LA-UR-12-22410
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Title: Wellbore Integrity Network

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Intended for: Joint Meeting of Networks of IEA Greenhouse Gas R&D Programme, 2012-06-18/2012-06-20 (Santa Fe, New Mexico, United States)

Wellbore Integrity Network

by J. William Carey (Los Alamos National Laboratory) and Stefan Bachu (Alberta Innovates)

In this presentation, we review the current state of knowledge on wellbore integrity as developed in the IEA Greenhouse Gas Programme's Wellbore Integrity Network. Wells are one of the primary risks to the successful implementation of CO_2 storage programs. Experimental studies show that wellbore materials react with CO_2 (carbonation of cement and corrosion of steel) but the impact on zonal isolation is unclear. Field studies of wells in CO_2-bearing fields show that CO_2 does migrate external to casing. However, rates and amounts of CO_2 have not been quantified. At the decade time scale, wellbore integrity is driven by construction quality and geomechanical processes. Over longer time-scales (> 100 years), chemical processes (cement degradation and corrosion) become more important, but competing geomechanical processes may preserve wellbore integrity.

Wellbore Integrity Network
Bill Carey & Stefan Bachu

Steering Committee

- Idar Akervol, SINTEF
- Stefan Bachu, Alberta Innovates
- Bill Carey, LANL (Chair)
- Mike Celia, Princeton U.
- Rich Chalaturnyk, U of Alberta
- Walter Crow, BP Alternative Energy
- Theresa Watson, ECRB

Meetings

- 2005 Houston, TX
- 2006 Princeton, NJ
- 2007 Santa Fe, NM
- 2008 Paris, France
- 2009 Calgary, Alberta
- 2010 Amsterdam, Netherlands
- 2011 Perth, Australia (Joint with modeling)

Philosophy and Purpose

- Forum for communication of research regarding the integrity of wellbores in contact with CO_2
- Focused discussions
- Diverse membership
  - Academia
  - Government research
  - Industry
  - Regulatory agencies
- Encourage collaborations among members
- Engage regulators and provide commentary/context on regulations
- Develop community-wide appreciation and understanding of key issues

What Does Failure of Wellbore Integrity Look Like to You?

Crystal Geyser: CO_2 from abandoned well
http://www.4x4now.com/cg.htm

Deep Horizon Blowout
Natural gas and oil
http://whistleblowersblog.org
Credit: US. Coast Guard

Slow casing leak
Natural gas
Watson and Bachu 2007

How Is Wellbore Integrity Achieved?

- Operational measures
  - Adequate weight drilling mud
  - Monitoring pressure for gas intrusion (“gas kick”)
  - Blowout preventers
- Design measures
  - Steel
  - Portland cement

