ATTACHMENT B: PRE-OPERATIONAL TESTING PROGRAM

DONALDSONVILLE SITE

Facility Information

Facility name: Ciel
CIEL NO.1

Facility contact: Lauren Read –Vice President BKVerde, LLC
1200 17th St, Suite 2100, Denver, CO 80202
Ph: +1 (720)375-9680; email: laurenread@bkvcorp.com

Well location: Donaldsonville, Ascension, Louisiana
NAD 1927 (Louisiana South Zone) X: 2,114,245.33′; Y: 511,857.41′

Introduction

The pre-injection testing activities at the following wells are described in this attachment: Class V in-zone monitor (IZM) well, Soleil No.1 Class VI injection (INJ) well, Ciel No.1; and above-zone monitor (AZM) well, Lune No.1. Testing and monitoring activities during the injection and post-injection phases are described in the Testing and Monitoring Plan, along with other non-well-related pre-injection baseline activities such as geochemical monitoring.

Pre-Injection Testing Plan – Injection Well Ciel No.1

The following tests and logs will be conducted during drilling and casing installation and after casing installation in accordance with the testing required under 40 CFR 146.87(a), (b), (c), and (d). The tests and procedures are described below and in the Proposed Injection Well Construction Information section of the permit application.

Deviation Checks

Deviation measurements will be conducted approximately every 100 feet during construction of the well.

Tests and Logs

The following tests and logs will be performed during drilling.

Logging Plan

Log data will be collected for the Ciel No.1 well.

Open hole log data will be acquired reflecting in-situ, structural, stratigraphic, physical, chemical, and geomechanical information for the Miocene formations, the upper confining unit, and other zones of interest. Wireline-conveyed open hole logs will be acquired at the surface and intermediate casing points and through the injection zone, including the injection targets. Open hole logs will not be acquired in the conductor casing hole.

Several logging requirements are necessary to meet Environmental Protection Agency (the regulatory agency) standards and the needs of a responsible operation. These logging requirements can be described using the three subsets detailed in **Table 1** and **Table 2**. These logging requirements include standard, advanced, and cased-hole logs. Standard logs include the gamma ray (GR), resistivity (Res), neutron (Neu), density (Den), caliper (Cali), and spontaneous potential (SP). Spontaneous potential is only used in zones with water-based mud. These data are used for primary injection interval and fluid characterization, including lithology, porosity, salinity, fracture identification, indications of permeability, and fluid saturations. The standard logs will answer most of the primary injection interval questions related to storage volume.

Advanced logs make up the second set of tools. These advanced logs include a multipole sonic tool, imaging tools (FMI), and a formation tester (MDT). These advanced tools meet the requirements of TAC §5.203(e)(2) and §5.203(f) (40 CFR §146.86 and §146.87). The sonic tool is a redundant porosity tool but is also key in understanding the geomechanics, stress direction, and existence of fractures in the injection interval and confining zones. The geomechanical interpretation is bolstered by the image logs, which can be interpreted for fracture identification, stratigraphy, stress direction, and dip. Using an MDT tool in concert with a dual packer will allow the acquisition of a fracture gradient for the confining and injection zones (minifrac). This information will help to determine optimal injection rates to maintain an effective seal. The advanced logs can answer most of the remaining borehole questions, including vertical connectivity, producibility, fluid chemistry, and geomechanics.

The planned cased-hole logs that will be run include cement bond logs (CBL) and other tools meant to set up baselines for the interval before injection; these are shown in **Table 2**. These baseline logs include casing inspection logs, an imaging caliper, and a pulsed neutronlog. Future logging of the injection interval with the same technology will allow the monitoring of the plume and the mechanical integrity of the wellbore.

The cased hole logging plan is in ***Table 2***.

Table 1. Ciel No.1 Open Hole Logging Plan

Run	Hole Section	Log Suite	Purpose	Hole Size (inches)	Depth (feet)
1	Surface	Quad combo: GR, Neu, Den, Res, Sonic	Identification of rock properties	17 1/2 x 26	0 to 2000

2	Intermediate	Quad combo: GR, Neu, Den, Res, Sonic	Identification of rock properties	17 1/2	2000 to 3800
3	Injection	Quad combo: GR, Neu, Den, Res, Dipole Sonic	Identification of rock properties; target data acquisition	12 1/4	3800 to 11500
4	Injection	Borehole Imager	Identification of rock properties; target data acquisition	12 1/4	3800 to 11500
5	Injection	Formation pressure tester - minifrac with dual packer and fluid sampler	Identification of rock properties; target data acquisition	12 1/4	3800 to 11500

