Understanding Key Aspects of Well Integrity: A Workshop

J. Daniel Arthur, P.E., SPEC; Tom Tomastik, CPG

Presented at:
Ground Water Protection Council
UIC Conference, Tulsa, Oklahoma
February 11 – 14, 2018
Well Integrity Workshop - Discussion

- Defining Well Integrity
- Resources
  - EPA Region V Guidance
  - Ohio UIC Program and MI Testing
  - Class II Well Integrity Testing in Texas
- Holistic Well Evaluation
- Mechanical Integrity Testing
  - Geophysical logging
  - Surface wellhead integrity
  - Downhole Video Logging
- Remediation Considerations
- Take-Aways
DEFINING WELL INTEGRITY
What is Well Integrity

• General Definition
  – Well Integrity is the Design, Installation, Operation and Maintenance of all Well Equipment to a standard that ensures the Safe Containment of Produced Well Fluids & Injectates for the Life of the well.

• EPA UIC Program
  – An injection well has mechanical integrity if (1) there is no significant leak in the casing, tubing, or packer; and (2) there is no significant fluid movement into an USDW through vertical channels adjacent to the injection wellbore.
Why do Integrity testing?

• To assure objectives are achieved and to avoid unwanted or unauthorized releases/failures.

• Integrity testing serves to confirm that our physical and mechanical systems are functioning as designed.

• Integrity testing and analysis is used in multiple aspects of unconventional operations:
  - pressure testing before fracturing
  - injection well integrity
  - pipelines
  - casing and cementing for protection of groundwater
  - assessing possible behind pipe integrity (e.g., methane intrusion)
  - impoundments/tanks to avoid releases

Source: All Consulting, 2015
Integrity Testing

- Integrity testing is a daily procedure in the energy industry, including throughout the development of unconventional resources.
- Integrity testing is utilized much more than might be imagined, especially by the public.
- Well integrity is a major topic of discussion for a variety of reasons:
  - Macondo Incident in the Gulf
  - Various pipeline releases
  - NGO/Public opposition (e.g., Gasland)
Well Integrity Considerations

• Internal Integrity
  – Tubing and Casing Integrity
  – Packers, Plugs, Perfs

• External Integrity
  – Cement, Mud, Annular fluids
  – Gas/Fluid Intrusion
    • Via Microannulus
    • Via Cement Channels
    • Through Cement Pores
    • Fracture Systems

Other Integrity Considerations

• Tanks and Trucks
• Pipelines
• Pumping Equipment
• Valves and Connections
• Well Pad, Pits, Impoundments
• Wellheads
• Geologic System and Confinement
• Other

Source: ALL Consulting, 2014
## Defining the Issue

<table>
<thead>
<tr>
<th>Type</th>
<th>Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>UIC Internal MIT</td>
<td>Multiple barriers of protection limits actual risk to groundwater, but if left unaddressed, could result in fluid movement into a USDW.</td>
</tr>
<tr>
<td>UIC External MIT</td>
<td>Risks are limited and would require failed water protection strings and sufficient pressure to force entry into a USDW.</td>
</tr>
<tr>
<td>Production Well Tubing Leak</td>
<td>Wells may or may not have a packer. Industry standards include casing design of sufficient strength to withstand pressures. Requires replacement, but risks are minimal. For example, some tubing leaks may simply leak to another annular space.</td>
</tr>
<tr>
<td>Production Well Casing Leaks</td>
<td>Risk of releasing hydrocarbons will depend on well configuration, existence of tubing, cement placement, etc. Often detectable through annular monitoring. There are risks of losing product to various formations intersected by the wellbore and in a worst and most severe case, losing control of the well. Most instances are relatively benign.</td>
</tr>
<tr>
<td>Wellhead</td>
<td>Leaks from the wellhead assembly present risks of releases to the surface.</td>
</tr>
</tbody>
</table>

**NOTE:** Issues with offshore production, gas lift wells, CO2 sequestration wells, and other special circumstances can impact the type and magnitude of risk. The above is primarily assuming onshore production and injection.
Significance of Well Integrity

• All operators are aware that a loss of well availability due to well integrity has many potential impacts:
  – A direct impact on profitability
    • Producers or injectors
  – Potential HSE consequences
    • Loss of product, stray gas, escape of sequestered material
  – Potential regulatory consequences that may ultimately limit access or the use of practices

• Well integrity is critical to any well type!
Variations in Well Integrity

- Timing based issues
  - During drilling/completion
  - During operation
  - After operation has ceased
  - After well abandonment
- Location based
  - Tubing versus annular space
- Risk based
  - Testing (e.g., with fresh water)
  - Chance of release to the environment
- Other

At Marcellus gas well in Bradford County, Pennsylvania. Examples of a coupling failure that occurred during a HF stage.

