pulsed Neutron

LIVE PL digital slickline production logging services

APPLICATIONS

- Locate oil, water, and gas contacts
- Identify known formations in development wells
- Conduct time-lapse logging of reservoir fluid interfaces
- Guide perforating by identifying gas contacts
- Evaluate gravel-pack placement
- Correlate from well to well

BENEFITS

- Leverage the efficiency and simplicity of slickline operations with the accurate depth control, digital capabilities, and real-time measurement quality of wireline-conveyed services
- Easily conduct operations with a short tool where rig-up height is constrained or space is limited
- Avoid the typical memory limitations of slickline logging with a high-performance lithium ion battery providing up to 15 hours of continuous operation
- Improve operational efficiency with tool combinability and multipurpose deployments
- Reduce risk in wax or debris accumulations by running with D-Jar* digital downhole adjustable jar

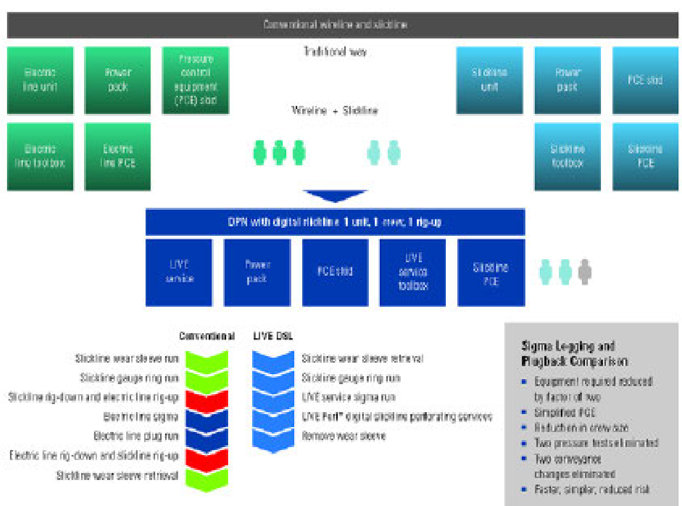
FEATURES

- Full compatibility with LIVE* digital slickline services
- Short, 1¹¹⁄₁₆-in-OD tool for through-tubing conveyance and negotiating restrictions
- Deployment on 0.108- or 0.125-in digital slickline
- Sigma, apparent porosity, and gas indicator measurements
- Sourceless pulsed neutron generator
- Accurate real-time onsite depth control
- Logging speed up to 1,800 ft/h
- No memory limitations

As the latest addition to LIVE PL* digital slickline production logging services, digital pulsed neutron (DPN) service provides crucial information, such as fluid contact monitoring and fluid identification behind casing, to inform wellsite decision making for optimizing reservoir management and production in mature fields.

DPN pairs the field-proven Schlumberger small-diameter high-output pulsed neutron generator (PNG) with dual scintillation gamma ray detectors to provide real-time sigma measurement in mixed-salinity cased hole environments. Dual neutron burst with adaptive timing is performed to ensure the measurement's insensitivity to borehole conditions and eliminate the need for environmental correction. Measurement precision is further honed by using the available job planner.

Measurement Specifications	Digital Pulsed Neutron
Output	Sigma, apparent porosity, gas indicator
Logging speed	1,800 ft/h [549 m/h]
Range of measurement	0 to 60 cu
Vertical resolution	2.5 ft [0.76 m]
Precision	<±2% cu
Borehole fluid or formation water salinity	>50,000 ppm
Mechanical Specifications	**Digital Pulsed Neutron**
Temperature rating	302 degF [150 degC]
Pressure rating	15,000 psi [103 MPa]
Casing size—min.	4½ in
Casing size—max.	9⅝ in
Outside diameter	1.72 in [4.37 cm]
Weight	37 lbm [17 kg]



The efficiency and simplicity of using DPN service on digital slickline with only one unit, one crew, and one rig-up save significant operational time over intervention operations that switch from slickline to electric wireline line for logging and back to slickline.

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8.13 Cement Bond Logging Tools

Schlumberger

Cement Bond Logging Tools

APPLICATIONS

- Evaluation of cement quality
- Determination of zone isolation
- Location of cement top

Cement bond tools measure the bond between the casing and the cement placed in the annulus between the casing and the wellbore. The measurement is made by using acoustic sonic and ultrasonic tools. In the case of sonic tools, the measurement is usually displayed on a cement bond log (CBL) in millivolt units, decibel attenuation, or both. Reduction of the reading in millivolts or increase of the decibel attenuation is an indication of better-quality bonding of the cement behind the casing to the casing wall. Factors that affect the quality of the cement bonding are

- cement job design and execution as well as effective mud removal
- compressive strength of the cement in place
- temperature and pressure changes applied to the casing after cementing
- epoxy resin applied to the outer wall of the casing.

SLIM ARRAY SONIC TOOL

The Slim Array Sonic Tool (SSLT) is a digital sonic tool that provides conventional openhole sonic measurements, standard CBL amplitude and Variable Density* log (VDL), and attenuation measurements, which are less affected by borehole environmental conditions. The SSLT can also make a short-spacing (1-ft [0.30-m]) CBL measurements for cement evaluation in fast formations. The two transmitters and six receivers of the SSLT sonde have transmitter–receiver spacings of 1, 3, 3.5, 4, 4.5, and 5 ft [0.30, 0.91, 1.07, 1.22, 1.37, and 1.52 m] to compute the following:

- standard 3-ft CBL and 5-ft VDL measurements
- borehole-compensated (BHC) attenuation from the 3.5- and 4.5-ft spacing receivers
- near-pseudoattenuation from the 3-ft spacing receivers
- short-spacing attenuation from the 1-ft spacing receiver for cement bond measurement in fast formations that may affect the standard 3-ft spacing.

Cement Bond Logging Tools

SLIMXTREME SONIC LOGGING TOOL

The SlimXtreme* Sonic Logging Tool (QSLT) provides the same measurements as the SSLT of the cement bond amplitude, attenuation, and Variable Density display for evaluation of the cement bond quality of a cemented casing in high-pressure and high-temperature environments.

CEMENT BOND LOG FROM DIGITAL SONIC LOGGING TOOL

The Digital Sonic Logging Tool (DSLT) uses the Sonic Logging Sonde (SLS) to measure the cement bond amplitude and provide a Variable Density display for evaluation of the cement bond quality of a cemented casing string. Variable Density or x-y waveform display of the sonic signal is presented in conjunction with the bond index and amplitude signal. The DSLT is also used in the open borehole environment for conventional sonic measurements of BHC (3- to 5-ft) transit time and long-spacing depth-derived BHC (DDBHC) (9- to 11-ft [2.74 to 3.35-m]) transit time.

CEMENT BOND LOG FROM HOSTILE ENVIRONMENT SONIC LOGGING TOOL

The Hostile Environment Sonic Logging Tool (HSLT) provides the same measurements of the cement bond amplitude and Variable Density display for evaluation of the cement bond quality of a cemented casing string as the SSLT in high-pressure and high-temperature environments.

SLIM CEMENT MAPPING TOOL

The Slim Cement Mapping Tool (SCMT) is a through-tubing cement evaluation tool combinable with the PS Platform* production logging service for a variety of well diagnostics. The two sizes are 1 11/16 in [4.29 cm] for the standard (302 degF [150 degC]) temperature rating and 2⅛ in [5.24 cm] with a 392 degF [200 degC] temperature rating. The SCMT is suitable for running workover operations and in new wells. SCMT operations provide a clear advantage in workover wells because there is no need to pull tubing above the zone of interest for cement evaluation. The SCMT is capable of running through most tubings to evaluate the casing below. In new wells the SCMT is an excellent tool for evaluating casing that is 7⅝ in [19.36 cm] or less.

