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Life Cycle Well Integrity:
Imperatives for Developing New and Mature Assets

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Outline of Presentation

- **Well Integrity**
  - Definition
  - Why is well integrity important
- **Well Integrity – Life cycle stages and governance (ISO 16530-1)**
- **Well Integrity Challenges**
  - HF Shale Wells
  - HPHT Wells
  - Injectors
- **Well Integrity – Best Practices**
  - Good cementing practices
  - HF Wells – Best practices
  - HPHT Wells – Best practices
- **Plugging and Abandonment**
  - Conventional P&A
  - HPHT well
- **Summary**

Well Integrity - Definition

- “Application of technical, operational, and organizational solutions to reduce the risk of an uncontrolled release and/or unintended movement of well fluids throughout the life-cycle of a well” (NORSOK Standard D-010 and API RP 90)
- “Containment and the prevention of the escape of fluids to subterranean formations or surface” (ISO 16530-1)

Well Integrity vs. Wellbore Integrity

- *Well integrity differs from Wellbore integrity (Borehole instability)* – open hole interval that does not retain its gauge and/or structural integrity
- Types of borehole instabilities:
  - Hole closure/narrowing;
  - Hole enlargement/washouts
  - Fracturing
  - Collapse
- Borehole instability prevention:
  - Maintain proper mud-weight; borehole fluid compatible with drilled formation
  - Use proper hydraulics to control equivalent circulating density (ECD)
  - Select proper hole trajectory

Well Integrity – What Does It Mean

- Keep hydrocarbons/produced fluids and injection fluids in pipe

- Why is Well Integrity Important?
  - Safety
  - Environment
  - Production
  - Reputation and social license to operate
  - Asset Value

Photo www.wellintegrity.net

Why is Well Integrity Important?

Montara Blowout – E. Timor Sea – 8/21/09

- Leaked for 74 days (est. flow 2000 BOPD). Stopped w/relief well – no fatalities
- Most likely hydrocarbons entered well thru 9 5/8" cemented casing shoe and flowed up the casing

Source: Montara Commission of Inquiry, 2010 – www.ag.au/cca

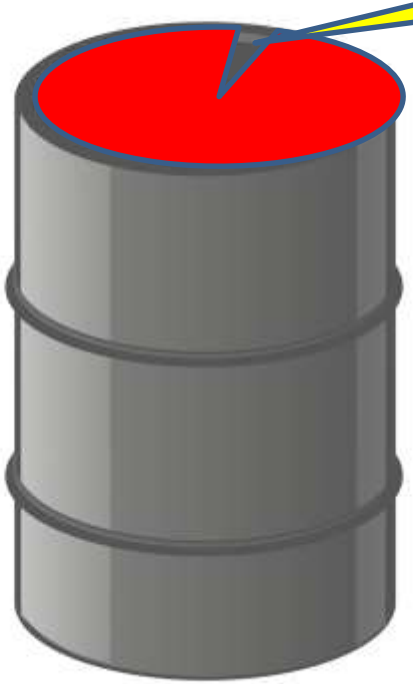
Why is Well Integrity Important?

- Macondo Blowout, *Gulf of Mexico, April 2010*
- 11 fatalities
- Est. 5 million barrels discharged into GOM over 87 days

(photo www.nytimes.com)

Economic Loss Due to Well Integrity Problems

5% loss in production equals $11.5 billion/year ($55 per Barrel)



Cost of constructing 115 new deepwater wells @ ~ $100 million/well

or

Drill/complete 1600 new oil-shale wells onshore @ ~ $7 million/well

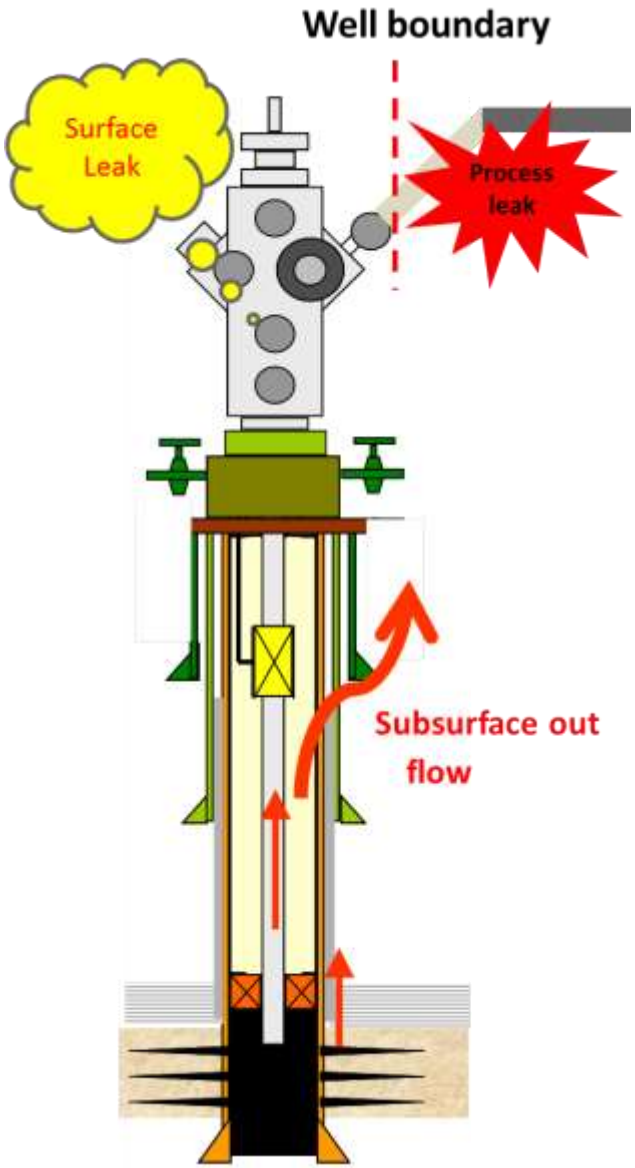
US Produces ~ 4.2 billion barrels/year (Avg 11.5 MMBOD)

