

## **Appendix 10**

### **Class VI Injection Well and Monitoring Well: Quality Assurance and Surveillance Plan**

**CTV V**

Update May 31, 2023

Prepared by:

**Carbon TerraVault Holdings, LLC**

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## Title and Approval Sheet

This Quality Assurance and Surveillance Plan (QASP) is approved for use and implementation at the Storage facility. The signatures below denote the approval of this document and intent to abide by the procedures outlined within it.

*William Chessum*

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Signature

William Chessum

6/29/2023

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Date

## **Distribution List**

The following project participants will receive the completed Quality Assurance and Surveillance Plan (QASP) and all future updates for the duration of the project.

William Chessum: CCS Project Manager

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## A. Project Management

### A.1. Project/Task Organization

#### A.1.a/b. Key Individuals and Responsibilities

The CTV V storage project, led by Carbon TerraVault Holdings LLC (CTV), includes participation from service providers. The responsibilities for Testing and Monitoring will be shared between CTV and the service providers.

CTV will be responsible for any data and submissions made to the EPA.

#### A.1.c. Independence from Project QA Manager and Data Gathering

CTV utilizes a third-party service provider to collect, transport and analyze samples as part of the Testing and Monitoring Plan.

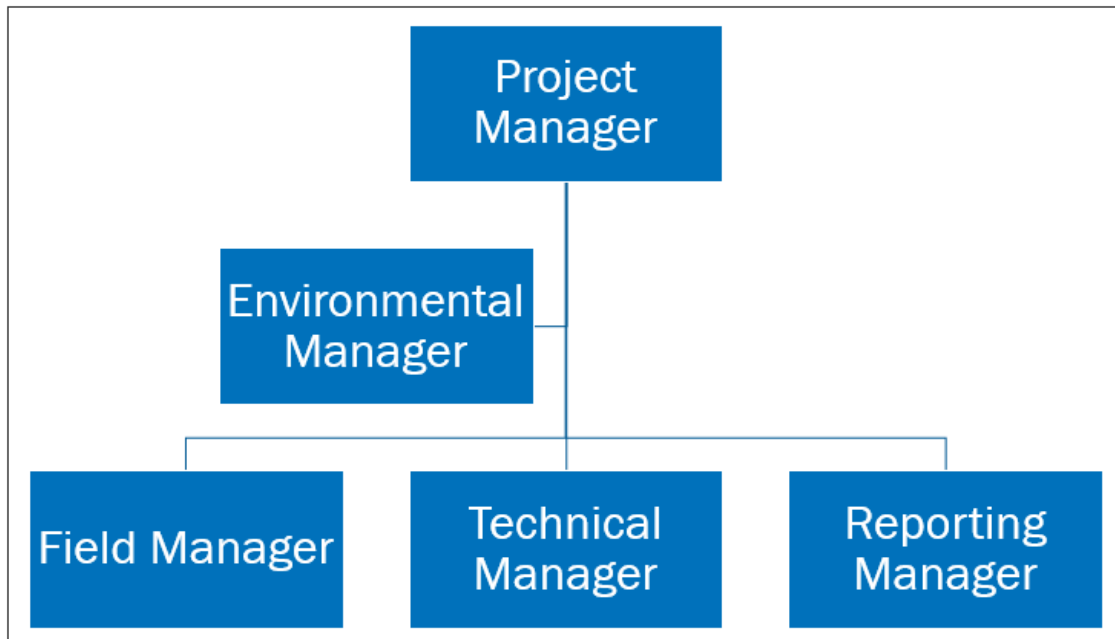
#### A.1.d. QA Project Plan Responsibility

CTV will be responsible for the Quality Assurance and Surveillance Plan. CTV will review the plan with service providers periodically.

#### A.1.e. Organizational Chart for Key Project Personnel

**Figure 1** shows the organizational structure for the project. Although these roles have not been filled because the project is not operational, the chart shows the breakdown in responsibilities for future positions.

**Figure 1:** Organizational Chart.





## **A.2. Problem Definition/Background**

### A.2.a. Reasoning

The project will inject and sequester CO<sub>2</sub> from industrial sources. The project requires a comprehensive monitoring plan that gathers data to assess confinement of the CO<sub>2</sub> injectate. To ensure accurate measurement and reporting this QASP outlines detail associated with the surveillance related to sampling, operating, and recording.

### A.2.b. Reasons for Initiating the Project

CTV initiated the project for Environmental, Social, and Governance (ESG) purposes and to reduce carbon footprint for CTV operations and for external emissions. The project area has available pore space and confinement.

### A.2.c. Regulatory Information, Applicable Criteria, Action Limits

CO<sub>2</sub> injection as per standard operating procedures and regulations requires that the injectate is confined in the reservoir and that groundwater is not impacted. As such the following monitoring is necessary:

1. Injection well mechanical integrity testing
2. Injection well testing and operating data collection
3. Groundwater monitoring
4. Validation of the CO<sub>2</sub> plume areal coverage as defined by numerical modeling

The information and data below define the steps to ensure that monitoring data quality provides the confidence and information to verify confinement.

## **A.3. Project/Task Description**

### A.3.a/b. Summary of Work to be Performed

A summary of the testing and monitoring for the storage project is presented in **Table 1**. A monitoring well summary is presented in **Table 2**.

### A.3.c. Geographic Locations

The project area is located in southern San Joaquin County.

### A.3.d. Resource and Time Constraints

CTV has obtained surface access for the duration of the project.

## **A.4. Quality Objectives and Criteria**

### A.4.a. Performance/Measurement Criteria

A summary of analytical and field parameters is presented in **Table 3**.

**Table 1. Summary of Testing and Monitoring.**

| Activity                       | Location(s)                     | Method           | Analytical Technique        | Lab/Custody | Purpose                                    |
|--------------------------------|---------------------------------|------------------|-----------------------------|-------------|--|
| Injection well                 |                                 |                  |                             |             |  |
| Carbon dioxide stream analysis | Compressor                      | Direct Sampling  | Chemical Analysis           | Eurofins    | Monitor Injectate                          |
| Injection rate and volume      | Injection Well (s)              | Flow meter       | Direct Measurement          | NA          | Monitor rate and volume                    |
| Injection pressure             | Injection wellhead(s)           | Pressure gauge   | Direct Measurement          | NA          | Monitor injection pressure                 |
| Annular pressure               | Injection Wellhead(s)           | Pressure gauge   | Direct Measurement          | NA          | Monitor annular pressure                   |
| Temperature                    | Along Wellbore(s)               | DTS              | Direct Measurement          | NA          | Monitor temperature                        |
| Downhole pressure/temperature  | Injection Well(s)               | Downhole gauge   | Direct Measurement          | NA          | Monitor reservoir pressure and temperature |
| Corrosion monitoring           | Between compressor and wellhead | Corrosion Coupon | NA                          | Eurofins    | Monitor corrosion of materials             |
| Mechanical integrity           | Injection Well(s)               | Temperature      | NA                          | NA          | Wellbore Integrity                         |
| Internal MIT                   | Injection Well(s)               | SAPT             | NA                          | NA          | Wellbore Integrity                         |
| Pressure Fall Off Test         | Injection Well(s)               | Pressure gauge   | Pressure Transient Analysis | NA          | Reservoir Assessment                       |

**Table 2. Monitoring Well Summary**

| Activity                               | Location(s)                       | Method          | Analytical Technique | Lab/Custody | Purpose                                |
|--|-----------------------------------|-----------------|----------------------|-------------|--|
| Monitoring Wells Above Confining Layer |                                   |                 |                      |             |  |
| Fluid Sampling (USDW)                  | USDW Monitoring Well              | Direct Sampling | Chemical Analysis    | Eurofins    | Monitor water quality                  |
| Pressure/Temperature (USDW)            | USDW Monitoring Well              | Gauge           | Direct Measurement   | NA          | Monitor pressure / temperature         |
| Pressure/Temperature Dissipation layer | Dissipation layer monitoring well | Gauge           | Direct Measurement   | NA          | Monitor pressure/Temperature           |
| Temperature Dissipation layer          | Dissipation layer monitoring well | DTS             | Direct Measurement   | NA          | Monitor Temperature                    |
| Fluid Sampling Dissipation layer       | Dissipation layer monitoring well | Direct Sampling | Chemical Analysis    | Eurofins    | Monitor water quality                  |
| Storage Reservoir                      |                                   |                 |                      |             |  |
| Pressure/Temperature                   | Monitor well (s)                  | Downhole gauge  | Direct Measurement   | NA          | Monitor reservoir pressure/temperature |
| Temperature                            | Monitor well (s)                  | DTS             | Direct Measurement   | NA          | Temperature                            |
| Fluid Sampling                         | Monitor well (s)                  | Direct Sampling | Chemical Analysis    | Eurofins    | Monitor water quality                  |
| Pulse Neutron Log                      | Monitor well (s)                  | Logging         | Logging              | NA          | Saturation                             |