The SCMT features a single transmitter, two receivers spaced at 3 and 5 ft from the transmitter, and eight segmented receivers 2 ft [0.61 m] from the transmitter. The output of the near (3-ft) receiver is used for CBL and transit-time measurement. The output of the far (5-ft) receiver is used for the VDL measurement. The eight segmented receivers generate a radial image of the cement bond variation.

MEMORY SLIM CEMENT BOND LOGGING TOOL

The Memory Slim Cement Bond Logging Tool provides through-tubing 3-ft CBL and 5-ft VDL measurements with the same accuracy and quality as surface-readout logs. Because of its slim size, the 1 11/16-in tool can be run into the zone of interest without having to remove the tubing from the well. The tool simultaneously records gamma ray, casing collar location, pressure, temperature, and waveforms in a single pass, with the waveforms fully digitized downhole. More than 40 h of combined tool running time is possible, including 16 h of continuous waveform recording time. Depth-recording systems are available for both hazardous and nonhazardous environments.

The Memory Slim CBL Tool can be run with other Memory PS Platform* production logging tools for complete well and reservoir evaluation in one descent. The tools and sensors can be conveyed in the borehole by drillpipe, coiled tubing, slickline, or unintelligent tractor. PS Platform software is used to perform onsite data processing or any necessary postprocessing and prepare the log presentation.

Measurement Specifications

	SSLT	QSLT	DSLT	HSLT	SCMT-C and SCMT-H	Memory Slim CBL Tool
Output	3-ft [0.91-m] CBL and attenuation, 1-ft [0.30-m] attenuation, 5-ft [1.52-m] Variable Density log	3-ft [0.91-m] CBL and attenuation, 1-ft [0.30-m] attenuation, 5-ft [1.52-m] Variable Density log	3-ft [0.91-m] amplitude CBL With SLS-C and SLS-D: 5-ft [1.52-m] Variable Density log	3-ft [0.91-m] amplitude CBL, 5-ft [1.52-m] Variable Density log	3-ft [0.91-m] amplitude CBL, 5-ft [1.52-m] Variable Density log, cement bond variation map	3-ft [0.91-m] CBL, 5-ft [1.52-m] Variable Density log, gamma ray, CCL, traveltime, cement compressive strength
Logging speed	3,600 ft/h [1,097 m/h]	3,600 ft/h [1,097 m/h]	3,600 ft/h [1,097 m/h]	3,600 ft/h [1,097 m/h]	1,800 ft/h [549 m/h]	1,800 ft/h [549 m/h]
Vertical resolution	Near attenuation: 1 ft [0.30 m] CBL: 3 ft [0.91 m] VDL: 5 ft [1.52 m]	Near attenuation: 1 ft [0.30 m] CBL: 3 ft [0.91 m] VDL: 5 ft [1.52 m]	CBL: 3 ft [0.91 m] VDL: 5 ft [1.52 m]	CBL: 3 ft [0.91 m] VDL: 5 ft [1.52 m]	CBL: 3 ft [0.91 m] VDL: 5 ft [1.52 m] Cement bond variation map: 2 ft [0.61 m]	CBL: 3 ft [0.91 m] VDL: 5 ft [1.52 m]
Depth of investigation	CBL: Casing and cement interface VDL: Depends on bonding and formation	CBL: Casing and cement interface VDL: Depends on bonding and formation	CBL: Casing and cement interface VDL: Depends on bonding and formation	CBL: Casing and cement interface VDL: Depends on bonding and formation	CBL: Casing and cement interface VDL: Depends on bonding and formation	CBL: Casing and cement interface VDL: Depends on bonding and formation
Mud type or weight limitations	None	None	None	None	None	None
Combinability	Part of SlimAccess* system	Part of SlimXtreme system	Combinable with most tools	Part of Xtreme* system, combinable with most tools	Combinable with PS Platform system	Combinable with Memory PS Platform system
Special applications	Logging through drillpipe, tubing, and in small casing Fast formations	Logging through drillpipe, tubing, and in small casing Fast formations			Logging through drillpipe, tubing, and in small casing Fast formations	Logging through drillpipe, tubing, and in small casing

Mechanical Specifications

	SSLT	QSLT	DSLT	HSLT	SCMT-C and SCMT-H	Memory Slim CBL Tool
Temperature rating	302 degF [150 degC]	500 degF [260 degC]	302 degF [150 degC]	500 degF [260 degC]	SCMT-C: 302 degF [150 degC] SCMT-H: 392 degF [200 degC]	302 degF [150 degC]
Pressure rating	14,000 psi [97 MPa]	30,000 psi [207 MPa]	20,000 psi [138 MPa]	25,000 psi [172 MPa]	15,000 psi [103 MPa]	15,000 psi [103 MPa]
Casing size—min.	3½ in [8.89 cm]	4½ in [11.43 cm]	5½ in [13.97 cm]	5½ in [13.97 cm]	SCMT-C: 2⅜ in [6.03 cm] SCMT-H: 2⅞ in [7.30 cm]	2⅞ in [7.30 cm]
Casing size—max.	8⅝ in [21.90 cm]	8⅝ in [21.90 cm]	13⅜ in [33.97 cm]	13⅜ in [33.97 cm]	7⅝ in [19.37 cm]	7⅝ in [19.37 cm]
Outside diameter	2.5 in [6.35 cm]	3 in [7.62 cm]	3.625 in [9.21 cm]	3.375 in [8.57 cm]	SCMT-C: 1.6875 in [4.29 cm] SCMT-H: 2.06 in [5.23 cm]	1.6875 in [4.29 cm]
Length	23.1 ft [7.04 m]	Without inline centralizer: 23 ft [7 m] With inline centralizer: 26.8 ft [8.17 m]	With SLS-E: 20.63 ft [6.29 m] With SLS-F: 23.81 ft [7.26 m]	25.3 ft [7.71 m]	SCMT-C: 23.45 ft [7.14 m] SCMT-H: 20.83 ft [6.35 m]	23.48 ft [7.15 m]
Weight	232 lbm [105 kg]	270 lbm [122 kg]	With SLS-E: 313 lbm [142 kg] With SLS-F: 350 lbm [159 kg]	440 lbm [199 kg]	SCMT-C: 100 lbm [45 kg] SCMT-H: 160 lbm [73 kg]	106.3 lbm [48.2 kg]
Tension	13,000 lbf [57,830 N]	13,000 lbf [57,830 N]	24,700 lbf [110,110 N]	20,000 lbf [88,960 N]	5,900 lbf [26,240 N]	5,900 lbf [26,240 N]
Compression	4,400 lbf [19,570 N]	4,400 lbf [19,570 N]	2,970 lbf [13,200 N]	6,000 lbf [26,690 N]	150 lbf [670 N]	150 lbf [670 N]