Well Integrity Process

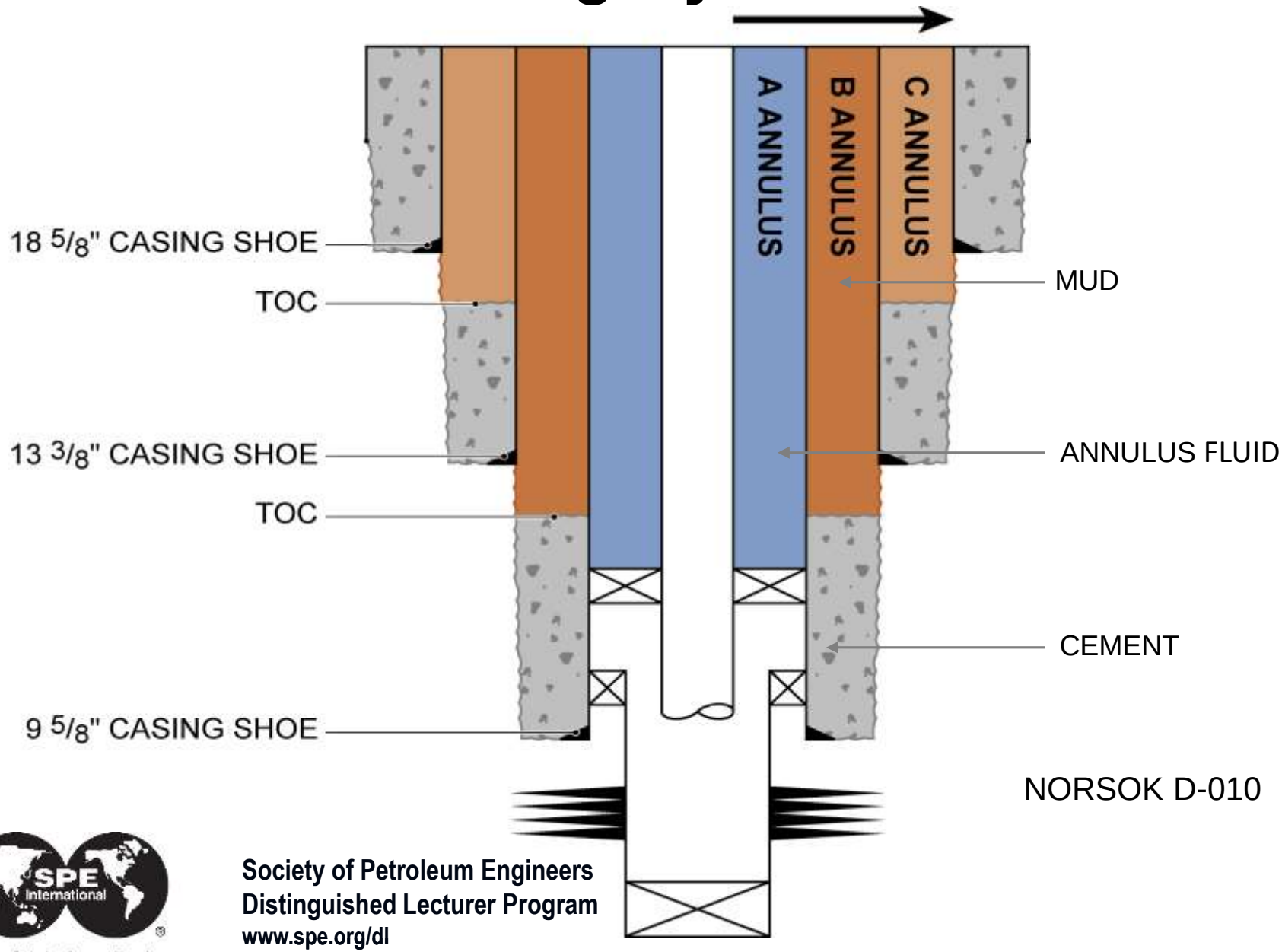
Assurance of Well Barriers over lifecycle:

- Barriers for subsurface that prevent outflow or inflow from subsurface
- Barriers that control the effect of loss of containment to surface
- Barriers that control the effect of loss of containment to process
- Barriers for safe well bore access

