The Aliso Canyon Event – Lessons Learned

Barry Freifeld, Preston Jordan, Lehua Pan, and Curt Oldenburg
Lawrence Berkeley National Laboratory
Steve Bauer, Doug Blankenship, Ronald Dykhuizen, Barry Roberts
Sandia National Laboratories
Scott Perfect and Joe Morris
Lawrence Livermore National Laboratory

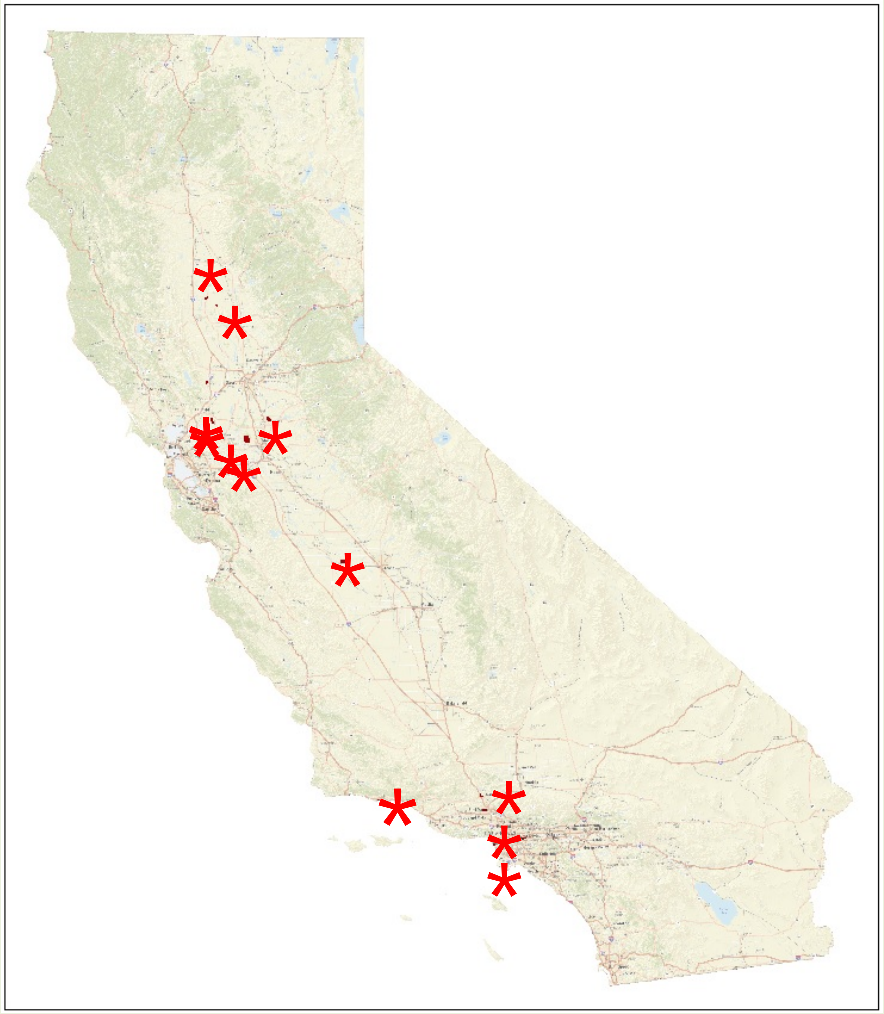
Background

- In October 2015, a leak developed at the Aliso Canyon Natural Gas Storage Facility that released large amounts of methane, impacted thousands of local residents, and took more than four months to seal.
- On February 17, 2016, state officials announced that the leak was permanently plugged. An estimated 97,100 tonnes of methane and 7,300 tonnes of ethane[1] was released into the atmosphere, making it the worst natural gas leak in U.S. history in terms of its environmental impact.
- A team of experts from DOE National Laboratories (LBNL, LLNL, and SNL) was assembled to support the California Department of Conservation, Division of Oil Gas & Geothermal Energy (Governor Browns Emergency Order Jan 6, 2016)
- DOE Formed an Interagency Task Force to address gas storage safety in April 2016. LBNL, LLNL, SNL, and NETL supported Well Integrity review

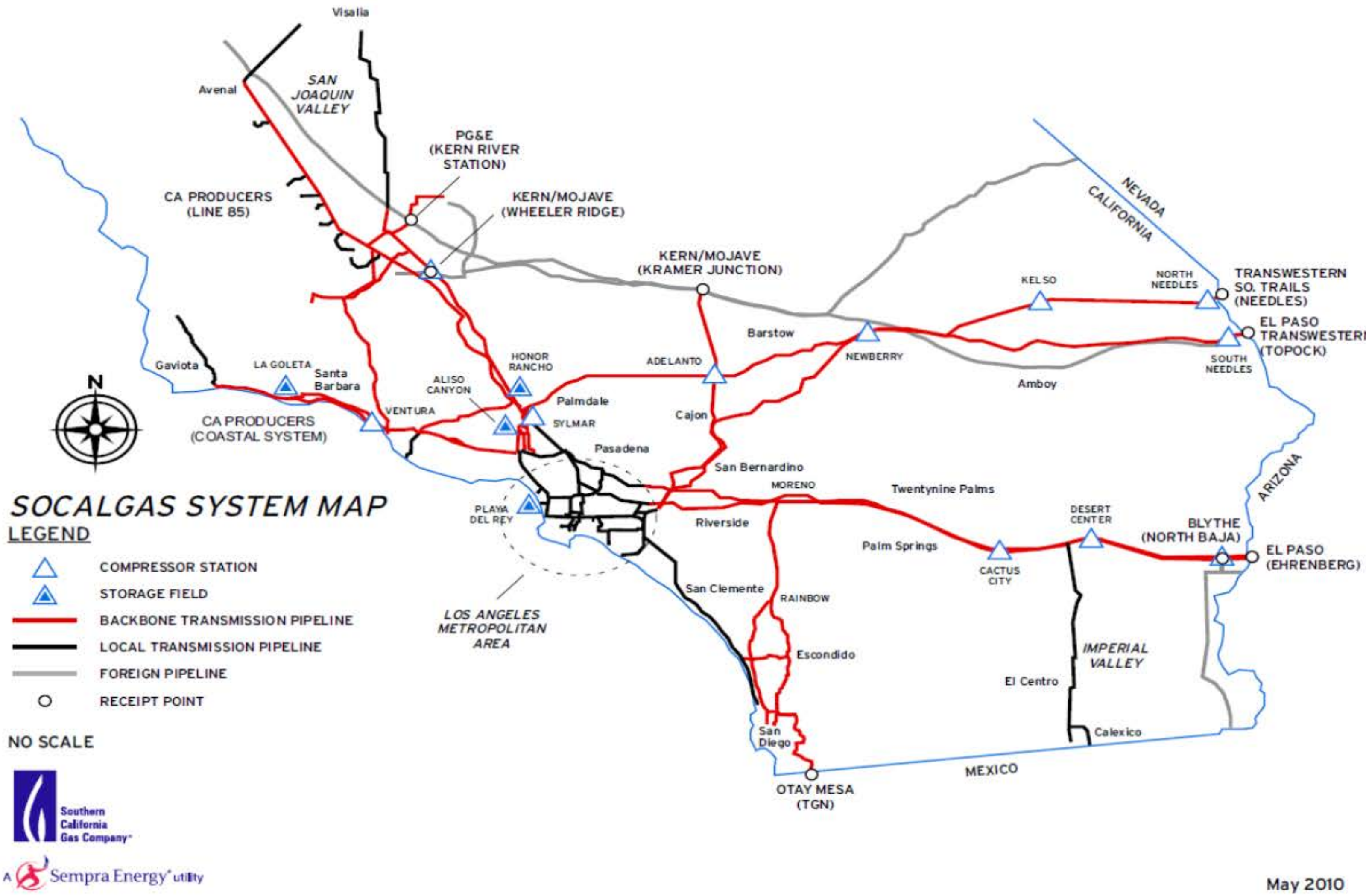
[1] CA DOC website (final leak estimate subject to revision)