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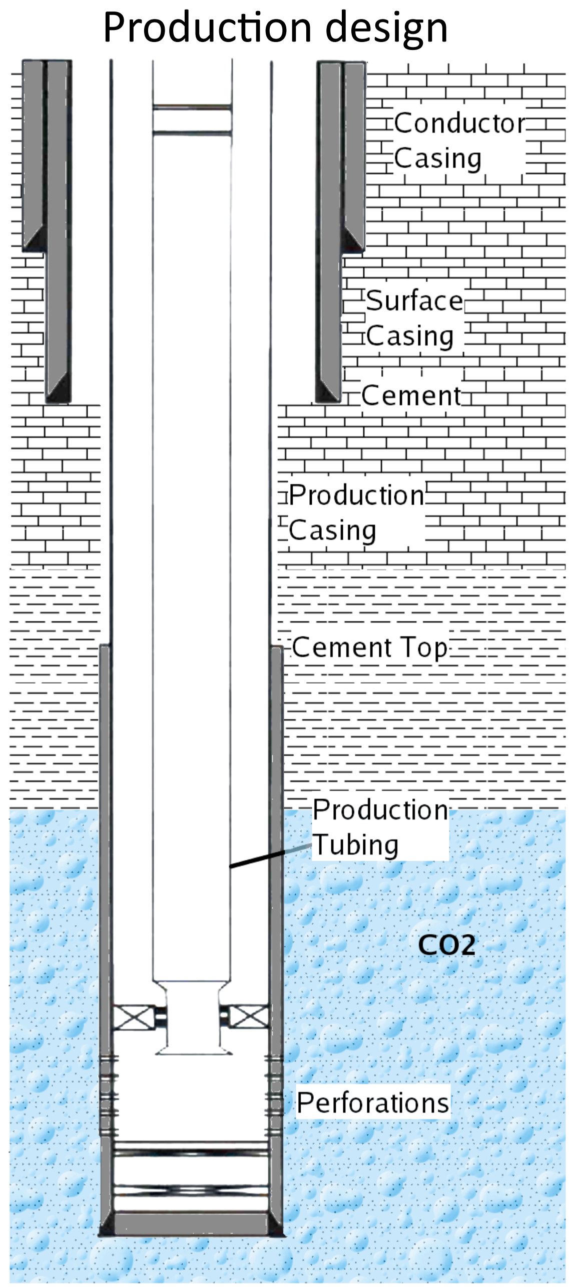