**Table 3. Summary of Analytical and Field Parameters for Fluid Samples.**

| Parameters   | Analytical Methods <sup>(1)</sup>                           | Detection Limit/Range      | Typical Precisions | QC Requirements   |
|--|---|----------------------------|--------------------|---|
| Cations (Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb, Se, Zn, Tl) | ICP-MS<br>EPA Method 6020                                   | 0.05 to 5 mg/L             | 15%                | Daily calibration of equipment/CCV/ Blank LCS, MS/MSD/ QC/ICV |
| Cations (Ca, Fe, K, Mg, Na, Si)                          | ICP-OES<br>EPA Method 6010B                                 | 0.1 to 2 mg/L              | 15%                | Daily calibration/CCV/ Blank LCS, MS/MSD/ QC/ICV              |
| Anions (Br, Cl, F, NO <sub>3</sub> , SO <sub>4</sub> )   | Ion Chromatography, EPA Method 300.0 rev 2.1, Part A (1993) | 0.02-0.13 mg/L             | 15%                | Daily calibration/CCV/ Blank LCS, MS/MSD/ QC/ICV              |
| Dissolved CO <sub>2</sub>                                | Coulometric titration<br>ASTM D513-11                       | 10 mg/L                    | NA                 | Duplicate analysis  |
| Total dissolved solids                                   | Gravimetry; Method 2540 C                                   | 10 mg/L                    | 10%                | Daily balance calibration, duplicates, blanks                 |
| Alkalinity   | Method 2320B  | 10 mg/L                    | 10%                | Duplicate analysis  |
| pH (field)   | EPA 150.1   | 2 to 12.5pH                | 0.2 pH             | Daily calibration, duplicates                                 |
| Specific conductance (field)                             | APHA 2510   | 0-200 mS/cm                | 1%                 | Daily calibration, duplicates                                 |
| Temperature (field)                                      | Thermocouple  | -5 to 50 C                 | 0.2 C              | Monthly calibration   |
| δ <sup>13</sup> C  | Isotope ratio mass spectrometry                             | 12.2 mg/L HCO <sub>3</sub> | 0.15%              | Duplicate analysis  |
| Hydrogen Sulfide   | ISBT 14.0 (GC/SCD)  | 1 mg/L                     | 5-10% of reading   | Daily calibration, duplicates                                 |
| Oxygen, Argon, and Hydrogen                              | ISBT 4.0 (GC/DID) GC/TCD                                    | 50 ppmv                    | 15%                | Daily calibration / CCV blank QC sample                       |

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

**Table 4. Summary of Analytical Parameters for CO<sub>2</sub> Stream.**

| Parameters                          | Analytical Methods <sup>(1)</sup>  | Detection Limit/Range      | Typical Precisions | QC Requirements                                |
|-------------------------------------|--|----------------------------|--------------------|--|
| Oxygen, Argon and Hydrogen          | ISCT 4.0 (GC/DID)  | 50 ppmv                    | 15%                | Daily calibration/CCV, blank, QC sample        |
| Nitrogen                            | ISCT 4.0 (GC/DID)  | 50 ppmv                    | 15%                | Daily calibration/CCV, blank, QC sample        |
| Carbon monoxide                     | ISBT 5.0 (Colorimetric)<br>ISBT 4.0 (GC/DID)   | 50 ppmv                    | 15%                | Daily calibration/CCV, blank, QC sample        |
| Total hydrocarbons                  | ISBT 10.0 THA (FID)  | 10 ppmv                    | 15%                | Daily calibration/CCV, blank, QC sample        |
| Ammonia                             | ISBT 6.0 (DT)  | 0.1 ppmv                   | 15%                | Daily calibration/CCV, blank, QC sample        |
| Methane, Ethane, Ethylene           | ISBT 10.1 (FID)  | 10 ppmv                    | 15%                | Daily calibration/CCV, blank, QC sample        |
| Hydrogen sulfide and Sulfur Dioxide | ISBT 14.0 (GC/SCD)   | 10 ppmv/1 ppmv             | 15%                | Daily calibration/CCV, blank, QC sample        |
| Ethanol                             | ISBT 11.0 (GC/FID)   | 0.5 ppmv                   | 20%                | Daily calibration/CCV, blank, LCS, MS/MSD, ICV |
| Oxides of Nitrogen                  | ISBT Colorimetric  | 0.2 ppmv                   | 15%                | Daily calibration/CCV, blank, QC sample        |
| δ13C                                | Isotope ratio mass spectrometry  | 12.2 mg/L HCO <sub>3</sub> | 15%                | Duplicate analysis                             |
| CO <sub>2</sub> purity              | ISBT 2.0 Caustic absorption<br>Zahm-Nagel ALI method SAM<br>4.1 subtraction method<br>(GC/DID)<br>GC/TCD | 50 ppmv                    | 15%                | Daily calibration/CCV, blank, QC sample        |

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

**Table 5. Summary of Analytical Parameters for Corrosion Coupons.**

| Parameters | Analytical Methods                  | Detection Limit/Range | Typical Precisions | QC Requirements    |
|------------|-------------------------------------|-----------------------|--------------------|--------------------|
| Mass       | NACE TM0169/ G31<br>EPA 1110A SW846 | 0.001 mg              | 10%                | Duplicate analysis |

**Table 6. Summary of Measurement Parameters for Field Gauges.**

| Parameters                      | Methods          | Detection Limit/Range                 | Typical Precisions | QC Requirements    |
|---------------------------------|------------------|---------------------------------------|--------------------|--------------------|
| Booster pump discharge pressure | ANSI Z540-1-1994 | 0.001 / 0 - 5,000 PSI                 | 0.01 PSI           | Annual calibration |
| Injection tubing temperature    | ANSI Z540-1-1994 | 0.001 Fahrenheit / 0 – 500 Fahrenheit | 0.01 Fahrenheit    | Annual calibration |
| Injection tubing pressure       | ANSI Z540-1-1994 | 0.001 / 0 - 5,000 PSI                 | 0.01 PSI           | Annual calibration |
| Annulus pressure                | ANSI Z540-1-1994 | 0.001 / 0 - 5,000 PSI                 | 0.01 PSI           | Annual calibration |
| Injection mass flow rate        | NA               | 0.1 % of flow rate                    | 0.01 lbs/hour      | Annual calibration |

**Table 7. Actionable Testing and Monitoring Outputs.**

| <b>Activity or Parameter</b>                                 | <b>Project Action Limit</b>  | <b>Detection Limit</b>                    | <b>Anticipated Reading</b>   |
|--|--|---|--|
| External and internal mechanical integrity (temperature log) | Temperature log indicates a mechanical integrity issue.                            | 0.01 Fahrenheit                           | Results will be compared to baseline. Deviation may be indicative of mechanical issue. |
| Surface and downhole pressure                                | Action will be taken when pressure is outside of expected of modeled range.        | 0.001 PSI                                 | No greater than the maximum operating pressure.  |
| Water quality (USDW)   | Action will be taken when water sample is outside of baseline analysis             | 0.2 pH                                    | CO <sub>2</sub> will decrease the water pH.  |
| Above-confining-zone pressure                                | Action will be taken if the pressure of the Etchegoin Formation pressure increases | 0.001 PSI as per installed pressure gauge | Reservoir pressure.  |

A.4.b. Precision

Field blanks will be collected once per sampling event to assess water sampling analysis accuracy. Service provider will be responsible for analytical precision as per their standard operating procedures.

A.4.c. Bias

Laboratory analysis bias will be assessed and addressed by the individual service provider as per their procedures and methodology.

There is no bias for direct pressure, temperature, and logging measurements.

A.4.d. Representativeness

CTV designed the monitoring network to ensure that samples acquired were representative of site conditions. Standard operating procedures during acquisition at the wellsite will ensure that samples are representative of the formation.

A.4.e. Completeness

Data completeness (amount of data obtained versus the expected data) of 90% for ground water sampling will be acceptable.

Direct measurements, such as pressure and temperature data, will be recorded 90% of the time.

A.4.f. Comparability

Data sets will always be compared to the baseline and previous analysis. Individual threshold changes will be assessed as well as small trend changes.

#### A.4.g. Method Sensitivity

The following tables provide detail on gauge sensitivities.

**Table 8. Pressure and Temperature—Downhole Gauge Specifications.**

| Parameter                            | Value                           |
|--------------------------------------|---------------------------------|
| Calibrated working pressure range    | 0 – 10,000 PSI                  |
| Initial pressure accuracy            | < 2 PSI                         |
| Pressure resolution                  | 0.005 PSI                       |
| Pressure drift stability             | < 1 PSI per year                |
| Calibrated working temperature range | 77 – 266 degrees Fahrenheit     |
| Initial temperature accuracy         | < 0.9 Fahrenheit                |
| Temperature resolution               | 0.009 Fahrenheit                |
| Temperature drift stability          | 0.1 degrees Fahrenheit per year |
| Max temperature                      | 302 degrees Fahrenheit          |
| Instrument calibration frequency     | Annual                          |

**Table 9. Representative Logging Tool Specifications.**

| Parameter           | RST (Pulse Neutron)  | CBL                                   |
|---------------------|----------------------|---------------------------------------|
| Logging speed       | 200 feet/hour        | 1,800 feet/hour                       |
| Vertical resolution | 15 inches            | 6 inches                              |
| Investigation       | Mechanical integrity | Cement bond with casing and formation |
| Temperature rating  | 302 Fahrenheit       | 350 Fahrenheit                        |
| Pressure rating     | 15,000 PSI           | 20,000 PSI                            |