Table 2. Ciel No.1 Cased-Hole Logging Plan

Run	Hole Section	Log Suite	Purpose	Casing Size (inches)	Depth (feet)
1	Surface casing	Ultrasonic, casing collar locator (CCL), CBL, Variable density log (VDL), GR, temperature	Cement investigation	20	0 to 2000
2	Intermediate casing	Ultrasonic, CCL, CBL, VDL, GR, temperature (bond log);	Cement investigation	13 3/8	0 to 3800
3	Intermediate casing	PNL baseline	Cement investigation	13 3/8	0 to 3800

4	Injection casing	Ultrasonic, CCL, CBL, VDL, GR, temperature (bond log);	Cement investigation	9 5/8	0 to 11500
5	Injection casing	PNL baseline	Cement investigation	9 5/8	0 to 11500

Demonstration of Mechanical Integrity

Table 3 is a summary of the mechanical integrity tests (MIT) and pressure falloff tests to be performed prior to injection:

Table 3. Pre-Operational Testing Schedule

Ciel No.1 Rule Citation	Rule Description	Test Description	Program Period
40 CFR 146.89(a)(1)	MIT—Internal	Internal casing pressure test	After casing cementing
40 CFR 146.87(a)(4)	MIT—External	Formation integrity test (FIT)	After drilling out of casing shoe
40 CFR 146.87(e)(1)	Testing prior to operating	Pressure falloff test	Prior to operation

BKVerde, LLC (BKVerde) will notify the regulatory agency at least 30 days prior to conducting the test and provide a detailed description of the testing procedure. Notice and the opportunity to witness the tests and logging runs shall be provided to the regulatory agency at least 48 hours in advance of a given test or logging run.

<u>Pre-Injection Testing Plan – Deep Monitoring Well Soleil No.1</u>

Deviation Checks

Deviation measurements will be conducted approximately every 100 feet during construction of the well.

Tests and Logs

To be performed during drilling

Coring Plan

Core samples will be collected during drilling of the Soleil No.1 well in the upper confining zone, the transition zone, gross injection interval, and the lower confining zone.

Sections of whole core cut in 30-feet increments and rotary sidewall cores will be collected from the upper confining zone and the Miocene sands (i.e., injection interval), as listed in **Table 4**. Whole core will follow low-invasion acquisition protocol using high-performance oil-based drilling fluid. Four-inch diameter whole cores will be drilled in the 8 ¾-inch section below intermediate casing. Because of anticipated poor consolidation and lack of cohesion in these siliciclastic rocks, special vented aluminum disposable core inner barrels and full-closure core catchers will be used. Wellsite core handling, stabilization, and preservation will follow strict guidelines to ensure seal and injection interval cores remain representative of in-situ rock properties. Sidewall cores will be acquired to fill gaps between whole core depths.

Detailed analytical programs will be conducted for seal and injection interval characterization to include the following:

1. Geoscience evaluation for core sedimentological descriptions; petrology and mineralogy to include thin-section petrography, X-ray diffraction, and scanning electron microscopy; fracture characterization (if warranted): and geochemistry.
2. Routine core analysis computed tomography and gamma ray scanning, photography, and determination of porosity, permeability, and grain size distribution. Pilot and fast-track studies will be conducted to optimize the analytical protocol and expedite results.
3. Rock mechanics will include Mohr-Coulomb failure analysis, quantification of mechanical impact on rock strength because of CO_2 injection and temperature effects (i.e., confining zone and the injection interval), uniaxial strain bulk rock and pore volume compressibility, thick-wall cylinder stability evaluation, and P/S-wave data acquisition.
4. Special core analysis (petrophysics) for electrical characterization, mercury injection to determine pore throat radii distribution and seal capacity, and other petrophysical measurements for wireline log calibration.
5. Special core analysis (reservoir engineering) to determine supercritical CO_2-brine multiphase flow (i.e., relative permeability) under steady-state conditions for drainage and imbibition (hysteresis effects), critical gas, trapped gas, threshold entry pressures, interfacial tension and contact angles, and capillary pressure measured using multiple methods.
6. Formation damage testing will include rock-CO_2-brine compatibility studies (static and dynamic) with mineralogical characterization before and after CO_2 contact, fines migration and critical velocity of solids evaluation, flow analyses to investigate acidity, and CO_2 fluid throughput effects.