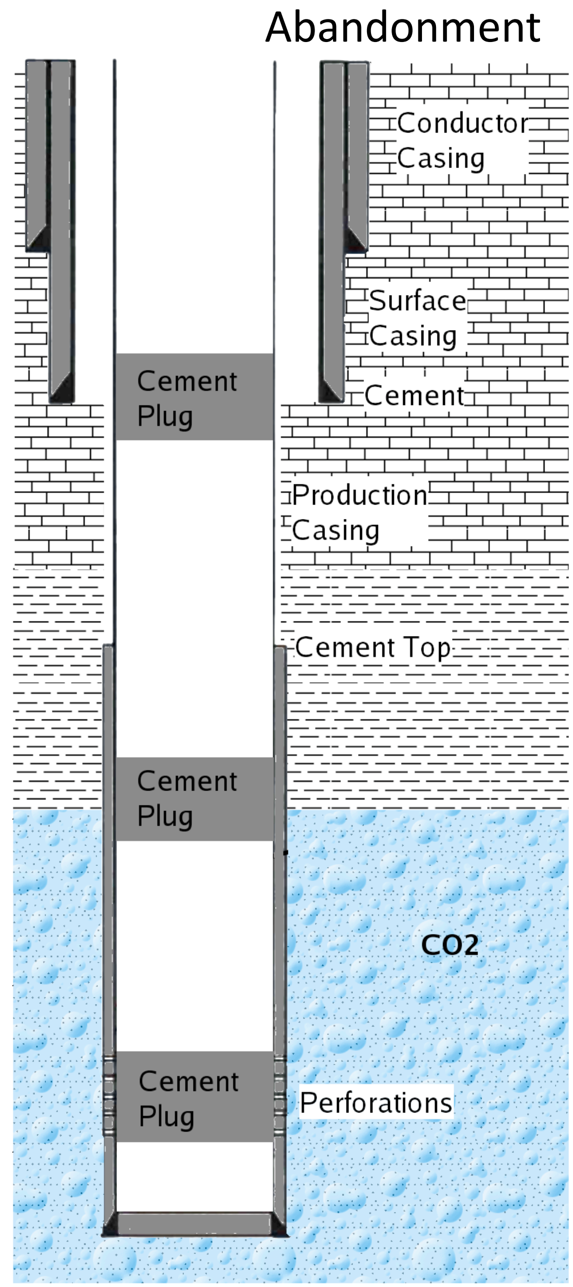
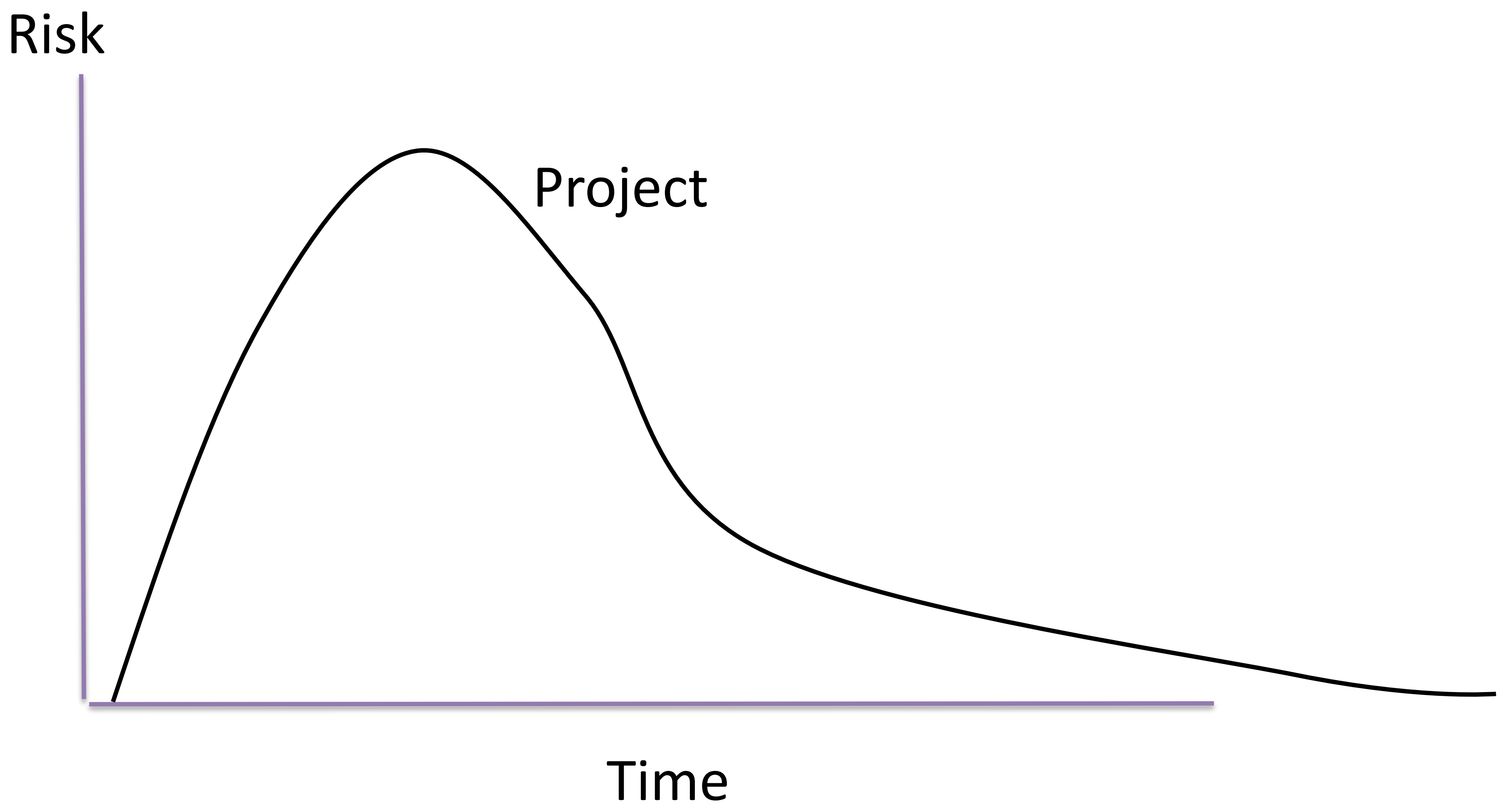
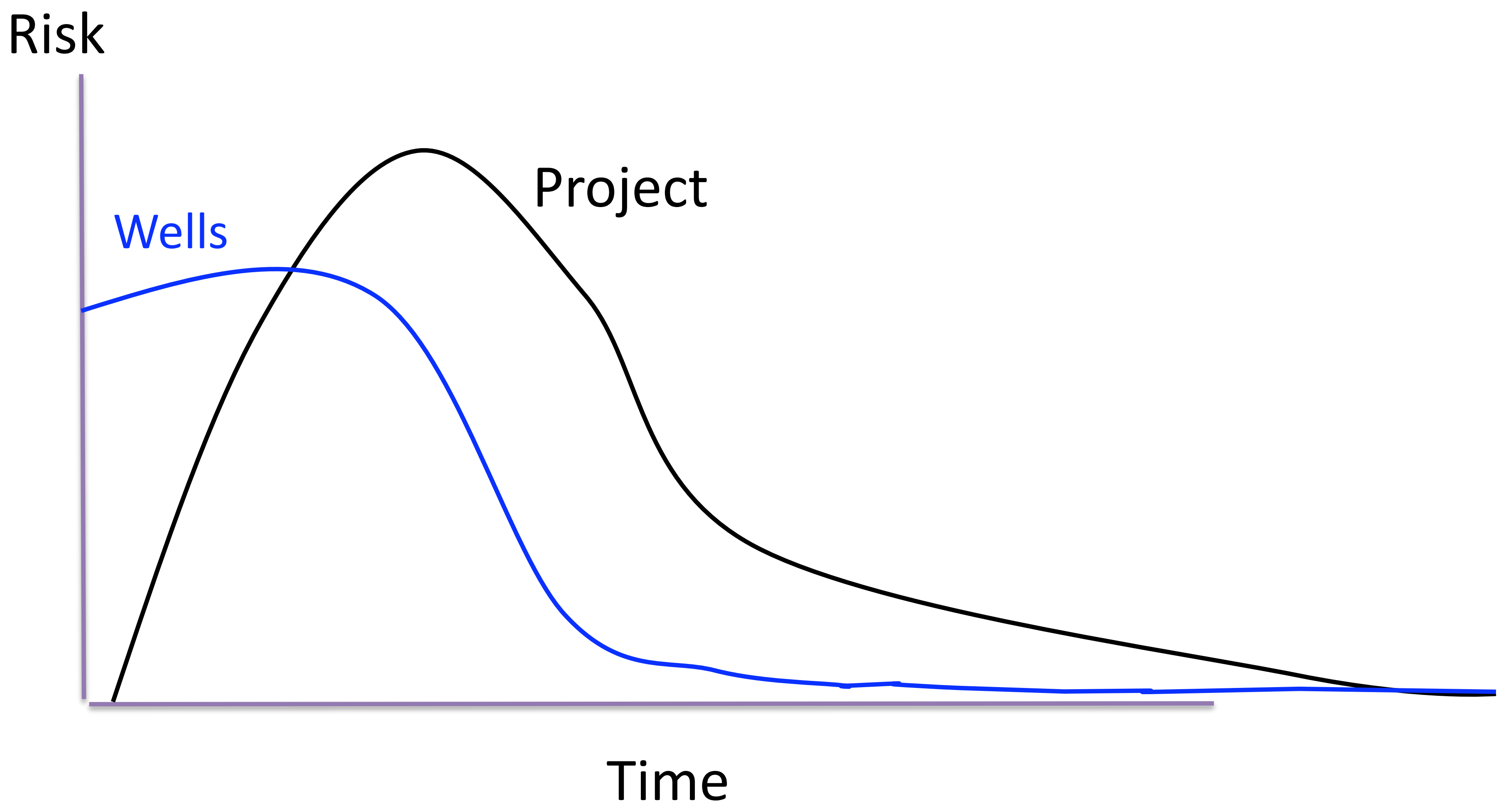