**Table 10. Pressure Field Gauge.**

| Parameter                         | Value                                     |
|-----------------------------------|---|
| Calibrated working pressure range | 0 to 5,000 PSI                            |
| Initial pressure accuracy         | < 0.05 %                                  |
| Pressure resolution               | 0.001 PSI                                 |
| Pressure drift stability          | 0.125% of upper range limit for 60 months |



**Table 11. Pressure Field Gauge—Injection Tubing Pressure.**

| Parameter                         | Value                                     |
|-----------------------------------|---|
| Calibrated working pressure range | 0 – 5,000 PSI and 4-20 mA                 |
| Initial pressure accuracy         | <0.05%                                    |
| Pressure resolution               | 0.001 PSI and 0.00001 mA                  |
| Pressure drift stability          | 0.125% of upper range limit for 60 months |

**Table 12. Pressure Field Gauge—Annulus Pressure.**

| Parameter                         | Value                                     |
|-----------------------------------|---|
| Calibrated working pressure range | 0 to 5,000 PSI                            |
| Initial pressure accuracy         | < 0.05 %                                  |
| Pressure resolution               | 0.001 PSI                                 |
| Pressure drift stability          | 0.125% of upper range limit for 60 months |

**Table 13. Temperature Field Gauge—Injection Tubing Temperature.**

| Parameter                            | Value   |
|--------------------------------------|---|
| Calibrated working temperature range | 0 to 500 degrees Fahrenheit and 4-20mA          |
| Initial temperature accuracy         | <0.0055%  |
| Temperature resolution               | 0.001 degrees Fahrenheit and 0.0001 mA          |
| Temperature drift stability          | 0.15% of output reading or 0.15 degrees Celsius |

**Table 14. Mass Flow Rate Field Gauge—CO<sub>2</sub> Mass Flow Rate.**

| Parameter                          | Value  |
|------------------------------------|--|
| Calibrated working flow rate range | Range spanning maximum anticipated injection rate per well with typical precision and accuracy of 0.5% |
| Initial mass flow rate accuracy    | 0.5 % of upper range limit   |
| Mass flow rate resolution          | 0.5% of upper range limit  |
| Mass flow rate drift stability     | Estimate <0.5% of output reading for 12 months   |

## **A.5. Special Training/Certifications**

### A.5.a. Specialized Training and Certifications

CTV will utilize lab and logging companies to acquire field data samples. All equipment will be provided and operated by the service provider.

### A.5.b/c. Training Provider and Responsibility

Training will be provided and assessed by the individual service providers.

## **A.6. Documentation and Records**

### A.6.a. Report Format and Package Information

CTV will prepare and submit semi-annual reports to the EPA. The reports will include all testing, data, and monitoring information as specified in the Testing and Monitoring Plan.

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

CTV will prepare and provide all necessary documents, records or electronic files as required.

### A.6.c/d. Data Storage and Duration

CTV will maintain the required project data collected in a datastore.

### A.6.e. QASP Distribution Responsibility

The project manager will be responsible for ensuring that those on the distribution list, and other essential staff, receive the most current copy of the QASP.

## **B. Data Generation and Acquisition**

### **B.1. Sampling Process Design**

#### B.1.a. Design Strategy

##### *Shallow Groundwater Monitoring Strategy*

Four groundwater monitoring wells (KI-M-USDW1, KI-M-USDW2, KI-M-USDW3, and KI-M-USDW4) will assess potential changes in the lowermost USDW within the undifferentiated (marine and non-marine) sediments above the secondary confining zone (Nortonville Shale). Although the proposed monitoring zone is a USDW based on having groundwater less than 10,000 ppm TDS, the water supply wells in the AoR are completed above the base of fresh water. Monitoring of the lowermost USDW is more protective than monitoring the fresh water aquifers because impacts would occur in the lowermost USDW before the fresh water aquifers..

CTV will also monitor pressure changes associated with the storage project and fluid analysis.

##### *Deep Groundwater Monitoring Strategy*

Between the upper confining zone (Capay Shale) and the secondary confining zone is the laterally continuous Domengine Formation. The Domengine sands will be monitored for potential CO<sub>2</sub> leakage via the

KI-M-D1 monitoring well. Any unlikely leakage from the storage reservoir up through the Capay Shale confining layer will dissipate in the Domengine Formation and increase its pressure.

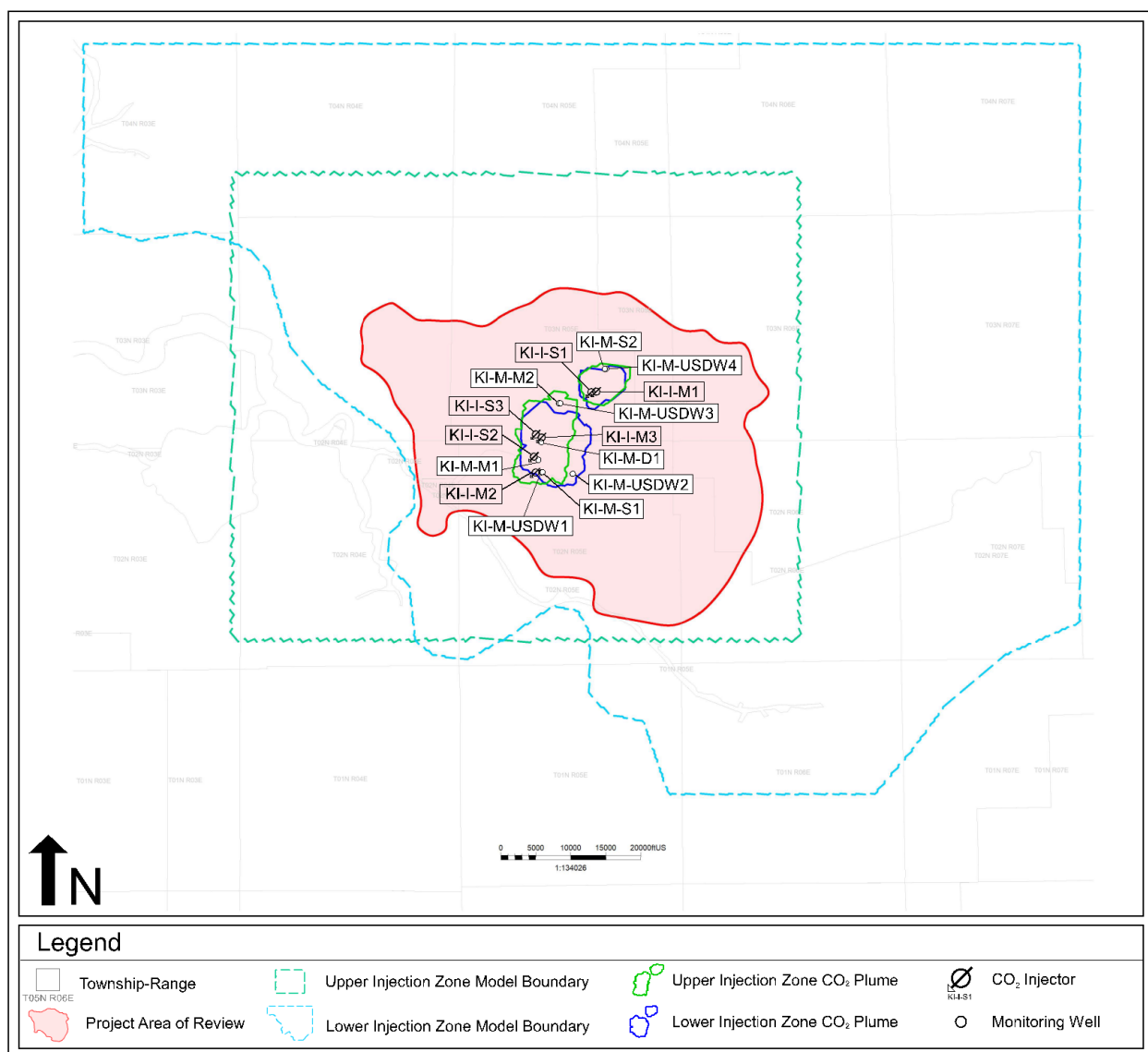
CTV will also monitor pressure changes associated with the storage project and fluid analysis.

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

The sampling activities are summarized in **Table 1**.

#### B.1.c. Site/Sampling Locations

Monitoring well locations for sampling are shown on the map in **Figure 2**.



**Figure 2:** Map showing the location of monitoring wells and injection wells.

#### B.1.d. Sampling Site Contingency

CTV has obtained surface access for the duration of the project.

#### B.1.e. Activity Schedule

The sampling activities are summarized in **Table 1**.

#### B.1.f. Critical/Informational Data

Documentation of information will include the following:

1. Sampling metadata that includes sample label, purging time and other sample collection procedures.
2. Data collected in the field (temperature and pH).
3. Chain of custody.
4. Data and analysis collected in the laboratory.
5. Calibration of Instrumentation and equipment.

#### B.1.g. Sources of Variability

Potential sources of variability include the following:

1. Natural and operational variability in fluid quality, temperature, and pressure.
2. Reservoir changes from outside the AoR (outside operator, precipitation/drought)
3. Changes in the sampling methods, service provider and instrumentation.

Variability will be minimized by the following:

1. Adhering to standard operating procedures.
2. Assessing data and results against baseline and previous results for trend and changes.
3. Service provider staff training.
4. Assessing calibration and calibrating procedures.
5. Quality control checks for samples.