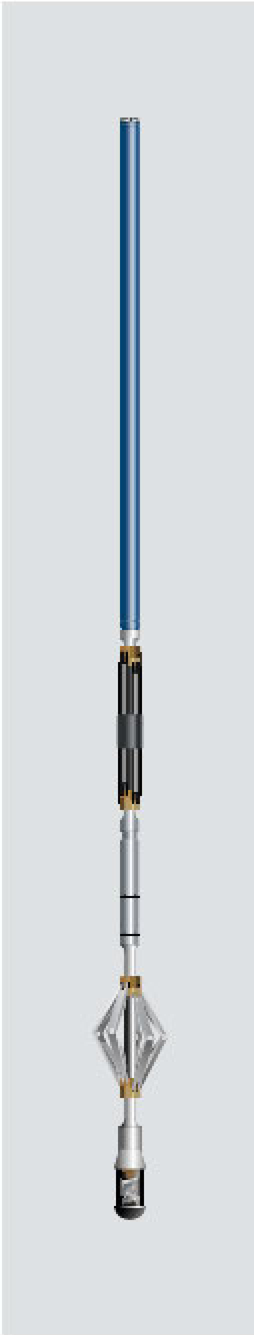
Cement Bond Logging Tools

APPLICATIONS

- Cement evaluation
- Casing inspection
  - Corrosion detection and monitoring
  - Detection of internal and external damage or deformation
  - Casing thickness analysis for collapse and burst pressure calculations

USI ULTRASONIC IMAGER TOOL

The USI* UltraSonic Imager tool (USIT) uses a single transducer mounted on an Ultrasonic Rotating Sub (USRS) on the bottom of the tool. The transmitter emits ultrasonic pulses between 200 and 700 kHz and measures the received ultrasonic waveforms reflected from the internal and external casing interfaces. The rate of decay of the waveforms received indicates the quality of the cement bond at the cement/casing interface, and the resonant frequency of the casing provides the casing wall thickness required for pipe inspection. Because the transducer is mounted on the rotating sub, the entire circumference of the casing is scanned. This 360° data coverage enables the evaluation of the quality of the cement bond as well as the determination of the internal and external casing condition. The very high angular and vertical resolutions can detect channels as narrow as 1.2 in [3.05 cm]. Cement bond, thickness, internal and external radii, and self-explanatory maps are generated in real time at the wellsite.



Cement Bond Logging Tools

Measurement Specifications	
	USIT
Output	Acoustic impedance, cement bonding to casing, internal radius, casing thickness
Logging speed	1,800 ft/h [549 m/h]
Range of measurement	Acoustic impedance: 0 to 10 MRayl [0 to 10 MPa.s/m]
Vertical resolution	Standard: 6 in [15.24 cm]
Accuracy	Less than 3.3 MRayl: ±0.5 MRayl
Depth of investigation	Casing-to-cement interface
Mud type or weight limitations†	Water-base mud: Up to 15.9 lbm/gal Oil-base mud: Up to 11.2 lbm/gal
Combinability	Bottom only tool, combinable with most tools
Special applications	Identification and orientation of narrow channels

† Exact value depends on the type of mud system and casing size.

Mechanical Specifications	
	USIT
Temperature rating	350 degF [177 degC]
Pressure rating	20,000 psi [138 MPa]
Casing size—min.	4½ in [11.43 cm]
Casing size—max.	13⅜ in [33.97 cm]
Outside diameter†	3⅜ in [8.57 cm]
Length†	19.75 ft [6.02 m]
Weight†	333 lbm [151 kg]
Tension	40,000 lbf [177,930 N]
Compression	4,000 lbf [17,790 N]

† Excluding the rotating sub

USIT Rotating Sub Mechanical Specifications					
	USRS-AB	**USRS-A**	**USRS-B**	**USRS-C**	**USRS-D**
Outside diameter	3.41 in [8.66 cm]	3.58 in [9.09 cm]	4.625 in [11.75 cm]	6.625 in [16.83 cm]	8.625 in [21.91 cm]
Length	9.8 in [24.89 cm]	9.92 in [25.20 cm]	9.8 in [24.89 cm]	8.3 in [21.08 cm]	8.3 in [21.08 cm]
Weight	7.7 lbm [3.5 kg]	7.7 lbm [3.5 kg]	10.6 lbm [4.8 Kg]	15.0 lbm [6.8 kg]	18.3 lbm [8.3 kg]

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8.14 Magnetic Flux Leakage Tool

Measurement Specifications	
Output	EM thickness, casing ID, casing properties, high- and low-frequency images, corrosion summary report†
Logging speed	ETHK (single and double strings): 3,600-ft/h [1,097-m/h] inspection pass for mandrel data
	Imaging (single string): 1,800-ft/h [549-m/h] standard-resolution inspection pass; 300-ft/h [91-m/h] high-resolution diagnostic pass
Range of measurement	Maximum metal thickness‡: 1.5 in [3.81 cm] at 8.75 Hz
Resolution	Attenuation < 60dB: 1%
	EM thickness: 15%§
Accuracy	Casing ID: ±0.05 in††
Mud type or weight limitations	Any borehole fluid
Combinability	All PS Platform services
	Multiple-tool answer products
Special applications	NACE compliant for H_2S and CO_2 resistance

Mechanical Specifications	
Temperature rating	302 degF [150 degC]
Pressure rating	15,000 psi [103 MPa]
Casing size—min.	2⅞ in (ID > 2.313 in)
Casing size—max.	13⅜ in for EM thickness
Outside diameter	2.125 in [5.4 cm]
Pad sensor arms	18 coupled
Max. diameter	9⅝-in casing
100% image coverage	7-in casing
Length	19.7 ft [6.0 m]
Weight	110 lbm [50 kg]
Tension	Fishing: 10,000 lbf [44,480 N]
Compression	Fishing: 3,000 lbf [13,340 N]

† Corrosion report for single casing strings
‡ Measurement depends on casing geometry, properties, and chrome content.
§ The resolution depends on the accuracy of casing electrical conductivity (sigma). The usual method is to use API specifications in a "good" casing section and adjust conductivity to match the nominal value, which has a typical 12.5% range (Oil Country Tubular Goods, API Spec 5CT, Specification for Casing and Tubing)
†† Casing ID (d_{ci}) < 6 in and tool eccentered = [30% × (d_{ci} – 2.2 in)]

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8.15 Downhole Pressure Gauge System

RANGER
GAUGE SYSTEMS

Downhole *In-Line* Digital Quartz Pressure/Temperature Probe

Ranger Permanent Hybrid Digital Addressable Surface Read Out (DASRO) Gauge

The Ranger® DASRO gauge is a Quartz Digital Addressable Surface Read Out Pressure/Temperature Probe based on a resonating quartz sensor with digital signal transmission and addressing ability for multiple gauge deployment on a single line. Additionally, the DASRO has a cablehead on each end to allow in-line installation without need for a "Y" block. The internal gauge electronics consists of two custom microelectronic circuits that are hermetically sealed. Each gauge has a pre-assigned digital address for multiple unit operation on the same signal conductor. Fault protection current limiting is included for both the gauge electronics and the primary line.

FEATURES

- **Two leak-testable cable-heads for in-line operation**
- **Dual built in current limiting assures that no one gauge can draw excessive current and that upstream readings are still available with a downstream line fault.**
- **Complete double redundancy for all cable current limiting circuit components. This feature, together with a built in automatic reset on power-up, allows the cable current limit function to continue to operate if one limiting channel should fail open. This protects against loss of communication with downstream gauges, due to a current limit component failure.**
- **No CPU or memory for reliable, long term, high temperature operation. Configuration data and addresses are permanent**
- **High reliability and quality due to hermetically sealed custom hybrid circuits. This type of circuit construction is a MUST for sustained, high-temperature, operation**
- **Hybrid circuits are fully tested and qualified per MIL-883E, Method 1010.7 Test Condition B**
- **Includes level two reliability testing to yield long operating life required for permanent applications**
- **Metal to metal seals, Swagelok® pressure fittings and welded Nitronic 50HS® housing construction throughout results in no elastomers**
- **Optional Inconel 718 pressure housings are available for very aggressive well environments.**
- **Integral quartz temperature sensor**
- **Pre-assigned address for multiple unit operation on the same single conductor**
- **1024 address capability assures that gauges will have unique addresses**
- **Low power consumption 250mW (typical)**

Specifications

Ranger DASRO gauge specifications are determined in accordance with the ANSI/ISA-S51.1-1979, American National Standard, "Process Instrumentation Terminology".