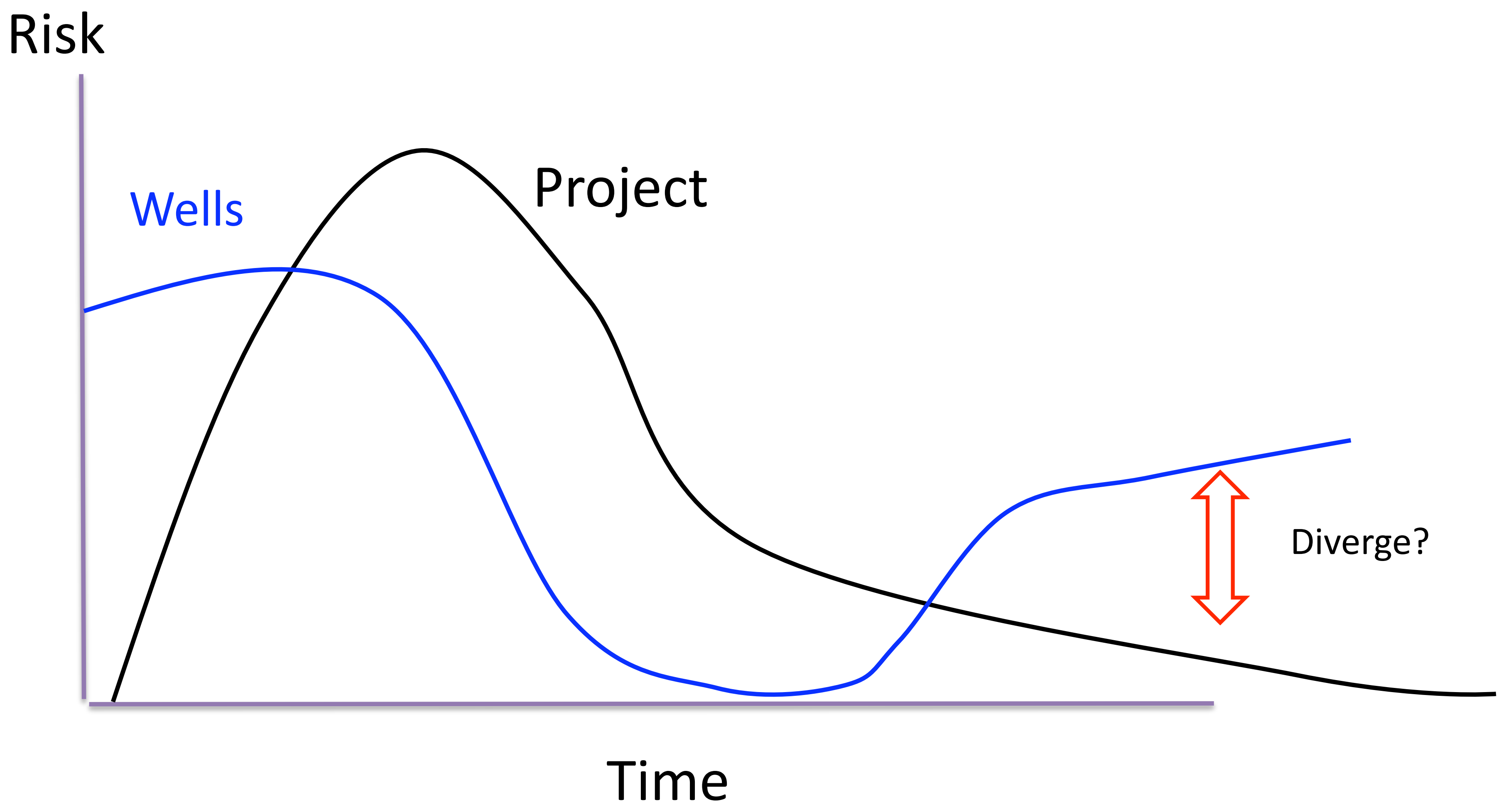
Long-term Risk and Wellbore Integrity



Long-term Risk and Wellbore Integrity



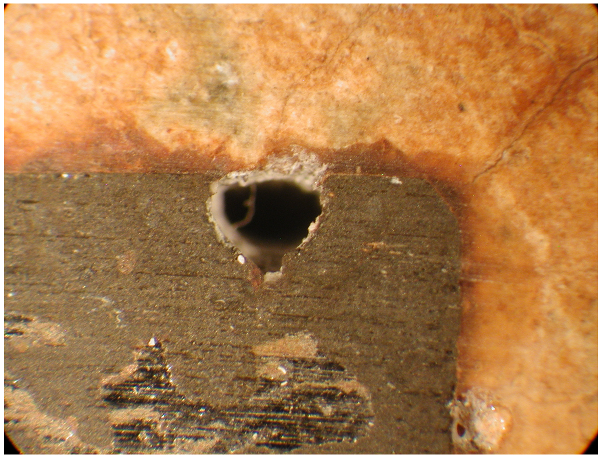
Long-term Risk and Wellbore Integrity



Leakage Modes Outside the Casing

- Cement performs well in the absence of high-flux leakage
  - Kutchko et al. (2007,2008, 2009); Carey et al. (2007); Crow et al. (2010)
  - High-temperature less certain (Fabbri et al. 2009)
- Corrosion less understood but reduced by presence of cement
  - Han et al. (2011)
- Leakage pathways dominated by interfaces
- Geomechanical impacts on wells not well understood
- Long-term behavior of leakage pathways uncertain

Carey et al. (2007)



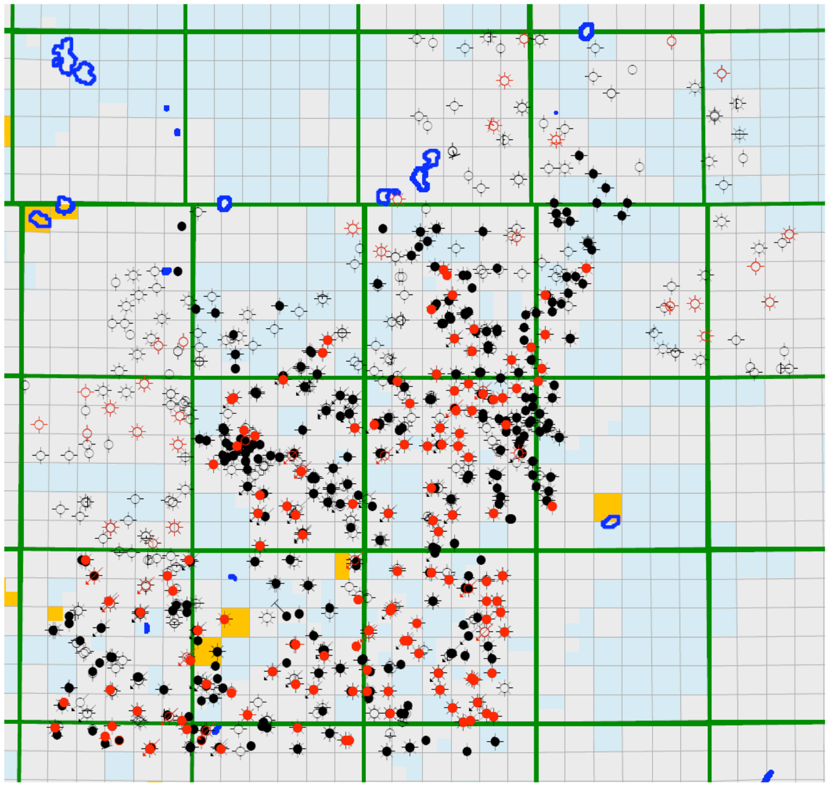
Carey et al. (2010)

Do Well Defects Self-Heal?

- Field and experimental observations show carbonate precipitation at interfaces and in defects (Carey et al. 2007, 2010; Bachu and Bennion 2009; Huerta et al. 2011)
- Cement deformation may close annuli and defects (Liteanu and Spiers 2011)
- Corrosion may be limited by iron-carbonate precipitation (Carey et al. 2010; Han et al. 2011)
- Weak caprocks can seal the external annulus (Williams et al. 2009; Ardila et al. 2009)

Frequency and Causes of Slow Leakage

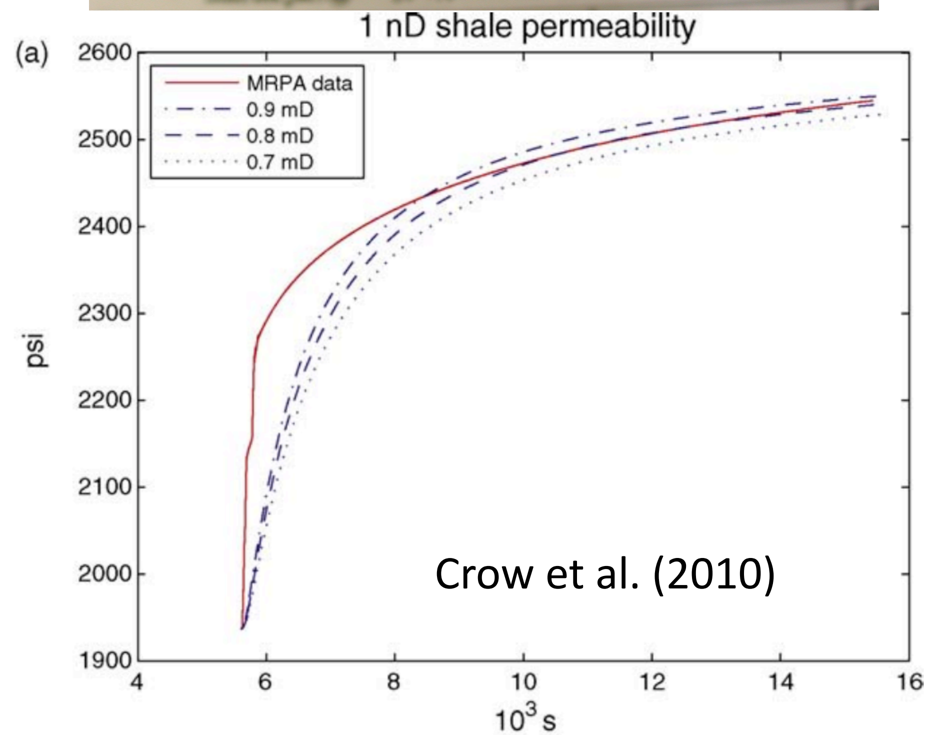
- Sustained casing pressure as analog
  - Major risk factors low cement top, external corrosion, geographic area, drilling activity (Watson and Bachu 2007,2008)
  - Permeability from Gulf of Mexico (Tao et al. 2010; Bourgoyne et al. 2009)
- Weyburn-Midale wellbore integrity program
  - Hawkes et al. (2011)
- Tremendous potential for insights on frequency and impacts from oil and gas operations



Watson and Bachu (2008)

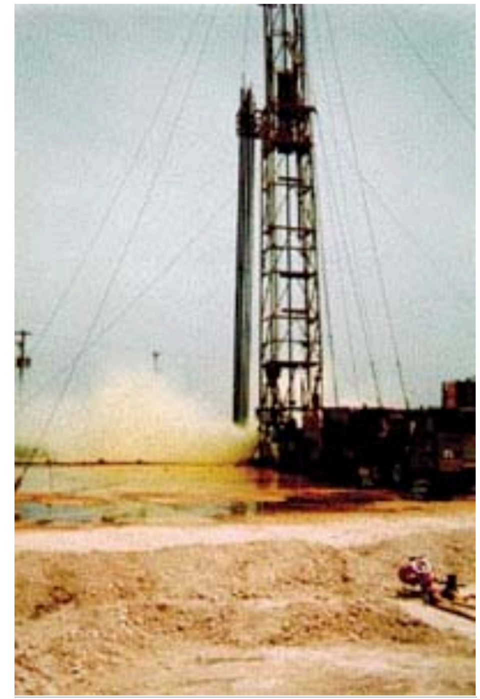
Field Measurements of Permeability

- Demonstrates (minor) CO_2 leakage
  - Carey et al. (2007); Crow et al. (2010)
- Permeability measurement
  - Crow et al. (2010); Gasda et al. (2011)
- Need to study an actual leaking well
  - (Relative) permeability
  - Leak rates
  - Monitoring methods

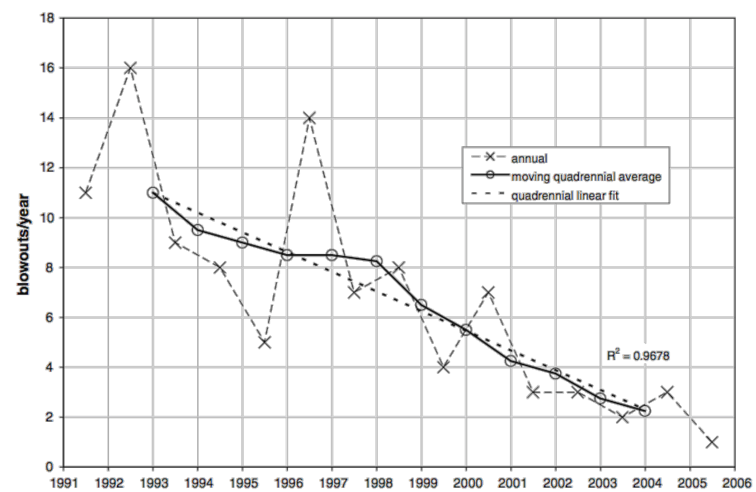


Blowouts

- Less work done on CO_2 blowouts
  - Sheep Mountain natural CO_2 reservoir blowout (125,000 tonnes in 17 days; Lynch et al. (1985)
- Frequency of events
  - Steam-enhanced oil recovery (Jordan and Benson (2008)
  - Recent work suggests construction, not aging, as an issue (Jordan and Carey (2012)
- Infrequent but large impact: additional studies needed to quantify risk