### **B.2. Sampling Methods**

#### B.2.a/b. Sampling SOPs

Refer to **Table 15** for stabilization criteria during well purging.

Laboratory SOPs have been developed by the service provider.

All procedures for sampling shall be consistent with the U.S. Environmental Protection Agency (US EPA) Groundwater Sampling Guidelines for Superfund and RCEAA Project Managers (May, 2002).

**Table 15. Stabilization Criteria of Water Quality Parameters During Well Purging.**

| Field Parameter      | Stabilization Criteria |
|----------------------|------------------------|
| pH                   | +/- 0.01               |
| Temperature          | +/- 1 °C               |
| Specific conductance | +/- 3%                 |

B.2.c. In-situ Monitoring

In-situ monitoring of water chemistry is not currently planned.

B.2.d. Continuous Monitoring

Pressure will be collected from monitoring wells.

B.2.e. Sample Homogenization, Composition, Filtration

To obtain a representative sample, each well will be purged at a flow rate between 10 GPM and 5- GPM. Samples will be collected within 24 hours of groundwater purge (or as required by the sample preservation requirements). If a monitoring well will not supply adequate water for sampling, the condition of the well will be investigated and may be considered for replacement.

Purging will continue until three successive measurements of the indicator parameters meet the stabilization criteria per **Table 15**.

B.2.f. Sample Containers and Volumes

Sample collection devices will be carefully chosen to minimize the potential for altering the quality of the sample. Teflon and stainless steel are preferred materials, although PVC, HDPE and other similar materials are considered sufficient in some cases.

Refer to the tables below as needed for sample container, preservation, and holding time information.

B.2.g. Sample Preservation

Samples will be preserved as per **Table 17**.

B.2.h. Cleaning/Decontamination of Sampling Equipment

Equipment used for sampling and other activities associated with on-site work will be de-contaminated before and after performance of a given activity. Disposable items will be disposed of as solid waste in an approved, permitted client facility.

B.2.i. Support Facilities

Support facilities will be provided by the service provider responsible for sampling and analysis.

#### B.2.j. Corrective Action, Personnel, and Documentation

The service provider will be responsible for testing instruments and equipment and performing corrective action on defective equipment. Corrective action taken on equipment will be documented.

### **B.3. Sample Handling and Custody**

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

See **Table 16** and **Table 17** for holding times.

#### B.3.b. Sample Transportation

CTV will ensure that samples are delivered to the laboratory for analysis by the service provider as soon as possible following sample collection. Samples will be transported to the laboratory on the same day as the sample collection.

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:

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

#### B.3.c. Sampling Documentation

For each test in the field, a worksheet will be compiled for each test interval documenting the procedures and results.

#### B.3.d. Sample Identification

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

**Table 16. Summary of Sample Containers, Preservation Treatments, and Holding Times for CO<sub>2</sub> Gas Stream Analysis.**

| <b>Sample</b>              | <b>Volume/Container Material</b> | <b>Preservation Technique</b> | <b>Sample Holding time (max)</b> |
|----------------------------|----------------------------------|-------------------------------|----------------------------------|
| CO <sub>2</sub> gas stream | One-liter tedlar bag             | None                          | 72 hours                         |

**Table 17. Summary of Anticipated Sample Containers, Preservation Treatments, and Holding Times for Ground Water Samples.**

| Target Parameters   | Volume/Container Material | Preservation Technique | Sample Holding Time |
|---|---------------------------|------------------------|---------------------|
| Cations:<br>Ca, Fe, Mg, K, Na, Si, Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb, Se, Tl | 100 mL plastic            | Nitric acid            | 180 days            |
| Anions:<br>Br, Cl, F, NO <sub>3</sub> and SO <sub>4</sub>                     | 100 mL plastic            | None                   | 48 hours            |
| Dissolved CO <sub>2</sub>   | 100 ml plastic            | None                   | 14 days             |
| Isotopes:<br>Carbon isotope 13  | 100 ml plastic            | None                   | 14 days             |
| Alkalinity  | 100 mL plastic            | None                   | 14 days             |
| Hydrogen Sulfide  | 100 mL plastic            | NaOH                   | 14 days             |
| Total Dissolved Solids  | 100 mL plastic            | None                   | 14 days             |

#### B.3.e. Sample Chain-of-Custody

Sample transport and handling will be strictly controlled by the service provider field technician to reduce the opportunity for tampered samples. Upon delivery to the laboratory samples will be given unique laboratory sample numbers and recorded in a logbook indicating the client, well number, date, and time of delivery.

### **B.4. Analytical Methods**

#### B.4.a. Analytical SOPs

All procedures to sample and analyze groundwater will be consistent with the U.S. Environmental Protection Agency Groundwater Sampling Guidelines for Superfund and RCRA Project Managers (May, 2002).

#### B.4.b. Equipment/Instrumentation Needed

Service providers are expected to provide and utilize the equipment and instruments necessary to perform the required testing and analysis.

Examples of equipment and instrumentation includes safety equipment, sample jars, decontamination supplies, pH meter, EC meters, temperature gauges, and materials to document chain of custody, results, and labels.

#### B.4.c. Method Performance Criteria

All analytical methods employed by CTV at the storage project are industry standard and well define. Method performance criteria is not necessary.

#### B.4.d. Analytical Failure

Service providers conducting analysis are responsible for assessing and addressing analytical failure per their internal procedures and standards.

#### B.4.e. Sample Disposal

Service providers conducting analysis are responsible for proper sample disposal per internal procedures and standards.

#### B.4.f. Laboratory Turnaround

Laboratory turnaround times will vary by the analysis being conducted. CTV will communicate to service providers that a 30-day turnaround time for most analysis' is expected.

#### B.4.g. Method Validation for Nonstandard Methods

All analytical methods employed by CTV at the Storage project are industry standard and well defined. Method performance criteria is not necessary.

### **B.5. Quality Control**

#### B.5.a. QC activities

Field quality control may involve the collection of two types of QC blanks, trip, and field blanks, to verify that the sample collection and handling processes have not impaired quality of the final samples.

Trip blank – Trip blanks are prepared for VOC analysis and transported with the empty sample container.

Field Blank- the field blank will be taken in the field to evaluate if certain sampling or cleaning procedures result in cross-contamination of site samples or if atmospheric contamination has occurred.

#### B.5.b. Exceeding Control Limits

In the case that control limits are exceeded, CTV will review the sampling procedures and results. In the case of a valid test, refer to the Emergency Response Plan for water contamination procedures.

#### B.5.c. Calculating Applicable QC Statistics

Charge Balance - Solutions must be electrically neutral, the total sum of all the positive charges (cations) must equal the total sum of all negative charges (anions).

$$\text{Charge Balance:} \quad \sum cations = \sum anions$$

Charge balance error (shown below) will be less than  $\pm 5\%$  for acceptable water analyses.

$$CBE = \frac{\sum cations - |\sum anions|}{\sum cations + |\sum anions|} \times 100$$



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

The service provider will test, inspect, and maintain the instrumentation and equipment used for testing, this will be completed as per the manufacturer's guidelines and the standard operating procedures.

## **B.7. Instrument/Equipment Calibration and Frequency**

### B.7.a. Calibration and Frequency of Calibration

Pressure and temperature gauges will be calibrated according to the manufacturer's recommendations. Calibration certificates will be kept on file.

Lab instrumentation and calibration will be checked weekly to ensure that results are within the control range of parameters.

### B.7.b. Calibration Methodology

Instruments will be calibrated for accurate readings. Calibrations will be conducted with individual instrument SOP's and in accordance with the manufacturer's supplied manual for each instrument.

### B.7.c. Calibration Resolution and Documentation

Instrument calibration resolution will be consistent with the manufacturer's recommendations. Documentation for instrument calibration will be maintained in a database.

## **B.8. Inspection/Acceptance for Supplies and Consumables**

### B.8.a/b. Supplies, Consumables, and Responsibilities

The service provider responsible for completing sample collection and analysis will be responsible for supplies and consumables.

Supplies and consumables used for sample collection and analysis will be selected to minimize the potential for altering the quality of the sample and analysis results.

## **B.9. Nondirect Measurements**

### B.9.a. Data Sources

Induced seismicity will be monitored continuously to ensure data consistency. CTV will partner with or use a third party to process the data.

### B.9.b. Relevance to Project

Passive seismic monitoring will be used to assess induced seismicity events as an indicator of stress changes in the subsurface. Thresholds and response for induced seismic events are discussed further in the Emergency Response Plan.

### B.9.c. Acceptance Criteria

Industry standard practices will be utilized for data gathering, processing and interpretation.

#### B.9.d. Resources/Facilities Needed

CTV will use a service provider for all necessary resources and facilities for passive seismic monitoring.

#### B.9.e. Validity Limits and Operating Conditions

CTV and service provider professionals will ensure that all results and processes are conducted as per standard industry practices.

### **B.10. Data Management**

#### B.10.a. Data Management Scheme

CTV will maintain the storage project data internally. Data will be backed up and held on secure servers.

#### B.10.b. Recordkeeping and Tracking Practices

All data associated with the project will be held securely and associated meta-data will be gathered and maintained to ensure tracking purposes.

#### B.10.c. Data Handling Equipment/Procedures

CTV employs robust data management procedures to ensure security of data gathered from the field and external data sources.

