SS-25 Root Cause Analysis
Webinar
CPUC Proceeding: I.19-06-016
November 1, 2019
ACKNOWLEDGEMENTS

• CPUC
• DOGGR
• SoCalGas
• Service Companies
Webinar Logistics

• This Webinar is scheduled from 9 AM to 12 PM PDT.
• Presentation should last less than an hour
• Parties to the CPUC Proceedings will email the questions during or after the presentation.
• We will take a 15 minute break after the presentation, collate and then answer the questions.
Main Report

• Released May 16, 2019
  – SS-25 Well Failure Causes
    • Cause of the Failure (Metallurgical/Water)
    • Sequence/Timing of the Failure Events
  – SS-25 Post Leak Events
    • Well Deliverability
    • Well Kill Attempts
    • Pathway of the Gas
  – Aliso Canyon Casing Integrity
    • Casing Failure History
    • Shallow Corrosion in the Field
    • Gas Storage Regulations
  – Root Cause
    • Methodology
    • Causes/Solutions
Presentation Outline

• Approach & Timeline
• SS-25 Failure
• Post SS-25 Leak Events
• Aliso Canyon Casing Integrity
• Root Causes
SS-25 Well History

- Drilled and completed Oct 1953 – Apr 1954
- Oil and gas well 1954 – 1973
- Converted to gas storage May 1973 – Jun 1973
- Workover Feb 1979, replaced annular flow safety system
- Well service Jan 1980, removed annular flow safety system valve and packoff
- Ran numerous temperature and noise logs 1974 – 2014
- Casing leak Oct 23, 2015; successfully controlled well Feb 11, 2016
- Plugged and abandoned Sep 13, 2018
SS-25 Wellbore for Gas Storage

- Injection and withdrawal through the tubing and casing
- Casing flow was through open ports in the annular flow safety system above the packer
- 11 ¾ in. cementing problems
- No leaks or failures in SS-25 until October 23, 2015
Phases

• An RCA is a systematic process for identifying the root causes of problems or events and defining methods for responding to and preventing them.

• Phase 0: Data collection, collation and analyses
• Phase 1: Site Evidence collection and documentation
• Phase 2: Site restoration to rig readiness
• Phase 3: Tubing, casing, and wellhead extraction
• Phase 4: Non-destructive evaluation and metallurgical examination
• Phase 5: Integration, interpretation, and final report
### SS-25 RCA Timeline 2016 – 2019

<table>
<thead>
<tr>
<th>Year</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>Phase 0 - Data Collection, Collation, and Analyses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phase 1 - Site Evidence Collection and Documentation</td>
<td></td>
<td>Phase 2 - Site Restoration to Rig Readiness</td>
</tr>
<tr>
<td>2017</td>
<td></td>
<td>Discussions with SoCalGas and DOGGR on Phase 3 operations</td>
<td>SS-25 Collect Fluid Samples, Extract Tree and Tubing, Log Casing, P&amp;A Lower Wellbore</td>
<td>SS-25 Extract Tubing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SS-25 Collect Casing, Log and Evaluate 7 in. Production Casing and 11 3/4 in. Surface Casing Rig 540</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td>Discussions with SoCalGas and DOGGR on Phase 3 operations</td>
<td>SS-9 TH-1 Borehole and Logging</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SS-25 Extract Casing Rig 540</td>
<td>SS-25B Logging</td>
</tr>
<tr>
<td>2019</td>
<td></td>
<td></td>
<td></td>
<td>Phase 4 - NDE and Metallurgical Lab Examination</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phase 5 - Integration, Interpretation, and Final Reports</td>
</tr>
</tbody>
</table>

**Legends:**
- Phase 0
- Phase 1
- Phase 2
- Phase 3
- Phase 4
- Phase 5
Phase 0: Data Collection, Collation and Analysis