The core analysis program, provided in **Table 4**, has been designed to thoroughly characterize seal and injection zones, determine the effects of CO_2-rock-brine interaction, and be compliant with Soleil No.1 requirements of the regulatory agency.

Table 4. Soleil No.1 Coring Program

Core Interval	Core Depth (feet true vertical depth subsea (TVDSS))	Lithology	Proposed Interval
1	4065–4095	Shale	Upper confining zone

2	4204–4234	Sandstone	Transition interval—Upper confining zone to Miocene sands formation
3 - 17	4340–4370 4825–4855 5220–5250 5525–5555 5995–6025 6600–6630 7180–7210 7500–7530 8235–8265 8435–8465 8700–8730 9090–9120 9535–9565 10435–10465 10855–10885	Sandstone	Intermediate injection interval—Miocene sands formation
18	11155–11185	Shale	Lower confining zone

Logging Plan

Log data will be collected for the Soleil No.1 well.

Open hole log data will be acquired reflecting in-situ, structural, stratigraphic, physical, chemical, and geomechanical information for the Miocene formation, the upper confining unit, and other zones of interest. Wireline-conveyed open hole logs will be acquired at the surface casing point, intermediate casing point, and the injection interval. Open hole logs will not be acquired in the conductor casing hole.

Several logging requirements are necessary to meet the EPA standards and the needs of a responsible operation. These logging requirements can be described using the three subsets detailed in ***Table 5*** and ***Table 6***. These logging requirements include standard, advanced, and cased-hole logs. Standard logs include the GR, Res, Neu, Den, Cali, and SP. Spontaneous potential is only used in wells with water-based mud. These data are used for primary injection interval and fluid characterization, including lithology, porosity, salinity, fracture identification, indications of permeability, and fluid saturations. The standard logs will answer most of the primary injection interval questions related to storage volume.

Advanced logs make up the second set of tools. These advanced logs include a multipole sonic tool, spectral gamma ray (SGR), nuclear magnetic resonance (NMR), and a formation pressure tester. These advanced tools meet the requirements of TAC **§5.203(e)(2)** and **§5.203(f)** (40 CFR **§146.86** and **§146.87**). The sonic tool is an additional porosity tool and is key in understanding the geomechanics, stress direction, and existence of fractures in the injection and confining zones. The geomechanical interpretation is bolstered by the image logs, which can be interpreted for fracture identification, stratigraphy, stress direction, and dip. The formation tester will determine formation pore pressure and mobility through pretests. The gradient produced by interpreting individual pore pressures will indicate zones of over- or under-pressure and the potential for different injection interval compartments. With viscosity as a known, the permeability can be easily estimated from mobility or through post-sample buildups. In-situ samples acquired at multiple depths will determine the physical and chemical properties of the water and the flowing temperature of the fluid. Using a formation testing tool with a dual packer will allow the acquisition of a fracture gradient for the confining and injection zones. This information will help to determine optimal injection rates to maintain an effective seal. The advanced logs can answer most of the remaining borehole upscale questions, including vertical connectivity, producibility, fluid chemistry, and geomechanics.

The planned cased-hole logs that will be run include CBLs and several other tools meant to set up baselines for the interval pre-injection, are shown in Table 6. These baseline logs include casing inspection logs, an imaging caliper, and an oxygen-activation log. Future logging of the well with the same technology will allow the monitoring of the plume and the mechanical integrity of the wellbore.

Table 5. Soleil No.1 Open hole Logging Plan

Run	Hole Section	Log Suite	Purpose	Hole Size (inches)	Depth (feet)
1	Surface casing	Quad combo : Neu, Den, Res, Sonic, GR	Identification of rock properties	17 ½	0 to 2000
2	Intermediate casing	Quad combo : Neu, Den, Res, Dipole Sonic, GR	Identification of rock properties	12 1/4	2000 to 3800
3	Monitoring casing	Spectral GR – spectroscopy tools -NMR	Identification of rock properties	8 3/4	3800 to 11500
4	Monitoring casing	Sonic scanner acoustic platform (geomechanics basket)	Target data acquisition	8 3/4	3800 to 11500

5	Monitoring casing	Pressure tester with extra-large diameter probe and fluid sampling, fluid analyzer, MDT pumpout, multisampler × 2	Target data acquisition	8 3/4	3800 to 11500
6	Monitoring casing	MDT stress testing with MDT dual packer	Target data acquisition	8 3/4	3800 to 11500