#### B.10.d. Responsibility

Project managers will be responsible for ensuring data management is properly maintained.

#### B.10.e. Data Archival and Retrieval

CTV will hold all data associated with the Storage project. A data store will be developed for reporting and retrieval.

#### B.10.f. Hardware and Software Configurations

CTV will ensure that software and hardware are appropriate to integrate the multiple data sources and maintain large quantities of data.

#### B.10.g. Checklists and Forms

CTV will generate forms, checklists, and procedures as necessary to ensure management, security and quality of all data collected.

## **C. Assessment and Oversight**

### **C.1. Assessments and Response Actions**

#### C.1.a. Activities to be Conducted

Monitoring results will be obtained as per **Table 1**. Results will be reviewed for QC criteria as per section B.5. In the case of data failure, new samples will be collected and analyzed. Evaluation for data consistency will be performed per the USEPA 2009 Unified Guidance (USEPA, 2009).

#### C.1.b. Responsibility for Conducting Assessments

CTV will utilize service providers to analyze sample data. These organizations will be responsible for conducting their own internal assessments.

#### C.1.c. Assessment Reporting

Assessment information will be reported to the project leads as outlined in A.1.

#### C.1.d. Corrective Action

Corrective action issues, data collection, and monitoring data will all be handled by CTV.

### **C.2. Reports to Management**

#### C.2.a/b. QA status Reports

CTV will notify the EPA and project leaders of QA report status if there are changes to the Testing and Monitoring Plan or the QASP.

## **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 the review of the results, chain of custody information, and review of the blank and duplicate information. All results will be stored in a database and compared to baseline and previous results. Data will be graphed to inspect trends and anomalies.

### **D.2. Verification and Validation Methods**

#### D.2.a. Data Verification and Validation Processes

Data will be verified by CTV upon receipt of results.

If anomalous data is suspected, CTV and the service provider will review the metadata associated with the sample to assess whether sampling, collection and the analysis conducted caused spurious results. In addition, instrument calibration will be reviewed if necessary.

#### D.2.b. Data Verification and Validation Responsibility

Data will be verified by CTV upon receipt of results.

#### D.2.c. Issue Resolution Process and Responsibility

CTV will oversee sample handling and assessment process. CTV management will determine actions necessary to resolve issues.

#### D.2.d. Checklist, Forms, and Calculations

CTV will develop checklists and a GIS database to store data, complete surveillance and ensure that permit requirements are met.

### **D.3. Reconciliation with User Requirements**

#### **D.3.a. Evaluation of Data Uncertainty**

CTV will develop a GIS database that will be used for surveillance. The database will ensure data quality using methods consistent with USEPA 2009 Unified Guidance.

#### **D.3.b. Data Limitations Reporting**

Service provider management will be responsible for ensuring that analysis in their laboratory is presented with data use limitations for reporting.

Project leaders and managers will be responsible for ensuring that results are vetted and evaluated to determine if performance criteria are met.

### **References**

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### **Appendices**

Schlumberger Wireline Log Quality Reference Manual

# Wireline Log Quality Control Reference Manual



# RST and RSTPro

## Overview

The dual-detector spectrometry system of the through-tubing RST® and RSTPro® reservoir saturation tools enables the recording of carbon and oxygen and Dual-Burst® thermal decay time measurements during the same trip in the well.

The carbon/oxygen (C/O) ratio is used to determine the formation oil saturation independent of the formation water salinity. This calculation is particularly helpful if the water salinity is low or unknown. If the salinity of the formation water is high, the Dual-Burst measurement is used. A combination of both measurements can be used to detect and quantify the presence of injection water of a different salinity from that of the connate water.

## Specifications

| Measurement Specifications          |   |
|-------------------------------------|---|
|                                     | RST and RSTPro Tools  |
| Output                              | Inelastic and capture yields of various elements, carbon/oxygen ratio, formation capture cross section (sigma), porosity, borehole holdup, water velocity, phase velocity, SpectroLith® processing                          |
| Logging speed <sup>1</sup>          | Inelastic mode: 100 ft/h [30 m/h] (formation dependent)<br>Capture mode: 600 ft/h [183 m/h] (formation and salinity dependent)<br>RST sigma mode: 1,800 ft/h [549 m/h]<br>RSTPro sigma mode: 2,800 ft/h [850 m/h]           |
| Range of measurement                | Porosity: 0 to 60 V/V   |
| Vertical resolution                 | 15 in [38.10 cm]  |
| Accuracy                            | Based on hydrogen index of formation  |
| Depth of investigation <sup>2</sup> | Sigma mode: 10 to 16 in [20.5 to 40.6 cm]<br>Inelastic capture (IC) mode: 4 to 6 in [10.2 to 15.2 cm]   |
| Mud type or weight limitations      | None  |
| Combinability                       | RST tool: Combinable with the PL Flagship® system and CPLT® combinable production logging tool<br>RSTPro tool: Combinable with tools that use the PS Platform® telemetry system and Platform Basic Measurement Sonde (PBMS) |

<sup>1</sup> See Tool Planner application for advice on logging speed.

<sup>2</sup> Depth of investigation is formation and environment dependent.

## Calibration

The master calibration of the RST and RSTPro tools is conducted annually to eliminate tool-to-tool variation. The tool is positioned within a polypropylene sleeve in a horizontally positioned calibration tank filled with chlorides-free water.

The sigma, WFL® water flow log, and PVL® phase velocity log modes of the RST and RSTPro detectors do not require calibration. The gamma ray detector does not require calibration either.

| Mechanical Specifications |   |                       |
|---------------------------|---|-----------------------|
|                           | RST-A and RST-C   | RST-B and RST-D       |
| Temperature rating        | 302 degF [150 degC]<br>With flask: 400 degF [204 degC]      | 302 degF [150 degC]   |
| Pressure rating           | 15,000 psi [103 MPa]<br>With flask: 20,000 psi [138 MPa]    | 15,000 psi [103 MPa]  |
| Borehole size—min.        | 1 1/8 in [4.60 cm]<br>With flask: 2 1/4 in [5.72 cm]        | 2 1/8 in [7.30 cm]    |
| Borehole size—max.        | 9 1/8 in [24.45 cm]<br>With flask: 9 1/8 in [24.45 cm]      | 9 1/8 in [24.45 cm]   |
| Outside diameter          | 1.71 in [4.34 cm]<br>With flask: 2.875 in [7.30 cm]         | 2.51 in [6.37 cm]     |
| Length                    | 23.0 ft [7.01 m]<br>With flask: 33.6 ft [10.25 m]           | 22.2 ft [6.76 m]      |
| Weight                    | 101 lbm [46 kg]<br>With flask: 243 lbm [110 kg]             | 208 lbm [94 kg]       |
| Tension                   | 10,000 lbf [44,480 N]<br>With flask: 25,000 lbf [111,250 N] | 10,000 lbf [44,480 N] |
| Compression               | 1,000 lbf [4,450 N]<br>With flask: 1,800 lbf [8,010 N]      | 1,000 lbf [4,450 N]   |



## Tool quality control

### Standard curves

The RST and RSTPro standard curves are listed in Table 1.

**Table 1. RST and RSTPro Standard Curves**

| Output Mnemonic | Output Name                                     |
|-----------------|---|
| BADL_DIAG       | Bad level diagnostic                            |
| CCRA            | RST near/far instantaneous count rate           |
| COR             | Carbon/oxygen ratio                             |
| CRRA            | Near/far count rate ratio                       |
| CRRR            | Count rate regulation ratio                     |
| DSIG            | RST sigma difference                            |
| FBAC            | Multichannel Scaler (MCS) far background        |
| FBEF            | Far beam effective current                      |
| FCOR            | Far carbon/oxygen ratio                         |
| FEFF            | Far capture gain correction factor              |
| FEFF            | Far capture offset correction factor            |
| FERD            | Far capture resolution degradation factor (RDF) |
| FIGF            | Far inelastic gain correction                   |
| FIOF            | Far inelastic offset correction factor          |
| FIRD            | Far inelastic RDF                               |
| IC              | Inelastic capture                               |
| IRAT_FIL        | RST near/far inelastic ratio                    |
| NBEF            | Near beam effective current                     |
| NCOR            | Near carbon/oxygen ratio                        |
| NEGF            | Near capture gain correction factor             |
| NEOF            | Near capture offset correction factor           |
| NERD            | Near capture RDF                                |
| NIGF            | Near inelastic gain correction                  |
| NIOF            | Near inelastic offset correction factor         |
| NIRD            | Near inelastic RDF                              |
| RSCF_RST        | RST selected far count rate                     |
| RSCN_RST        | RST selected near count rate                    |
| SBNA            | Sigma borehole near apparent                    |
| SFFA_FIL        | Sigma formation far apparent                    |
| SFNA_FIL        | Sigma formation near apparent                   |
| SIGM            | Formation sigma                                 |
| SIGM_SIG        | Formation sigma uncertainty                     |
| TRAT_FIL        | RST near/far capture ratio                      |

## Operation

The RST and RSTPro tools should be run eccentric. The main inelastic capture characterization database does not support a centered tool, thus it is important to ensure that the tool is run eccentric. However, for a WFL water flow log, a centered tool is recommended to better evaluate the entire wellbore region.