- Written records for the Aliso Canyon field and the SS-25 well
- Correspondence; internal and external to the field and company
- Field Operations
- Data requests
- Over 57,000 files collected and reviewed
- To understand the history of the well and field, model field processes, injection and withdrawal, etc.
SS-25 Root Cause Analysis

SS-25 Failure
Phase 1: Site Evidence Collection and Analysis

- Locate, document, and collect any physical evidence at the site surface that may be related to the leak event
- Assess condition of the wellbore and casing using through tubing logs

<table>
<thead>
<tr>
<th>Log</th>
<th>Log Name</th>
<th>Measures or detects</th>
</tr>
</thead>
<tbody>
<tr>
<td>MID</td>
<td>Magnetic Image Defectoscope</td>
<td>Metal loss and other anomalies in multiple strings</td>
</tr>
<tr>
<td>HPT</td>
<td>High precision temperature</td>
<td>Temperature and temperature changes in the wellbore</td>
</tr>
<tr>
<td>SNL</td>
<td>Spectral noise log</td>
<td>Sound caused by fluid movement in the annuli or the formation</td>
</tr>
<tr>
<td>MVRT</td>
<td>Micro Vertilog</td>
<td>Magnetic flux leakage inspection for internal and external metal loss</td>
</tr>
<tr>
<td>ICAL</td>
<td>Caliper</td>
<td>Mechanical measurement of internal diameter</td>
</tr>
<tr>
<td>GR</td>
<td>Gamma ray</td>
<td>Natural formation gamma rays</td>
</tr>
<tr>
<td>Camera</td>
<td>Video camera</td>
<td>Down and side-view video images</td>
</tr>
<tr>
<td>DTS</td>
<td>Distributed temperature sensing</td>
<td>Temperature vs. depth using fiber optics technology</td>
</tr>
</tbody>
</table>
SS-25 HPT Logging Results April 2016
SS-25 MID 7 in. Casing Inspection Results
April 2016

Deep significant metal loss adjacent to a connection at 895 ft
Verified by Micro Vertilog
Probable failure location
Phase 2: Rig Readiness

Wellhead Inspection
Crater Repair
Phase 2: Shallow Geology

- Geophysical data acquired at the SS-25 wellsite from:
  - Electrical Resistivity Tomography (ERT), 15 lines
  - Seismic, 4 lines
  - Nuclear magnetic resonance (NMR) survey
  - 4 shallow boreholes (cuttings/core analysis and wireline logging)

Physical properties of the geological layers, location of water, and to look for shallow faults
Phase 3: Tubulars Extraction

- Documents, protocols, permitting, and procedures
  - Work plans, HAZID and ETOP
  - Tubing, casing, wellhead extraction protocol
  - Tubular handling protocol and procedures to prevent damage to evidence
  - Evidence security protocol
  - Fluid and solids sampling procedures
  - Tubing and casing logistics protocols
  - Meetings and draft documents for regulatory permitting
  - SS-25A and SS-25B
  - P-35, P-34, SS-12, P-45, SS-44A casing and fluid samples
- Protocols reviewed by CPUC, DOGGR, PHMSA, National Labs, and SoCalGas
Tubing Extraction and Video Camera Results
August 2017

• Logs indicated 7 in. casing metal loss at approximately 895 ft
• Downhole Camera run below end of tubing to determine location of parted 7 in. casing

Upper parted casing pulled out of the well
Phase 3: 7 in. Casing Extraction

- Extraction of the upper 7 in. casing was accomplished without difficulty
- Essential for the RCA to extract the lower parted casing with minimal or no damage
- Lower parted casing was essential to establishing the sequence of the failures
- 1025 feet of 7 in. casing was extracted
Pawl Tool to Recover Lower 7 in. Casing Section without Damage

- Tool custom designed for this application
- Tool passes over the top of the casing stub
- Spring-loaded pawls catch on the connection OD upset to recover the casing section after the casing is cut
- Camera used to guide the tool over the casing
7 in. and 11 ¾ in. Casing Evaluation Tools

Objective was to gather as much information as possible on the condition of the casing and the wellbore before extracting the casing.