Pressure Sensor
Thickness shear mode quartz resonator (with INCONEL® isolation bellows)

Total System Pressure Accuracy
±0.02% of full scale including linearity, hysteresis and repeatability over calibrated temperature range

Pressure Repeatability
≤0.01% of full scale

Pressure Resolution
0.01 psi or better

Temperature Sensor
Quartz resonator

Temperature Accuracy
±0.5°C (±0.9°F) within calibrated temperature range. Pressure accuracy is independent of indicated temperature accuracy.

Temperature Resolution
0.005°C (0.01°F)

Standard Calibrated Temperature Ranges
25°C to 125°C (77°F to 257°F)
25°C to 150°C (77°F to 302°F)
25°C to 175°C (77°F to 347°F)
25°C to 200°C (77°F to 392°F)

Operating Temperature Range
-20°C to 200°C (-4°F to 392°F)

Sample Rate
Complete pressure and temperature transmission in approximately one-second intervals

Operating and Calibrated Pressure Ranges
0 - 344.75 Bars (atm - 5,000 psia)
0 - 689.50 Bars (atm - 10,000 psia)
0 - 1103.20 Bars (atm - 16,000 psia)
0 - 1378.95 Bars (atm - 20,000 psia) - Optional

Dimensions (OD x L)
32.5mm x 81.3cm (1.281" x 46.5")

Weight
4.76 kg (10.5 lbs.)

Pressure Housing Wetted Material
Nitronic 50HS®

Sensor Wetted Materials
INCONEL® 600/625/718

Requirements of Conductor Cable
Single conductor coaxial cable with low conductor resistance. The maximum DC loop resistance is determined by the number of gauges on one line and the surface power supply. Can be up to 500 ohms with a capacitance of up to 1 ufd for a single unit installation and using a 30 volt surface power supply.

Reliability Testing Levels

- Level II (Basic for all units)
  -20°C Test to confirm fully and correct operation (Not calibrated)
  Calibration and testing to full temperature and pressure ratings
  15-day burn-in at full pressure and temperature calibrated ranges
  Current protection testing at room and full temperature
  Gauge shock and vibration testing
  Final QC inspection

DASRO Configurations / Model Numbers

Dual Cable Head SIDE pressure inlet	(Model No: 68**xx**D DASRO) – Same length
Single Cable Head SIDE pressure inlet	(Model No: 68**x**1D DASRO) – Same length
Single Cable Head BOTTOM pressure inlet	(Model No: 62**xx**D DASRO) – Shorter
Dual Gauge Dual Cable Head SIDE pressure inlets (two)	(Model No: 68**x**2D DASRO) – Longer
Dual Gauge Single Cable Head SIDE pressure inlets (two)	(Model No: 68**x**4D DASRO) – Longer
Single FOT Cable Head BOTTOM pressure inlet	(Model No: 62**x**3D DASRO) – Special length
Single Cable Head ¾" OD BOTTOM pressure inlet	(Model No: 42**xx**C DASRO) – Shorter
Dual Cable Head 1.00" OD SIDE pressure inlet	(Model No: 108**xx**A DASRO)

"x" or "xx" = Denotes calibrated temperature range. Example: A 175C calibrated gauge 68xxB = 6875B, 68x1B = 6871B, 62xxB = 6275B, 68x2B = 6872B, 62x3B = 6273B or 42xxB=4275B

APPENDIX B—SCHLUMBERGER WIRELINE LOG QUALITY CONTROL REFERENCE MANUAL

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Wireline Log Quality Control Reference Manual

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Logging Quality Control Reference Manual

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Foreword

The certification of acquired data is an important aspect of logging. It is performed through the observation of quality indicators and can be completed successfully only when a set of specified requirements is available to the log users.

This Log Quality Control Reference Manual (LQCRM) is the third edition of the log quality control specifications used by Schlumberger. It concisely provides information for the acquisition of high-quality data at the wellsite and its delivery within defined standards. The LQCRM is distributed to facilitate the validation of Schlumberger wireline logs at the wellsite or in the office.

Because the measurements are performed downhole in an environment that cannot be exhaustively described, Schlumberger cannot and does not warrant the accuracy, correctness, or completeness of log data.

Large variations in well conditions require flexibility in logging procedures. In some cases, important deviations from the guidelines given here may occur. These deviations may not affect the validity of the data collected, but they could reduce the ability to check that validity.

Catherine MacGregor
President, Wireline

Schlumberger

Introduction

Data is a permanent asset of energy companies that may be used in unforeseen ways. Schlumberger is committed to and accountable for managing and delivering quality data. The quality of the data is the cornerstone of Schlumberger products and services.

Data quality

Quality is conformance to predefined standards with minimum variation. This document defines the standards by which the quality of the data of Schlumberger wireline logs is determined. The attributes that form the data quality model are

- accuracy
- repeatability
- integrity
- traceability
- timeliness
- relevance
- completeness
- sufficiency
- interpretability
- reputation
- objectivity
- clarity
- availability
- accessibility
- security.

Accuracy

Accuracy is how close to the true value the data is within a specified degree of conformity (e.g., metrology and integrity). Accuracy is a function of the sensor design; the measurement cannot be made more accurate by varying operating techniques, but it can fail to conform to the defined accuracy as a result of several errors (e.g., incorrect calibration).

Repeatability

Repeatability of data is the consistency of two or more data products acquired or processed using the same system under the same conditions. Reproducibility, on the other hand, is the data consistency of two or more data products acquired or processed using different systems or under different conditions. The majority of wireline measurements have a defined repeatability range, which is applicable only when the measurement is conducted under the same conditions. Repeatability is used to validate the measurement acquired during the main logging pass, as well as identify anomalies that may arise during the survey for relogging.

Integrity

The integrity of data is essential for the believability of data. Data with integrity is not altered or tampered with. There are situations in which data is altered in a perfectly acceptable manner (e.g., applying environmental corrections, using processing parameters for interpretation). Any such changes, which involve an element of judgment, are not done to intentionally produce results inconsistent with the measurements or processed data and are to the best and unbiased judgment of the interpreter. Results of interpretation activities are auditable, clearly marked, and traceable.

Traceability

Traceability of data refers to having a complete chain defining a measurement from its point of origin (sensor) to its final destination (formation property). At each step of the chain, appropriate measurement standards are respected, well documented, and auditable.

Timeliness

Timeliness is the availability of the data at the time required. Timeliness ensures that all tasks in the process of acquiring data are conducted within the time window defined for such tasks (e.g., wellsite calibrations and checks are done within the time window defined).

Relevance

Relevance is the applicability and helpfulness of the acquired dataset within the business context (e.g., selection of the right service for the well conditions). Most services have a defined operating envelope in which the measurement is considered valid. Measurements conducted outside their defined envelope, although the measurement process may have been completed satisfactorily, are almost always irrelevant (e.g., recording an SP curve in an oil-base mud environment).

Completeness

Completeness ensures that the data is of sufficient breadth, depth, and scope to meet predefined requirements. This primarily means that all required measurements are available over the required logging interval, with no missing curves or gaps in curves over predefined required intervals of the log.

Sufficiency

Sufficiency ensures that the amount of data that is acquired or processed meets the defined objectives of the operation. For example, when the defined objective is to compute the hole volume of an oval hole, a four-arm caliper service—at minimum—must be used. Using a single-arm caliper service would not provide sufficient information to achieve the defined objective and would inadvertently result in overestimation of the hole volume.