### Formats

The format in Fig. 1 is used mainly as a hardware quality control.

- Depth track
  - Deflection of the BADL\_DIAG curve by 1 unit indicates that frame data are being repeated (resulting from fast logging speed or stalled data). A deflection by 2 units indicates bad spectral data (too-low count rate).
- Track 1
  - CRRA, CRRR, NBEF, and FBEF are shown; FBEF should track openhole porosity when properly scaled.
- Track 6
  - The IC mode gain correction factors measure the distortion of the energy inelastic and elastic spectrum in the near and far detectors relative to laboratory standards. They should read between 0.98 and 1.02.
- Track 7
  - The IC mode offset correction factors are described in terms of gain, offset, and resolution degradation of the inelastic and elastic spectrum in the near and far detectors. They should read between -2 and 2.
- Track 8
  - Distortion on these curves affects inelastic and capture spectra from the near and far detectors. They should be between 0 and 15. Anything above 15 indicates a tool problem or a tool that is too hot (above 302 degF [150 degC]), which affects yield processing.

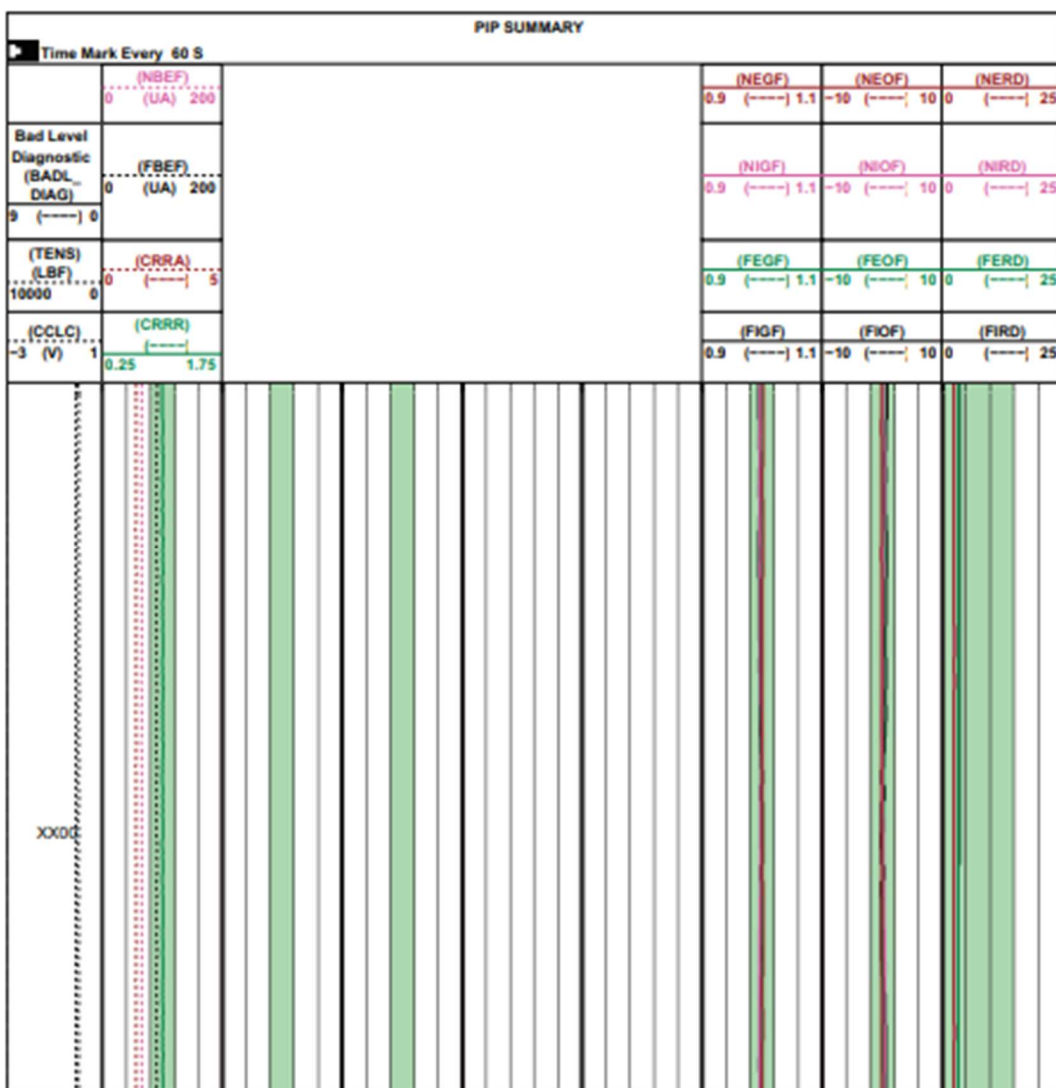


Figure 1. RST and RSTPro hardware format.



The format in Fig. 2 is used mainly for sigma quality control.

- Depth track
  - Deflection of the BADL\_DIAG curve by 1 unit indicates that frame data are being repeated (resulting from fast logging speed or stalled data). A deflection by 2 units indicates bad spectral data (too-low count rate).
- Tracks 2 and 3
  - The IRAT\_FIL inelastic ratio increases in gas and decreases with porosity.
  - DSIG in a characterized completion should equal approximately zero. Departures from zero indicate either the environmental parameters are set incorrectly or environment is different from the characterization database (e.g., casing is not fully centered in the wellbore or the tool is not eccentric). Shales typically read 1 to 4 units from the baseline of zero because they are not characterized in the database.

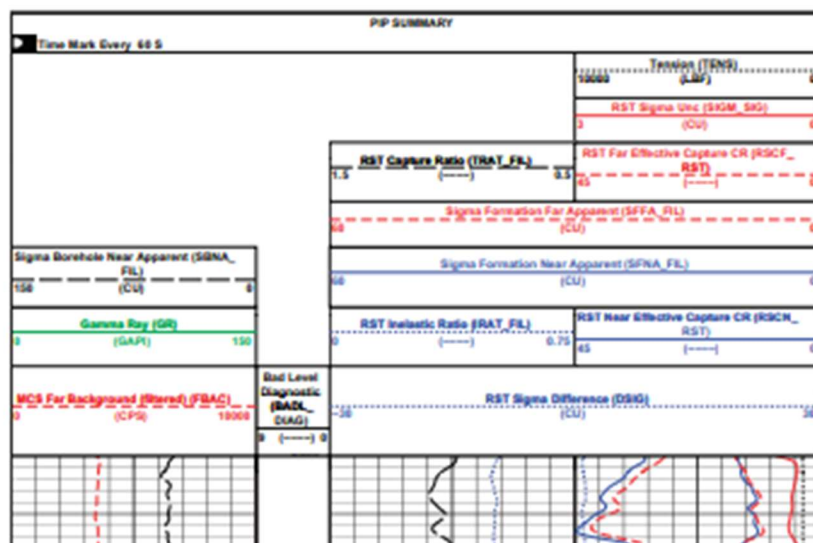


Figure 2. RST and RSTPro sigma standard format.

### Response in known conditions

In front of a clean water zone, COR is smaller than the value logged across an oil zone. Oil in the borehole affects both the near and far COR, causing them to read higher than in a water-filled borehole. In front of shale, high COR is associated with organic content.

The computed yields indicate contributions from the materials being measured (Table 2).

**Table 2. Contributing Materials to RST and RSTPro Yields**

| Element | Contributing Material                         |
|---------|---|
| C and O | Matrix, borehole fluid, formation fluid       |
| Si      | Sandstone matrix, shale, cement behind casing |
| Ca      | Carbonates, cement                            |
| Fe      | Casing, tool housing                          |

Bad cement quality affects readings (Table 3). A water-filled gap in the cement behind the casing appears as water to the IC measurement. Conversely, an oil-filled gap behind the casing appears as oil to the IC measurement.

**Table 3. RST and RSTPro Capture and Sigma Modes**

| Medium        | Sigma, cu |
|---------------|-----------|
| Oil           | 18 to 22  |
| Gas           | 0 to 12   |
| Water, fresh  | 20 to 22  |
| Water, saline | 22 to 120 |
| Matrix        | 8 to 12   |
| Shale         | 35 to 55  |

# Cement Bond Tool

## Overview

The cement bond log (CBL) made with the Cement Bond Tool (CBT) provides continuous measurement of the attenuation of sound pulses, independent of casing fluid and transducer sensitivity. The tool is self-calibrating and less sensitive to eccentricity and sonde tilt than the traditional single-spacing CBL tools. The CBT additionally gives the attenuation of sound pulses from a receiver spaced 0.8 ft [0.24 m] from the transmitter, which is used to aid interpretation in fast formations.

A CBL curve computed from the three attenuations available enables comparison with CBLs based on the typical 3-ft [0.91-m] spacing. This computed CBL continuously discriminates between the three attenuations to choose the one best suited to the well conditions. An interval transit-time curve for the casing is also recorded for interpretation and quality control.

A Variable Density\* log (VDL) is recorded simultaneously from a receiver spaced 5 ft [1.52 m] from the transmitter. This display provides information on the cement/formation bond and other factors that are important to the interpretation of cement quality.