Table 6. Soleil No.1 Cased-Hole Logging Plan

Run	Hole Section	Log Suite	Purpose	Casing Size (inch)	Depth (feet)
1	Surface	Ultrasonic, CCL, CBL, VDL, GR, temperature	Cement investigation	13 3/8	0 to 2000
2	Intermediate	Ultrasonic, CCL, CBL, VDL, GR, Temperature (bond log)	Cement investigation	9 5/8	0 to 3800
3	Intermediate	PNL baseline	Cement investigation	9 5/8	0 to 3800
4	Monitoring	Ultrasonic, CCL, CBL, VDL, GR, Temperature (bond log)	Cement investigation	5 1/2	0 to 11500
5	Monitoring	PNL baseline	Cement investigation	5 1/2	0 to 11500

Table 7. MITs

Test Name	Test Description	Program Period
MIT—Internal	Internal casing pressure test	After casing cementing
MIT—External	Formational integrity test (FIT)	After drilling out of casing shoe

Pre-Injection Testing Plan – Shallow Monitoring Well Lune No.1

Deviation Checks

Deviation measurements will be conducted approximately every 100 feet during construction of the well.

Tests and Logs

Logging Plan

Log data will be collected for the Lune No.1 well.

Open hole log data will be acquired reflecting in-situ, structural, stratigraphic, physical, chemical, and geomechanical information for the Miocene formation, the upper confining unit, and other zones of interest. Wireline-conveyed open hole logs will be acquired at the surface casing point and upper confining zone. Open hole logs will not be acquired in the conductor casing hole.

There are several logging requirements necessary to meet the EPA standards and the needs of a responsible operation. These logging requirements can be described using the three subsets detailed in **Table 8** and **Table 9.**

These logging requirements include the standard logs, advanced logs, and cased-hole logs. Standard logs include the GR, Res, Neu, Den, Cali, and SP. Spontaneous potential is only used in wells with water-based mud. This data is used for primary injection interval and fluid characterization, including lithology, porosity, salinity, fracture identification, indications of permeability, and fluid saturations. The standard logs will answer most of the primary injection interval questions related to storage volume.

No advanced logs will be run on the shallow monitoring well. The planned cased-hole logs that will be run include CBLs and several other tools meant to set up baselines for the interval pre-injection, are shown in

. The baseline logs include casing inspection logs, imaging caliper, and an oxygen-activation log. Future logging of this well with the same technology will allow the monitoring of the plume and the mechanical integrity of the wellbore.

Table 8. Lune No.1 Open Hole Logging Plan

Run	Hole Section	Log Suite	Purpose	Hole Size (inches)	Depth (feet)
1	Surface	Triple combo: GR, Neu, Den, Res	Identification of rock properties	11	0 to 2000

2	Monitoring	Triple combo: GR, Neu, Den, Res	Identification of rock properties	7 7/8	2000 to 4200
3	Monitoring	Formation pressure tester - minifrac with dual packer and fluid sampler if we cannot get in Ciel No.1	Identification of rock properties	7 7/8	2000 to 4200

Table 9: Lune No.1 Cased-Hole Logging Plan

Run	Hole Section	Log Suite	Purpose	Casing Size (inch)	Depth (feet)
1	Surface	Ultrasonic, CCL, CBL, VDL, GR, Temperature	Cement investigation	8 5/8	0 to 2000
2	Monitoring	Ultrasonic, CCL, CBL, VDL, GR, Temp (Bond Log)	Cement investigation	5-1/2	2000 to 4200
3	Monitoring	PNL baseline	Cement investigation	5-1/2	2000 to 4200

Demonstration of Mechanical Integrity

Below is a summary of the MITs to be performed on the monitoring well(s), Soleil No.1 and Lune No.1, after installation and prior to commencing CO_2 injection operations. Notice and the opportunity to witness the test or log shall be provided to the regulatory agency at least 48 hours in advance of a given test/log.

Description of each MIT and the time when the test will be performed, e.g., prior to operation.

Annulus Pressure Test Procedures for Injection Well: Ciel No.1

BKVerde will perform an annulus pressure test on the injection well, Ciel No.1 to detect any significant leaks when the casing is subjected to a pressure equivalent to that which the casing would be exposed if the tubing or packer failed. To assure the integrity of the injection casing, the tubing/casing annulus will be tested at a pressure equal to the maximum allowed injection pressure or 1,000 psi, whichever is greater. The annular test pressure will be a difference of at least 200 psi either greater or less than the injection tubing pressure.