Background - Gas Storage in California

Year – Field	Size (BCF)
1941 – La Goleta	21.5
1942 – Playa Del Rey	2.4
1973 – Aliso Canyon	86.0
1975 – Honor Rancho	24.2
1975 – Kirby Hills	15.0
1976 – McDonald Island	82.0
1979 – Los Medanos	18.0
1979 – Pleasant Creek	2.3
1997 – Wild Goose	75.0
2001 – Lodi	17.0
2010 – Princeton	11.0
2010 – Gill Ranch	20.0
TOTAL	**385.4**



Appendix
SoCalGas Territory Map



(From Feb 19, 2016 CEC, CPUC, CalISO Briefing)

Aliso Canyon Gas Storage Facility

- Facility is one of the largest in the U.S.
  - Serves 11 million citizens
  - Holds 86 billion cubic feet of working gas
- Winter and summer peak demands require gas from storage
- SoCalGas also operates three other smaller gas storage fields
- Over 2012-2015 withdrawals from Aliso average of 134 out of 151 winter days and 70 out of 214 summer days

Average # Days of Withdrawal from Aliso

	January	February	March	April	May	June	July	August	September	October	November	December
Avg # of Days of Aliso Withdrawal (2012-2015)	31	21	18	7	3	5	13	18	12	12	26	31

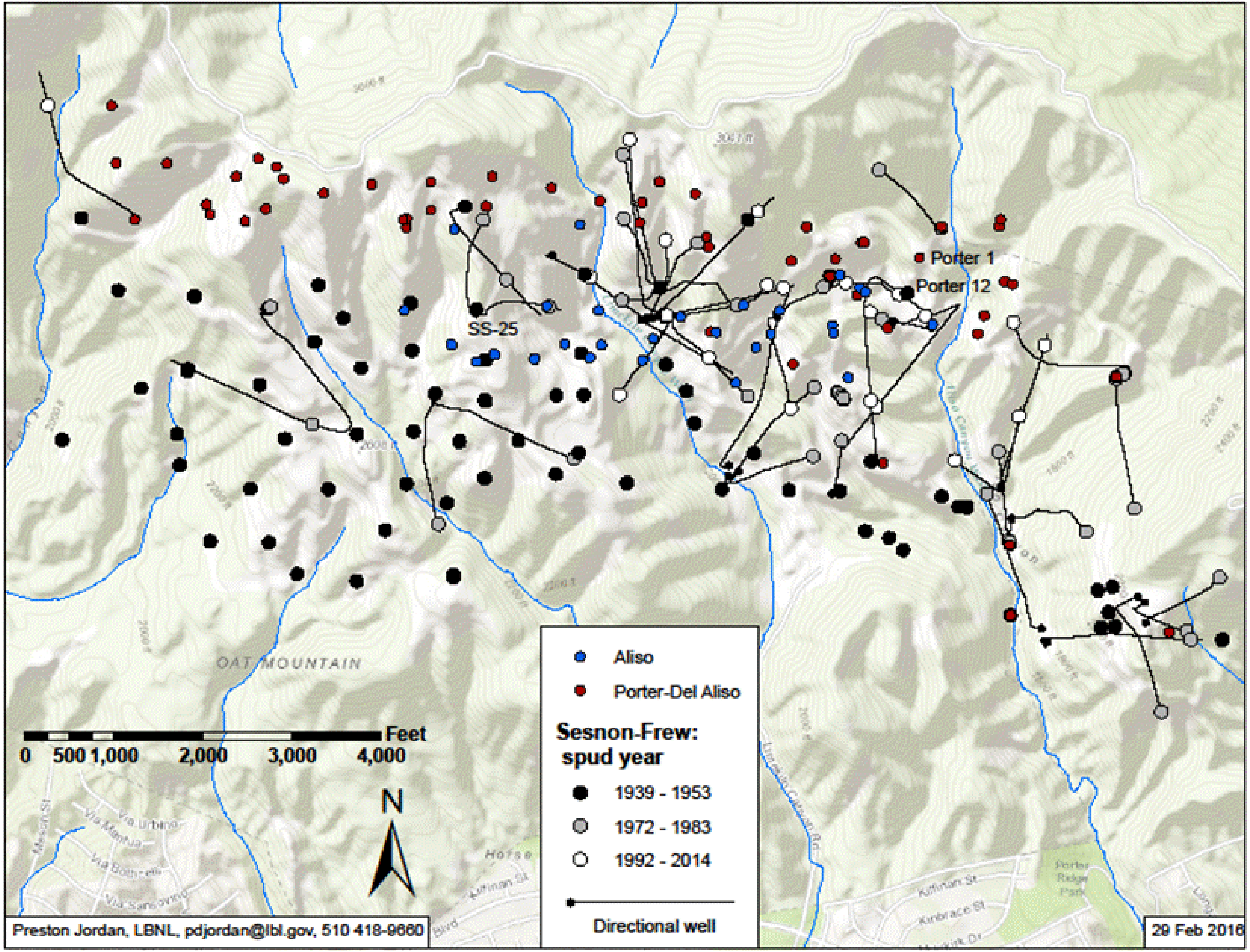
(From Feb 19, 2016 CEC, CPUC, CalISO Briefing)

Chronology of Lab Team

- Dec 8, Initial request from State of CA to LLNL, SNL and LBNL
- Dec 10, Establishment of technical support group
- Dec 16, Initial site visit of Lab Team to Aliso Canyon
- Jan 6, Governor Emergency Order
- Jan 15, Site visit with SoCalGas/Boots & Coots to discuss top kills and relief well
- Feb 11, Relief well intercept, leak stopped
- Feb 16, DOE/PHMSA visit to site, Roundtable w/Secretary Moniz & Administrator Dominguez
- Feb 17, Permanent cement (public notice Feb 18)
- July 8, DOGGR releases draft gas storage rules