Source: Hopmans, 2015

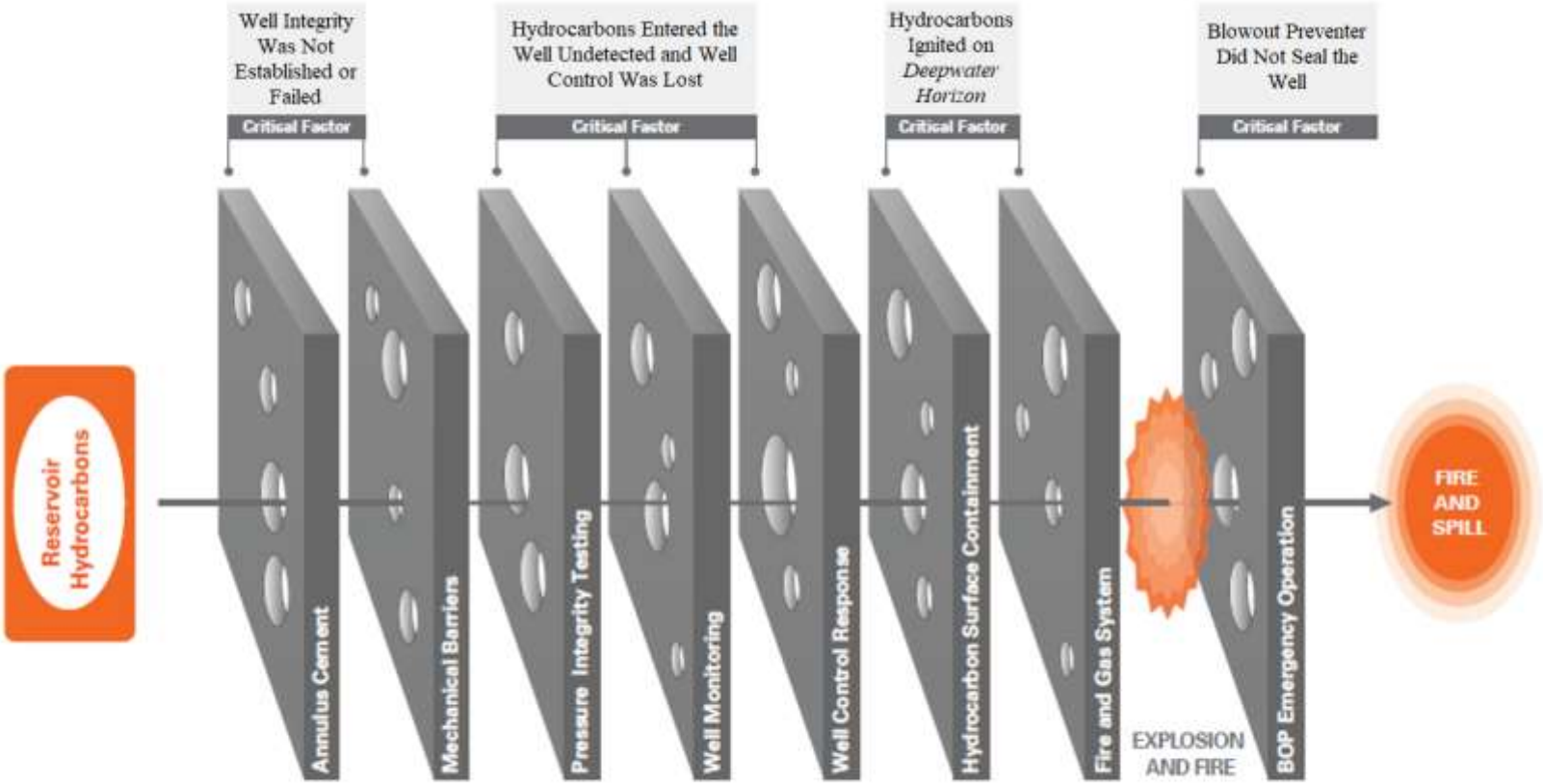


Well Integrity Barriers



NORSOK D-010

Barriers Breached & Relationship of Barriers to Critical Factors



Adapted from James Reason (Hampshire: Ashgate Publishing Limited, 1997).

Barriers Breached and the Relationship of Barriers to the Critical Factors.

BP's Deepwater Investigation Report, 2010

Well integrity – Life cycle governance (ISO 16530-1)

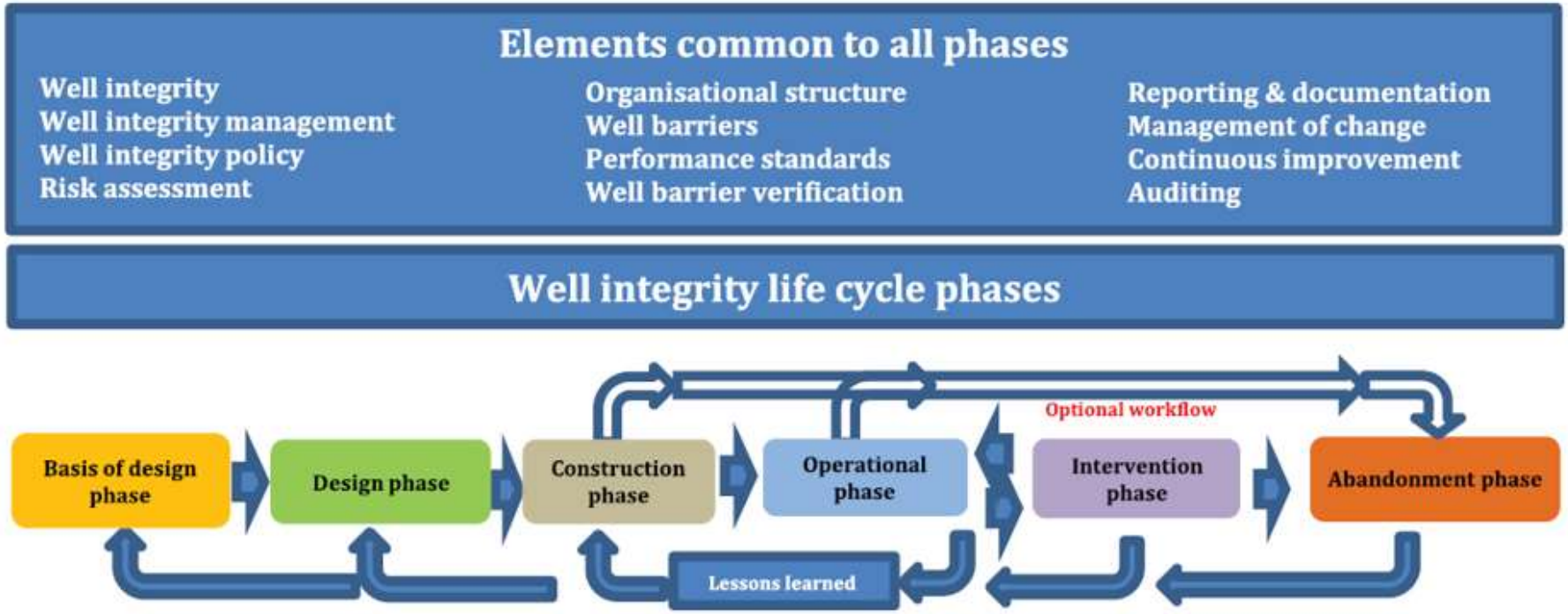


Figure 1 — Elements common to the phases of well integrity management

References: (1) ISO 16530-1-2017 – Well Integrity Part 1: Life cycle governance – www.iso.org; (2) https://oilandgasuk.co.uk/product/well-life-cycle-integrity-guidelines; (3) www.hse.gov.uk/offshore/ed-well-integrity.pdf; (4) http://www.hse.gov.uk/offshore/wells.htm