Source: www.citizensvoice.com
Well Integrity Moving Forward

• This workshop presents just a glance at some of the facets of well integrity chosen by ALL Consulting.
• Well integrity is a critical aspect of all production and injection activities from and is best managed using a lifecycle well integrity management program.
• Much headway has been made in the realm of well integrity, but continued research and refinement in practices will undoubtedly occur.
• Unconventional resource development has played a key role to improving and better understanding well integrity practices.
Regional Guidance #5 covers the “Determination of Mechanical Integrity of Injection Wells.

The guidance is applicable to all classes of injection wells.

Although constructed by Region V, the information was developed with nationwide input and collaboration with the Robert S. Kerr Lab.

The guidance provides basic verbal discussion of both internal and external integrity testing methods.
Internal Integrity Test Methods

- Standard Annulus Pressure Test (SAPT)
- Standard Annulus Monitoring Test (SAMT)
- Radioactive Tracer Survey (RTS)
- Water-Brine Interface Test (W-BIT)
- The “Ada” Pressure Test
- Water-in-Annulus Test (WIAT)
External Integrity Test Methods

- Temperature Log
- Noise Log
- Oxygen Activation Log
- Radioactive Tracer Survey
- Cement Records
OHIO UIC PROGRAM AND MI TESTING

Source: ALL Consulting, 2017

Source: DMRM, 2007
Ohio UIC Program

- ODNR requires at least three (3) layers of steel casing to protect aquifers.
- Surface casing set at least 50 feet below deepest USDW.
- Initial mechanical integrity demonstration required prior to any injection.
- Pressure testing required to maximum allowable injection pressure.
Ohio Injection Wells

- As of 2018, there are 234 SWDs permitted in Ohio.
- In 2016, over 29 million barrels of waste water were injected.
- Currently, there are 217 SWDs in operation in Ohio.

Source: ODNR, 2018
Injection only through tubing and packer.
Continuous monitoring is required to maintain Mechanical Integrity (MI).
Five-year MI is not required since continuous monitoring is performed, but failure of internal MI requires a full MI test.
Additional rules implemented in 2012 can require additional testing and logging including:
- Tracer Surveys
- Noise Logs
- Temperature Logs
- Other logs or test as approved by Ohio DOGRM
Internal Mechanical Integrity Testing

- Internal MI testing requires the SAPT prior to injection.
- Annulus must be filled with freshwater and corrosion inhibitor.
- Packer must be set within 100 feet of the top of the injection zone unless a variance is granted.
- Testing is required to at least the maximum allowable surface pressure and is monitored for 15 minutes with no more than a 5% decline allowed.
- Minimum test pressure is 300 psig.
- Ohio DOGRM witnesses 100% of all MITs.
External MI is demonstrated by either cementing records or cement bond log.

- Requires at least 300 feet of cement above the top of the injection zone.
- Cement bond log is required when there is a lack of sufficient cement.
CLASS II INJECTION WELL INTEGRITY (INTERNAL) IN TEXAS
When Integrity Tests are Required

- Prior to beginning injection
- Every 5 years by Statewide Rule
- More frequently by Permit Special Conditions
  - For wells with short surface casing
- After workover:
  - When tubing-packer-casing seal is disturbed
  - When casing is repaired
- Whenever mechanical integrity is in doubt
Texas RRC Form H-5

- 48 hours notice required to the District Office.
- Form H-5 must be filed within 30 days.
- Pressure recording chart is required if not witnessed by the RRC.
SAPT Requirements

• Pressure Recorder
  – One-pen record for casing test pressure
  – Test pressure within 30-70% of chart
  – Clock rotation must not exceed 24 hours
  – Chart must be signed by Operator’s field rep.

• Pressure Gauge
  – Gauges required on tubing and each casing annulus
  – Gauges verify chart record readings
  – Test pressure within 30-70% of gauge
  – Gauge face marked in 5% increments of test pressure
Test Pressure Requirements

• If permit pressure is 200 psi or less
  – 200 psig minimum test pressure required
• If permit pressure is between 200-500 psi
  – Test at permit pressure
• If permit pressure is 500 psi or more
  – Injectors with tubing & packers test at 500 psig
  – Casing injectors test at max permitted pressure
• Maintain 200 psi tubing/casing differential
Two-Part Tests

- When the tubing pressure is within 200 psi of the required minimum test pressure, the test can be run in two parts:
  - Run first part at the required pressure
  - Run second part at a pressure either 200 psi higher or 200 psi lower than the tubing pressure
Example of Two Part Test