<table>
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<tr>
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<tr>
<td>GR</td>
<td>Gamma ray</td>
<td>Natural formation gamma rays</td>
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<tr>
<td>HRVRT</td>
<td>High resolution Vertilog</td>
<td>Magnetic flux leakage inspection for internal and external metal loss</td>
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<tr>
<td>MID</td>
<td>Magnetic Image Defectoscope</td>
<td>Metal loss and other anomalies in multiple strings</td>
</tr>
<tr>
<td>PNX</td>
<td>Pulsed neutron</td>
<td>Water saturation, carbon oxygen ratio, presence of gas</td>
</tr>
<tr>
<td>IBC</td>
<td>Isolation scanner</td>
<td>Solid-liquid-gas map of annulus material, hydraulic communication map, acoustic impedance, flexural attenuation, casing thickness image, internal radius image</td>
</tr>
<tr>
<td>SSCAN</td>
<td>Sonic scanner</td>
<td>Cement bond quality, formation characterization, identification of fractures</td>
</tr>
<tr>
<td>UCI-NEXT</td>
<td>Ultrasonic corrosion imager,</td>
<td>High resolution ultrasonic casing ID and OD imaging, lithology type, water and hydrocarbon identification</td>
</tr>
<tr>
<td></td>
<td>LithoScanner</td>
<td></td>
</tr>
<tr>
<td>CPET</td>
<td>Corrosion and protection</td>
<td>Identifies anodic/cathodic cells indicating active corrosion</td>
</tr>
<tr>
<td>CHDT</td>
<td>Cased hole dynamics tester</td>
<td>Drills a hole through the casing, measures pressure, collects fluid sample, plugs the hole</td>
</tr>
</tbody>
</table>
Phase 4: NDE and Metallurgical

- Examined casing and tubing joints from SS-25 using automated UT
- Conducted internal and external laser assessments on the extracted casing
- Connection testing and documenting flow rates on all casing connections extracted from SS-25
- Mechanical Testing including tensile, Charpy, chemistry and fracture mechanics
- Fractographic work using Scanning Electron Microscope and Focused Ion Bean (FIB).
- Energy dispersive spectroscopy, Raman spectroscopy, Inductively couple plasma (ICP)
- Microbiological analyses including MPN, qPCR and Amplicon Metagonics
7 in. Casing Rupture

- Axial rupture region
  - Bulged
  - Wall Loss maximum at Origin
  - Chevron Marks towards origin
7 in. Axial Rupture Origin Verified

Crack initiated within the groove.
Cracked region unstably grew and the axial rupture resulted
7 in. Casing Corrosion at Failure Location

- Metal Loss with striated grooves
- Grooves off axial around 10 to 15 degrees and not associated with any microstructural feature
- Numerous tunnels parallel to the axial rupture fracture surface
- Organic matter within tunnels
- Anerobic environment
- Amplicon Metagenomics- Predominantly Methanogens a form of Archaea that have been known to cause corrosion