ISO 16530-1 stages of the well life cycle

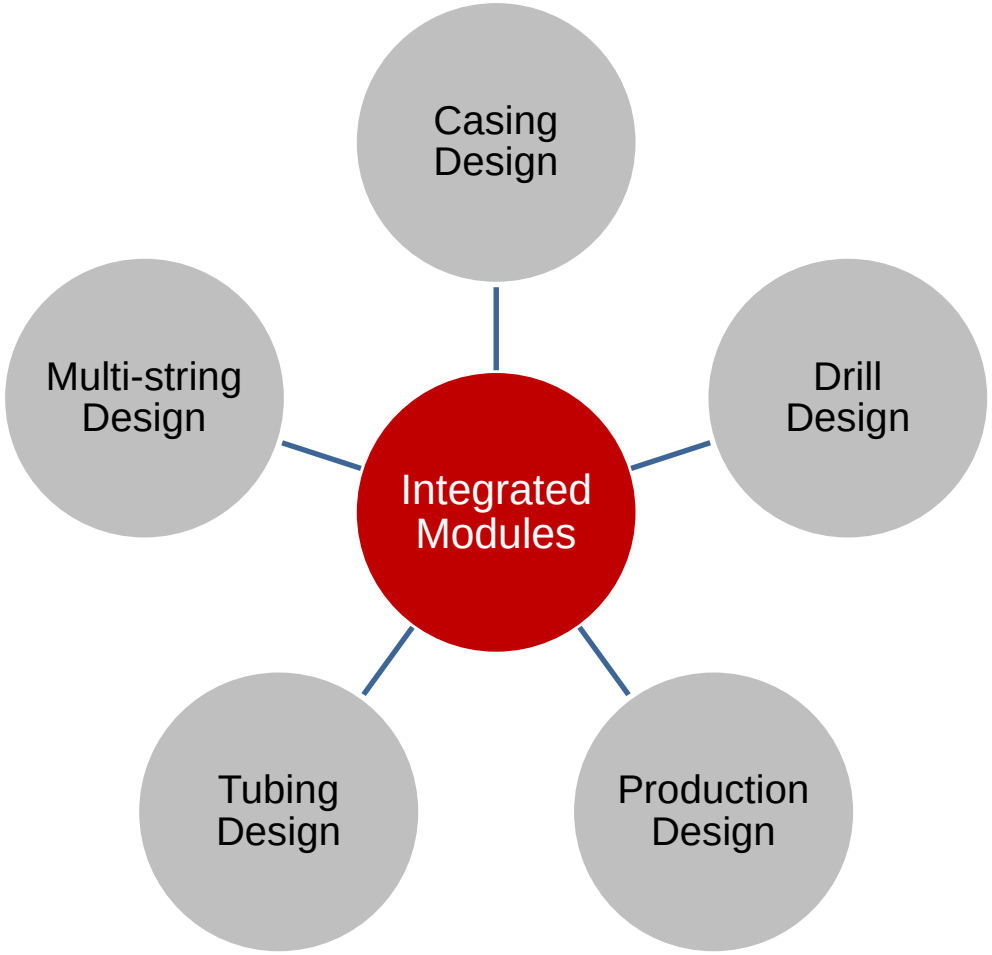
- The **"Basis of Design Phase"** identifies the probable safety and environmental exposure to surface and subsurface hazards and risks that can be encountered during the well life cycle. Once identified, these hazards and risks are assessed such that control methods of design and operation can be developed during subsequent phases of the well life cycle

- The **"Design Phase"** identifies the controls that are to be incorporated into the well design, such that appropriate barriers can be established to manage the identified safety and environmental hazards. The design addresses the expected, or forecasted, changes during the well life cycle and ensures that the required barriers in the well's design are based on risk exposure to people and the environment

ISO 16530-1 stages of the well life cycle, contd

- The **"Construction Phase"** defines the required or recommended elements to be constructed (including rework/repair) and verification tasks to be performed in order to achieve the intended design. It addresses any variations from the design which require a revalidation against the identified hazards and risks
- The **"Operational Phase"** defines the requirements or recommendations and methods for managing well integrity during operation
- The **"Intervention Phase" (including intervention work-overs)** defines the minimum requirements or recommendations for assessing well barriers prior to, and after, any well intervention that involves breaking the established well barrier containment system
- The **"Abandonment Phase"** defines the requirements or recommendations for permanently abandoning a well **(no time limit on lifetime legal liability)**

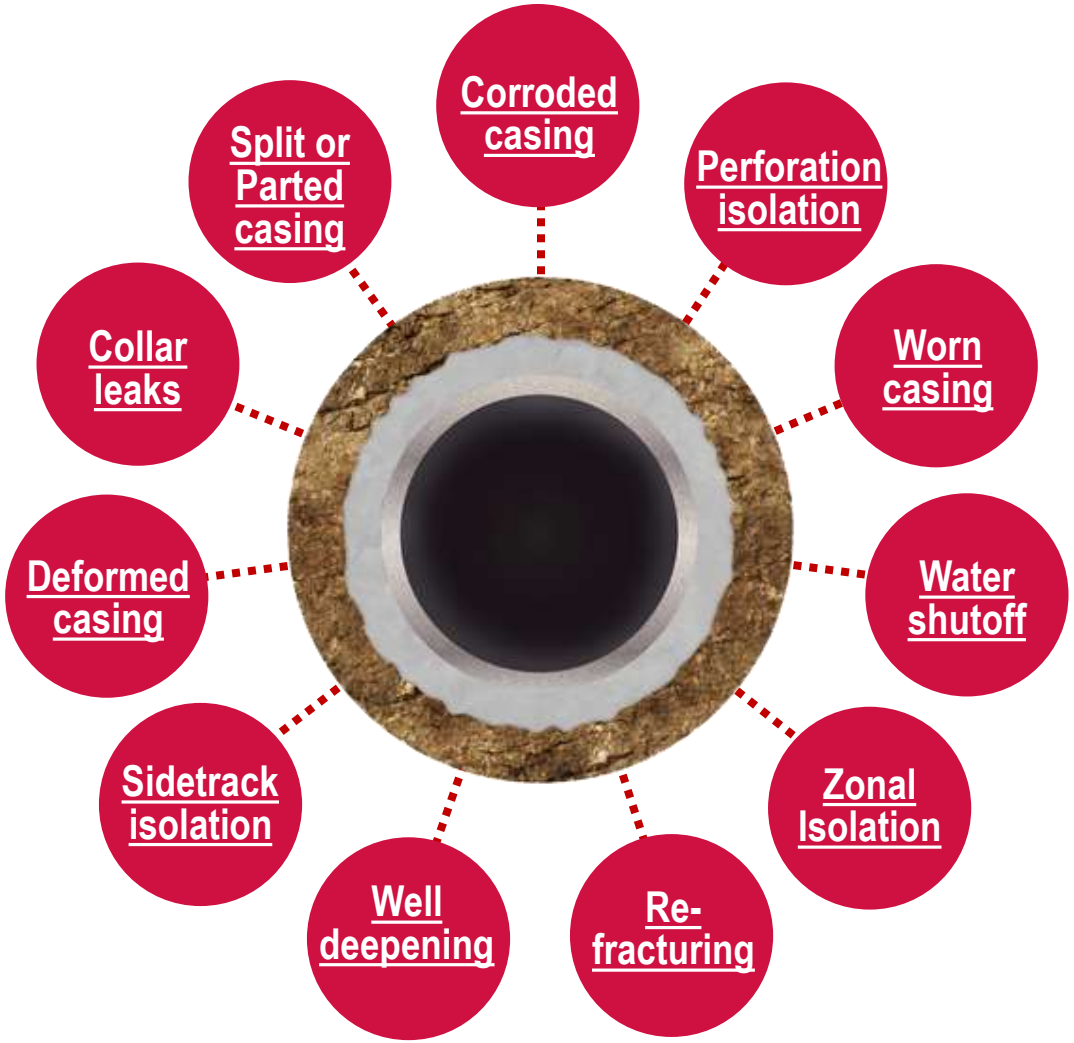
Overview of State-of-Art Casing Design Software