Source: Texas Railroad Commission
Length of Test

- A liquid-filled annulus is required for wells that inject liquids.
- For liquid-filled annulus, test pressure must stabilize within 10% of the required test pressure for at least 30 minutes.
- For a gas-filled annulus, test pressure must stabilize within 10% of the required test pressure for at least 60 minutes.
- Use of high viscosity packer fluids is prohibited.
Anomalies/Re-Tests

• Explain any pressure anomaly that occurs during the pressure test
• List characteristic, e.g. temperature changes of injection fluid, that might explain a small pressure change
• If the H-5 is reporting a Re-test as a result of a previous test that received a Fail or Inconclusive result, check the “Yes” box in Item 14 and explain, in Item 24, any remedial action that was taken
Examples

Successful Test

Pressure increases during test

<<High Tubing Pressure

February 2018

Copyright © 2018 ALL Consulting 31
Inconclusive Test Results

• The test pressure was less than required
• Pressure differential not at least 200 psi
• Pressure not within 30-70% of chart
• Test conducted for less than 30 or 60 minutes
• District Office not notified 48 hours in advance
• Test Pressure was within 10% but never stabilized
• Item on Form H-5 was either Blank or Incorrect
• Packer Depth shallower than that Permitted
Test Failure Options

• A Failed test, as determined by the RRC review process, generates a notice, sent by mail, instructing the operator to Repair & Retest, or Plug the well within 60 days.
  – Injection must cease immediately and may not resume until well is repaired and successfully retested.

• If the well is to be plugged, send a copy of the District Office approved W-3A to UIC in Austin and the W-3 when well is plugged
  – This will expedite the resolving of the Failure since UIC does not normally get copies of the W-3A or W-3 forms
HOLISTIC WELL EVALUATION

Well Integrity Certainty

- Timeline Analysis
- Pressure & Vent Rates
- Monitoring Data Analysis
- Casing & Cementing
Holistic Well Evaluation

- Well evaluation may compliment a regional or area analysis, but should consider issues of concern away from the well itself.
- Developing an understanding of regional geology & hydrogeology, drilling & completion practices, well integrity practices, historic area issues, etc. are combined in holistic analysis.
- Very detailed well information may be required depending on the issue(s) of concern.
- No single data result is likely to conclusively demonstrate an overall finding relative to MI. Rather, it’s a combination.
MECHANICAL INTEGRITY TESTING
Mechanical Integrity Testing Methods

• Geophysical logging
  – Temperature logging
  – Noise (Audio) logging
  – Cement evaluation logging
  – Radioactive tracer and spinner surveys
  – Corrosion logging
• Surface wellhead integrity
  – Pressure testing
  – Venting flow rate testing
  – Infrared imagery
  Downhole videography

Source: All Consulting, 2015
TEMPERATURE LOGGING
Temperature Logs

- Temperature logging – one of the oldest forms of production logging.
- Normal gradient – temperature typically increases uniformly with depth in natural setting.
- Deviations from normal gradient may be from fluid or gas entering the wellbore.
- Temperature logs are used to identify depths at which deviations from the gradient occur.

Source: ALL Consulting, 2015
Temperature Log Interpretation

Fluid Entrance from Formation

Fluid Entrance & Downward Fluid Movement

Gas Intrusion

Temperature Gradient

Recorded Temperature

Recorded Temperature

Temperature Gradient

Temperature Gradient
NOISE (AUDIO) LOGGING
• First described by Arco in ~1955 as a “quantitative “ tool, but utility was questionable.
• In 1973, Dr. McKinley (Exxon) started pointing out the utility of noise logging and ultimately worked with EPA and published a document on MI.
• For identification of gas movement behind pipe, noise logging can be crucial.
• Typically run with a temperature log and interpreted using other logs and data for the subject well.
• Unfortunately, interpretation is not commonly as straightforward as you might think!
Gas Migration and Noise (Audio) Logging

- When evaluating gas movement behind pipe as opposed to liquid, audio analysis is a fundamental tool.
- McKinley demonstrated in 1979 that gas movement makes more noise than liquid movement past a detector.
- Although noise logging can be used to assess liquid movement behind pipe, it is ideal for assessing gas movement!