### Table 13: Predominant Species Composition of Individual Casing Scale Samples

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanobacterium</td>
<td>0.6</td>
<td>0.9</td>
<td>0.4</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Desulfovibrio sp.</td>
<td>23.7</td>
<td>22.1</td>
<td>27.9</td>
<td>26.6</td>
<td>26.6</td>
<td>24.0</td>
<td>22.3</td>
<td>24.1</td>
<td>22.6</td>
</tr>
<tr>
<td>Methanothrix sp.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0.01</td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0</td>
</tr>
<tr>
<td>Methanocorpusulum</td>
<td>0</td>
<td>0</td>
<td>2.9</td>
<td>0</td>
<td>0.01</td>
<td>0.6</td>
<td>0</td>
<td>0.01</td>
<td>0</td>
</tr>
<tr>
<td>Alkalibacter sp.</td>
<td>5.8</td>
<td>32.4</td>
<td>0.1</td>
<td>0</td>
<td>0.04</td>
<td>0.1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.08</td>
</tr>
<tr>
<td>Alkalibacter sp.</td>
<td>24.0</td>
<td>31.1</td>
<td>24.1</td>
<td>12.2</td>
<td>26.7</td>
<td>6.4</td>
<td>2.8</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Alkalifex sp.</td>
<td>12.6</td>
<td>0.6</td>
<td>0.2</td>
<td>0.4</td>
<td>0.01</td>
<td>0.1</td>
<td>0.3</td>
<td>0.02</td>
<td>0.013</td>
</tr>
<tr>
<td>Haloarchaeosaccharus holophagus</td>
<td>1.1</td>
<td>0.2</td>
<td>3.0</td>
<td>2.6</td>
<td>7.6</td>
<td>11.08</td>
<td>2.4</td>
<td>1.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Ecteola sp.</td>
<td>6.8</td>
<td>0.8</td>
<td>0.02</td>
<td>0.1</td>
<td>0.01</td>
<td>0.02</td>
<td>0.06</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Select traits and list of organisms found to be present in greater than 1% of the total population of well 50-25 casing joints CO25 and CO26. Values are the percent abundance, color coded as such: Yellow are >10%, Blue are 1%-10%, Gray are 0%.

Microbial Corrosion at Failure Location
7 in. Casing Parting

- Circumferential Parting a separate event
- Indications of a brittle fracture confirmed with fractographic work
- Separate initiation
- Temperature estimated based on fracture toughness measurements to range from -76°F to -38°F
7 in. Casing Failure Sequence

- External corrosion with 85% wall reduction
- Corrosion caused by microbes resulting in grooves
- Notch acted like a stress concentrator
- Large patch of corrosion
- Axial rupture
- Cooled (-60°C to -39°C) and then circumferential parting

Two separate events-failure sequence
Water and Corrosive Media

- Two boreholes were drilled at SS-9 to assess location of ground water. Two distinct sources of ground water were identified.
  - Shallow (340 to 440 ft)
  - Deeper (900 to 1000 ft)
- Logged to assess the water layers
- Cased hole dynamics tester
  - Low salinity ground water clearly identified in certain samples
7 in. Casing Failure Sequence

October 23, 2015

- Well opened for injection between 3 and 4 AM
- Axial Rupture happened first
- Gas flow increased to a total of 160 mmscf/D
- Metal cooling resulted in brittleness and circumferential parting within hours of axial rupture
- All failures same day
7 in. Corrosion

- Annulus groundwater ingress and egress
- Dry and wet seasons
- External corrosion due to microbes
Summary

• Failure Sequence established
• Leak Sequence was identified
• Corrosion mechanism that caused the axial rupture was microbial
• Groundwater was the corrosive media
SS-25 Root Cause Analysis

Post Leak Events
Post Leak Events

• Blade’s objectives in analyzing these events were to answer the following questions:
  – When did the failure occur?
  – What was the initial leak rate? How did this leak rate change over time?
  – What phenomenon caused the low temperatures that facilitated the brittle circumferential parting identified by the metallurgical analysis?
  – What was the leak path? How did the leak path change over time?
  – How did the injection network respond to the failure? Could the failure have been detected in real time by a surveillance system?
  – Why did each of the kill attempts fail?
  – How much gas leaked from the reservoir during the incident?
# SS-25 Blowout Timeline