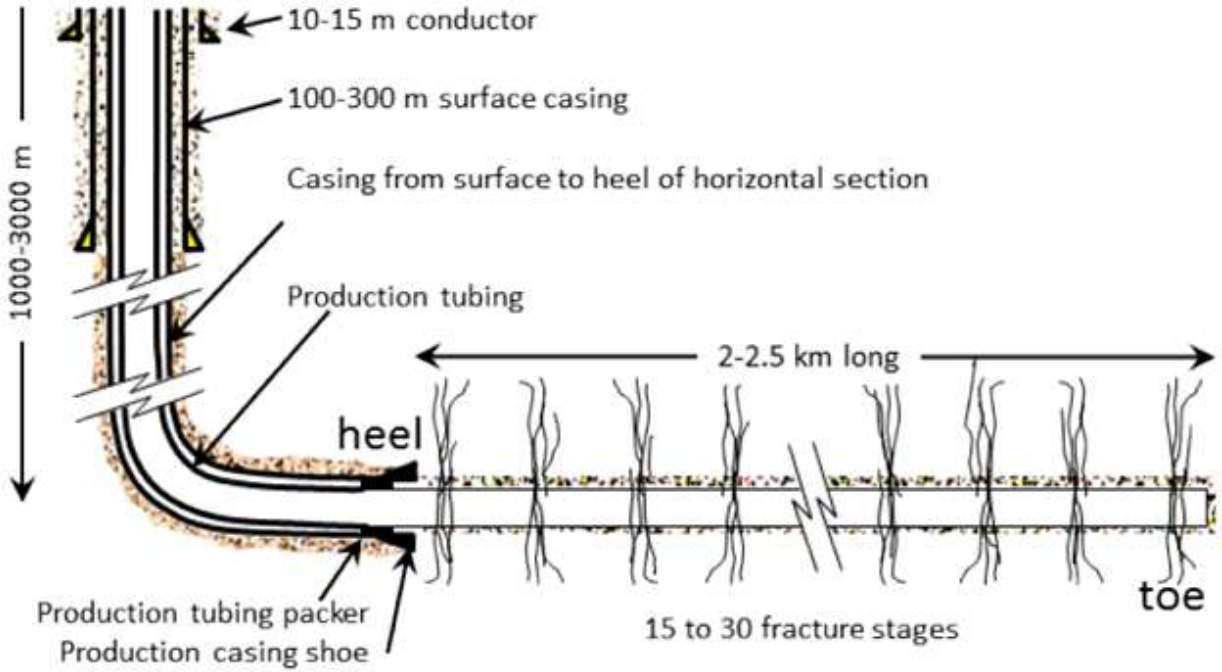
Common Well Integrity Challenges

Weatherford, 2014

Common Well Integrity Challenges



HF Shale Wells – Well Integrity Challenges

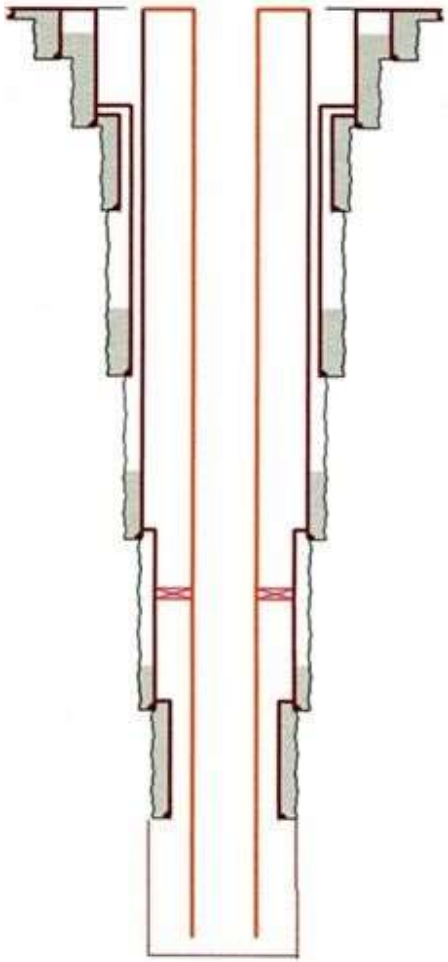


Source: M. Dusseault et al, 2014

- Fracture stimulation loads critical for casing design
- Poor cementing can be catastrophic
- Connections must meet all anticipated loads
- Casing failures during fracturing major concern (w/potential for blowouts)
- High regional stress → casing deformation in the lateral
- Fracture driven interactions

