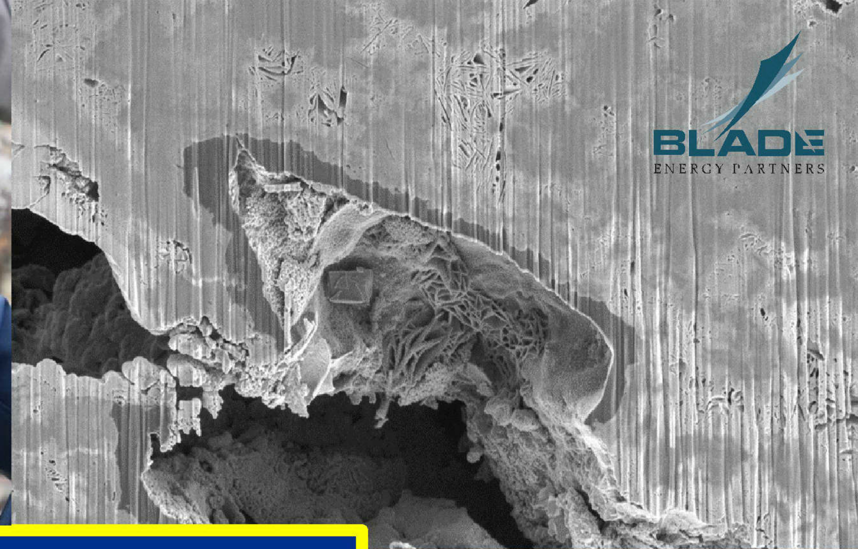

Root Cause Analysis of the Uncontrolled Hydrocarbon Release from Aliso Canyon SS-25

May 16, 2019

MAIN REPORT

The RCA work necessitated a substantial amount of testing, analyses, modeling, and interpretations. All of the technical details and discussions are provided in four volumes of supplementary reports. The integrated work is reflected in this Main Report.

MAIN REPORT

Root Cause Analysis of the Uncontrolled Hydrocarbon Release from Aliso Canyon SS-25

SUPPLEMENTARY REPORTS

Volume 1: Approach

- Phase 0 Summary
- Phase 1 Summary
- Phase 2 Summary
- Phase 3 Summary
- Phase 4 Summary

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

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

Volume 4: 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

SS-25 RCA Main Report

Root Cause Analysis of the Uncontrolled Hydrocarbon Release from Aliso Canyon SS-25

Purpose:
Root Cause Analysis Report

BLADE ENERGY PARTNERS

2600 Network Boulevard, Suite 550
Frisco, Texas 75034

+1 972-712-8407 (phone)
+1 972-712-8408 (fax)

16285 Park Ten Place, Suite 600
Houston, Texas 77084

1-800-319-2940 (toll free)
+1 281-206-2000 (phone)
+1 281-206-2005 (fax)

www.blade-energy.com

Date:
May 16, 2019

this section, the solutions that the ARCA process identified will be discussed first, and followed by the discussion on root causes.

5.3.1 Mitigation Solutions

Twelve solutions were identified that would have mitigated or prevented the primary effect – the uncontrolled release of hydrocarbons for 111 days from SS-25 well.

- **Solution 1: Production Casing Should be Cemented to the Surface**

  Corrosion initiated on the OD of the 7 in. casing because the environment in the annulus around that casing, above 11 3/4 in. casing set at 990 ft, was conducive to corrosion. Cementing the casing to surface changes the environment to one that is not conducive to corrosion, and the cement as a barrier that protects the OD from corrosion.

  This only applies to new wells and not existing wells that may not have originally been cemented to surface. For these wells, the uncemented section needs to be inspected for wall loss and then re-inspected at regular intervals. The fact that there is an uncemented interval does not automatically mean that corrosion will occur, but the casing wall thickness needs to be monitored. The fact that the casing may have wall loss from corrosion also does not automatically mean that the casing is bad or unsafe. Once the amount of wall loss is known, a new burst pressure rating can be calculated to determine whether the well can be safely operated or not. Whether the casing is cemented or not, periodic wall thickness monitoring is a current regulatory requirement [75].

- **Solution 2: Regulations Should Require Wall Thickness Inspections**

  The pre-2015 DOGGR regulations specified a mechanical integrity test program that allowed running a periodic temperature logging tool to meet the regulatory requirements. However, a temperature log does not measure wall thickness. Wall thickness inspections should be included in the mechanical integrity test program since they are a leading indicator of possible casing integrity issues with the wells.

- **Solution 3: Internal Policy Should Require Casing Wall Thickness Inspections**

  SoCalGas's internal well inspection policies should be expanded to include wall thickness inspections. The wells should be prioritized based on risk.

- **Solution 4: A Risk Based Well Integrity Management System Should be Implemented**

  An integrity management system should proactively identify potential problems, determine the associated risks, and then implement actions to prevent the problem from occurring or mitigates the risks. This is similar to the PHMSA required Transmission Integrity Management Program, Distribution Integrity Management Program, and the Storage Integrity Management Program that SoCalGas requested implementation funding for in 2014. Key components of such a system include:

  - A scope that is field-wide.
  - A baseline understanding of well conditions and operating environment.
  - An identification of well integrity risks such as the estimation of corrosion rates and other field wide trends.
  - Well design and operating standards.