<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>Event(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 23, 2015</td>
<td>1</td>
<td>SS-25 leak was discovered at 3:15 PM and injection header valve was closed at 3:30 PM.</td>
</tr>
<tr>
<td>October 24, 2015</td>
<td>2</td>
<td>Wellhead seals were tested and repaired without any effect on the SS-25 leak.</td>
</tr>
<tr>
<td>October 25, 2016</td>
<td>3</td>
<td>Field injection was stopped.</td>
</tr>
<tr>
<td>November 6, 2015</td>
<td>15</td>
<td>Tubing ice plug was cleaned out using coiled tubing.</td>
</tr>
<tr>
<td>November 8, 2015</td>
<td>17</td>
<td>Production logs (temperature, noise, spinner, pressure) were run in SS-25.</td>
</tr>
<tr>
<td>November 12, 2015</td>
<td>21</td>
<td>Field depressurization was started.</td>
</tr>
<tr>
<td>November 13, 2015</td>
<td>22</td>
<td>Kill attempt #2. Failed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blowout vent opened 20 ft from the wellhead and shot “debris 75 ft into the air.” SS-25 “blew out in the conventional sense “</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relief well was planning started.</td>
</tr>
<tr>
<td>November 15, 2015</td>
<td>24</td>
<td>Kill attempt #3. Failed.</td>
</tr>
<tr>
<td>November 17, 2015</td>
<td>26</td>
<td>Notice of Intention to Drill New Well for P-39A relief well was filed with Division of Oil, Gas and Geothermal Resources (DOGGR).</td>
</tr>
<tr>
<td>November 18, 2015</td>
<td>27</td>
<td>Kill attempt #4. Failed.</td>
</tr>
<tr>
<td>November 20, 2015</td>
<td>29</td>
<td>SoCalGas decided to drill P-39A relief well.</td>
</tr>
<tr>
<td>November 23, 2015</td>
<td>32</td>
<td>Permit to drill P-39A relief well was issued by DOGGR.</td>
</tr>
<tr>
<td>November 24, 2015</td>
<td>33</td>
<td>Kill attempt #5. Failed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 ft × 10 ft crater was created at well site by fluids from kill job.</td>
</tr>
<tr>
<td>November 25, 2015</td>
<td>34</td>
<td>Kill attempt #6. Failed.</td>
</tr>
<tr>
<td>December 4, 2015</td>
<td>43</td>
<td>P-39A relief well was spudded (started drilling).</td>
</tr>
<tr>
<td>February 11, 2016</td>
<td>112</td>
<td>Relief well intersected with SS-25 and brought it under control. Leak was stopped.</td>
</tr>
<tr>
<td>February 14–17, 2016</td>
<td>115–118</td>
<td>SS-25 was permanently isolated from the gas storage reservoir with cement.</td>
</tr>
</tbody>
</table>
Well Deliverability

- Nodal-analysis well (inflow/outflow) model was built using available SS-25 data over its history and from an adjacent monitoring well SS-5 data
  - Well flow occurrences just prior and after the failure
  - Well flow following failure after shut in
- Well Outflow-Inflow model was developed using PROSPER
  - Estimated reservoir pressure in SS-25 and compared to adjacent monitoring SS-5 BHP
- Well Deliverability (or Gas Flow rate) was estimated the model developed
Inflow Performance Relationship (IPR)

- IPR – Bottom hole Pressure as a function of production rate
- IPR estimates that were matched to the 9 good well tests.
- Best estimate properties were established (80 md and 0 skin)
- Initial flow rates using the detailed PROSPER model was matched with two other methods of estimation
Estimated Leak Rate vs. Time Modeling

- Using flowing wellhead pressure, Shut in tubing to estimate bottom hole pressure and annulus dimensions to estimate flow rate - Upflow
- Matches the more detail Upflow-Inflow PROSPER models.