Interpretability

Interpretability of data requires that the measurement is specified in appropriate terminology and units and that the data definitions are clear and documented. This is essential to ensure the capability of using the data over time (i.e., reusability).

Reputation

Reputation refers to data being trusted or highly regarded in terms of its source, content, and traceability.

Objectivity

The objectivity of data is an essential attribute of its quality, unbiased and impartial, both at acquisition and at reuse.

Clarity

Clarity refers to the availability of a clear, unique definition of the data by using a controlled data dictionary that is shared. For example, when "NPHI" is referred to, it must be understood by all that NPHI is the thermal neutron porosity in porosity units (m^3/m^3 or ft^3/ft^3), computed from a thermal neutron ratio that is calibrated using a single-point calibration mechanism (gain only), and is the ratio of counts from a near and a far receiver, with the counts corrected only for hole size and not corrected for detector dead time.

Clarity ensures objectivity and interpretability over time.

Availability

Availability of data ensures the distribution of data only to the intended parties at the requested time (i.e., no data is disclosed to any other party than the owner of the data without prior written permission).

Accessibility

Accessibility ensures the ease of retrievability of data using a classification model. Wireline data are classified into three datasets:

- Basic dataset is a limited dataset suitable for quicklook interpretation and transmission of data.
- Customer dataset consists of a complete set of data suitable for processing (measurements with their associated calibrations), recomputing (raw curves), and validating (log quality control [LQC] curves) the measurements of the final product delivered. The customer dataset includes all measurements required to fully reproduce the data product with a complete and auditable traceability chain.
- Producer dataset includes Schlumberger-proprietary data, which are meaningful only to the engineering group that supports the tool in question (e.g., the 15th status bit of ADC015 on board EDCIB023 in an assembly).

Security

The security of data is essential to maintain its confidentiality and ensure that data files are clean of malware or viruses.

Calibration theory

The calibration of sensors is an integral part of metrology, the science of measurement. For most measurements, one of the following types of calibrations is employed:

- single-point calibration
- two-point calibration
- multiple-point calibration.

Because most measurements operate in a region of linear response, any two points on the response line can be compared with their associated calibration references to determine a gain and an offset (two-point calibration) or a gain (single-point calibration). The gain and offset values are used in the calibration value equation, which converts any measured value to its associated calibrated value.

There are three events that measurements may have one or more of:

- Master calibration: Performed at the shop on a quarterly or monthly basis, a master calibration usually comprises a primary measurement done to a measurement standard and a reference measurement that serves as a baseline for future checks. The primary measurement is the calibration of the sensor used for converting a raw measurement into its final output.
- Wellsite before-survey calibration or check: Measurements that have a master calibration are normally not calibrated at the wellsite; rather, the reference measurement conducted in the master calibration is repeated at the wellsite before conducting the survey to ensure that the tool response has not changed. Measurements that do not have a master calibration may employ a wellsite calibration that is conducted prior to starting the survey.
- Wellsite after-survey check: Some measurements employ an after-survey check (optional for most measurements) to ensure that the tool response has not changed from before the survey.

All such events are recorded in a calibration summary listing (CSL) (Fig. 1).

The calibration summary listing contains an auditable trail of the event:

- equipment with serial numbers
- actual measurement and the associated range (minimum, nominal, and maximum)
- time the event was conducted.

For the event to be valid, the measurement must fall within the defined minimum and maximum limits, using the same equipment (verified through the mnemonics and serial numbers), and performed on time (verified through the time stamp on the summary listing).

More details on the calibrations associated with the wide range of Schlumberger wireline measurements are in the *Logging Calibration Guide*, which is available through your local Schlumberger representative.

Hostile Natural Gamma Ray Sonde / Equipment Identification

Primary Equipment:	
HNGS Sonde	HNGS - BA
Auxiliary Equipment:	
HNGS Sonde Housing	HNSH - BA
Gamma Source Radioactive	GSR - U

Hostile Natural Gamma Ray Sonde Master Calibration — Detector 1 Calibration

Phase	Measurement	Value	Minimum	Nominal	Maximum
Master	Na 511 Peak Set Point	42.00	38.00	40.00	42.00
Master	Th Peak Loc	211.9	201.0	209.6	218.3
Master	Th Peak Res %	7.396	5.000	7.000	9.000
Master	Background Count Rate CPS	96.67	20.00	142.5	265.0
Master	Gain Ratio	0.9936	0.9400	1.000	1.060
Master:					

Hostile Natural Gamma Ray Sonde Master Calibration — Detector 2 Calibration

Phase	Measurement	Value	Minimum	Nominal	Maximum
Master	Na 511 Peak Set Point	41.00	38.00	40.00	42.00
Master	Th Peak Loc	211.1	201.0	209.6	218.3
Master	Th Peak Res %	6.985	5.000	7.000	9.000
Master	Background Count Rate CPS	96.01	20.00	142.5	265.0
Master	Gain Ratio	1.017	0.9400	1.000	1.060
Master:					

Figure 1. Example of a master calibration.

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Schlumberger

Depth Control and Measurement

Overview

Depth is the most fundamental wireline measurement made; therefore, it is the most important logging parameter. Because all wireline measurements are referenced to depth, it is absolutely critical that depth is measured in a systematic way, with an auditable record to ensure traceability.

Schlumberger provides through its wireline services an absolute depth measurement and techniques to apply environmental corrections to the measurement that meet industry requirements for subsurface marker referencing.

The conveyance of tools and equipment by means of a cable enables the determination of an absolute wellbore depth under reasonable hole conditions through the strict application of wellsite procedures and the implementation of systematic maintenance and calibration programs for measurement devices. The essentials of the wireline depth measurement are the following:

- Depth is measured from a fixed datum, termed the depth reference point, which is specified by the client.
- The Integrated Depth Wheel (IDW) device (Fig. 1) provides the primary depth measurement, with the down log taken as the correct depth reference.
- Slippage in the IDW wheels is detected and automatically compensated for by the surface acquisition system.
- The change in elastic stretch of the cable resulting from changing direction at the bottom log interval is measured and applied to the log depth as a delta-stretch correction.
- Other physical effects on the cable in the borehole, including changes in length owing to wellbore profile, temperature, and other hole conditions, are not measured but can be corrected for after logging is complete.
- Subsequent logs that do not require a primary depth measurement are correlated to a reference log specified by the client, provided that enough information exists to validate the correctness of the depth measured on previous logs.
- Traceability of the corrections applied should be such that recovery of absolute depth measurements is possible after logging, if required.

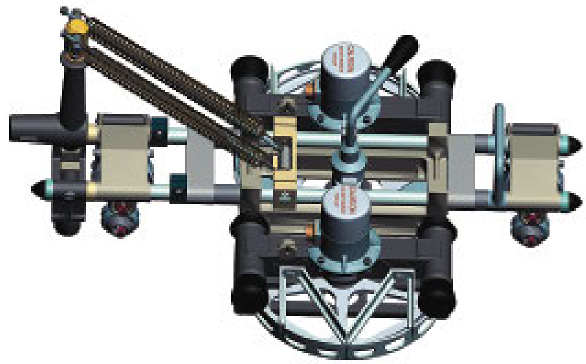

Figure 1. Integrated Depth Wheel device.

By strict application of this procedure, Schlumberger endeavors to deliver depth measurement with an accuracy of ±5 ft per 10,000 ft and repeatability of ±2 ft per 10,000 ft [±1.5 m and ±0.6 m per 3,050 m, respectively] in vertical wells.