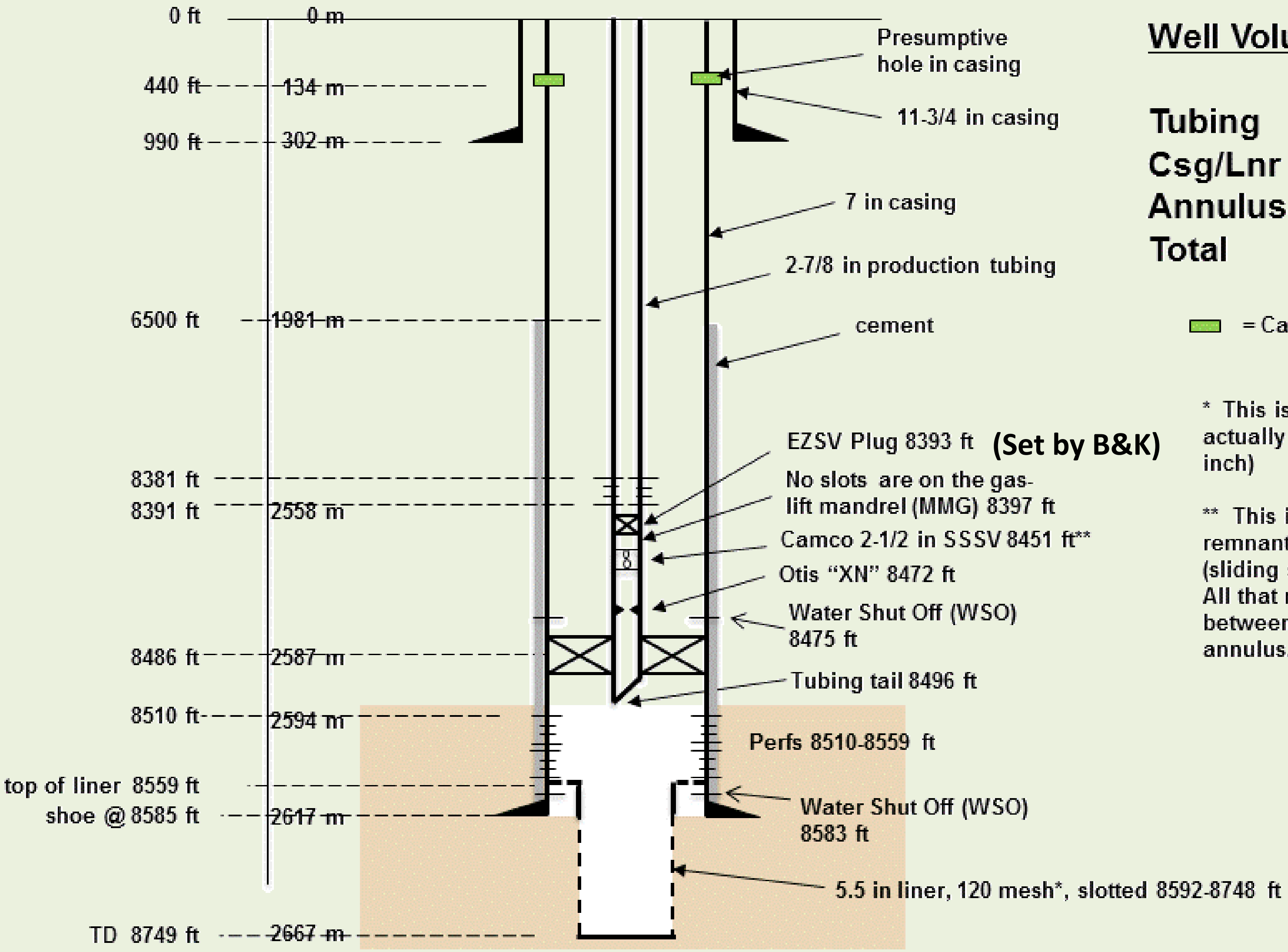
Lab Team Activities

- Review and consultation on Emergency regs, Restart procedures, New CA regulations, Reviews of confirmation of well sealing and of investigation plans
- Review of history and operations at Aliso Canyon to understand the design and operations impacting Sesnon-25
- Informal review of other state well integrity regulations and regulations directly applied to natural gas storage
- Periodic informal updates submitted to DOE/HQ as requested to inform WH and interagency task force
- DOE/FE initiated a multi-lab research team (SNL, LBNL, LLNL, and NETL) with the charter to provide a report back in 6 months on natural gas well integrity and best practices, initiation of discussions for Well Integrity Workshop
- Presentations to AGA, SMRI on the AC event



Porter 1
Porter 12
SS-25
OAT MOUNTAIN
Aliso
Porter-Del Aliso
Sesnon-Frew: spud year
1939 - 1953
1972 - 1983
1992 - 2014
Directional well
Feet
0
500
1,000
2,000
3,000
4,000
N
Preston Jordan, LBNL, pdjordan@lbl.gov, 510 418-9660
29 Feb 2016

Components in the SS-25 well create a complex flow path for gas and kill fluid



Well Volume

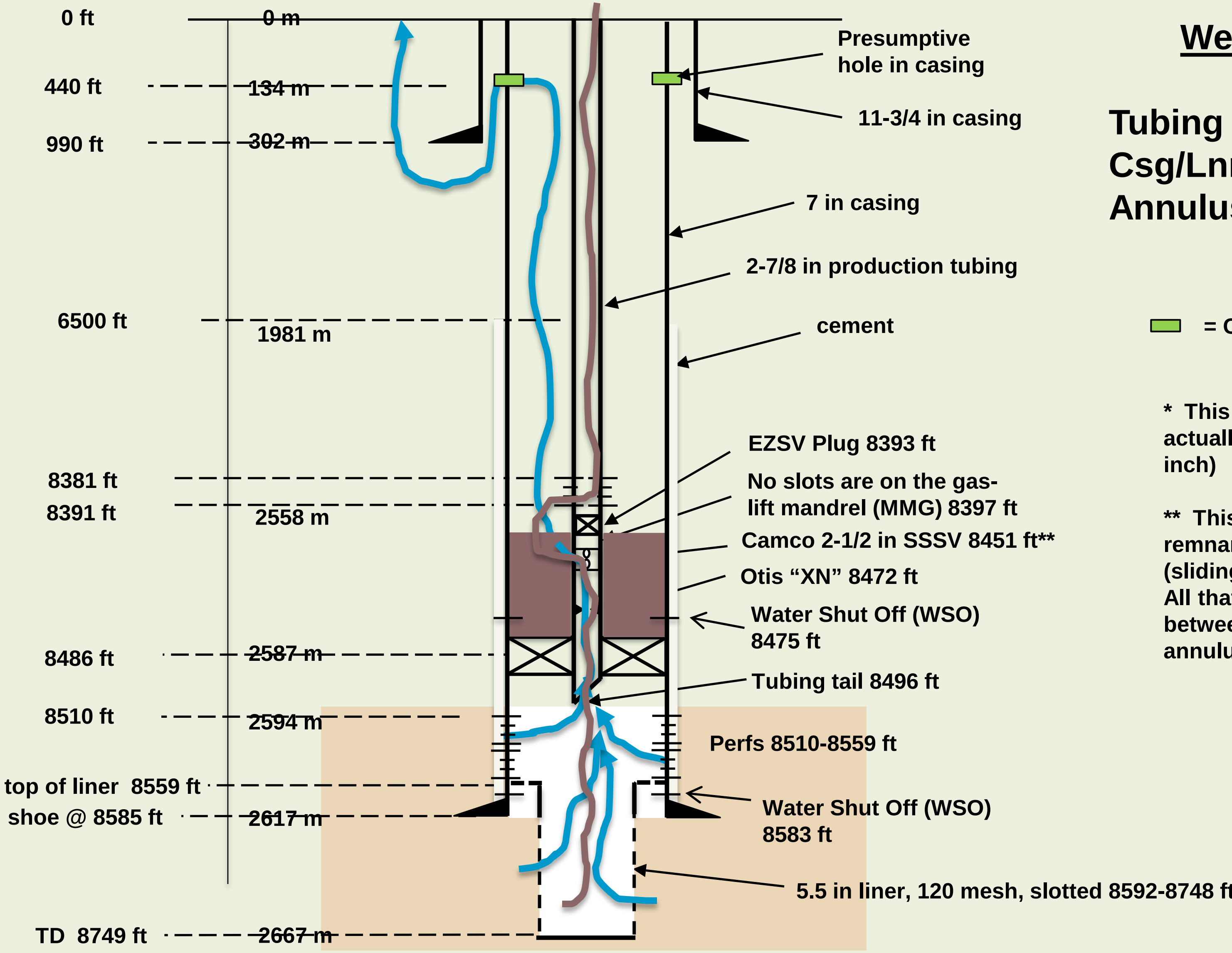
	Cu.Ft.	Bbl
Tubing	276	49
Csg/Lnr	37	7
Annulus	1469	262
Total	1782	318

= Casing Break

* This is believed to be actually 120 Gauge (0.120 inch)

** This is actually the remnants of an SSV (sliding sleeve valve). All that remains are slots between tubing and annulus.