Different methods provided similar flow rates
Scientific Aviation Leak Rate vs. Time Modeling

[Graph showing scientific aviation measurements and curve fit with data points for blade rate estimation: best fit, new pipe, badly corroded pipe.]
Well Flow Nodal Analysis Leak Rate vs. Time Modeling

Flow rates during each kill attempts essential for appropriate Kill Modeling
SS-25 Kill Attempts

- Drillbench Blowout Software was used for the modeling
- Kill attempt 1 – 6 used low density fluid, 8.3 – 10 ppg at 5 – 13 bpm
- Kill modeling predicts a kill was possible with 12 – 15 ppg fluid at 6 – 8 bpm
- No evidence of kill modeling through Kill attempt 6
- Kill attempt 7 was distinctly different and nearly successful; however conditions had deteriorated on location and was not safe to continue

**Table 21: Kill Attempt #3 Alternatives**

<table>
<thead>
<tr>
<th>Gas Rate (MMscf/D)</th>
<th>Kill Fluid</th>
<th>Kill Rate (bpm)</th>
<th>Gas Flow Stopped?</th>
<th>Time to Stop Gas Flow (min.)</th>
<th>Time for One Circulation (min.)</th>
<th>Time Less than One Circulation</th>
<th>Surface Pressure when Influx Ceased (psia)</th>
<th>Maximum Pump Pressure (psi)</th>
<th>Successful Kill? Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td>12 ppg</td>
<td>8</td>
<td>Yes</td>
<td>35</td>
<td>35</td>
<td>Yes</td>
<td>2,416</td>
<td>2,431</td>
<td>Yes</td>
</tr>
<tr>
<td>15 ppg</td>
<td>6</td>
<td>Yes</td>
<td>43</td>
<td>46</td>
<td>Yes</td>
<td>0</td>
<td>1,521</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

Modeling and Assessment demonstrate that Kill could have been successful with heavier fluids at a higher pump rate
SS-25 Root Cause Analysis

Aliso Canyon Casing Integrity
Rationale

• Assess casing Integrity issues on a field wide basis
• Similarities or differences in mechanisms between SS-25 and other wells
• Assess the trend of casing leaks with age or other factors
Casing Failure Analysis Process

• Reviewed well files for Aliso Canyon gas storage wells
  – Drilling and completion reports
  – Workover and well servicing reports
  – Well log data
  – Well design
    • Casing size, wall thickness, grade, connection, setting depth, cementing
    • Tubing size, wall thickness, grade, connection, packer depth, completion equipment
  – Dates
    • Spud, completion, workover, well servicing, P&A (if applicable)

• Conformation of casing failures reported in the well file data

• Indications of casing failures leading to a workover
  • Anomalies from temperature, noise, or inspection logs
  • Annulus or anomalous pressure data
  • Visual, smell, sound, etc.
Aliso Canyon Historical Casing Failures

- 124 gas storage wells were evaluated for casing integrity
- 49 wells had casing failures
- 99 failures (63 casing leaks, 29 tight spots, 4 parted casing, 3 other)
- Repairs executed
  - Squeeze cementing
  - Inner casings
  - Scab liners
  - Casing patches
  - P&A
- No failure analysis reported
- No patterns of failures
  - Wide range of depths
  - Field wide failures

Number of Aliso Canyon Gas Storage Wells Reviewed, Wells with Casing Problems and Casing Failures by Spud Date
• Regulations required annual temperature surveys
• SS-25 complied with the requirements.
• No temperature anomalies—similar to previous surveys
1988 Memo for Casing Inspection of 20 Wells

- Plan to log 20 wells (SS-25 was on the list as low priority)
- 7 wells were logged within 2 years; 5 wells showed external wall loss from 20 – 60%
- Inspection logs were not run in SS-25
General Rate Case Submission

• GRC 2016 (testimony in 2014)
  – Historically, most of the well work was reactive in response to corrosion or other problems identified by routine surveillance. Well integrity issues were becoming more frequent.
  – Recognized the possibility of undetected hazards that could lead to major failures. Half of the 229 storage wells (4 fields) were more than 57 years old.
  – New funding requested for SIMP: a detailed assessment on underground assets—a proactive system to minimize risk
SS-25 Root Cause Analysis

Root Cause Analysis
Root Cause Analysis

• The final step was to integrate all of the data, analyzes, reviews and conclusions to understand the root causes.