Specifications

Measurement Specifications	
Accuracy	±5 ft per 10,000 ft [±1.5 m per 3,050 m]
Repeatability	±2 ft per 10,000 ft [±0.6 m per 3,050 m]

Calibration

The IDW calibration must be performed every 6 months, after 50 wellsite trips, or after 500,000 ft [152,400 m] have passed over the wheel, whichever comes first. The IDW device is calibrated with a setup that is factory-calibrated with a laser system, which provides traceability to international length standards.

Tension devices are calibrated every 6 months for each specific cable by using a load cell.

For more information, refer to the *Logging Calibration Guide*, which is available through your local Schlumberger representative.

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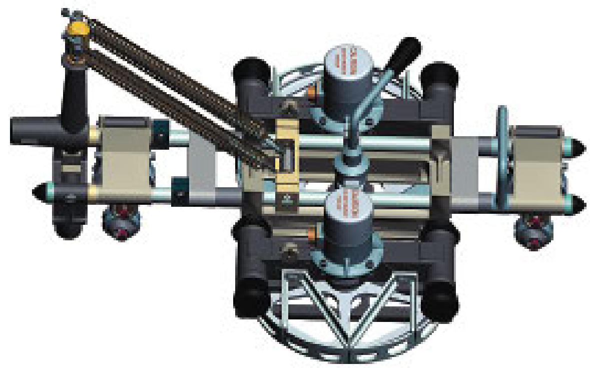

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For more information, refer to the *Logging Calibration Guide*, which is available through your local Schlumberger representative.

The high-precision IDW device uses two wheels that measure cable motion at the wireline unit. Each wheel is equipped with an encoder, which generates an event for every 0.1 in [0.25 cm] of cable travel. A wheel correction is applied to obtain the ideal of one pulse per 0.1 in of cable travel.

Integration of the pulses results in the overall measured depth, which is the distance measured along the actual course of the borehole from the surface reference point to a point below the surface.

A tension device, commonly mounted on the cable near the IDW device, measures the line tension of the cable at the surface.

Depth control procedure

On arrival at the wellsite, the wireline crew obtains all available information concerning the well and the depth references (wellsite data) from the client's representative. Information related to the calibrations of the IDW device and the tension device is entered in the surface acquisition system.

First trip

First log

The procedure for the first log in a well consists of the following major steps:

1. Set up the depth system, and ensure that wheel corrections are properly set for each encoder.
2. Set tool zero (Fig. 2) with respect to the client's depth reference.
3. Measure the rig-up length (Fig. 3) between the IDW device and the rotary table at the surface. Investigate, and correct as necessary, any significant change in the rig-up length from that measured with the tool close to the surface.
4. Run in the hole with the toolstring.
5. Measure the rig-up length (Fig. 3) between the IDW device and the rotary table at bottom.
6. Correct for the change in elastic stretch resulting from the change in cable or tool friction when logging up.
7. Record the main log.
8. Record one or more repeat sections for repeatability analysis.[†]
9. Pull the toolstring out of the hole and check the depth on return to surface.

To set tool zero on a land rig, fixed platform, or jackup, the toolstring is lowered a few feet into the hole and then pulled up, stopping when the tool reference is at the client's depth reference point (Fig. 2).

Figure 2. Tool zero.

[†]Operational considerations may dictate a change in the order of Steps 6–8.

The following procedure for setting tool zero is used on floating vessels, semisubmersible rigs, and drillships equipped with a wave motion compensator (WMC):

1. With the WMC deactivated, stop the tool reference at the rotary table, and set the system depth to zero.
2. Lower the tool until the logging head is well below the riser slip joint, then flag the cable at the rotary table and record the current depth.
3. Have the driller pull up slowly on the elevators, until the WMC is stroking about its midpoint.
4. Raise or lower the tool until the cable flag is back at the rotary table.
5. Set the system depth to the depth recorded in Step 2.

Measuring the cable rig-up length ensures that the setup has not changed while running in the well (e.g., slack in the logging cable, movement of the logging unit, the blocks, or the sheaves). The following procedure is used to measure the rig-up length of the cable (Fig. 3):

1. Run in the hole about 100 ft [30 m], flag the cable at the IDW device, and note the depth.
2. Lower the toolstring until the flag is at the rotary table. Subtract the depth recorded in Step 1 from the current depth. The result is the rig-up length at surface (RULS).
3. Record RULS.

The speed used to proceed in the hole should avoid tool float (caused by excessive force owing to mud viscosity acting on the tool) or birdcaging of the cable. To the extent possible and operational considerations permitting, a constant speed should be maintained while running downhole. At the bottom of the hole, the measurement process is conducted to obtain the rig-up length at bottom (RULB), which is also recorded. If RULB differs from RULS by more than 1 ft [0.3 m], the rig-up has changed and the cause of the discrepancy must be investigated and eliminated or corrected for.

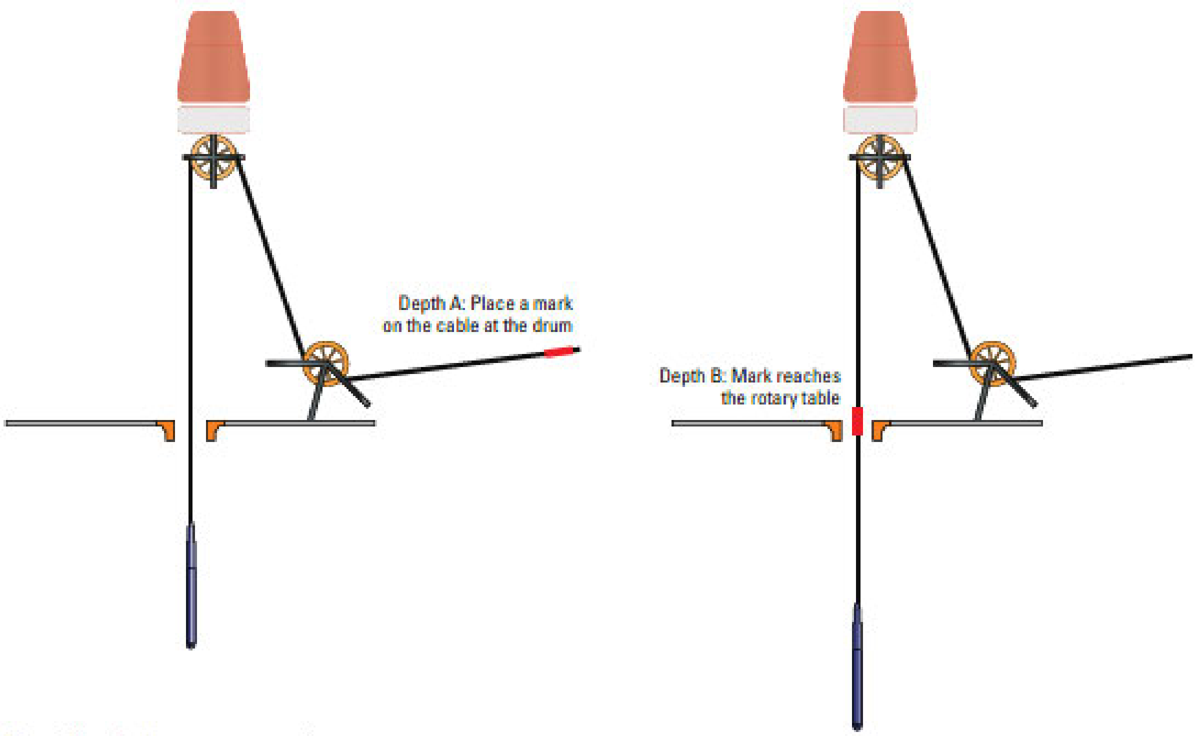

Figure 3. Rig-up length measurement procedure.