- The use of multiple diagnostic methods for integrity testing (e.g., noise, temperature, corrosion inspection, and cement bond logs and pressure tests).
- The establishment of safe operating limits for each well.
- Risk management that evaluates risks and consequences in order to guide well integrity monitoring requirements and development of mitigation plans.
- A data tracking and reporting system.
- Periodic reviews to assess the system effectiveness.

Despite the casing leaks and casing failure history of the Aliso Canyon field, well integrity can be effectively managed with a robust risk management plan that includes probability of failure balanced with consequence of failure. Both aspects have to be addressed, and these wells can be safely operated for a long period of time.

- **Solution 5: Conduct a Casing Corrosion Study**

  Storage wells with good casing and tubing designs can last for long periods and operate safely. Casing corrosion is not uncommon, and its existence does not automatically mean that the casing is going to fail or is unsafe. However, developing an understanding of why corrosion occurs is important for the establishment of corrosion rates and appropriate mitigation plans. The production and surface casing strings should be studied separately. At Aliso Canyon the extent of groundwater and its access to the surface and production casing were not understood before the incident. Detailed investigation, including a study of all forms of corrosion in the field, should be undertaken. The differences in various sectors of the field should be understood and quantified. For example, using cathodic protection should be evaluated for surface casings and applied as needed. Production casings at risk of corrosion should be identified after a detailed assessment of the well design, drilling and completion data, and failure history. Corrosion can be monitored and mitigated. However, the causes and associated risks need to be formally evaluated and understood, and safe operating limits of a well need to be defined.

- **Solution 6: Conduct a Casing Failure Analysis**

  Despite numerous casing failures, no data were provided to indicate that failure causes were investigated. Casing failures need to be formally investigated so that their causes are identified and their implications are understood. Understanding and interpreting failures are critical to defining the propensity or risk of such failures field wide. Such analysis is an important part of any risk assessment. The cause may be straightforward, well specific, and easily mitigated. However, if the cause appears systemic, or the potential consequences are serious, then a more comprehensive investigation is needed to evaluate the potential risks to other wells in the field so that the appropriate mitigation steps are taken. For example, failure investigation of casing OD corrosion in another well might have directed attention to SS-25 and other similar wells. Running an inner string or plugging a well are valid mitigations, but prior to such actions, the cause of the casing leak or failure should be understood. The type of investigation should be commensurate with the risk and consequence of the failure, and should be part of the well integrity management system.

- **Solution 7: Regulations Should Require a Level 1 (Per API RP 585) Analysis of All Failures**

  API RP 585 *Pressure Equipment Integrity Incident Investigation,* discusses failure investigation of pressure equipment. The Aliso Canyon wells are a form of complex pressure vessels. A Level 1 type analysis of failures, as a minimum requirement, will identify the immediate causes of the failures or near misses and allow operators to understand the implications, if any.

- **Solution 8: Well Specific Detailed Well-control Plan**

  The top-kill attempts were unsuccessful. There were many causes for this that have already been discussed. Every storage well should have the following at a minimum:

  - A well-specific IPR curve. A clear understanding of this deliverability based on pressure.
  - A well specific kill plan based on transient modeling. Plans may be similar; however, a plan should be quantitatively developed for various scenarios (e.g., deep or shallow failure).
  - A relief well plan for each well that considers the surface location and overall approach.

- **Solution 9: Tubing Packer Completion–Dual Barrier System**

  SS-25 was operated so that gas injection and withdrawal was done through the 2 7/8 in. tubing and the 7 in. casing × 2 7/8 in. tubing annulus. As such, the 7 in. casing acted as a single barrier and when it failed, there was nothing behind it to contain the wellbore pressure and fluids. A tubing-packer completion provides two barriers. Gas injection and withdrawal is done only through the tubing. The packer isolates the production casing by tubing annulus from the gas flow. If the tubing fails, the casing acts as a second barrier preventing the wellbore pressure and fluids from escaping the wellbore. This allows the well to be killed and the tubing to be replaced. However, the casing must be designed to withstand the wellbore operating pressures throughout the life of the well.

- **Solution 10: Implement Cathodic Protection as Appropriate**

  Following the corrosion study there should be a good understanding of the groundwater intervals and the associated corrosion risk for existing wells. The surface casings that have inadequate cement isolation should be cathodically protected. This would prevent or stop the shallow corrosion of surface casings that might fail and allow water to enter the surface by production casing annulus causing corrosion on the production casing.

- **Solution 11: Ensure Surface Casings Are Cemented to Surface for New Wells**

  This applies to new wells and is already a regulatory requirement. Surface casing strings are not intended to act as a pressure barrier once the well has been completed. However, a fully cemented surface casing provides protection from corrosion. It will therefore isolate the production casing by surface casing annulus thereby reducing the risk of corrosion on the production casing.

  It is difficult to assess the quality of the surface casing cement on existing wells because the casing is not directly accessible. Wellbore integrity assessments therefore need to focus on the production casing.

- **Solution 12: Well Surveillance Through Surface Pressure (Tubing and Annuli)**

  The lack of real-time pressure measurements prevented the immediate identification of the 7 in. casing failure. The constant monitoring of the tubing, production casing and surface casing pressures will provide better insight into operational deviations in all wells. If this type of system had been installed on SS-25, it would have provided insight into the time of the leak, the opportunity to shut in the well immediately, size of the leak, and the extent of the problem. Furthermore, the information could have used during well-control effort improving the chances of an early success.

Table 42 lists all of the root causes identified during the ARCA process. The twelve solutions discussed address all the root causes. Table 42 also shows which of the solutions have already been addressed by