Annulus Pressure Test Criteria

1. The duration of the pressure test is 30 minutes.
2. Both the annulus and tubing pressures will be monitored and recorded every 5 minutes.
3. If there is a pressure change of 10% or more from the initial test pressure during the 30-minute duration, the test well has failed to demonstrate mechanical integrity and will be shut-in to determine the cause for remediation.
4. If there is no significant pressure change in 30 minutes from the time the pressure source is disconnected from the annulus, the test may be completed as passed.

Annulus Pressure Test: Recordkeeping and Reporting

The following procedure will be followed for recordkeeping and reporting of the test:

1. All the test results must be recorded in digital format.
2. The annulus pressure will be recorded at 5-minute intervals. Tests run by operators in the absence of an inspector from the regulatory agency must be conducted according to these procedures and recorded and a pressure recording chart documenting the actual annulus test pressures must be attached to the submittal.
3. The tubing pressure at the beginning and end of each test must be recorded.
4. The volume of the annulus fluid bled back at the surface after the test will be measured and recorded. This can be done by bleeding the annulus pressure off and discharging the associated fluid into a five-gallon container. The volume information can be used to verify the approximate location of the packer.

Annulus Pressure Test: Pre-test Planning

1. Scheduling the test will be done at least 2 weeks in advance.
2. Information on the well completion (location of the packer, location of perforations, previous cement work on the casing, size of casing and tubing, etc.) and the results of the previous MIT test will be reviewed by the field inspector in advance of the test. Regional Underground Injection Control (UIC) guidance will also be reviewed. Information relating to the previous MIT and any well workovers will be reviewed and taken into the field for verification purposes.
3. Wells may be shut-in for a 12- to 24-hour period prior to the test to assure that the temperature of the fluid in the wellbore is stable. Pressure falloff testing of any neighboring wells that could be influenced by this shut-in will be avoided.
4. The casing/tubing annulus will be filled with inhibited fluid at least 24 hours in advance, if possible.
5. Filling the annulus will be undertaken through one valve with the second valve open to allow air to escape. After the operator has filled the annulus, a check will be made to assure that the annulus will remain full. If the annulus cannot maintain a full column of fluid, the operator will notify the UIC Director and begin a rework. The operator will measure and report the volume of fluid added to the annulus. If not already the case, the casing/tubing valves will be closed, at least 24 hours prior to the pressure test.

Annulus Pressure Test Procedure

1. Read tubing pressure and record on the form. If the well is shut-in, the reported information on the actual maximum operating pressure will be used to determine test pressures.
2. Read pressure on the casing/tubing annulus and record value on the form. If there is pressure on the annulus, it will be bled off prior to the test. If the pressure will not bleed-off, the guidance on well failures will be followed.
3. Ask the operator for the date of the last workover and the volume of fluid added to the annulus prior to this test and record information on the form.
4. Hook-up well to pressure source and apply pressure until test value is reached.
5. Immediately disconnect pressure source and start test time (if there has been a significant drop in pressure during the process of disconnection, the test may have to be restarted). The pressure gauges used to monitor injection tubing pressure and annulus pressure will have a pressure range, which will allow the test pressure to be near the mid-range of the gauge. Additionally, the gauge must be of sufficient accuracy and scale to allow an accurate reading of a 10% change to be read. For instance, a test pressure of 600 psi will be monitored with a 0 to 1,000-psi gauge. The scale will be incremented in 20-psi increments.
6. Record tubing and annulus pressure values every 5 minutes.
7. At the end of the test, record the final tubing pressure.
8. If the test fails, check the valves, bull plugs, and casing head for possible leaks. The well will be retested.
9. If the second test indicates a well failure, the Region UIC Director will be informed of the failure within 24 hours by the operator, and the well will be shut-in within 48 hours. A follow-up letter will be prepared by the operator that outlines the cause of the MIT failure and proposes a potential course of action. This report will be submitted to the regulatory agency within 5 days.
10. Bleed off well into a bucket, if possible, to obtain a volume estimate. This will be compared to the calculated value obtained using the casing/tubing annulus volume and fluid compressibility values.

Annulus Pressure Test Procedures for Monitoring Wells, Soleil No.1 and Lune No.1

BKVerde will perform an annulus pressure test on the monitoring wells, Soleil No.1 and Lune No. 1 to detect any significant leaks when the casing is subjected to a pressure equivalent to that which the casing would be exposed if the tubing or packer failed. To assure the integrity of the long-string casing, the tubing/casing annulus will be tested at a pressure equal to 500 psi. The annulus test criteria, planning, and procedure are the same as for the injection well, as detailed in the previous section of this document.