The rig-up length correction (RULC = RULS – RULB) is applied by adding RULC to the system depth. RULC is recorded in the Depth Summary Listing (Fig. 5).

To correct for the change of elastic stretch, the log-down/log-up method (Fig. 4) is applied as close as is reasonable to the bottom log interval:

1. Continue toward the bottom of the well at normal speed.
2. Log down a short section (minimum 200 ft [60 m]) close to the bottom, making sure to include distinctive formation characteristics for correlation purposes.
3. At the bottom, open calipers (if applicable) and log up a section overlapping the down log obtained in Step 2.
4. Using the down log as a reference, adjust the up-log depth to match the down log.
5. The adjustment is the stretch correction (SCORR) resulting from the change in tension. SCORR should be added to the hardware depth before logging the main pass.
6. Record SCORR and the depth at which it was determined in the Depth Summary Listing (Fig. 5).

If it is determined to be too risky to apply the delta-stretch correction before starting the log, the log can be recorded with no correction and then depth-shifted after the event with a playback. This procedure must be documented clearly in the Depth Summary Listing remarks. Such a procedure is justified when the well is excessively hot or sticky, and following the steps previously outlined could lead to a significant risk of tool problems or failure to return to bottom (and thus to loss of data).

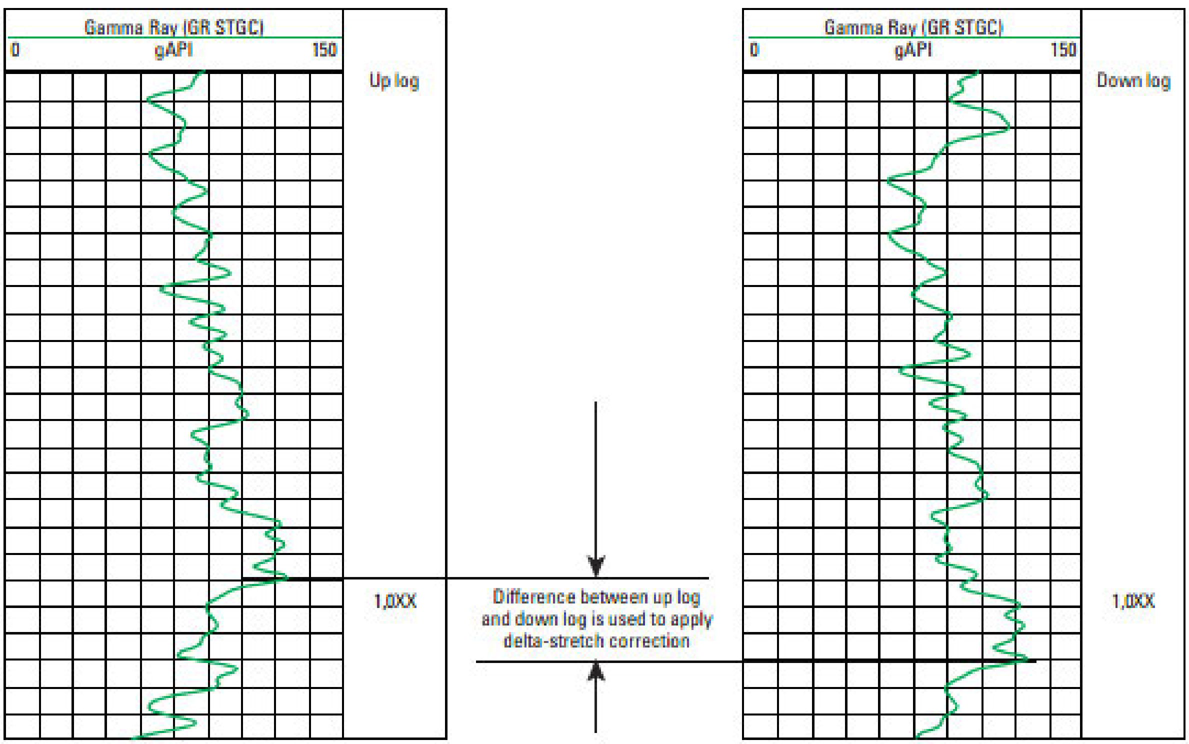

Figure 4. Stretch correction.

After pulling out of the hole, tool zero is checked at the surface, as was done before running in the hole, and the difference is recorded in the Depth Summary Listing (Fig. 5). In deviated wells in particular, environmental effects may lead to a re-zero error, with the depth system reading other than zero when the tool reference is positioned opposite the log reference point after return to the surface. Recording this difference is an essential step in controlling the quality of any depth correction computed after the log, because that depth correction process should include an estimate of the expected re-zero error.

All information related to the procedure followed for depth control should be recorded in the Depth Summary Listing (Fig. 5) for future reference.

DEPTH SUMMARY LISTING

Date Created: 10-Dec-20XX 12:09:15

Depth System Equipment

Depth Measuring Device		Tension Device		Logging Cable	
Type :	IDW-B	Type :	CMTD-B/A	Type :	7-46P
Serial Number:	4XX	Serial Number:	82XXX	Serial Number:	83XX
Calibration Date:	10-Dec-20XX	Calibration Date:	10-Dec-20XX	Length:	18750 FT
Calibrator Serial Number:	15XX	Calibrator Serial Number:	98XX	Conveyance Method:	Wireline
Calibration Cable Type:	7-46P	Number of Calibration Points:	10	Rig Type:	LAND
Wheel Correction 1:	-3	Calibration RMS:	11		
Wheel Correction 2:	-2	Calibration Peak Error:	15		

Depth Control Parameters

Log Sequence:	First Log in the Well
Rig Up Length At Surface:	352.00 FT
Rig Up Length At Bottom:	351.00 FT
Rig Up Length Correction:	1.00 FT
Stretch Correction:	5.00 FT
Tool Zero Check At Surface:	0.50 FT

Depth Control Remarks

1. Subsequent trip to the well. Downlog correlated to reference log XXX by YYY company dated DD-MM-YYYY.
2. Non-Schlumberger reference log. Full 1st trip to the well depth control procedure applied, which required the addition of XX ft to the down log.
3. Delta-stretch correction was conducted at 12XXX ft and applied to depth prior to recording the main log.
4. Z-chart used as a secondary depth check.

Figure 5. Depth Summary Listing for the first trip, first log in the well.

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Subsequent logs

The depth of subsequent logs on the same trip is tied into the first log using the following procedure:

1. Properly zero the tool as for the first log.
2. The rig-up length does not need to be measured if the setup has not changed since the previous log.
3. Match depths with the first log by using a short up-log pass.
4. Run the main log and repeat passes as necessary.
5. Record the re-zero error in the Depth Summary Listing. This is part of the traceability that makes possible the determination of absolute depth after the event, if required.

Subsequent logs should be on depth with the first log over the complete interval logged. However, particularly when toolstrings of different weights are run in deviated wells, the relative depths of the logs can change over long logging intervals. Subsequent correction should enable removing all discrepancies.

The amount and sign of the correction applied and the depth at which it was determined must be recorded in the Depth Summary Listing. For any down log made, the delta-stretch correction should also be recorded, as well as the depth at which it was determined.

All information related to the procedure followed for depth control of subsequent logs of the first trip should be recorded in the Depth Summary Listing (Fig. 6).