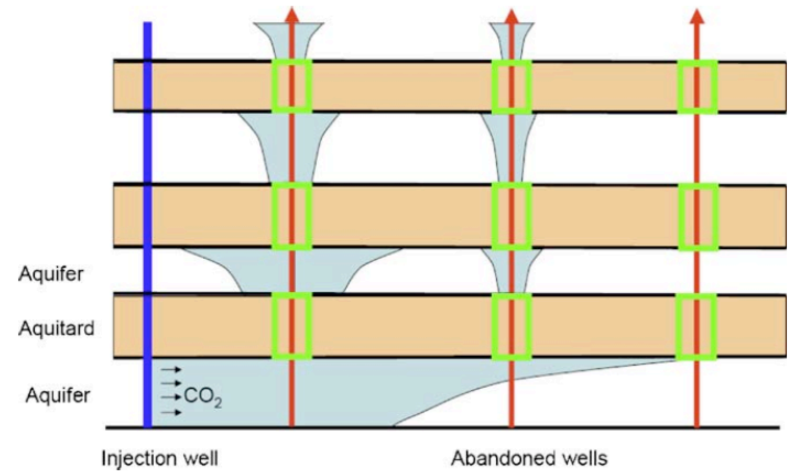
Skinner (2003)

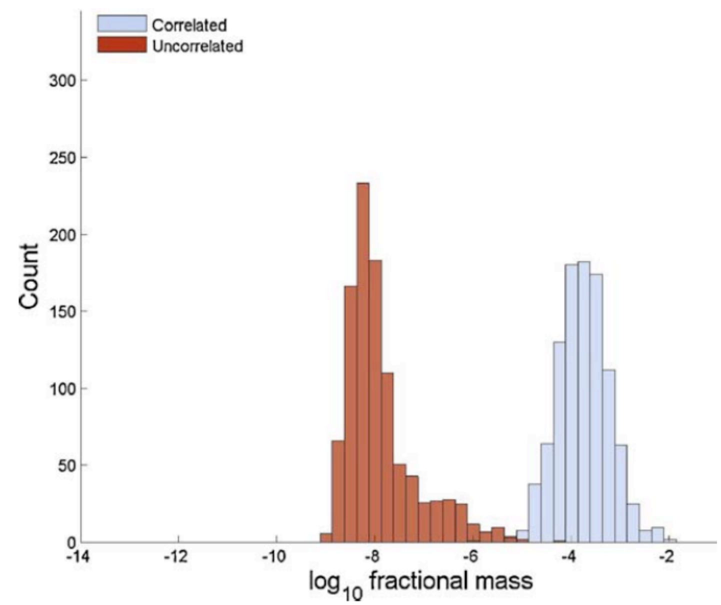


Jordan et al. (2008)

CO_2 Leakage Risk

- Computational studies of wellbore leakage
  - Nordbotten et al. (2004, 2005)
  - Brine may be more significant than CO2
- Risk assessment of leakage from wellbores
  - Viswanathan et al. (2008); Oldenburg et al. (2009)
- Field-based distributions of effective permeability essential but unavailable





Celia et al. (2011)

Monitoring

- Standard mechanical integrity tests
  - External tests rarely used
- New approaches to cement bond logs
  - Loizzo et al. (2011)
- Fiber-optics
  - Freifeld et al. (2009)
- Weyburn monitoring program
  - Chalaturnyk et al.
- Great need for additional work in identifying and quantifying CO_2 and brine leakage

Remediation

- Wells can be remediated
  - Variety of sealants
  - Milling operations
- Complications
  - Abandoned wells are cut-off below ground and difficult to re-enter
  - Unknown well locations
- Need case histories of remediation including costs and effectiveness of treatment

Network Achievements

- Discussions and sharing of experience between industry, academia and research labs
- Dissemination of knowledge
- Stimulation of research ideas
- Identification of areas of agreement/disagreement and of research needs
- Establishment of collaborations

Challenges

- Difficult to expand beyond a core-group of motivated people
  - Meeting participation: 55-75
- Wellbore research needs industry data—proprietary and regulatory issues limit access
- Organizing meetings with good participation increasingly difficult
- "One meeting among many"
- Need for fresh formats and ideas

EPA regulation issues/questions

- No established connection between CO_2-resistant materials and long-term, well integrity (external well leakage)
- External mechanical integrity tests are specified, but little CO_2-specific research exists on this topic!
- What materials comply with guidelines for CO_2-resistant wells?
- How are non-injection wells within the area-of-review different/same in design/monitoring requirements?
  - How do you demonstrate that an abandoned well is not a risk?

Key Risk Assessment Topics in Wellbore Integrity

- Frequency of well failure
  - Acute versus chronic events
  - Impact of wellbore leakage
- Relationship of wellbore construction and operational history to leakage potential
- Detection and monitoring of wellbore leakage
- Mitigation and prevention of wellbore leakage
- Effective permeability of wells including time-dependent leakage rates
- Long-term performance of wells