Pressure Falloff Test Procedures

BKVerde will perform pressure falloff tests prior to the start of injection to meet the EPA requirements of 40 CFR 146.90(f). The operator will notify the regulatory agency, at least 30 days prior to conducting the test, and provide a detailed description of the testing procedure. The purpose of the test is to identify wellbore problems and injection interval characteristics. The test comprises a short period of injection followed by a period of shut-in for recording the pressure ***decline***. Injection rate and injection time are based on the estimated properties of each injection zone determined from analyzing the logs and core data from Ciel No.1 and Soleil No.1.

Testing Location and Frequency

Pressure falloff tests will be conducted on the Class VI injection well prior to the start of CO_2 injection. Results of the test and the analysis will be submitted to the regulatory agency electronically within 30 days of the test, per 40 CFR 146.91(e) and 146.91(b)(3). The operator does not foresee testing during the injection period, unless indicated by well injectivity performance. The pressure falloff test will be conducted in accordance with the regulatory agency guidelines on four of the 19 injection zones.

Falloff Test Requirements

The report to the regulatory agency will provide general information and an overview of the falloff test, an analysis of the pressure data obtained during the test, a summary of the test results, and a comparison of the results with the parameters used in the no-migration demonstration. Some of the following operator and well data will not change, so once acquired, it can be copied and submitted with each report. The falloff test report should include the following information:

1. Company name and address.
2. Test well name and location.
3. The name and phone number of the facility contact person. The contractor contact may be included if approved by the facility in addition to a facility contact person.
4. A photocopy of an open hole log (SP or GR) through the injection interval illustrating the type of formation and thickness of the injection interval. The entire log is not necessary.
5. Well schematic showing the current wellbore configuration and completion information, as detailed below:
    - Wellbore radius.
    - Completed interval depths.
    - Type of completion (perforated, screen and gravel packed, open hole).
6. Depth of fill depth and date tagged.
7. Offset well information:
    - Distance between the test well and offset well(s) completed in the same interval or involved in an interference test.
    - Simple illustration of locations of the injection and offset wells.
8. Chronological listing of daily testing activities.
9. Electronic submission of the raw data (time, pressure, and temperature) from all pressure gauges in a digital format. A READ.ME file will list all files included and any necessary explanations of the data. A separate file containing any edited data used in the analysis may be submitted as an additional file.

10. Tabular summary of the injection rate or rates preceding the falloff test. At a minimum, rate information for 48 hours prior to the falloff or for a time equal to twice the time of the falloff test is recommended. If the rates varied and the rate information is greater than 10 entries, the rate data should be submitted electronically as well as a hard copy of the rates for the report. Including a rate vs. time plot is also an effective way to illustrate the magnitude and number of rate changes prior to the falloff test.
11. Rate information from any offset wells completed in the same interval. At a minimum, the injection rate data for the 48 hours preceding the falloff test should be included in a tabular and electronic format. Adding a rate vs. time plot is also helpful to illustrate the rate changes.
12. Hard copy of the time and pressure data analyzed in the report.
13. Pressure gauge information:
    - List of all the gauges utilized to test the well.
    - Depth of each gauge.
    - Manufacturer and type of gauge including the full range of the gauge.
    - Resolution and accuracy of the gauge as a percentage of full range.
    - Calibration certificate and manufacturer's recommended frequency of calibration.
14. General test information:
    - Date of the test.
    - Time synchronization: A specific time and date should be synchronized to an equivalent time in each pressure file submitted. Time synchronization should also be provided for the rate(s) of the test well and any offset wells.
    - Location of the shut-in valve (e.g., note if at the wellhead or number of feet from the wellhead).
15. Injection interval parameters (determination):
    - Formation fluid viscosity (direct measurement or correlation).
    - Porosity (well log correlation or core data).
    - Total compressibility (correlations, core measurement, or well test).
    - Formation volume factor (correlations, usually assumed one for water).
    - Initial formation injection interval pressure.
    - Date injection interval pressure was last stabilized (injection history).
    - Justified interval thickness.
16. Injectate plume:
    - Cumulative injection volume into the completed interval.
    - Calculated radial distance to the waste front.
    - Average historical waste fluid viscosity, if used in the analysis.
17. Injection period:
    - Time of injection period.
    - Type of test fluid.
    - Type of pump used for the test (e.g., plant or pump truck).
    - Type of rate meter used.
    - Final injection pressure and temperature.
18. Falloff period:
    - Total shut-in time, expressed in real time and elapsed time.
    - Final shut-in pressure and temperature.

- Time well went on vacuum, if applicable.

19. Pressure gradient:
    - Gradient stops for depth correction.
20. Calculated test data: include all equations used and the parameter values assigned for each variable within the report.
    - Radius of investigation.
    - Slope or slopes from the semi-log plot.
    - Transmissibility.
    - Permeability.
    - Calculation of skin.
    - Calculation of skin pressure drop.
    - Discussion and justification of any injection interval or outer boundary models used to simulate the test.
    - Explanation for any pressure or temperature anomaly if observed.
21. Graphs:
    - Cartesian plot: pressure and temperature vs. time.
    - Log-log diagnostic plot: pressure and semi-log derivative curves. Radial flow regime should be identified on the plot.
    - Semi-log and expanded semi-log plots: radial flow regime indicated, and the semi-log straight line drawn.
    - Injection rate(s) vs. time: test well and offset wells.
22. A comparison of all parameters with those used in the demonstration, including references where the parameters can be found.
23. If necessary and/or applicable, a copy of the latest radioactive tracer run to fulfill the mechanical integrity testing requirement for the State and a brief discussion of the results.
24. Compliance with any unusual approval conditions such as the submission of a flow profile survey. These additional conditions may be addressed either in the falloff testing report or in an accompanying document.

Falloff Test Planning

The radial flow portion of the test is the basis for all pressure transient calculations. Therefore, the injectivity and falloff portions of the test should be designed not only to reach radial flow, but also to sustain a period sufficient for analysis of the radial flow period.

Successful well testing involves the consideration of many factors, most of which are within the operator's control. Some considerations in the planning of a test include the following:

- Adequate storage for the injectate should be ensured for the duration of the test.
- Offset wells completed in the same formation as the test well should be shut-in, or at a minimum, provisions should be made to maintain a constant injection rate prior to and during the test.
- Install a crown valve on the well prior to starting the test so the well does not have to be shut-in to install a pressure gauge.
- The location of the shut-in valve on the well should be at or near the wellhead to minimize the wellbore storage period.
- The condition of the well, junk in the hole, wellbore fill, or the degree of wellbore damage (as measured by skin) may impact the length of time the well must be shut-

in for a valid falloff test. This is critical for wells completed in relatively low transmissibility injection zones or wells that have large skin factors.

- Cleaning out the well and acidizing may reduce the wellbore storage period and therefore the shut-in time of the well.
- Accurate recordkeeping of injection rates is critical including a mechanism to synchronize times reported for injection rate and pressure data. The elapsed time format usually reported for pressure data does not allow an easy synchronization with real time rate information. Time synchronization of the data is especially critical when the analysis includes the consideration of injection from more than one well.
- Any unorthodox testing procedure, or any testing of a well with known or anticipated problems, should be discussed with the regulatory agency staff prior to performing the test.

Other pressure transient tests may be used in conjunction or in place of a falloff test in some situations. For example, if surface pressure measurements must be used because of a corrosive waste stream and the well will go on vacuum following shut-in, a multi-rate test may be used so that a positive surface pressure is maintained at the well. However, other pressure transient tests will be subject to prior approval of the regulatory agency.

If more than one well is completed into the same injection zone, operators are encouraged to send at least two pulses to the test well by way of rate changes in the offset well following the falloff test. These pulses will demonstrate communication between the wells and, if maintained for sufficient duration, they can be analyzed as an interference test to obtain inter-well injection zone parameters.

Falloff Pretest Planning

1. Determine the time needed to reach radial flow during the injectivity and falloff portions of the test:
   - Review previous well tests, if available
   - Simulate the test using measured or estimated injection zone and well completion parameters.
   - Calculate the time to the beginning of radial flow using the empirically based equations provided in the US regulatory agency Region 6 falloff testing guideline. The equations are different for the injectivity and falloff portions of the test with the skin factor influencing the falloff more than the injection period.

     - Injectivity period

$$t > \frac{(200000 + 12000 * s) * C}{\frac{k * h}{\mu}}$$

     - Falloff period

$$t > \frac{170000 * C * e^{0.14*s}}{\frac{k * h}{\mu}}$$

where
t: time to radial flow (hours)
s: skin factor
C: wellbore storage coefficient (barrels/psi, bbl/psi)
k: formation permeability (mD)
h: interval thickness (feet)
μ: injectate viscosity (cP)

- Allow adequate time beyond the beginning of radial flow to observe radial flow so that a well-developed semi-log straight line occurs. A good rule of thumb is three to five times the time to reach radial flow to provide adequate radial flow data for analysis.