Source: McKinley, 1994
## Noise (Audio) Logs

<table>
<thead>
<tr>
<th>Frequency Cuts</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 200 Hz</td>
<td>• Noise in the range from 10 Hz to 100 Hz generally accounts for mechanical or surface noise including cable vibrations caused by the motors of logging trucks, by lubricator motion, and other surface disturbances</td>
</tr>
</tbody>
</table>
| 200 Hz – 600 Hz| • Eliminates most surface noise while still being low enough to detect the action of gas moving upward through liquid (McKinley, Bowler and Rumble, 1973).  
• Discrete bubbling – reflected by a spectrum peak in the 300 to 600 Hz range (McKinley, Bowler and Rumble, 1973)  
• Mild Slugging – spectrum peak above 200 Hz decreases with only a slight indication of bubble peak, (McKinley, Bowler and Rumble, 1973)  
• Severe Slugging - more energy is transferred into a band around 200 Hz. (McKinley, Bowler and Rumble, 1973)  
• Above 200 Hz, channel type leaks exhibit the same frequency structure as does free-stream, grid-generated turbulence (McKinley, Bowler and Rumble, 1973). |
| 1,000 Hz – 2,000 Hz | • Noise spectra show presence of free-stream turbulence which is characteristic of single-phase flow (McKinley, Bowler and Rumble, 1973).  
• Above 1,000 Hz two-phase leaks are indiscernible from single-phase leaks (McKinley, Bowler and Rumble, 1973). |
The amplitude distribution varies depending on single or dual-phase flow.
Single v. Dual Phase Flow

Noise Log characteristics of single phase leak

Noise Log characteristics of a gas-liquid, two phase leak

February 2018  Copyright © 2018 ALL Consulting
Restrictions and Two-Phase Flow

NOTE: the example above is from McKinley (1973) and although a great example, actual conditions can vary. The example to the right shows two-phase flow and a restriction as evident from the RCBL.
Noise logging rarely yields ideal results

Even with good cement, audio amplitudes within the 30 mV range are common

However, sometimes a near perfect log is obtained - this example also is void of near surface disturbance, which is common with noise logging (i.e., increased noise activity in the upper 500’)

Remember, noise logs, like most logs, have settings controlled by the logging engineer and so logs can vary based on factors other than external well integrity
In this example, gas intrusion is observed above 2,000’ with apparent flow upward.

Flow appears to be single phase flow (gas only).

The noise log confirms the absence of deep gas in the annular space.
Similar to the previous slide, gas intrusion in the well’s mid-section is identified.

However, noise amplitudes are much higher than the prior example.

This may indicate higher rates or flow through tighter restrictions.

Review of the entire log also shows higher sensitivity on the lower portion of the log – this suggests that sensitivities may be artificially higher than actual.

The noise log confirms the absence of deep gas in the annular space.
Another Noise Log Example

• In this example, gas intrusion is observed at about 3,500’
• Flow appears to be single phase flow (gas only)
• Audio peaks likely due to restrictions or second gas intrusion point present
• The noise log confirms the absence of deep gas in the annular space
T/A LOGGING QUALITY CONTROL
Temperature and Noise (Audio) Logging

• Temperature and audio (T/A) logging, in association with cement evaluation type logging, is the most useful tool to confirm gas movement behind pipe.

• Effective T/A logging requires planning and well preparation.

• T/A logging should be complemented by other information (e.g., vent rate, RCBL, etc.).

• T/A logging can confirm the general source (e.g., producing zone versus shallower interval).

Source: ALL Consulting, 2013
Quality Control for T/A Logging

- Logging practices must be standardized to ensure consistent results
- The well must be properly prepared prior to logging
  - Production tubing should be removed
  - All casing and annuli must be completely fluid filled
  - Wellbore should be refilled, if needed, after completion of temperature log
  - The well must be allowed to stabilize for a minimum of 12 to 24 hours
- Well must be configured properly to ensure intended results are achieved
- Logs should be completed in sets to evaluate gas flow under varying wellbore conditions
  - Production casing closed and surface casing open: Intended to induce flow in annular space(s) to identify and characterize flow
  - Production casing open and surface casing closed: Intended to evaluate whether or not flow, if occurring, is exiting the wellbore
T/A Logging Procedures

- Temperature is logged from top to bottom and noise is typically logged on the upward pass.
- The logging company will log temperature on the downward pass at a consistent speed of no more than 30 ft/min.
- Anomalies identified on the temperature log should be documented and evaluated closely during noise logging.
- After completion of the temperature log on the downward pass, fluid levels in all casings should be re-filled as required.
- All unnecessary equipment should be turned off to minimize noise prior to the commencement of the upward pass.
- Noise logging intervals commonly range from 25 to 250 feet; data collection intervals can be made more dense in the event an issue is identified.
CEMENT EVALUATION LOGGING
Cement Evaluation Logs

- Cement evaluation logs are utilized to locate cemented sections in the wellbore and to evaluate the quality of the cement bonding in these zones.
- Cement evaluation logs do not provide a measure of fluid movement (either water or gas).
- Evaluating cement and cement bond quality in the presence of wellbore gas intrusion can be challenging.
- Multiple wellbore conditions must be taken into consideration to accurately interpret cement evaluation logs.

Radial Cement Bond Log of 7” casing in Oil and Gas production well

Source: Youngquist Bros, 2016
Logging Options

Acoustic Cement Bond Log (CBL)

Digital Magnelog (DMAG): Electromagnetic multi-frequency, multi-spacing casing inspection log.