DEPTH SUMMARY LISTING

Date Created: 10-Dec-20XX 14:38:50

Depth System Equipment

Depth Measuring Device		Tension Device		Logging Cable	
Type :	IDW-B	Type :	CMTD-B/A	Type :	7-46P
Serial Number:	4XX	Serial Number:	82XXX	Serial Number:	83XX
Calibration Date:	10-Dec-20XX	Calibration Date:	10-Dec-20XX	Length:	18750 FT
Calibrator Serial Number:	15XX	Calibrator Serial Number:	98XX	Conveyance Method:	Wireline
Calibration Cable Type:	7-46P	Number of Calibration Points:	10	Rig Type:	LAND
Wheel Correction 1:	-3	Calibration RMS:	11		
Wheel Correction 2:	-2	Calibration Peak Error:	15		

Depth Control Parameters

Log Sequence:	Subsequent trip In the Well
Reference Log Name:	AIT-GR
Reference Log Run Number:	1
Reference Log Date:	10-Dec-20XX

Depth Control Remarks

1. Subsequent log on 1st trip correlated to first log in the well from XX000 to XX200 ft
2. Speed correction not applied.
3. Z-chart used as a secondary depth check.
4. Correction applied to match reference log = XX ft, determined at depth XXX00 ft.
5. No rigup changes from previous log.

Figure 6. Depth Summary Listing for first trip, subsequent logs.

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Subsequent trips

If there is not enough information in the Depth Summary Log from previous trips to ensure that correct depth control procedures have been applied, subsequent trips are treated as a first trip, first log in the well.

If sufficient information from previous trips was recorded to show that correct depth control procedures were applied, the previous logs can be used as a reference. The subsequent trips proceed as if running the initial trip with the following exceptions:

1. In conjunction with the client, decide which previous log to use as the downhole depth reference. Ensure that a valid copy of the reference log is available for correlation purposes. If the depth reference is a wireline log from a oilfield service provider other than Schlumberger, proceed as for the first log in the well, and investigate and document any discrepancies found with respect to the reference log.
2. Run in the hole and record a down log across an overlap section at the bottom of the reference log. If the overlap section is off by less than 5 ft per 10,000 ft, adjust the depth to match the current down log with the reference log. This adjustment ensures that the down section of the current log is using the same depth reference as the correlation log. Record any corrections made as the subsequent trip down log correction.
3. If the overlap log is off by more than 5 ft per 10,000 ft, investigate and resolve any problems. Record any depth discrepancies. Consult with the client to decide which log to use as the depth reference.
4. Run down to the bottom of the well at a reasonable speed so that the tool does not float.
5. Log main and repeat passes, correcting for stretch following the first trip procedure.
6. The logging pass should overlap with the reference log by at least 200 ft, if possible. The depth should match the reference log. Any discrepancies should be noted in the Depth Summary Listing or the log remarks.

All information related to the depth control procedure followed should be recorded in the Depth Summary Listing (Fig. 7).

DEPTH SUMMARY LISTING

Date Created: 10-Dec-20XX 14:26:56

Depth System Equipment

Depth Measuring Device		Tension Device		Logging Cable	
Type :	IDW-B	Type :	CMTD-B/A	Type :	7-46P
Serial Number:	4XX	Serial Number:	82XXX	Serial Number:	83XX
Calibration Date:	10-Dec-20XX	Calibration Date:	10-Dec-20XX	Length:	18750 FT
Calibrator Serial Number:	15XX	Calibrator Serial Number:	9851	Conveyance Method:	Wireline
Calibration Cable Type:	7-46P	Number of Calibration Points:	10	Rig Type:	LAND
Wheel Correction 1:	-3	Calibration RMS:	11		
Wheel Correction 2:	-2	Calibration Peak Error:	15		

Depth Control Parameters

Log Sequence:	Subsequent trip to the well
Reference Log Name:	AIT-GR
Reference Log Run Number:	1
Reference Log Date:	10-Dec-20XX
Subsequent Trip Down Log Correction:	1.00 FT

Depth Control Remarks

1. Subsequent trip to the well.
2. Down pass correlated to reference log within +/- 0.05%.
3. Correlation to reference log performed from XX000 to XX200 ft.
4. Correction applied to match reference log = XX ft, determined at depth XXX00 ft..
5. Z-chart used as a secondary depth check.

Figure 7. Depth Summary Listing for subsequent trips.

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Spudding

Spudding is not a recommended procedure, but it is sometimes necessary to get past an obstruction in the borehole. It generally involves making multiple attempts from varying depths or using varying cable speed to get past an obstruction.

If the distance pulled up is small, the error introduced is also small. In many cases, however, the tool is pulled back up for a considerable distance (i.e., increasing cable over wheel) in an attempt to change its orientation. Then, the correction necessary to maintain proper depth control becomes sizeable.

If multiple attempts are made, the correction necessary to maintain proper depth control also becomes sizeable.

When possible, log data is recorded over the interval where spudding occurs in case consequent damage occurs to the equipment that prevents further data acquisition. If it is not possible to pass an obstruction in the well, data is recorded while pulling out of the hole for remedial action.

Absolute depth

Measurements made with wireline logs are often used as the reference for well depth. However, differences are usually noted between wireline depth and the driller's depth. Which one is correct? The answer is neither. For more information, refer to SPE 110318, "A Technique for Improving the Accuracy of Wireline Depth Measurements."

Wireline depth measurement is subject to environmental corrections that vary with many factors:

- well profile
- mud properties
- toolstring weight
- cable type
- temperature profile
- wellbore pressure
- logging speed.

All these effects may differ from one well to another, so the depth corrections required also differ. Because of the number of factors involved, the corrections can be applied through a numerical model.

Logging down

Any short element of cable that is spooled off the winch drum as a tool is lowered downhole takes up a tension sufficient to support the weight of the tool in the well plus the weight of the cable between the winch and the tool, minus any frictional force that helps support the tool and cable. This prestretched cable passes the IDW device and its length is thus measured in the stretched condition. When this element of cable is downhole, the tension at the surface can be quite different. However, the tension on this element remains the same because it is still supporting the weight of the tool plus the weight of the cable between itself and the tool minus the frictional force.

If it is assumed that the frictional force is constant and that temperature and pressure do not affect the cable length, the tension on the cable—and thus the cable length—stays constant as the tool is lowered in the hole. Considering that all such elements remain at constant length once they have been measured, it follows that the down log is on depth. This means that the encoder-measured depth incorporates the stretched cable length, and no additional stretch correction is required.

Logging up

When the tool reaches the bottom of the well, the winch direction is reversed. This has the effect of inverting the sign of the frictional component acting on the tool and cable. In addition, if a caliper is opened, the magnitude of the frictional force can change. As a result, the cable everywhere in the borehole is subject to an increase in tension, and thus an increase in stretch.

For the surface equipment to track the true depth correctly, a delta-stretch correction must be added to compensate for the friction change (Fig. 4). Once the correction has been applied, the argument used while running in hole is again applicable, and the IDW correctly measures the displacement of the tool provided there are no further changes in friction.‡

Deviated wells

In deviated wells, the preceding depth analysis applies only to the vertical section of the well. Once the tool reaches the dogleg, lateral force from the wellbore supports part of the tool weight. The tool is thus shallower than the measured depth on surface; i.e., the recorded data appear deeper than the actual tool position. This is commonly referred to as tool float.

Correction modeling

Correction modeling software estimates the delta-stretch correction to be applied at the bottom of the well, as well as the expected tool re-zero depth upon return to the surface. This software can be used to correct the depth after logging. Contact your local Schlumberger representative for more information.

‡The main assumptions remain that the friction is constant (other than the change due to reversal of direction of cable motion), and that temperature and pressure effects on the cable may be ignored.