HPHT Wells – Well Integrity Challenges

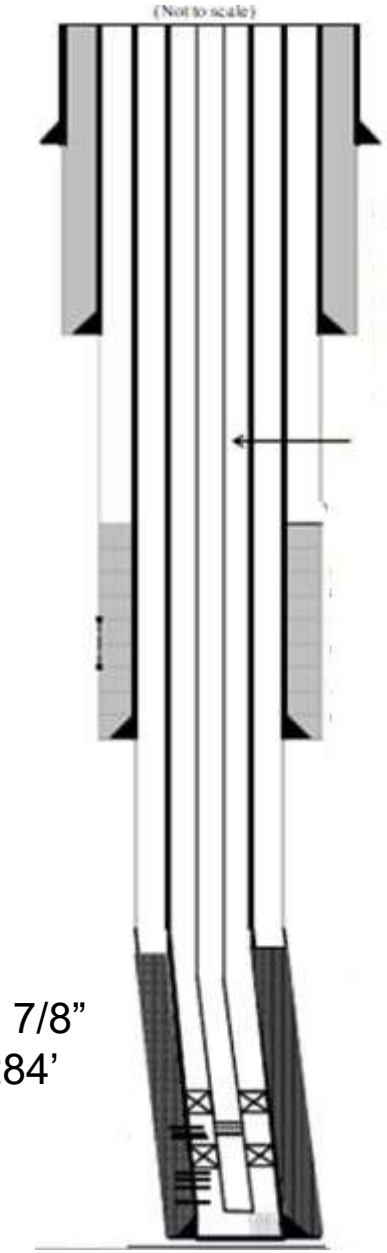
- P>15000 psi (103 MPa;
  Some wells: P>35000 psi(~240MPa)
  T>350^0 F (177^0 C)
  Mud weights > 17 ppg with narrow drilling mud windows
- Complex loading conditions
- Over-pressured formations at shallow depths
- Design focus on metallurgy and sealing; limited by wellbore size
- Trapped annular pressure
- Geothermal gradients < earth's geothermal gradient
- Large temp change between mud-line and perforation depth (100s of ^{0} F)



BSEE/Wild Well, 2018

Injectors - Well Integrity Challenges

- Injectors 2 to 3 times more likely to leak than producer wells
  - Thermal induced higher loads
  - Injectors get less focus
- Injected fluid charging a non-target zone:
  - Potential for kicks drilling offsets
  - Narrow mud windows; difficult reaching TD
- Change of well status/application
- CO2-EOR/CO2-Storage, WAG, acid gas injection wells:
  - Risk of CO2 blowout
  - Corrosion resistant tubular and cements



16” Conductor @ 61’

11 ¾” 42# H-40 STC Surface Casing in 14 ¾” hole @ 993’ Inhibited brine TOC @ 3050’

8 5/8” J-55 LTC Intermediate Casing @ 4047’ in 10 5/8” hole

TOC @ 5420’

5 ½” 17# J-55 LTC prod casing @ 6697’ in 7 7/8” hole

2 7/8” tbg @ 6533’, 5 ½” x 2 7/8” pkr @ 5971’, Perfs 5892’-6284’

Source: Core Energy, IEAGHG, 2018

Example 1: Casing coupling failures in P-110 casing

- Coupling experiences a longitudinal split, usually after cementing to during frac job
- Abort frac stage
- Can be associated with trace H_2S/Probable Sulfide Stress Cracking (SSC) Embrittlement

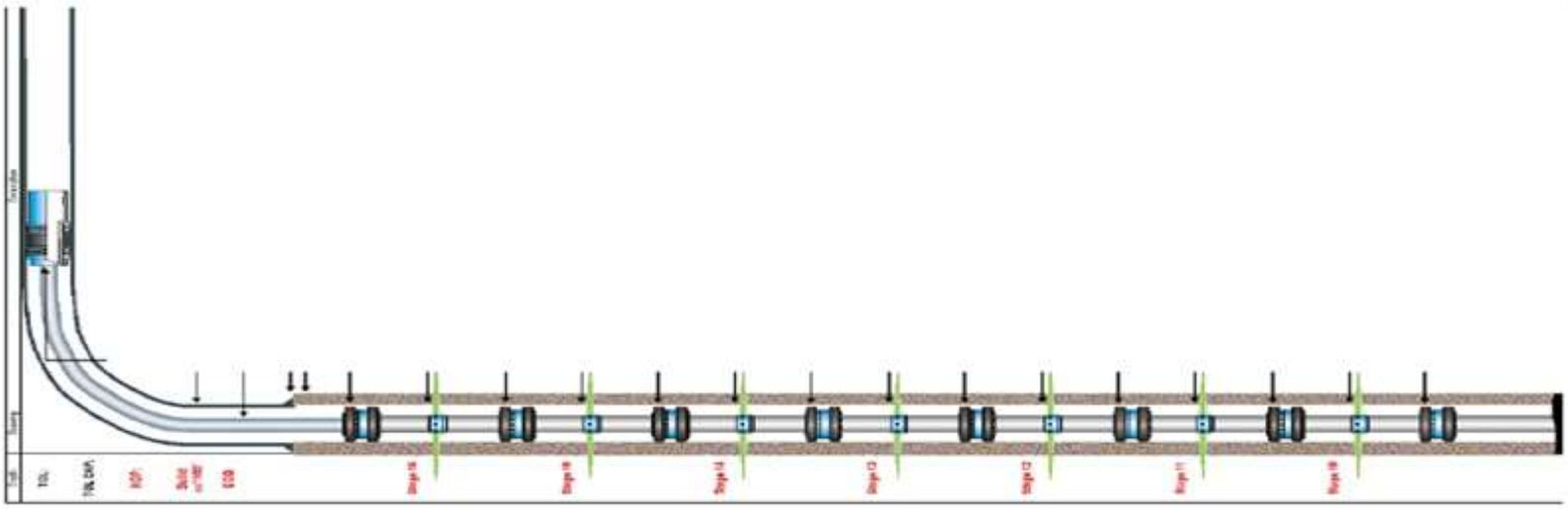
Source: Magill, 2013

Example 2: Split failures near heel

- Occurs after multiple fracs and near the heel
- Appears related to P-110 (not L-80)
- Pipe mills aware of problem and addressing it