• A systematic process, supported by data, evidence and technical analysis is necessary to identify the true underlying problems that contributed to the event.

• Blade selected a structured, evidenced based RCA process that makes no preconceived or predefined assumptions about possible causes.

• The process first defines a primary effect followed by identification of causes.
Root Cause Analysis-Primary Effect
Root Cause Analysis

• The next step was to explore the causes for each of the three effects to determine what had caused them and why.
• This process continued until identification of causes was no longer possible.
Root Cause Analysis

The investigation into the SS-25 incident revealed two types of causes: Direct causes and Root causes.

• **Direct Causes** are those that if identified and mitigated, would have prevented the SS-25 incident and would also prevent similar incidents.

• **Root Causes** are those that if identified and mitigated, would have prevented SS-25 type incidents and other well integrity incidents through the use of procedures, best practices, design, management system, standards, and regulations.
Causes

• Direct
  – Axial rupture due to microbial corrosion on the OD of the 7 in. casing
  – Unsuccessful top kills because of insufficient fluid density and pump rates

• Root
  – Lack of follow-up investigation
  – Lack of risk assessments for well integrity
  – Lack of dual barriers
  – Lack of wall thickness inspections (regulations or internal policy)
  – Lack of well specific well control plans
  – Lack of real-time continuous well surveillance
  – Lack of knowledge on the locations of ground water
  – Lack of systematic practices of external corrosion protection for surface casing strings
Solutions

• SoCalGas Current Practices and DOGGR Regulations implement the following:
  – A Risk Based Well Integrity Management System Should be Implemented
  – Casing Wall thickness inspection
  – Tubing Packer Completion – Dual Barrier System
  – Implement Cathodic Protection when appropriate
  – Well Surveillance Through Surface Pressure (Tubing and Annuli)
  – Well Specific Detailed Well Control Plan
  – Conduct a Casing Corrosion Study

• Additional Possible Solutions
  – Conduct a Casing Failure Analysis
  – Ensure Surface Casings Are Cemented to Surface for New Wells
Main Report

• Detail Summary and Root Causes
• Supplementary Reports
  – Four Volumes
Supplementary Report – Volume 1

• Approach:
  – Phase 0 Summary Report
  – Phase 1 Summary Report
  – Phase 2 Summary Report
  – Phase 3 Summary Report
  – Phase 4 Summary Report
Supplementary Report – Volume 2

• SS-25 Well Failure Causes
  – SS-25 Casing Failure Analysis
  – SS-25 7 in. Speedtite Connection Testing and 11 3/4 in. STC Assessment
  – SS-25 Analysis of Microbial Organisms on 7 in. Production Casing
  – SS-25 7 in. Casing Internal Corrosion Assessment
  – SS-25 Inspection Log Analyses
  – SS-25 Temperature, Pressure, and Noise Log Analysis
  – Aliso Canyon Field: Hydrology
  – SS-25 Geology Summary
  – SS-25 7 in. Casing Load Analysis
  – SS-25 Tubulars NDE Analyses
  – SS-25 Annular Flow Safety System Review
Supplementary Report – Volume 3

• Post SS-25 Leak Events
  – SS-25 Nodal Analysis with Uncontrolled Leak Estimation
  – Aliso Canyon Injection Network Deliverability Analysis Prior to Uncontrolled Leak
  – Analysis of the Post-Failure Gas Pathway and Temperature Anomalies at the SS-25 Site
  – SS-25 Transient Well Kill Analysis
• Aliso Canyon Casing Integrity
  – Analysis of Aliso Canyon Wells with Casing Failures
  – Aliso Canyon Shallow Corrosion Analysis
  – Aliso Canyon Surface Casing Evaluation
  – Review of the 1988 Candidate Wells for Casing Inspection
  – Gas Storage Well Regulations Review
  – Aliso Canyon Field Withdrawal/Injection Analysis
  – Aliso Canyon: Regional and Local Seismic Events Analysis
Questions and Answers