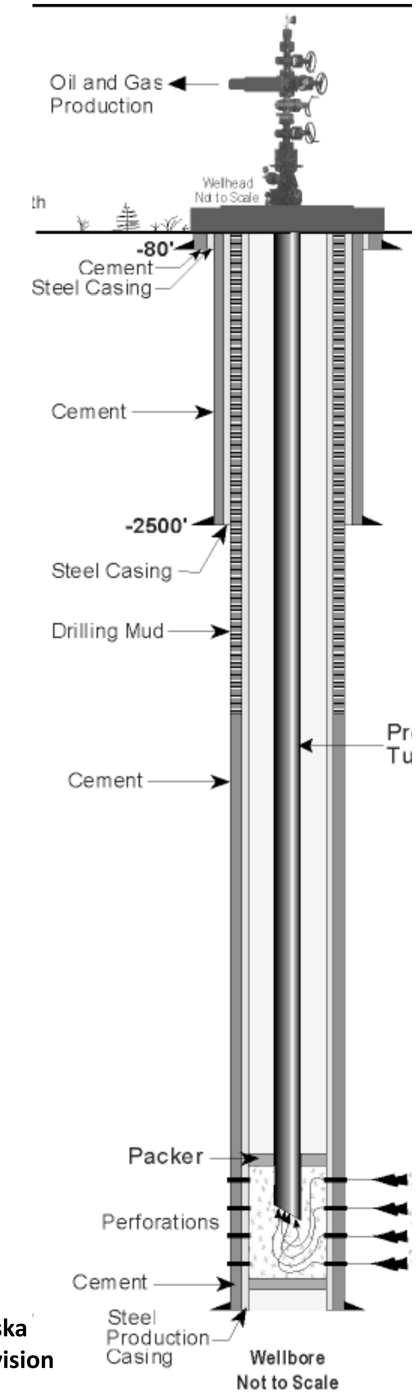
Wellbore Integrity: What can go wrong?

Pre-production

- **Formation damage during drilling (caving)**
- **Casing centralization (incomplete cementing)**
- **Adequate drilling mud removal**
- **Incomplete cement placement (pockets)**
- **Inadequate cement-formation bond**
- **Inadequate cement-casing bond**
- **Cement shrinkage**
- **Contamination of cement by mud or formation fluids**

Production

- **Mechanical stress/strain**
  - **Formation of micro-annulus at casing-cement interface**
  - **disruption of cement-formation bond**
  - **Fracture formation within cement**
- **Geochemical attack**
  - **Corrosion of casing**
  - **Degradation of cement**
    - **Carbonation**
    - **Sulfate attack**
    - **Acid attack**

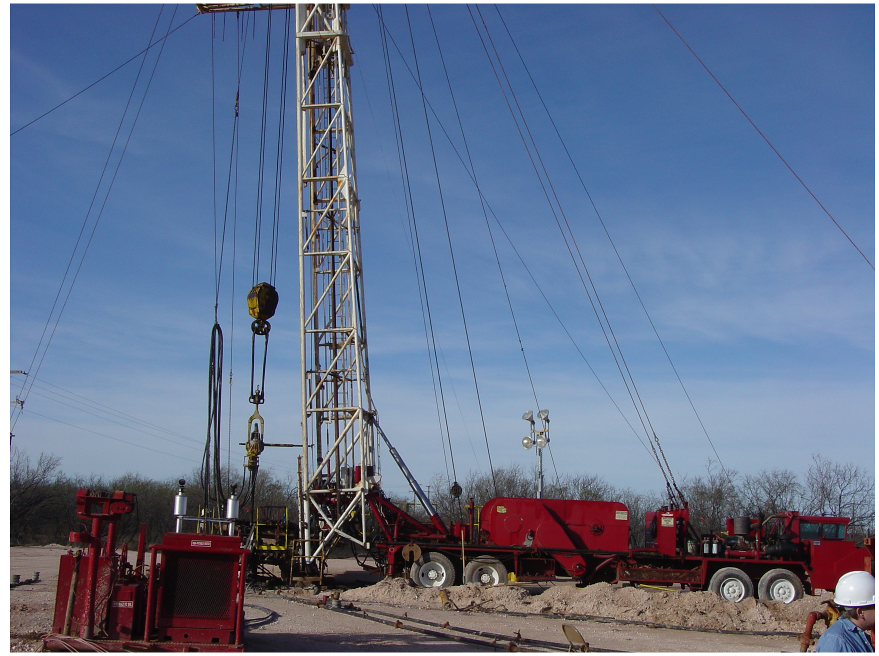


State of Alaska
Oil and Gas Division

Main Topics Considered

- Cement stability in CO_2
- Steel corrosion
- Geomechanical performance
- Design of CO_2-resistant cement
- Best practices in well completions
- Well abandonment practices
- Detailed modeling of fluid-wellbore interactions
- Field-scale modeling of wellbore performance
- Field studies of wellbore performance
  - Individual well samples
  - Field-wide performance statistics (e.g., SCP)
- Wellbore leakage monitoring
- Wellbore integrity analogs
  - Acid gas
  - Thermal stimulation
- Remediation technologies
- Regulatory approaches to WBI
- Risk assessment of well leakage

Old Wells vs. New Wells



- New wells for carbon storage sites are likely to be purpose-built and may contain novel, CO_2-resistant construction materials
- Old wells were designed for a limited service life (40-50 years)
  - Wells above the storage reservoir could provide a pathway upward for CO_2
- The construction practices and abandonment conditions of old wells may be unknown
- Uncertainties with old wells drive some project to areas (or depths) without significant well penetrations
- However, this means giving up on some of the most economically feasible and well studied potential reservoirs

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