## Specifications

| Measurement Specifications     |   |
|--------------------------------|---|
| Output                         | Attenuation measurement, CBL, VDL image, transit times                    |
| Logging speed                  | 1,800 ft/h [549 m/h] <sup>†</sup>   |
| Range of measurement           | Formation and casing dependent  |
| Vertical resolution            | CBL: 3 ft [0.91 m]<br>VDL: 5 ft [1.52 m]<br>Cement map: 2 ft [0.61 m]     |
| Accuracy                       | Formation and casing dependent  |
| Depth of investigation         | CBL: casing and cement interface<br>VDL: depends on bonding and formation |
| Mud type or weight limitations | None  |

<sup>†</sup> Speed can be reduced depending on data quality.

| Measurement Specifications |                      |
|----------------------------|----------------------|
| Temperature rating         | 350 degF [177 degC]  |
| Pressure rating            | 20,000 psi [138 MPa] |
| Borehole size—min.         | 3.375 in [8.57 cm]   |
| Borehole size—max.         | 13.375 in [33.97 cm] |
| Outside diameter           | 2.75 in [6.965 cm]   |
| Weight                     | 309 lbm [140 kg]     |

## Calibration

Sonde normalization of sonic cement bond tools is performed with every Q-check. Q-check frequency is also dependent on the number of jobs run, exposure to high temperature, and other factors.

The sonic checkout setup used for calibration is supported with two stands, one on each end. A stand in the center of the tube would distort the waveform and cause errors. One end of the tube is elevated to assist in removing all air in the system, and the tool is positioned in the tube with centralizer rings.

## Tool quality control

### Standard curves

CBT standard curves are listed in Table 1.

Table 1. CBT Standard Curves

| Output Mnemonic | Output Name   |
|-----------------|---|
| CCL             | Casing collar locator amplitude   |
| DATN            | Discriminated BHC attenuation   |
| DBI             | Discriminated bond index  |
| DCBL            | Discriminated synthetic CBL   |
| DT              | Interval transit time of casing (delta-t)   |
| DTMD            | Delta-t mud (mud slowness)  |
| GR              | Gamma ray   |
| NATN            | Near 2.4-ft attenuation   |
| NBI             | Near bond index   |
| NCBL            | Near synthetic CBL  |
| R32R            | Ratio of receiver 3 sensitivity to receiver 2 sensitivity, dB                       |
| SATN            | Short 0.8-ft attenuation <sup>†</sup>   |
| SB1             | Short bond index <sup>†</sup>   |
| SCBL            | Short synthetic CBL <sup>†</sup>  |
| TT1             | Transit time for mode 1 (upper transmitter, receiver 3 [UT-R3])                     |
| TT2             | Transit time for mode 2 (UT-R2)   |
| TT3             | Transit time for mode 3 (lower transmitter, receiver 2 [LT-R2])                     |
| TT4             | Transit time for mode 4 (LT-R3)   |
| TT6             | Transit time for mode 6 (UT-R1)   |
| ULTR            | Ratio of upper transmitter output strength to the lower transmitter output strength |
| VDL             | Variable Density log  |

<sup>†</sup> In fast formations only





The format in Fig. 2 is also used both as an acquisition and quality control format.

- Track 1

- The transit time pairs should overlay (TT1C overlays TT3C, and TT2C overlays TT4C) because these pairs are derived from equivalent transmitter-receiver spacings. In very good cement sections, the transit-time curve may be affected by cycle skipping. DT and DTMD may be also affected.

- Track 2

- The ULTR and R32R ratios are quality indicators of the transmitter or receiver strengths. They should be  $0 \text{ dB} \pm 3 \text{ dB}$ , unless one of the transmitters or receivers is weak. Both curves should be checked for consistency and stability.

- Track 3

- DATN should equal NATN in free-pipe sections. In the presence of cement behind casing and in normal conditions, NATN reads higher than DATN.

- Track 4

- VDL is a map of the waveform amplitude versus depth that should have good contrast. It provides information on the cement/formation bond, which is important for cement quality interpretation. The VDL image should be cross checked that it matches the DCBL readings.

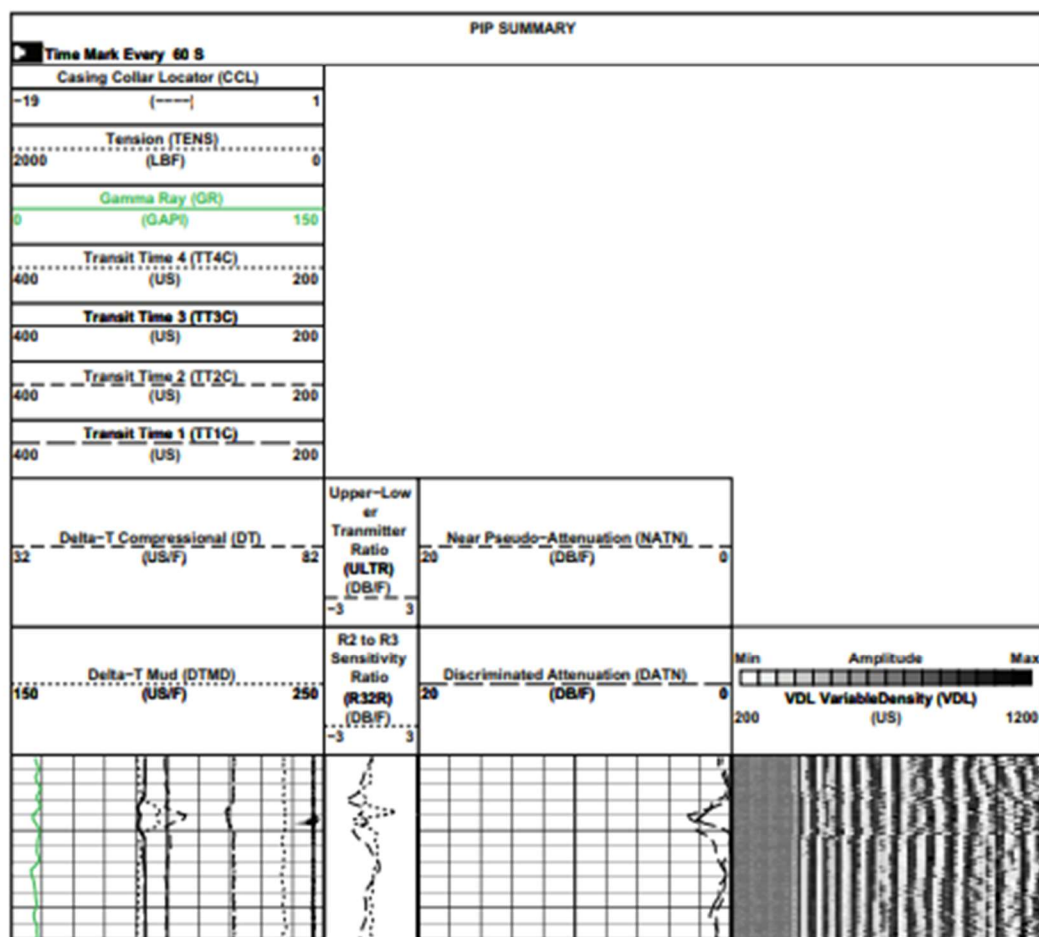


Figure 2. Additional CBT standard format for CBL and VDL.

### Response in known conditions

- DT in casing should read the value for steel ( $57 \text{ us/ft} \pm 2 \text{ us/ft}$  [ $187 \text{ us/m} \pm 6.6 \text{ us/m}$ ]).
- DTMD should be compared with known velocities (water-base mud:  $180\text{--}200 \text{ us/ft}$  [ $590\text{--}656 \text{ us/m}$ ], oil-base mud:  $210\text{--}280 \text{ us/ft}$  [ $689\text{--}919 \text{ us/m}$ ]).
- Typical responses for different casing sizes and weights are listed in Table 2.

**Table 2. Typical CBT Response in Known Conditions**

| Casing Size, in | Casing Weight, lbm/ft | DCBL in Free Pipe, mV | TT1, us | TT2, us | TT5, us         |
|-----------------|-----------------------|-----------------------|---------|---------|-----------------|
| 4.5             | 11.6                  | $84 \pm 8$            | 252     | 195     | 104             |
| 5               | 13                    | $77 \pm 7$            | 259     | 203     | 112             |
| 5.5             | 17                    | $71 \pm 7$            | 267     | 210     | 120             |
| 7               | 24                    | $61 \pm 6$            | 290     | 233     | 140             |
| 8.625           | 38                    | $55 \pm 6$            | 314     | 257     | 166             |
| 9.625           | 40 <sup>†</sup>       | $52 \pm 5$            | 329     | 272     | NM <sup>‡</sup> |

<sup>†</sup> Although the CBT operates in up to 13 3/8-in casing, the VOL presentation mainly shows casing arrivals where casings of 9 5/8 in and larger are logged.

<sup>‡</sup> NM = not meaningful.

# Cement Bond Logging

## Overview

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.

The recorded CBL provides a continuous measurement of the amplitude of sound pulses produced by a transmitter-receiver pair spaced 3-ft [0.91-m] apart. This amplitude is at a maximum in uncemented free pipe and minimized in well-cemented casing. A transit-time (TT) curve of the waveform first arrival is also recorded for interpretation and quality control.

A Variable Density\* log (VDL) is recorded simultaneously from a receiver spaced 5 ft [1.52 m] from the transmitter. The VDL display provides information on the cement quality and cement/formation bond.