2. Adequate and consistent injection fluid should be available so that the injection rate into the test well can be held constant prior to the falloff. This rate should be high enough to produce a measurable falloff at the test well given the resolution of the pressure gauge selected. The properties of the fluid should be consistent. Any mobility issues should be identified and addressed in the analysis if necessary.
3. Bottomhole pressure measurements are required. One pressure gauge is required.
4. If two pressure gauges are utilized during the test, one gauge will serve as a backup, or for verification in cases of questionable data quality. The two gauges do not need to be the same type.

Conducting the Falloff Test

1. Tag and record the depth to any fill in the test well.
2. Simplify the pressure transients in the injection zone.
   - Maintain a constant injection rate in the test well prior to shut in. This injection rate should be high enough and maintained for a sufficient duration to produce a measurable pressure transient that will result in a valid falloff test.
   - Offset wells should be shut-in prior to and during the test. If shut-in is not feasible, a constant injection rate should be recorded and maintained during the test and then accounted for in the analysis.
   - Do not shut-in two wells simultaneously or change the rate in an offset well during the test.
3. The well must be shut-in at the wellhead or as near to the wellhead as feasible to minimize wellbore storage and after flow. The shut-in must be accomplished as instantaneously as possible to prevent erratic pressure behavior during the test.
4. Maintain accurate rate records for the test well and any offset wells completed in the same injection interval.
5. Measure and record the properties of the injectate periodically during the injectivity portion of the test to confirm the consistency of the test fluid.
6. The surface readout downhole pressure gauge must be located at or near the top of the injection interval unless previous testing indicates a more appropriate location. A surface

readout should be provided to allow flexibility in determining appropriate pressure measuring and recording time intervals and to ensure valid test data is generated and false testing runs can be identified and aborted.

7. The injection rate and injection liquid density for the test must be held constant prior to shut in.
8. The injection rate must be high enough and continuous for a period sufficient to produce a pressure buildup that will result in valid test data.
9. The injection rate must result in a pressure buildup such that a semi-log straight line can be determined from the Horner plot. The injection rate should be the maximum injection rate that can be feasibly maintained constant to maximize pressure changes in the formation and provide valid test results, but the injection pressure will not exceed the maximum allowable surface injection pressure specified in the permit.
10. If the stabilization injection period is interrupted, for any reason and for any length of time, the stabilization injection period must be restarted.
11. The falloff portion of the test must be conducted for a length of time sufficient such that the pressure is no longer influenced by wellbore storage or skin effects and enough data points lie within the infinite acting period and the semi log straight line is well developed.

Evaluation of the Test Results

A licensed geologist or licensed professional engineer, knowledgeable in the methods of pressure transient test analysis, must evaluate the test results.

1. The following information and evaluations must be provided with the test report:
    - Prepare a Cartesian plot of the pressure and temperature versus real time or elapsed time.
    - Confirm pressure stabilization prior to shut-in of the test well.
2. Look for anomalous data, pressure drop at the end of the test, determine if pressure drop is within the gauge resolution.
3. Prepare a log-log diagnostic plot of the pressure and semi-log derivative.
    - Identify the flow regimes present in the well test.
    - Use the appropriate time function depending on the length of the injection period and variation in the injection rate preceding the falloff.
    - Mark the various flow regimes, particularly the radial flow period
    - Include the derivative of other plots, if appropriate (e.g., square root of time for linear flow)
    - If there is no radial flow period, attempt to type curve match the data.
4. Prepare a semi-log plot.
    - Use the appropriate time function depending on the length of injection period and injection rate preceding the falloff.
    - Draw the semi-log straight line through the radial flow portion of the plot and obtain the slope of the line.
    - Calculate the transmissibility.
    - Calculate the skin factor and skin pressure drop.
    - Calculate the radius of investigation.
5. Explain any anomalous data responses. The analyst should investigate physical causes other than injection zone responses.

6. All equations used in the analysis must be provided with the appropriate parameters substituted in them.

Note: Tests conducted in relatively transmissive injection zones are more sensitive to the temperature compensation mechanism of the gauge because the pressure buildup response evaluated is smaller. For this reason, the plot of the temperature data should be reviewed. Any temperature anomalies should be noted to determine if they correspond to pressure anomalies.