Kill fluid flows out of perfs in tubing at 8381 ft and encounters high-velocity gas flow in the casing



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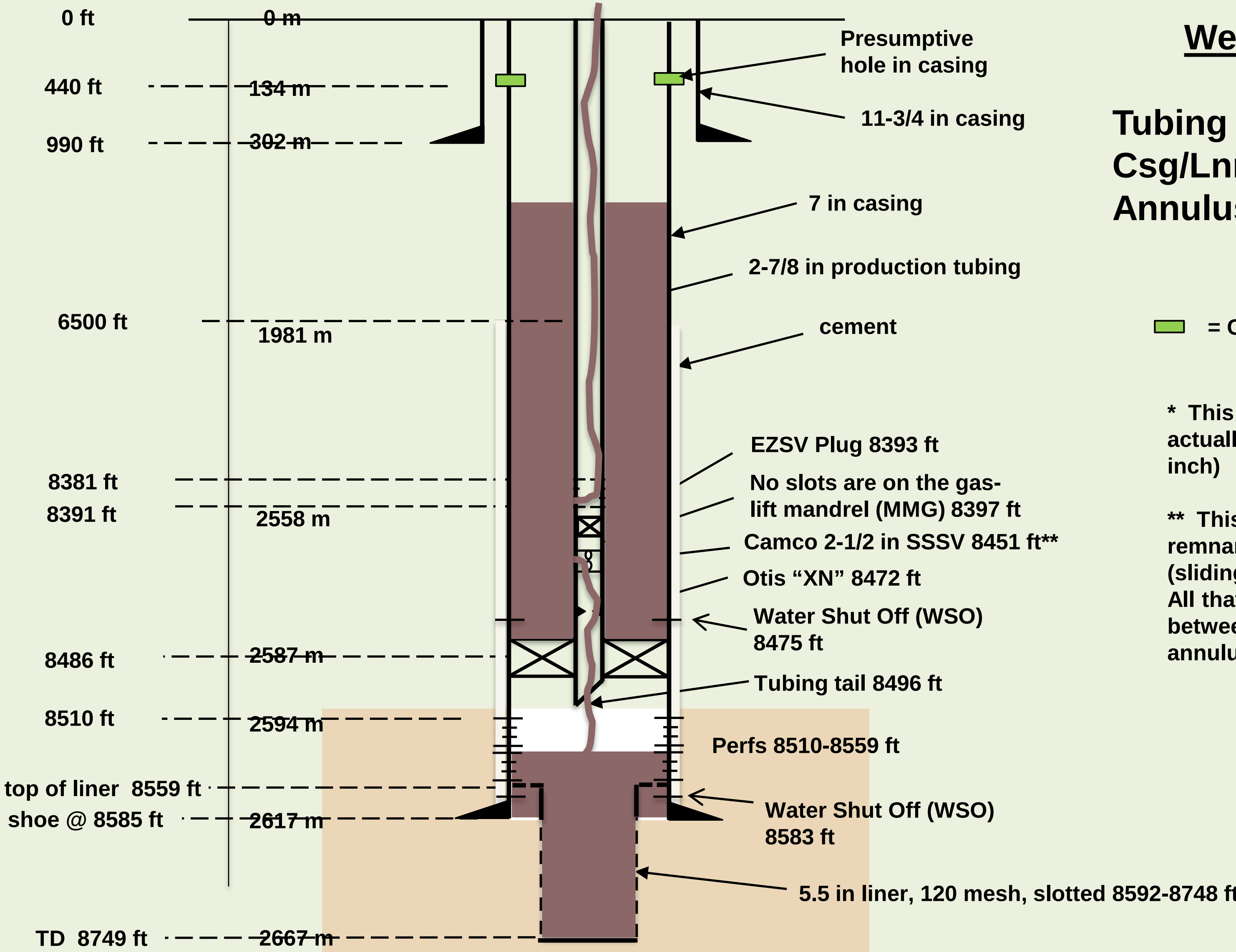
The well can be killed if the kill fluid can overcome being lifted upward by flowing gas in the casing



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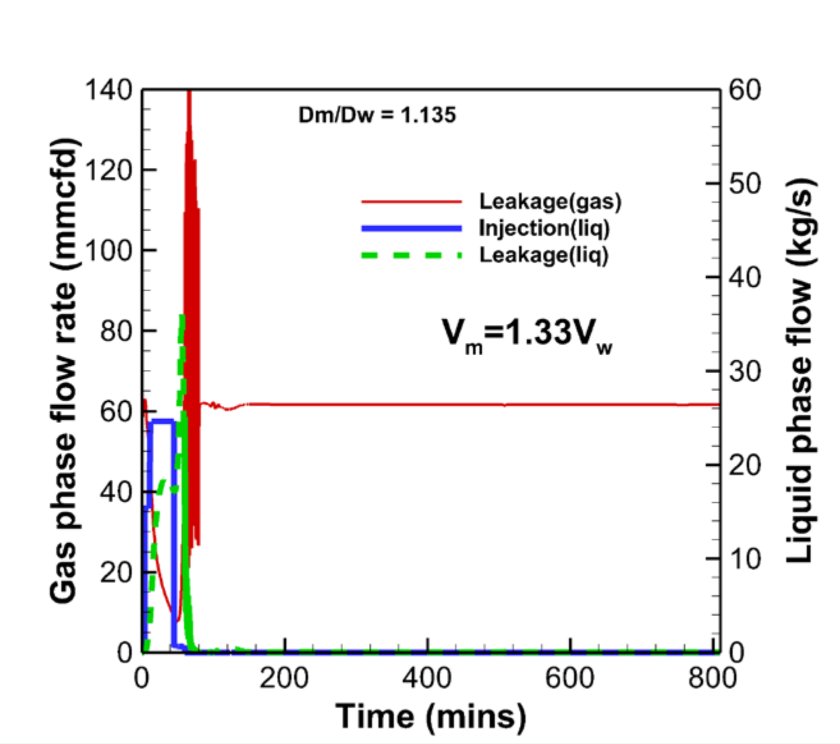
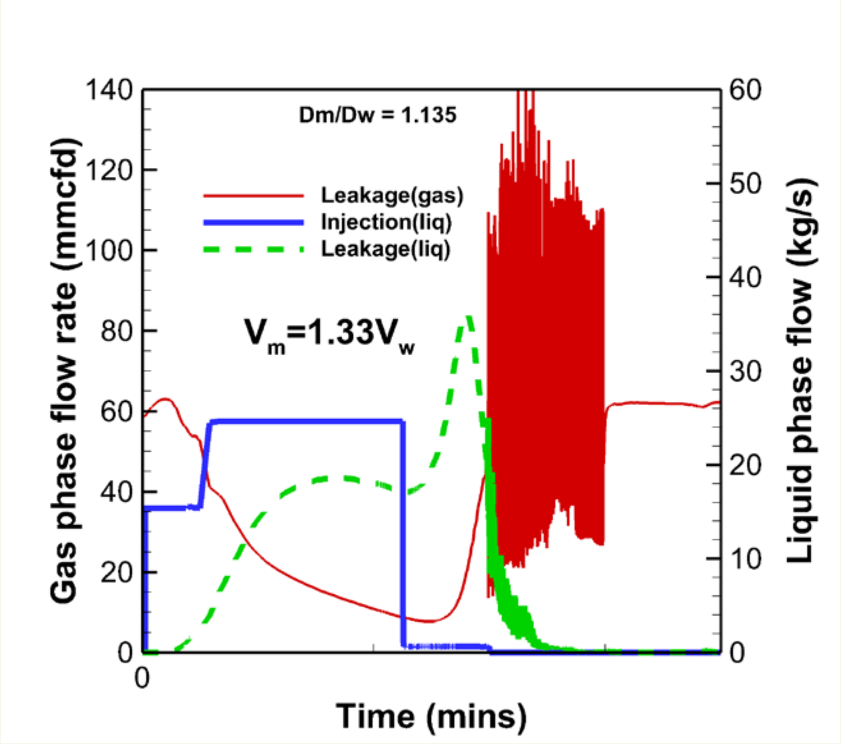
Top Kill Failures

- Top kills with increasingly aggressive materials, injection rates, and volumes were used on eight occasions:
  - Oct 24, Nov 6, 13, 15, 18, 24, 25, Dec 22
- Top kills resulted in increased cratering around SS-25 and dangerous wellhead stability
- Ground preparation for a relief well began November 13. Drilling commenced December 4.