## Specifications

### Measurement Specifications

|                                | Digital Sonic Logging Tool (DSLTL) and Hostile Environment Sonic Logging Tool (HSLT) with Borehole-Compensated (BHC)                        | Slim Array Sonic Tool (SSLT) and SlimXtreme* Sonic Logging Tool (QSLT)   |
|--------------------------------|---|--|
| Output                         | SLS-C, SLS-D, SLS-W, and SLS-E; <sup>†</sup><br>3-ft [0.91-m] CBL<br>Variable Density waveforms   | 3-ft [0.91-m] CBL and attenuation<br>1-ft [0.30-m] attenuation<br>5-ft [1.52-m] Variable Density waveforms                   |
| Logging speed                  | 3,600 ft/h [1,097 m/h]  | 3,600 ft/h [1,097 m/h]   |
| Range of measurement           | 40 to 200 us/ft [131 to 656 us/m]   | 40 to 400 us/ft [131 to 1,312 us/m]  |
| Vertical resolution            | Amplitude (mV): 3 ft [0.91 m]<br>VDL: 5 ft [1.52 m]   | Near attenuation: 1 ft [0.30 m]<br>Amplitude (mV): 3 ft [0.91 m]<br>VDL: 5 ft [1.52 m]                                       |
| Depth of investigation         | Synthetic CBL from discriminated attenuation (DCBL): Casing and cement interface<br>VDL: Depends on cement bonding and formation properties | DCBL: Casing and cement interface<br>VDL: Depends on cement bonding and formation properties                                 |
| Mud type or weight limitations | None  | None   |
| Special applications           |   | Conveyed on wireline, drillpipe, or coiled tubing<br>Logging through drillpipe and tubing, in small casings, fast formations |

<sup>†</sup> The DSLT uses the Sonic Logging Sonde (SLS) to measure cement bond amplitude and VDL evaluation.

| Mechanical Specifications |   |   |   |   |
|---------------------------|---|---|---|---|
|                           | DSL   | HSL                                       | SSL   | QSL   |
| Temperature rating        | 302 degF [150 degC]   | 500 degF [260 degC]                       | 302 degF [150 degC]   | 500 degF [260 degC]   |
| Pressure rating           | 20,000 psi [138 MPa]  | 25,000 psi [172 MPa]                      | 14,000 psi [97 MPa]   | 30,000 psi [207 MPa]  |
| Casing ID—min.            | 5 in [12.70 cm]   | 5 in [12.70 cm]                           | 3½ in [8.89 cm]   | 4 in [10.16 cm]   |
| Casing ID—max.            | 18 in [45.72 cm]  | 18 in [45.72 cm]                          | 8 in [20.32 cm]   | 8 in [20.32 cm]   |
| Outside diameter          | 3¾ in [9.21 cm]   | 3¾ in [9.53 cm]                           | 2½ in [6.35 cm]   | 3 in [7.62 cm]  |
| Length                    | SLS-C and SLS-D: 18.7 ft [5.71 m]<br>SLS-E and SLS-W: 20.6 ft [6.23 m]              | With HSL-W sonde:<br>25.5 ft [7.77 m]     | 23.1 ft [7.04 m]<br>With inline centralizers:<br>29.6 ft [9.02 m] | 23 ft [7.01 m]<br>With inline centralizers:<br>29.9 ft [9.11 m]   |
| Weight                    | SLS-C and SLS-D: 273 lbm [124 kg]<br>SLS-E and SLS-W: 313 lbm [142 kg]              | With HSL-W sonde:<br>440 lbm [199 kg]     | 232 lbm [105 kg]<br>With inline centralizers:<br>300 lbm [136 kg] | 295 lbm [134 kg]<br>With inline centralizers:<br>407 lbm [185 kg] |
| Tension                   | 29,700 lbf [132,110 N]  | 29,700 lbf [132,110 N]                    | 13,000 lbf [57,830 N]   | 13,000 lbf [57,830 N]   |
| Compression               | SLS-C and SLS-D:<br>1,700 lbf [7,560 N]<br>SLS-E and SLS-W:<br>2,870 lbf [12,770 N] | With HSL-W sonde:<br>2,870 lbf [12,770 N] | 4,400 lbf [19,570 N]  | 4,400 lbf [19,570 N]  |

## Calibration

Sonde normalization of sonic cement bond tools is performed with every Q-check. Scheduled frequency of Q-checks varies for each tool. Q-check frequency is also dependent on the number of jobs run, exposure to high temperature, and other factors.

The sonic checkout setup used for calibration is supported with two stands, one on each end. A stand in the center of the tube would distort the waveform and cause errors. One end of the tube is elevated to assist in removing all air in the system, and the tool is positioned in the tube with centralizer rings.

## Tool quality control

### Standard curves

CBL standard curves are listed in Table 1.

Table 1. CBL Standard Curves

| Output Mnemonic | Output Name                       |
|-----------------|-----------------------------------|
| BI              | Bond index                        |
| CBL             | Cement bond log (fixed gate)      |
| CBLF            | Fluid-compensated cement bond log |
| CBSL            | Cement bond log (sliding gate)    |
| CCL             | Casing collar log                 |
| GR              | Gamma ray                         |
| TT              | Transit time (fixed gate)         |
| TTSL            | Transit time (sliding gate)       |
| VDL             | Variable Density log              |

## Operation

The tool must be run centralized.

A log should be made in a free-pipe zone (if available). Where a micro-annulus is suspected, a repeat section should be made with pressure applied to the casing.

## Formats

The format in Fig. 1 is used for both acquisition and quality control.

- Track 1
  - TT and TTSL should be constant through the log interval and should overlay. These curves deflect near casing collars. In sections of very good cement, the signal amplitude is low; detection may be affected by cycle skipping. GR is used for correlation purposes, and CCL serves as a reference for future cased hole correlations.
- Track 2
  - CBL measured in millivolts from the fixed gate should be equal to CBSL measured from the sliding gate, except in cases of cycle skipping or detection on noise.
- Track 3
  - VDL is a presentation of the acoustic waveform at a receiver of a sonic measurement. The amplitude is presented in shades of a gray scale. The VDL should show good contrast. In free pipe, it should be straight lines with chevron patterns at the casing collars. In a good bond, it should be gray (low amplitudes) or show strong formation signals (wavy lines).



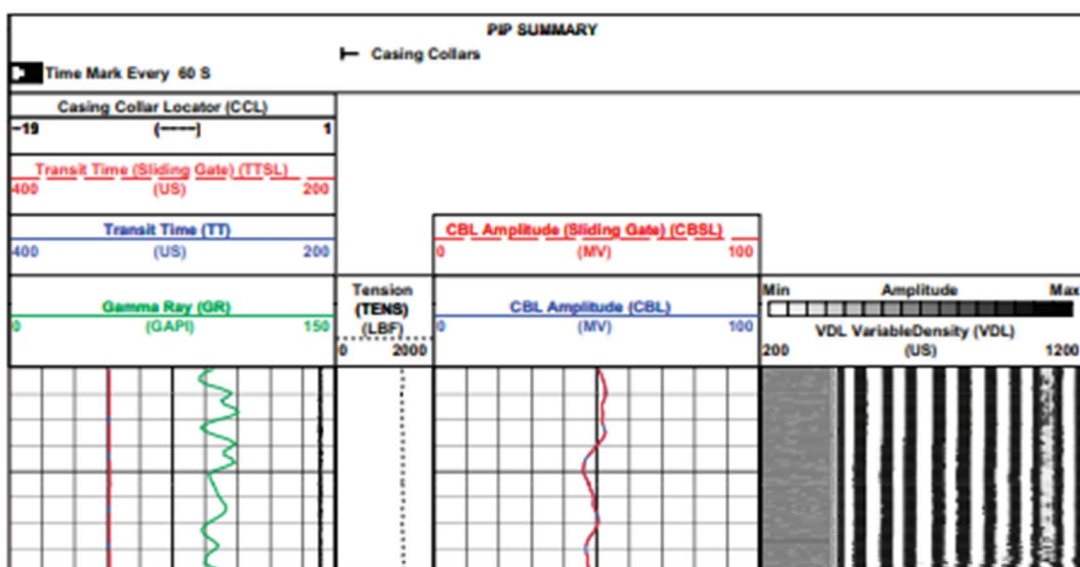


Figure 1. DSLT standard format.

## Response in known conditions

The responses in Table 2 are for clean, free casing.

| Table 2. Typical CBL Response in Known Conditions |                |                       |   |
|---|----------------|-----------------------|---|
| Casing OD, in                                     | Weight, lbm/ft | Nominal Casing ID, in | CBL Amplitude Response in Free Pipe, mV |
| 5   | 13             | 4.494                 | 77 ± 8                                  |
| 5.5   | 17             | 4.892                 | 71 ± 7                                  |
| 7   | 23             | 6.366                 | 62 ± 6                                  |
| 8.625   | 36             | 7.825                 | 55 ± 6                                  |
| 9.625   | 47             | 8.681                 | 52 ± 5                                  |
| 10.75   | 51             | 9.850                 | 49 ± 5                                  |
| 13.375  | 61             | 12.515                | 43 ± 4                                  |
| 18.625  | 87.5           | 17.755                | 35 ± 4                                  |