Source: Magill, 2013

Example 3: Jewelry failures in lateral



- Mandrel leak occurs in packer/sleeve
- Use quality mandrels. Option - Quit using jewelry and fully cement liner and perforate each interval

Source: Magill, 2013

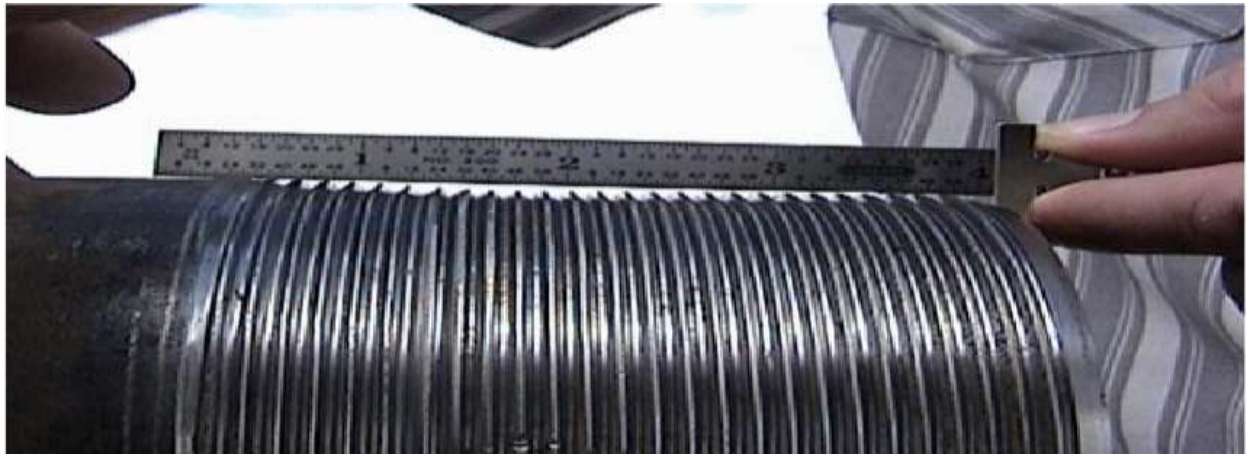
Example 4: Vibrations in wellhead

- Pressure/rate pulsations from pumps/lines resulting in vibration-induced crack in casing wall at last engaged thread of frac head

Source: Magill, 2013

Example 5: Poor joint strength in production casing near surface

- Cross threading common with API connections. Switch to cross-thread resistant premium connections
- Jump –out – hanging load exceeded joint strength



Source: Magill, 2013

Good Cementing Practices

- Wellbore geometry
- Centralization
- Mud conditioning
- Displacement
- Casing movement
- Accurate BHCT and downhole pressure

Good Cementing Practices Applications

Successful HPHT cementing (B. Jain, 2015):

- Stress simulations
- Optimized fluid design for mud, spacer, cement, downhole rheology
- Job execution meets with design; lab testing; QA/QC

Successful HF shale well cementing (Williams/Keese 2011):

- Use stable, non-polymeric cements
- Use flexible, expanding cementing systems (FECS)

Successful CO_2 well cementing (IEAGHG, 2018):

- Consider modified Portland; non-Portland; CO_2 resistant cements

Maintaining Well Integrity during Production

Primary concern with annular pressure - potential loss of well control (either at surface or subsurface)

- ***Annular casing pressure (ACP)*** *(API RP-90, NORSOK D-010, ISO 16530-1)*
  - *Sustained casing pressure*
  - *Thermal casing pressure*
  - *Operator-imposed casing pressure*

Well Integrity - Best Practices during Production

- *User-friendly, complete and up-to-date* well data (including handovers)
- Analyze data, audit losses due to well integrity
  - leakage depth
  - inspect pulled equipment
  - implement mitigation measures
- Monitoring – flowing and annular pressures; gas and fluid rates/composition

HF Wells - Best Practices

- Fracture stimulation loads critical for casing design
- Obtain good primary cementing
- Place TOC as deep as possible to minimize loads
- Get cement inside previous casing shoe; reduce tortuosity (ream build section)

Source: Sugden et al, 2012

HF Wells - Best Practices, contd

- Proper selection and running of connections is critical with good metal-to-metal seal
- Minimize parent-child well interactions - increase well spacing, zipper fracs, cubed development
- Isolate pump surges from WH/Frac tree.

HPHT Wells - Best Practices

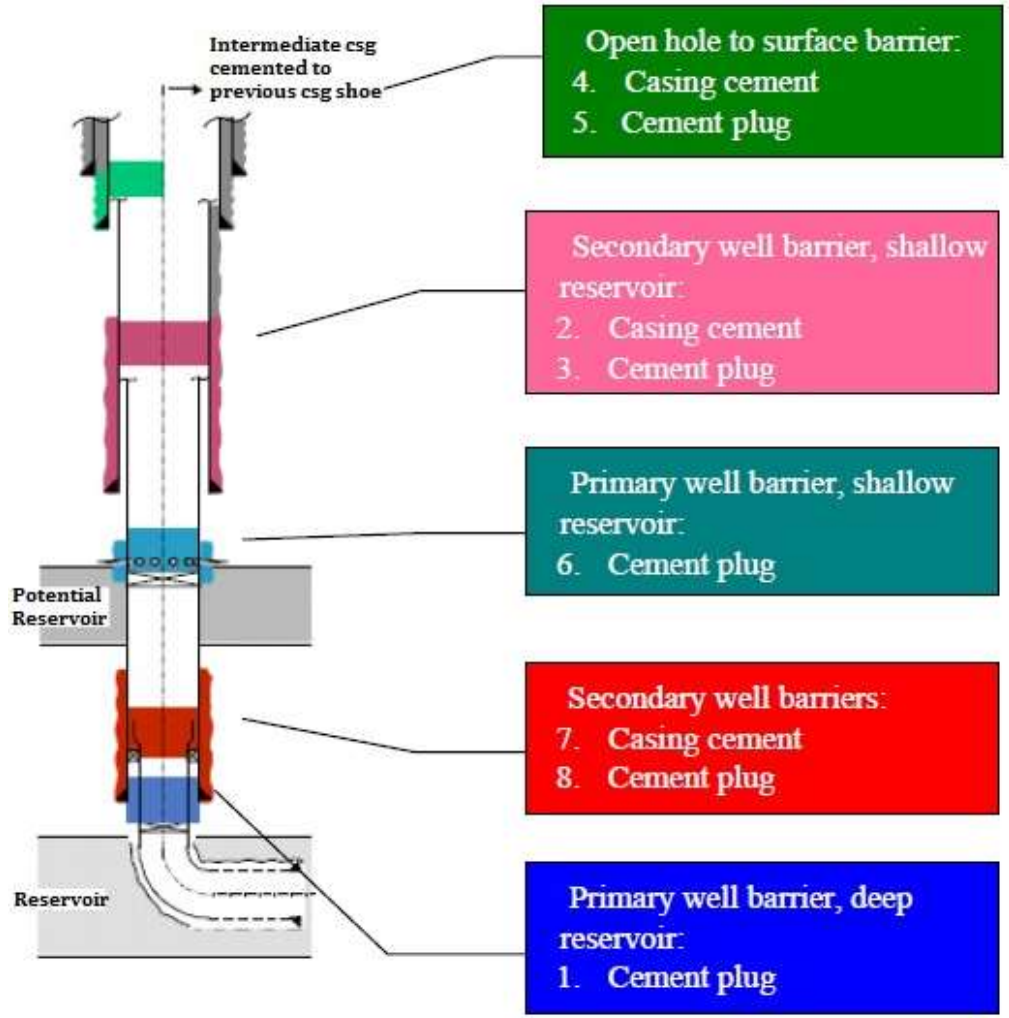
- Need different approaches than in non-HPHT wells
- Consider managed pressure drilling – MPD (narrow mud windows)
- Advanced tubular design
- Logging and drilling tools to withstand HPHT and fit into small diameter wellbores
- Use appropriate metallurgy/alloys

HPHT Wells - Best Practices, contd

- Most HT wells use OBM systems
  - Pros – retain rheology at elevated temps
  - Cons -higher downhole temps compared to WBMs (expose tools to higher temps)
- Requires specialized equipment, tools and training
- Safety - Function test all equipment

Typical Well Plugging & Abandonment

- Quality of a P&A evaluated by type of plugging material and plug placement technique
- Plugging materials: cements, formation, grouts, thermosetting, gels, metals (bismuth/thermite)
- Placement techniques: Balanced plug, Dump-bailer, Two-plug and Jet grouting
- Successful P&A protects environment, with downhole integrity, regulatory compliance

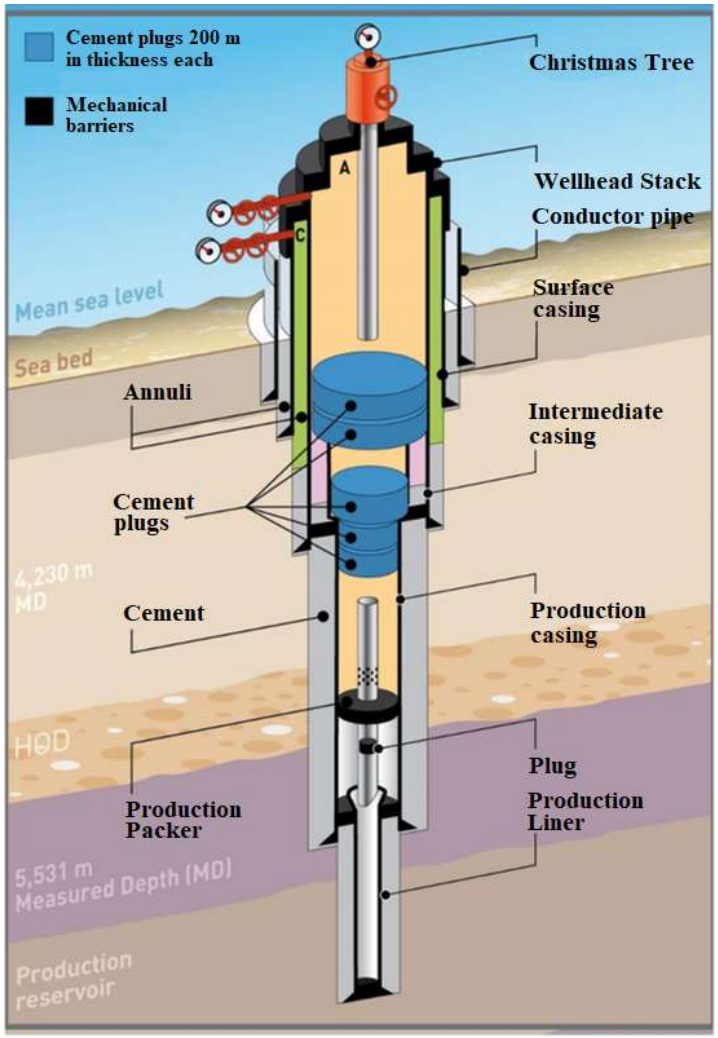


Source: Randhol and Carlsen/SINTEF, 2001

Plugging & Abandonment HPHT Well

- P&A cost may equal 25% of drilling cost and 45% of decommissioning cost offshore

- P&A challenges:
  - Poor primary cementing/loss of cement integrity
  - Tectonic stresses
  - Partial abandonment (slot recovery process – North Sea)
  - Cut and pull production casing
  - Rigless P&A



Source: Gibson, 2016

Summary

- Imperatives to minimize loss of well control and well integrity:
  - Original well design must meet critical casing and cementing requirements
  - Best practices for well construction/production for different well types/applications/environments
  - Appropriate well integrity testing and monitoring procedures
- O&G industry has the technology, knowledge, experience:
  - To operate in challenging environments
  - To avoid potential catastrophic impacts to safety, environment, reputation, economic loss and maintain Social License to operate
  - To assure well integrity throughout the life cycle of the well

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