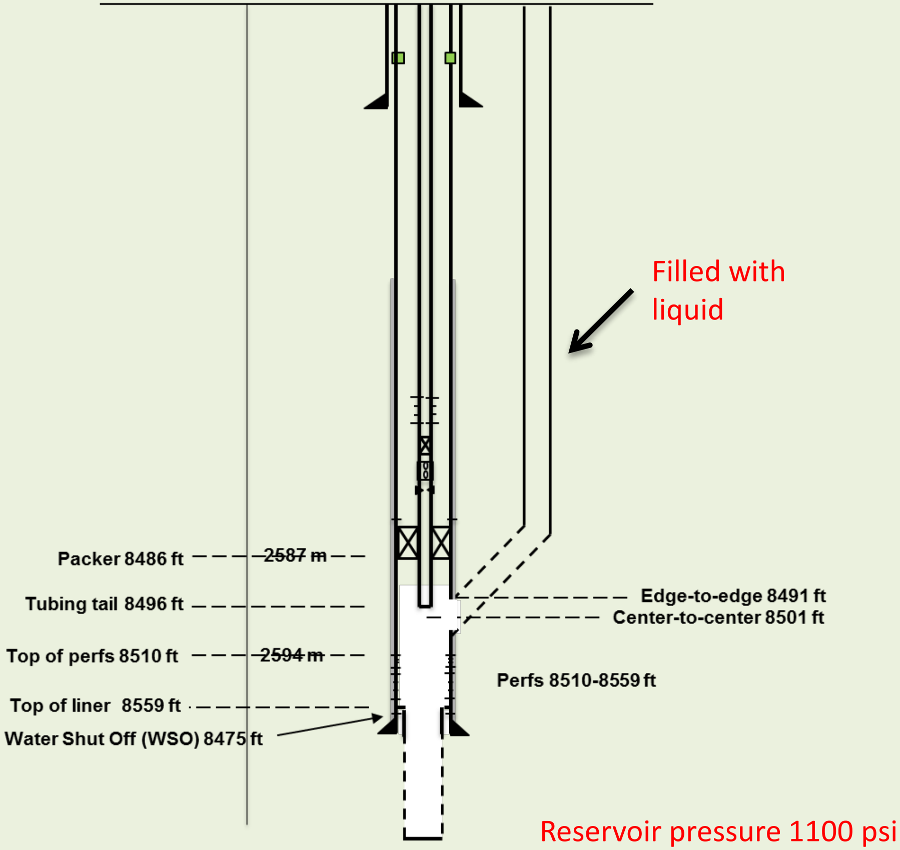
333 bbl of 9.4 ppg $CaCl_2$ does not kill the well

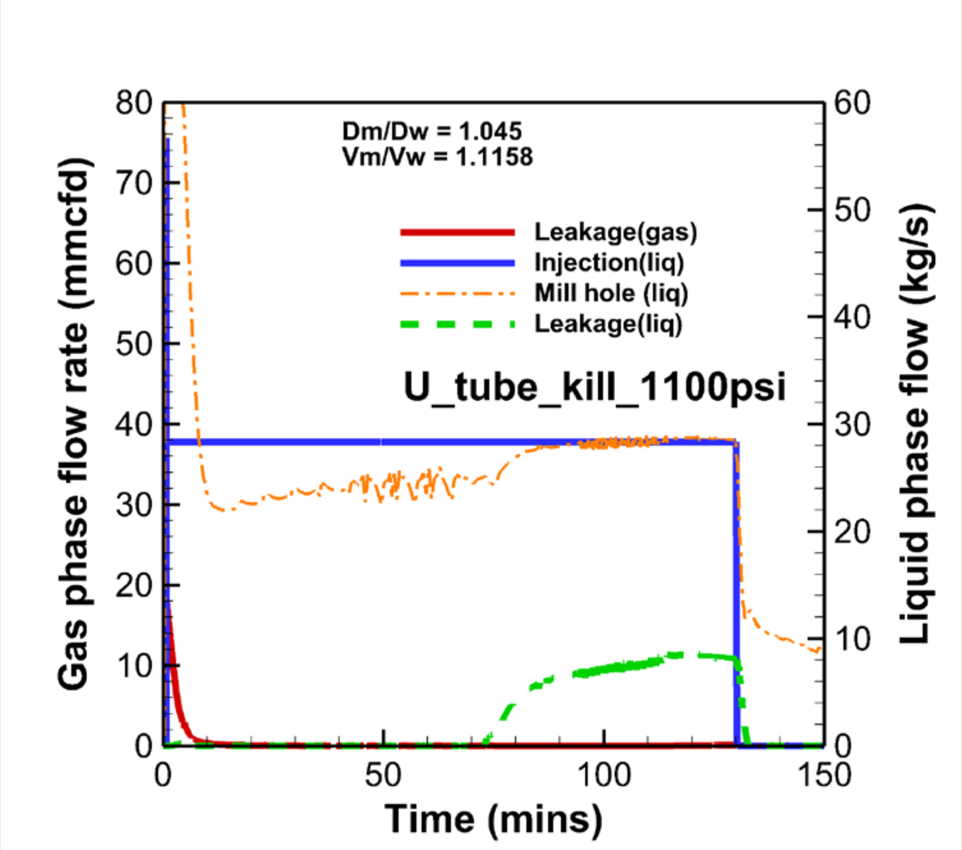




- For the viscosity of 9.4 ppg $CaCl_2$ fluid (about 33% higher than water), the gas leakage decreased for a short period but the well was not killed. The gas leakage rate resumed to or even beyond the previous rate (left panel)
- In this case, the gas leakage increased first in response to the pressure increase due to injection, but then decreased as liquid leakage increased (right panel)
- After the liquid leakage reached the highest value, the gas leakage became violently oscillatory until about 80 min when almost all injected liquid has been removed from the well.
- The well was never killed.

Using relief well, gas flow stops within 10 min after milling into SS-25 (see poster)





- In this simulation RW is initially filled with liquid (9.0 ppg $CaCl_2$ fluid).

The mass flow rate through the milled hole is limited not to exceed 150 kg/s for numerical stability.

- Gas leakage stops within 10 min after milling into SS-25 9.0 ppg $CaCl_2$ fluid.
- Liquid leakage increases with time after ~70 min after both wells are filled with liquid (assuming continuous injection at 10 bpm).