Radial Analysis Bond Log (RAL): Improved cement evaluation capabilities

Segmented Bond Log (SBT): Quantitatively measures cement bond integrity in six angular segments.

Note: These examples provided by Baker Hughes as an example of various logging options.
Assessing Casing and Cement

- Prior to considering logging, understanding cementing methods is critical
- Insights regarding hole preparation, procedures, cement types, additives, etc. is important
  - For instance, a lighter weight cement may show differently on a bond log than a heavier cement
- Cementing Records
- Logging tools used for assessing cement bonding
- Physical testing

Source: ALL Consulting, 2016
Cement Bond Long Interpretation

**Good Cement**
- Low Amplitude
- Strong VDL

**Partial Cement**
- Varied Amplitude
- Varied VDL

**No Cement**
- High Amplitude
- VDL Straight
- Collars “Ringing”

**Microannulus**
- Varied Amplitude
- Varied VDL
- Pressured/No Pressure

Source: www.bridge7.com
Log Calibration Challenges

• Calibration is key in the use of any type of cement evaluation log
• Common calibration techniques involve finding an area of “free pipe” which is common in many wells
• Lack of a distinct free pipe area in which to perform calibration may lead to a less than ideal log
• Understanding calibration is necessary for cement evaluation log interpretation
• Acoustic cement bond logs require centralization to ensure accurate readings and interpretation
Well Integrity Evaluation Using Cement Bond Log

• Run wireline Cement Bond Log (CBL) in 13-3/8” casing at 0 and 1,500 psig casing pressure

• Use free pipe section at 400’ depth to calibrate CBL before wireline runs using 5 foot receiver wave forms to compensate for large diameter casing

Source: ALL Consulting, 2016
Additional Log Interpretation

Example of Free Pipe

Example of poor quality cement

Source: ODNR, 2013
A Microannulus (MA) is typically defined as a small separation between casing and cement where gas can travel, but not liquid.

A misconception is that if a well has a MA, it is continuous over the entire wellbore.

Actual conditions and testing reveal that often times, a MA occurs over discrete intervals (see example).

Recognizing the presence of the MA is important when assessing EWI related to stray gas intrusion in a wellbore annular space.
Cement Bond Log at 0 psig

- CBL of 13-3/8” casing (0 psig casing pressure)
- Amplitude range 30-50 mV
- VDL, collars ringing (note chevron pattern)
- VDL free pipe signal, “railroad tracks”

Source: Youngquist Bros, 2016
Cement Bond Log at 1,500 psig

- CBL of 13-3/8” casing (1,500 psig casing pressure)
- Amplitude 7-20 mV
- VDL strong profile, “no railroad tracks”, no ringing collars
- Comparison of CBLs (0 psig vs 1,500 psig casing pressure) indicates presence of micro-annulus
Estimating Top of Cement

• Estimating the Top of Cement (TOC) is not always as easy as one might think
• Even reaching a calculated TOC can be complex with the way wells are drilled today, with long-reach horizontals, varying hole sizes, varying cements, lead cement contamination, etc.
• Cement evaluation logs sometimes yield unclear results or may be performed under varying conditions (e.g., multiple passes conducted under varying pressures)
• Attempting to define TOC requirements as a regulatory requirement may be unrealistic or misguided
TRACER AND SPINNER SURVEYS
Radioactive Tracer Survey (RTS)

- An RTS is commonly used to test the mechanical integrity of the well
- The RTS detects the movement of the tracer fluid
- If mechanical integrity is compromised (tracer fluid is observed to split and travel in different directions), the test must identify the upward limit (i.e., shallowest well depth) of tracer fluid movement
- The RTS is run during active injection
- Typically set detector sensitivity low
- Prior to running the injection test a base log should be run to determine the baseline Gamma response of the formation
- Two different RTS procedures include Slug Tracking and Velocity Shot

Source: ALL Consulting, 2018
Radioactive Tracer Survey Tool

- Two basic parts to the RTS tool:
  - Top – reservoir and pump to deploy the tracer
  - Bottom – one or two GR detectors
    - Tools with Geiger counter sensors:
    - Tools with scintillation crystals;
    - Both tool types in current use
  - Casing collar locator often placed in between the two GR detectors
  - A temperature sensor often included in the tool assembly
  - Components of the tool may be rearranged
- The GR tool has a limited depth of investigation - 90% of gamma rays detected by the GR tool originate within one foot of the tool

Source: McKinley, 1994

February 2018
Radioactive Tracer

- Radioactive material (most commonly Iodine$^{131}$) is used to tag field brine
- I$^{131}$ has a half-life of 8.05 days
- Because of its negative charge, I$^{131}$ is not usually strongly adsorbed to the formation surface
- The tagged brine is injected near the zone of interest
  - A typical shot is approximately 1/100th of the tool reservoir volume
  - A typical shot contains approximately 0.05 microcuries of I$^{131}$
  - Equal to approximately 1,500 times typical GR background

Source: ALL Consulting, 2018

Tracer passes showing Iodine 131 going into perforations
RTS Slug Tracking Procedure

- Eject shot (slug) of tracer fluid above zone of interest
- Run RTS tool at timed intervals to observe movement of tracer fluid
- In this example:
  - Most fluid enters formation through perforations from ~9,560 to ~9,593
  - Some tracer observed below perforations
  - Second slug released at 9,604 feet – logged, did not show movement (not shown on this display)
  - Therefore, flow of tracer below the bottom perforation (logging runs H-K) observed occurring behind the casing

Example Drag Survey

Source: McKinley, 1994
RTS Velocity Shot Procedure

• Eject shot (slug) of tracer fluid above zone of interest
• Run RTS tool continuously at set, slow retrieval speed, time the passage of the tracer slug between the two detectors
• In this example:
  – Slug travels 5.5 vertical feet in 13.8 seconds (=24 feet/min)
  – Data can be used to confirm injection flow rates

Example Velocity Shot Survey

Source: McKinley, 1994
Example Survey of Casing Leak

• Injection well with positive pressure while shut-in
• Slug of tracer fluid placed above perforations
• 5 drags run on 5 consecutive days
• The centroid of the tracer slug moved upwards approximately 1 foot over four days indicating a small leak
• Note the logging tool must remain in the well for the entire survey time
Example Slug Tracking for Flow Behind Pipe

- Set detector sensitivity to 200 API units/inch
- Can run either slug tracking or stationary velocity surveys
- Slug tracking:
  - First check for loss behind pipe from uppermost perforations
  - Run background GR log before ejecting slug
  - Eject tracer slug ~20 feet above top perf
  - Run successive logs at same sensitivity as background log
  - After tracer logs are run, rerun background GR log as QA/QC check
  - Look for tracer that has split off from the main slug and migrated back uphole as an indication of flow behind pipe (see runs 4 and 5)

Arrows indicate Flow Behind Pipe

Source: McKinley, 1994
Example Velocity Shot of Flow Behind Pipe

- In this case the bottom detector was set 1 foot above the top of the perforations (8,146 to 8,152 feet)
- The log records the tracer slug as it passes the top detector and then the bottom detector

Source: McKinley, 1994
RTS CRITICALITIES

- Best suited to injection wells (single phase), not as commonly used in producing wells
- Tool configuration may be modified to suit the specific use
- The well should be stable (~72 hours at a stable flow rate) prior to logging
- Best if tool is centralized
- RA fluid must be soluble in or neutrally buoyant in the well fluids
- Baseline GR should be run prior to the RTS and final baseline run after ejection of all tracer slugs.
- Ejection times from shot to shot should be consistent
- Open hole wellbore must also have a caliper survey run for flow profiling
Spinner Survey

- Helical flowmeter well logging device
  - Vane-like spinner
- In situ velocity measurement
  - Injection wells
  - Production wells
- Results typically interpreted using multi-pass method
- Spinner flowmeter diagrams
  - Small diameter continuous, Full bore continuous, and Diverting

Sources: Smolen, 1996 and Schlumberger (n.d.)
Spinner Flowmeters

- Jeweled Bearing Continuous Flowmeter (1-3/8” to 2-1/8” diameter)

- Continuous spinners
  - Small diameter spinners used to measure flow in injection casing and tubing
  - Full bore spinners fold up for passage through tubing and open up to sample larger fraction of borehole

- Diverting spinners are run stationary at depths of interest

Source: Halliburton Energy Services, Inc., 2016
Injection Survey

• Injection survey to determine single rate injection profile
  – 1 Down shut-in pass
  – 3 Up/3 Down shut-in spinner calibration passes in 9-5/8” casing
  – 3 Up/3 Down 5 BPM injection passes
  – Pressure/Temperature stationary passes
  – Temperature/Pressure Decay 16 hour post injection

Source: Baker Hughes, Inc., 2016
Spinner Survey Interpretation

- Overlay of total injection and incremental injection versus temperature curves
- Temperature decay curve
  - Delayed warm-back signature indicates zone that receives injection fluid
- Geothermal curve
- Single rate injection profile indicates 3,088 BPD (42% of total injection) from depth interval of 8,422 to 8,428’
Oxygen Activation Log

- Pulsed neutron oxygen activation logging tool
- Utilized for leakage inspection
- Channeling
- Casing deformation determination

Source: www.ogj.com
CORROSION LOGGING
Because it is almost impossible to prevent corrosion, it is becoming more apparent that controlling and monitoring the corrosion rate may be the most economical solution.