Aliso Canyon Moving Forward
Safety Review General & Battery 1

- 114 gas storage injection and withdrawal wells
- 100% noise and temperature logs
- Transparency – DOGGR website
    - News releases
    - Safety Testing and Review Requirements
    - Test Results of Aliso Canyon Wells
    - Emergency Orders and Regulations
    - Maps, every log used, reports
- Decision point
    - Plug and abandon permanently or
    - Plug in tubing and fluid in tubing and annulus months or
    - Conduct full suite of tests to return to injection withdrawal

Safety Review Battery 2 & Resumption

- All injection and withdrawal wells
  - Casing inspection (HRVRT and USIT) and caliper log
  - Cement bond log
  - Positive pressure test
- SoCalGas may resume injection
  - All wells either P&A'd, isolated from the reservoir, or passed all tests
  - After public workshop and comment period
  - Upon authorization by State Oil and Gas Supervisor
  - With approval of the California Public Service Commission
  - Tubing only production, with minimal pressure on isolated annulus
- Potentially November 2016 with 20+ wells

DOE National Laboratories Support of Interagency Effort

Task 1. Host Well Integrity Workshop in Broomfield, CO – July 12-13, 2016 to gather operators, regulators, and technical specialists

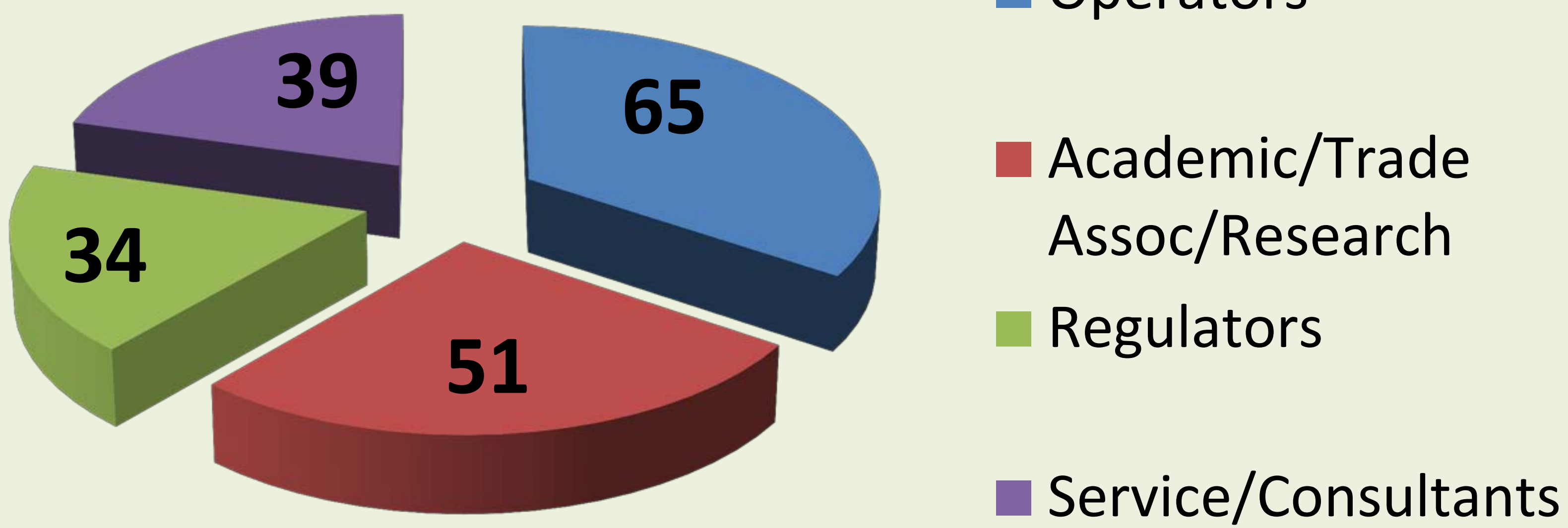
Task 2. Analysis of the Aliso Canyon Event and surrounding circumstances

Task 3. Evaluation of potential for problems at other storage sites

Task 4. Review risk assessments and hazard assessments for existing storage sites, Ensuring safe storage in the future

Recommendations
Technology needs
Future investigations and research

Denver Workshop Attendance 190+



Participation by Location

Texas	41		Kentucky	2
California	30		Massachusettes	2
Washington DC	22		New York	2
Colorado	17		Virginia	2
Oklahoma	15		Alaska	1
West Virginia	7		Alabama	1
Louisiana	5		Missouri	1
Michigan	5		Montana	1
New Mexico	5		Oregon	1
Ohio	4		South Dakota	1
Utah	4		Tennessee	1
Nebraska	3			
Pennsylvania	3		Canada	2
Illinois	2		Germany	1
Kansas	2		Japan	1

Denver Workshop Outcomes

- www.eesa.gov/wellintegrity
- Divergent opinions and deep dive into several issues
  - Federal vs state responsibility & Interstate vs intrastate
  - Regulations (prescriptive vs “risk-based”)
  - Well construction (barriers, ISO/TS 16530)
  - API 1170 & 1171
  - Transition period (17,500 existing wells)

Denver Workshop Outcomes

Key takeaways –

- State of California released proposed regulations (CA has all intrastate storage)
- Formal Risk Management (almost all agree this is needed)
- Down hole safety valves need more attention (Pros and cons to their use and not enough hard data)
- Uncertainty in how PHMSA will regulate and what rights states will have

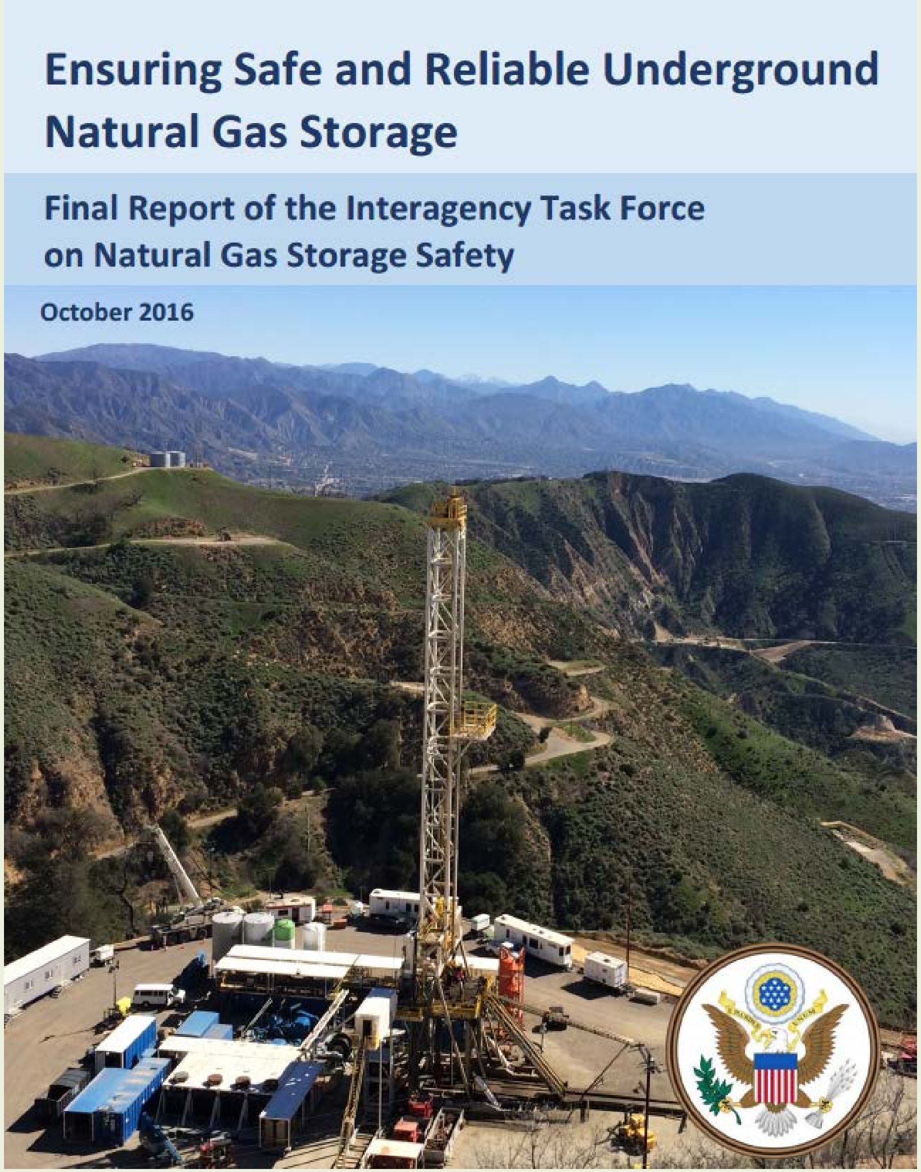
Interagency Task Force Report

Task Force Members:

- DOE (Chaired by Secretary Moniz)
- DOT PHMSA (Co-Chairs Undersecretary Orr and Administrator Dominguez)
- EPA, HHS, DOC, DOI, FERC, & Executive Office of the President

Three working groups:

- "Well Integrity" Workgroup led by DOE Office of Fossil Energy
- "Reliability" led by DOE Office of Electricity Delivery and Energy Reliability
- "Health and Environment" led by EPA and HHS's Centers for Disease Control and Prevention



Well Integrity Recommendations

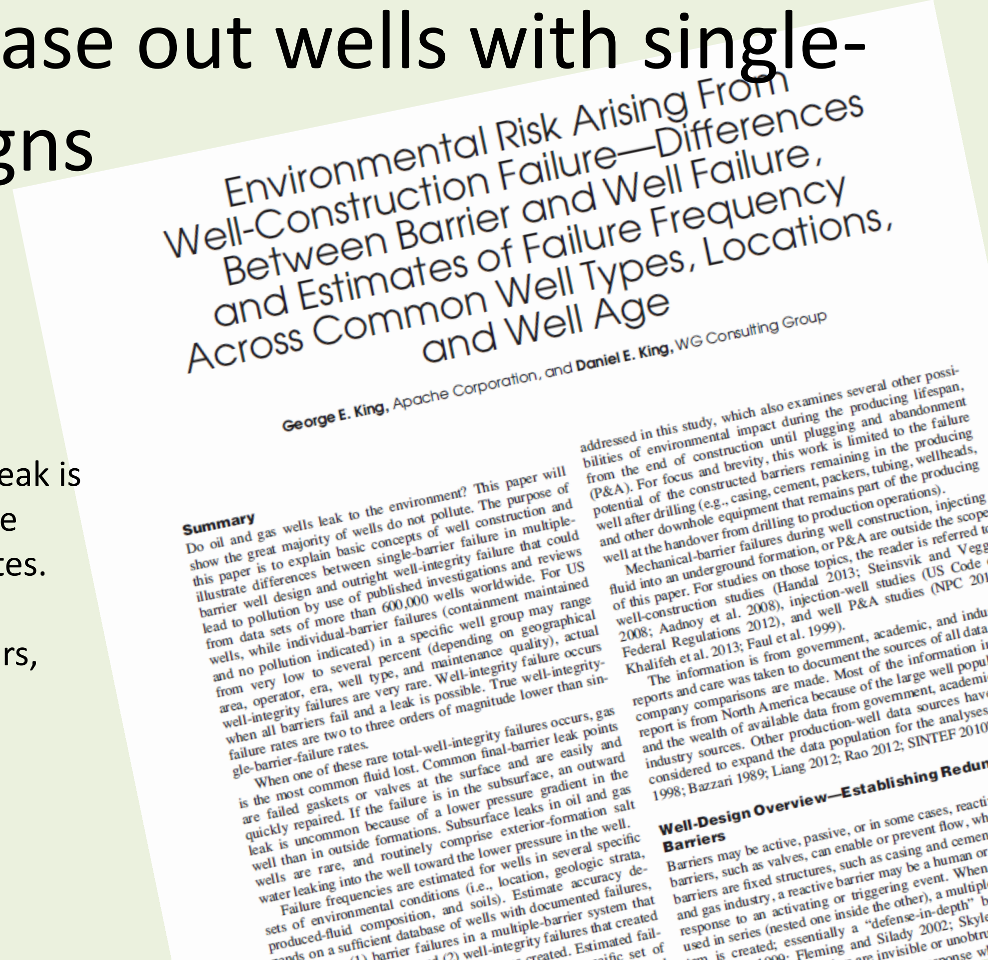
- Topic I: Ensuring Well Integrity

1. Operators should phase out wells with single-point-of-failure designs

SPE-166142-PA 2013 King and King

Well-integrity failure occurs when all barriers fail and a leak is possible. True well-integrity-failure rates are two to three orders of magnitude lower than single-barrier-failure rates.

When one of these rare total-well-integrity failures occurs, gas is the most common fluid lost.



Environmental Risk Arising From Well-Construction Failure—Differences Between Barrier and Well Failure, and Estimates of Failure Frequency Across Common Well Types, Locations, and Well Age

George E. King, Apache Corporation, and **Daniel E. King**, WG Consulting Group

Summary

Do oil and gas wells leak to the environment? This paper will show the great majority of wells do not pollute. The purpose of this paper is to explain basic concepts of well construction and illustrate differences between single-barrier failure in multiple-barrier well design and outright well-integrity failure that could lead to pollution by use of published investigations and reviews from data sets of more than 600,000 wells worldwide. For US wells, while individual-barrier failures (containment maintained and no pollution indicated) in a specific well group may range from very low to several percent (depending on geographical area, operator, era, well type, and maintenance quality), actual well-integrity failures are very rare. Well-integrity failure occurs when all barriers fail and a leak is possible. True well-integrity-failure rates are two to three orders of magnitude lower than single-barrier-failure rates.

When one of these rare total-well-integrity failures occurs, gas is the most common fluid lost. Common final-barrier leak points are failed gaskets or valves at the surface and are easily and quickly repaired. If the failure is in the subsurface, an outward leak is uncommon because of a lower pressure gradient in the well than in outside formations. Subsurface leaks in oil and gas wells are rare, and routinely comprise exterior-formation salt water leaking into the well toward the lower pressure in the well.

Failure frequencies are estimated for wells in several specific sets of environmental conditions (i.e., location, geologic strata, produced-fluid composition, and soils). Estimate accuracy depends on a sufficient database of wells with documented failures, (1) barrier failures in a multiple-barrier system that created (2) well-integrity failures that created. Estimated fail-

addressed in this study, which also examines several other possibilities of environmental impact during the producing lifespan, from the end of construction until plugging and abandonment (P&A). For focus and brevity, this work is limited to the failure potential of the constructed barriers remaining in the producing well after drilling (e.g., casing, cement, packers, tubing, wellheads, and other downhole equipment that remains part of the producing well at the handover from drilling to production operations).

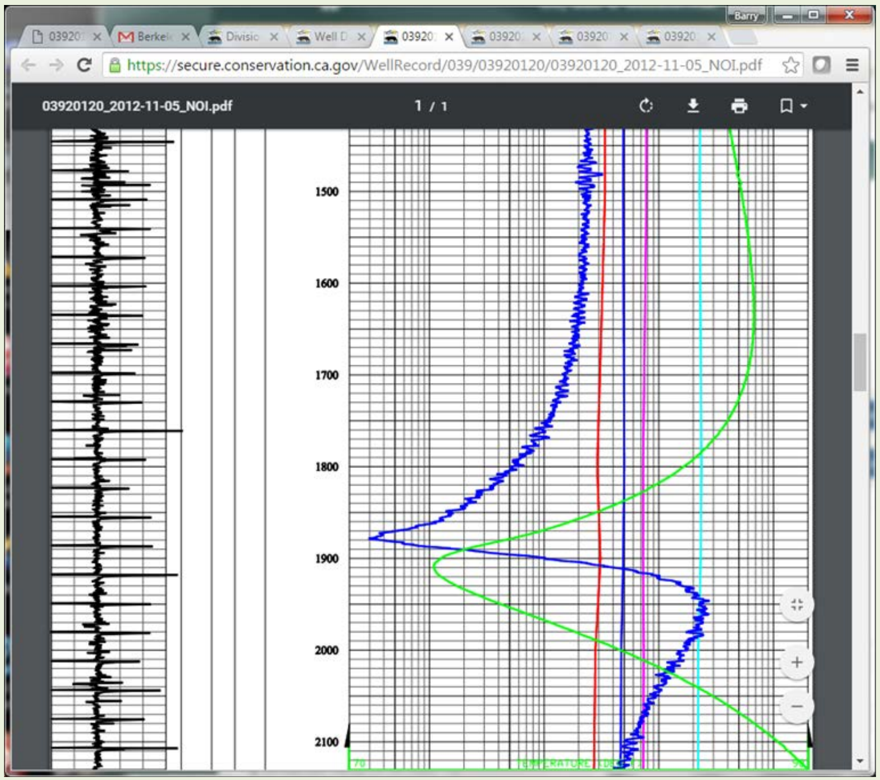
Mechanical-barrier failures during well construction, injecting fluid into an underground formation, or P&A are outside the scope of this paper. For studies on those topics, the reader is referred to well-construction studies (Handal 2013; Steinsvik and Vegg 2008; Aadnoy et al. 2008), injection-well studies (US Code of Federal Regulations 2012), and well P&A studies (NPC 201 Khalifeh et al. 2013; Faul et al. 1999).

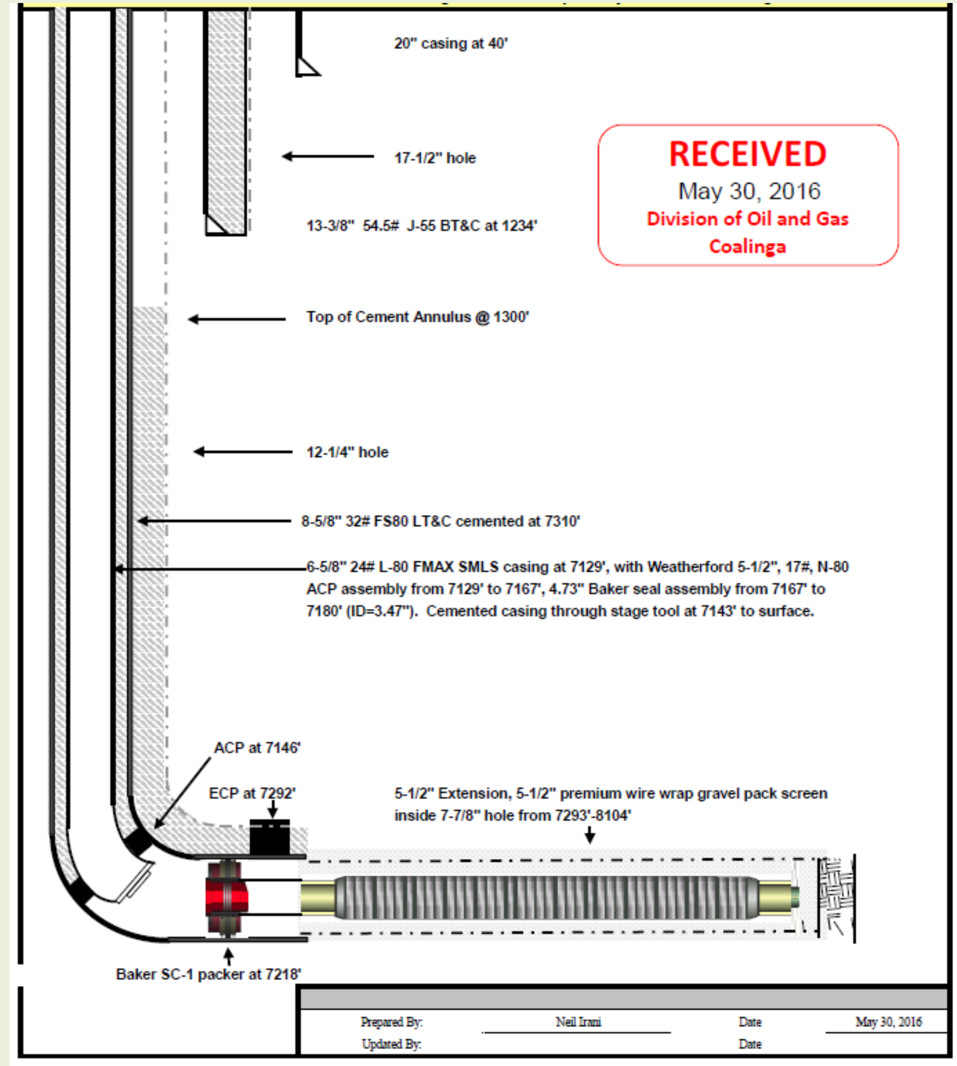
The information is from government, academic, and indu reports and care was taken to document the sources of all data company comparisons are made. Most of the information i report is from North America because of the large well popul and the wealth of available data from government, academi industry sources. Other production-well data sources have considered to expand the data population for the analyses 1998; Bazzari 1989; Liang 2012; Rao 2012; SINTEF 2010

Well-Design Overview—Establishing Redun Barriers

Barriers may be active, passive, or in some cases, reacti barriers, such as valves, can enable or prevent flow, wh barriers are fixed structures, such as casing and cemen and gas industry, a reactive barrier may be a human or response to an activating or triggering event. When used in series (nested one inside the other), a multipl is created; essentially a "defense-in-depth" b

Example: Single-point-failure design





Large leak at 1900 ft depth took operator four years to fix. Well was still operated under both injection and production. Scab was initial fix but failed to work. Final solution was to install a 6-5/8" liner inside 8-5/8" casing

Well Integrity Recommendations

- Topic I: Ensuring Well Integrity

2. Operators should undertake rigorous well integrity evaluation programs
3. Operators should prioritize integrity tests that provide hard data on well performance

This is consistent with PHMSA's Advisory Bulletin ADB-2016-02 which recommended that all operators begin a systematic evaluation of their wells and implement voluntary consensus standards API RP 1170 & 1171.

Review of existing data, records. Where gaps exist collect evaluation data (noise, temperature, corrosion, CBL, pressure test, etc…)

Document risk management plan to guide future monitoring, maintenance and upgrades; establish design standards and safe operating pressures for existing casing and tubing.

Well Integrity Recommendations

- Topic I: Ensuring Well Integrity

4. Operators should deploy continuous monitoring for wells and critical gas handling infrastructure

Continuous monitoring of annular and tubing pressure, as well as leak detection tied to a real-time network can provide timely warning of off normal conditions.

Well Integrity Recommendations

- Topic II: Risk Management Recommendations

1. Risk management plans should be comprehensive and reviewed periodically
2. Operators should institute more complete and standardized records management systems
3. Operators should develop and implement risk management transition plans within one year from when new standards are issued
4. Operators and regulators should address a broad range of risk factors

Well Integrity Recommendations

- Topic III: Research and Data Gathering Needs

1. DOE and DOT should conduct a joint study of downhole safety valves
2. DOE and DOT should conduct a joint study of casing-wall thickness assessment tools
3. Industry and other stakeholders should review and evaluate wellbore simulation tools
4. Data gathering gaps should be addressed
   I. Location of unknown wells
   II. Proximity of UGS facilities to population centers
   III. State regulators and PHMSA should collaborate to aggregate data related to well integrity performance

Well Integrity Recommendations

- Topic IV: Immediate Regulatory Action
  - PHMSA is tasked by PIPES Act of 2016 to initiate regulatory action by the end of this year.
  - Industry recommended practices APR RP 1170 & 1171 should be incorporated into Part 192 regulations in a manner that can be enforced.
- RPs not designed as regulatory system –

API RP 1171 Scope:

"The contents of this RP are not all inclusive or intended to replace the utilization of detailed information and procedures found in textbooks, manuals, technical papers, or other documents.

This document is intended to supplement, but not replace, applicable local, state, and federal regulations."

Conclusions

- Operators should phase out single-point-of-failure well designs
- Develop detailed risk management plans that should be periodically reviewed and updated
- Operators should develop plans and layout timelines to remediate substandard wells and consider risks during this transition period
- Sharing data on well integrity and additional research will progressively improve safety of natural gas storage fields


Thank you.
Questions?