Source: DMRM, 2010
Corrosion Mechanisms and Types

- **Electrochemical Corrosion**
  - Types: galvanic, crevice/pitting, stray current corrosion

- **Chemical Corrosion**
  - Types: hydrogen sulfide, polysulfides, sulfur, carbon dioxide, strong acids, concentrated brines, biological effects

- **Mechanical and mechanical-corrosive effects**
  - Types: cavitation, erosion, corrosion fatigue, sulfide stress corrosion, chloride stress cracking, stress corrosion cracking
Integrity Evaluation by Multi-Finger Caliper Log

Multi-finger caliper log wireline tool at Oil and Gas well

Close-up view of 40-finger feeler section

Source: ALL Consulting, 2016

Source: ALL Consulting, 2016
Multi-Finger Caliper Log from O&G Well

- Feeler deflection as % wall thickness
- Feeler deflection curves
- Casing wear observed on Joints 209 and 208
- Pipe analysis (metal loss, wall penetration)

Source: Expro, 2016
Multi-Finger Caliper Log from O&G Well (cont’d)

• Penetration profile
• 55 joints <10% wall penetration
• 193 joints 10-20% wall penetration
• Casing wear observed
  – 57% wall penetration on Joint 209 at 9,666’
  – 54% wall penetration on Joint 208 at 9,664’
• No loss of well integrity

Source: Expro, 2016
Corrosion Rate Device

- Corrosion Protection Evaluation Tool (CPET)
- Wireline tool with 4 sets of 3 electrodes, 2-foot spacing
- Collect stationary measurements of potential differences and casing resistance between electrode pairs to calculate casing current at each depth/station
- Difference in current between stations is used to calculate radial current density and compute the corrosion rate

Source: Schlumberger, 2004
Ultrasonic Imager Tool (USIT)

- Single rotating transducer to provide full coverage
- Ultrasonic sound pulses reflect off and resonate within the casing wall
- Transit time of first received echo gives the internal casing radius
- Frequency analysis of resonance signal provides casing thickness
- Allows internal and external metal loss computation

Source: Schlumberger, 2015
Composite Corrosion Logs

- Combine multiple corrosion tools to provide data for a composite corrosion log
- The example composite log uses data from caliper, electromagnetic, and ultrasonic devices to give a detailed picture of the casing corrosion condition

Source: www.spec2000.net
WELLHEAD PRESSURE TESTING
Testing Methods

- Visual inspection is a necessity!
- Pressure Testing
  - Shut-In Surface Casing Pressure Testing
  - Production Casing Build-Up/Leak-Off Testing
  - Pressure Differential Testing
- Pressure testing can be done as a single testing event or can be done using multiple tests to assess trends.
- Continuous pressure recordings are key.

Source: ALL Consulting, 2015
Pressure Testing

• Build-up and fall-off testing are used for various purposes:
  – Characterizing & evaluating integrity
  – Checking integrity of perforations
• For wells having more than one exterior annulus (e.g., 3-string well), all annular spaces should be tested.
• Transducers and data loggers should be utilized to ensure accurate and continuous monitoring and to allow for more detailed characterization and evaluation.
• Annular pressures are generally stopped if pressures exceed 300 psig as a safety precaution.
Shut-In Casing Pressure

Pressure (psig) vs. Time (hours)

Copyright © 2018 ALL Consulting
Pressure Testing Equipment

- Pressure transducers and data loggers should be utilized to ensure accurate and continuous monitoring and to allow for more detailed characterization and evaluation.
- Pressure transducers should be of an appropriate range to ensure accurate results.
- All equipment should be calibrated prior to testing and operated according to manufacturer’s specifications.
- A release valve or alarm should be used during testing to prevent overpressurizing the annulus.
- Continuous monitoring is key!
Shut-in Pressure Test Equipment Setup

Pressure Transducer & Data Logger

Test Assembly

Surface Casing Riser

Source: ALL Consulting, 2014
Importance of Electronic Data

• Electronic data loggers are the preferred method for logging pressure test data
• Electronic data provides the analyst with the ability to assess and compare pressure test results in multiple ways

Source: Texas Railroad Commission
Pressure test signatures collected using continuous monitoring devices allow detailed evaluation of annular pressure and its significance.

Pressure curve analysis facilitates a more robust assessment of trends than would otherwise be possible.

Source: ALL Consulting, 2012

Source: ALL Consulting, 2014
An added benefit of the continuous data collection is that it also has proven to be a valuable tool in identifying testing errors.

Source: ALL Consulting, 2012
Influences on Pressure Curves

- Formation Influences
- Multiple Influences
- Leaks, Weather, or?
- Peak Followed by Stabilization

Source: ALL Consulting, 2012

February 2018
Pressure Trend Analysis

- Assessing pressures for well integrity requires continuous recording for purposes of assessing pressure signatures, anomalies, and trends.
- Casing annular pressures may be exposed to open borehole and various geologic units that may create varied signatures compared to a SAPT of a casing/tubing annulus.
- Weather and external conditions can also impact results, making continuous recording a necessity.
Identifying Pressure Trends
Pressure Decline Analysis

[Graph showing pressure decline from Jul-11 to Jan-13 with key points labeled 132, 111, 90, 72, 62. A shaded area indicates the range of expected decline.]
Quality Control for Pressure Testing

- Pressure testing annular spaces requires quality control to achieve a good test
- If piping is exposed, freeze precautions may be required
- Equipment should be tested and managed to avoid mud-plugging
- Continuous recordings are important to confirm quality of results
- Gauges used should be of appropriate scale compared to pressure recorded
  - Using a 10,000 psig gage to measure 20 psig pressure is inappropriate
- Testing Procedures are recommended for field personnel to utilize

Source: All Consulting, 2012
VENT RATE TESTING
Vent Rate Testing

- Vent Rate testing is done to obtain an understanding of the relative volume of gas venting from the casing annuli.
- Testing can be done using a flow meter, manometer, or balloon test – depending on the flow rate.
- When flow rates are not detected by a flow meter or manometer, a balloon test can be used to provide a qualitative assessment of the flow rate.
- Even if no venting is identified, balloon tests provide good visual documentation.
Manometer Testing

- Used to quantify gas venting volumes from casing and casing annuli
- Measured in inches of water using a U-tube manometer or digital manometer
- Measurement converted to a flow rate recorded as thousand cubic feet per day (MCF/d)
- If flow rates are not detected with a manometer, a balloon test should be conducted to provide a qualitative assessment of flow rate or confirm the absence of a flow rate

Source: ALL Consulting, 2014
The balloon test was developed to provide a qualitative assessment of minor flow rates by documenting a visual indication of the volume of flow over a specified time period.

Balloon testing is conducted when a flow cannot be detected using a manometer or flow meter.

The test consists of allowing a small balloon (4 to 6 inches) to inflate for 10 minutes or until the balloon was fully upright.

Test duration is recorded and condition of the balloon logged with the photographic documentation.

Balloon tests are characterized by the varying levels of inflation observed (e.g., minimal, partial, upright inflation).
Example Balloon Tests

• Balloon tests require categorization as they don’t offer a quantitative result

• The above shows examples of minimal, partially, and upright inflation

• For consistency, care should be taken to ensure balloons with similar characteristics are used (e.g., size and weight)
Methane Monitoring

- Leak detection monitoring is performed to confirm presence of hydrocarbon leaks at the wellhead.
- Field procedures are developed to ensure that consistent methods are employed and quality data is obtained.
- Gas Detector monitors are used to determine if a combustible environment is present.

Infrared (IR) Videography

Source: ALL Consulting, 2015
Example of IR Camera Imaging

Wellhead in visible light

Hydrocarbon vapors are visible in infrared

Source: ALL Consulting, 2015
IR Detection

- Infrared video imaging can be a valuable tool to evaluate well conditions
- Infrared video can provide a visual representation of gas flow from the wellhead or cellar
DOWNHOLE VIDEO LOGGING
Video Logging

- Downhole video logging can be an additional tool utilized for well integrity
- Used in combination with other tools to assess well integrity issues

Source: DMRM, 2010
Video Inspection of Oil Well

Wireline video camera tool with LED light

Source: ALL Consulting, 2016

Source: Expro, 2016
REMEDIAL CONSIDERATIONS

Source: ALL Consulting, 2014
Thinking Ahead...

• Careful consideration must be given to determining the magnitude of a well integrity issue.
• Keep in mind that the best option for remediation of wellbore gas intrusion may simply be controlled venting.
• Physical remedial activities, such as perforating the production casing and squeezing with cement or other products is, challenging!
• Well remediation should only be undertaken in situations where the lack of well integrity is deemed a significant threat to a USDW, to an injection zone, to a hydrocarbon producing zone, or to different saltwater-bearing strata that would compromise the intended purpose of the well in question.
TAKE-AWAYS...
Considerations...

- A combination of testing methods and analyses can be used effectively to assess well integrity.
- Regulatory Agencies tend to seek tests and analysis methods that provide a black & white answer, but tend to recognize the complexities.
- Most testing methods do not offer an absolute and definitive answer regarding well integrity.
- Sometimes, achieving an absolute finding is difficult or impossible. This is why EPA allows some leak-off on the SAPT – achieving a zero leak-off is generally impossible considering all the factors involved.
- Some issues are simply a nuisance and not a significant environmental or safety concern.
Citation Information: