# 360° Engineering Analysis for Managing Well Integrity

*Moderator:*
Valerie Wilson

360°

*Presenters:*
Dr. Robello Samuel
Aniket Kumar

## Speakers' Introduction

Dr. Robello Samuel
*Halliburton Technology Fellow (Drilling)*
*Halliburton*

Aniket Kumar
*Principal Product Engineer (Drilling)*
*Halliburton*

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## Poll Question

Are you a ____________ SPE member?

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## Poll Question

Which Geographical area are you from?



## Poll Question

What is your affiliation?



## Poll Question

What is your area of expertise?

## What Will We Cover!

- Why is Well Integrity Important?
- Three Areas for Evaluating Well Integrity:
  - ***Inside the Wellbore***
  - ***Outside the Wellbore***
  - ***Beyond the Wellbore***
- Importance of Engineering Analyses
- Best Practices
- Wrap up and Q&A

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## Movie Clip

Several Things have to happen before this!

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## What is Well Integrity?

**NORSOK D-010**

engineering,

"Application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well"

**API RP-96 Deepwater Well Design Considerations**

engineering,

Well integrity is the application of technical, operational, and organizational solutions to reduce the risk of uncontrolled release of formation fluids throughout the life cycle of the deepwater well.

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## Well Integrity Vocabulary

Webinars

- **Well Barrier Element:** one or several dependent components that are combined to form a barrier envelope that prevents uncontrolled flow of fluids within or from a well
- **Well Integrity Management:** A combination of technical, operational and organizational processes ensuring a well's integrity during the operating life cycle
- **Well Integrity Management System (WIMS):** An operator's internally agreed upon system that is applied to all wells

SPE International

Source: ISO/TS 16530-2 Well Integrity – Part 2: "Well Integrity for the Operational Phase", 1st Edition 2013.

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## Well Integrity Vocabulary

Webinars

- **Well Assurance:** Assurance that wells are designed with proper engineering standards with risks quantified and minimized, reliability and safety of the well maximized.
- **Well Reliability:** Probability that the well will perform as intended under known conditions for a specified time providing the dependability of expected results over and over. Provides insight into the failure mechanism of a well.

  ***Reliability*** *is theoretically defined as the probability of success (Reliability=1-Probability of Failure).*

SPE International

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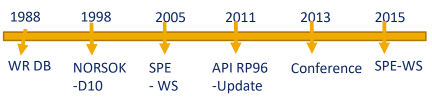
## Not New to Our Industry!

Webinars

- Uptick in the number of well drilled in the coming years compared to the number of wells drilled in the last 50 years.
- Focus will slowly shift towards the design that can provide integrity throughout the life of the well.




SPE International

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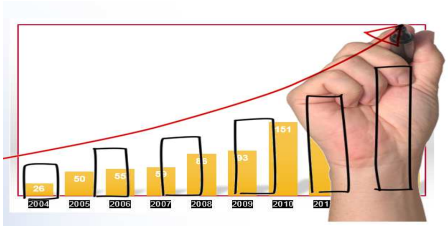
## Technical Papers on WIMS




Sharp uptick in publications

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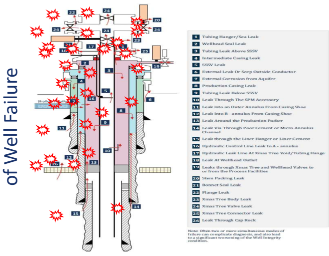
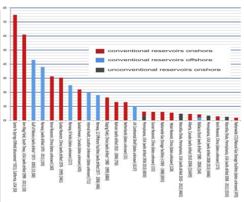
## Sample Well Integrity Challenges

26 Typical Modes of Well Failure

**Well Complexity**



**Well & Barrier Failures**




*ISO/TS 16530-2 Well Integrity

**Marine and Petroleum Geology, Volume 56, 2015, Richard J. Davies et al

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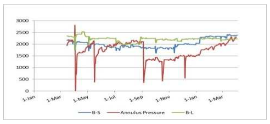
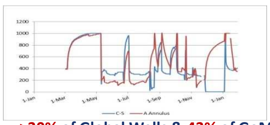
## Additional Challenges

**Sustained Casing Pressure**

Water Injection Well



Oil Production Well

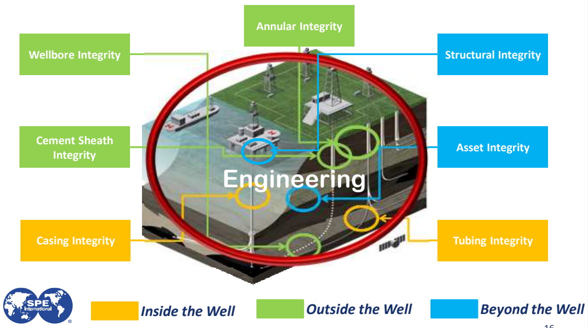


>30% of Global Wells & 43% of GoM

**Well Preventive Maintenance**

## Total Well Integrity Ecosystem

Webinars

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## Poll Question

Webinars

How Many of your Wells have faced **Well Integrity** Challenges in their Lifecycle?

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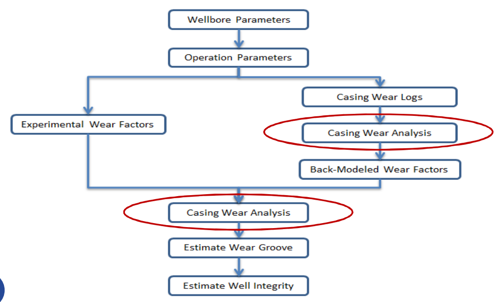
Webinars

*Well Integrity: Inside the Wellbore*

## Casing Wear

## Casing Wear Estimation

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## The Casing Wear Puzzle

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## Modeling Approach

- Fundamental Wear Modeling Equation

$$WV = W_f \times SF_{tj} \times \pi \times D_{tj} \times RPM \times t \times \frac{L_{tj}}{L_p}$$

- Simulated Five Different Operations –
  - ✓ Drilling
  - ✓ Slide Drilling
  - ✓ Backreaming
  - ✓ Rotating Off-Bottom
  - ✓ Reciprocation
- Drillstring Movement in Steps of 30ft

$$S_{op} = |MD_{end} - MD_{start}| \;/\; 30ft$$

- Wear Simulated on 10ft Casing Sections

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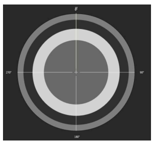
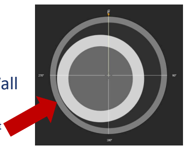
## Soft String vs. Stiff String

- Soft String Model Fit for Torque & Drag Modeling
- Does Not Estimate Drillstring & Casing Contact
- Over Predicts Casing Wear



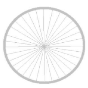
- Stiff String Model Fit for Casing Wear Analysis
- Predicts Drillstring Contact Points With Casing Wall
- Required To Model Multiple Wear Grooves

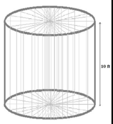





## Modeling Multiple Wear Grooves

- 10ft Casing Sections Simulated as a 3-D Mesh
- Casing Cross-sections Comprised of 72 Slices
- Wear Volume Allocated Based on Contact Points
- Wear Grooves Modeled Using Crescent Shaped Groove Geometry
- Groove Distribution Resulting From Prior Operations Combined

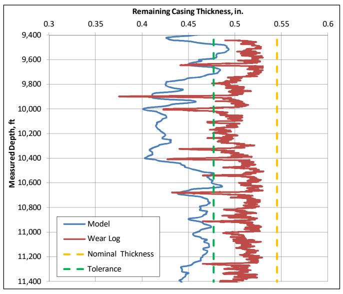




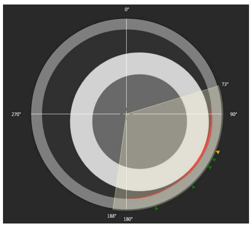


## Field Example

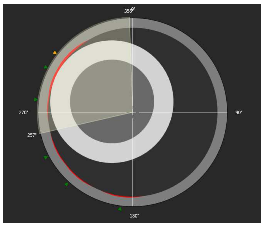
- Multi-lateral Well – North Sea
- 2 Casing Sizes in Main Wellbore
  - 10-3/4 in. till 9,140 ft
  - 9-5/8 in. till 20,020 ft
- 4 Sidetracks Drilled
- Total of 9 Operations Performed
- 9-5/8 in. Casing Logged
  - 9,445 ft to 16,540 ft



## Multiple Wear Grooves



Depth: 10,400 ft



Depth: 5,700 ft

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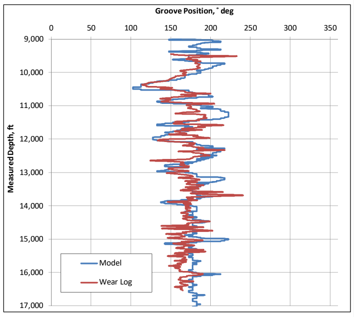
## Azimuthal Groove Position

- 0˚ Shows High Side
- 180˚ Shows Low Side
- Tangent Section Was Logged
- Most Wear Around Low Side

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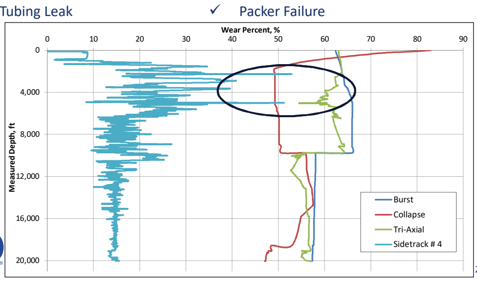
## Maximum Allowable Wear

1. Burst Loads
   - ✓ Drill Ahead
   - ✓ Gas Over Mud Ratio
   - ✓ Tubing Leak
2. Collapse Loads
   - ✓ Drill Ahead
   - ✓ Cementing
   - ✓ Packer Failure
3. Axial Loads

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## Poll Question

How Many of your Wells have faced **Casing Wear** Challenges in their Lifecycle?

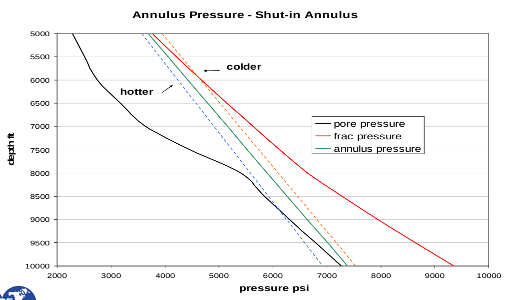


*Well Integrity: Inside the Wellbore*

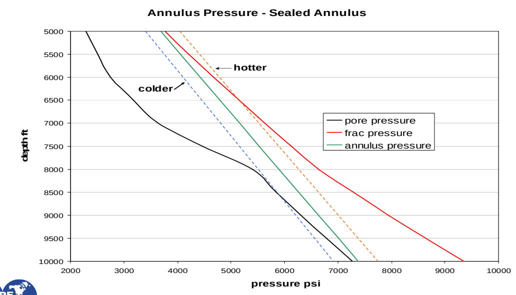
**Annular Pressure Buildup**

**Wellhead Growth**

## Annular Pressure: Shut-in Annulus



## Annular Pressure: Sealed Annulus

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## Annulus Fluids Change with Time

- Drilling mud density achieved with suspended particles of high density
- Particles are suspended by the shear strength of the gelled fluid, they are not soluble
- Oil-based fluids not noted for their gel forming properties
- Settling of barite is called “Barite sag”

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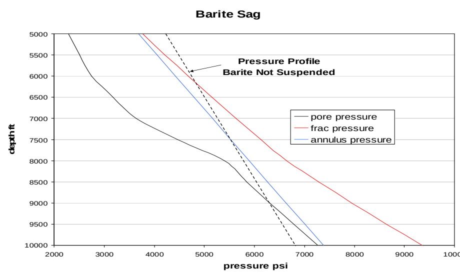
## Barite Sag

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## Annulus Fluids Change with Time

- Drilling mud sealed in annulus by "filter cake"
- Annulus fluid sealed by low permeability formation
- Annulus pressures greater than pore pressure over some of depth interval, so tendency for drilling fluids to diffuse into formation
- What is the long-term effect of filtration? How does "filter cake" age and what its long term effectiveness?

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## What We Don't Know!

- **Specifics of wellbore heat transfer for drilling:**
  - Heat transfer in eccentric annulus with pipe rotation
  - Heat transfer with cuttings transport
  - Free convection in eccentric annulus with non-Newtonian fluids
- **Specifics of fluid flow of non-Newtonian fluids:**
  - Flow in eccentric annulus with pipe rotation (secondary flow, vortex…)
  - Turbulent flow of non-Newtonian fluids (incomplete knowledge)
  - Transient flow of non-Newtonian fluids (is gelled fluid a solid?)
- **PVT and transport properties of drilling muds (incomplete knowledge)**
- **PVT and transport properties of brines (incomplete knowledge)**
- **Long term behavior of drilling muds (e.g. barite sag, filter cake aging)**

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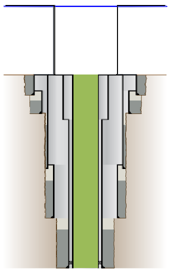
## Demonstration: What we Know

**Well Integrity Analysis**
**Subsea Well Configuration**

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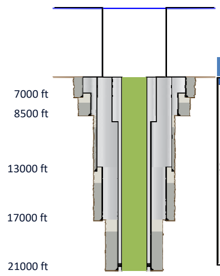
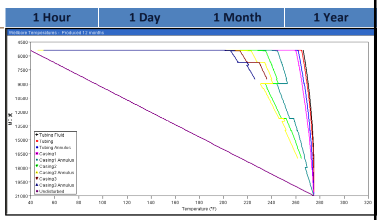
## Demonstration: What we Know

### Wellbore Temperatures

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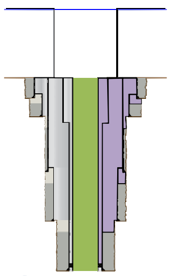
## Demonstration: What we Know

### Trap Annular Pressure

Produce 1 year



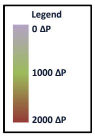
18 5/8" Surface Liner: **560 ΔP**

16" Intermediate Casing: **774 ΔP**

13 5/8" Intermediate: **1730 ΔP**

9 5/8" x 7" Production: **368 ΔP**

5 1/2" Production Tubing: **0 ΔP**

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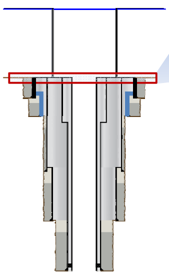
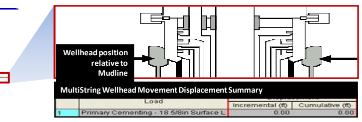
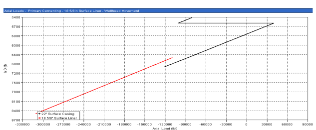
## Demonstration: What we Know





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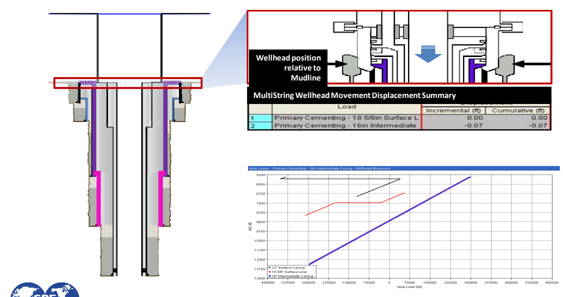
## Demonstration: What we Know




| | Load | Incremental (ft) | Cumulative (ft) |
|---|---|---|---|
| 1 | Primary Cementing - 18 5/8in Surface L | 0.00 | 0.00 |
| 2 | Primary Cementing - 16in Intermediate | -0.07 | -0.07 |

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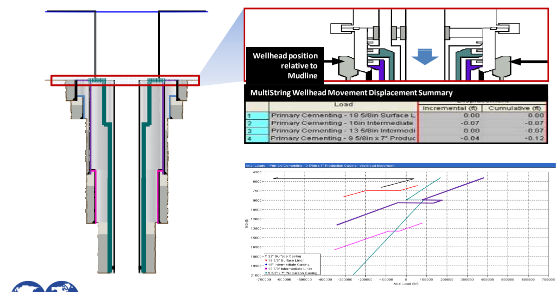
## Demonstration: What we Know




| | Load | Incremental (ft) | Cumulative (ft) |
|---|---|---|---|
| 1 | Primary Cementing - 18 5/8in Surface L | 0.00 | 0.00 |
| 2 | Primary Cementing - 16in Intermediate | -0.07 | -0.07 |
| 3 | Primary Cementing - 13 5/8in Intermedi | 0.00 | -0.07 |
| 4 | Primary Cementing - 9 5/8in x 7" Produc | -0.04 | -0.12 |

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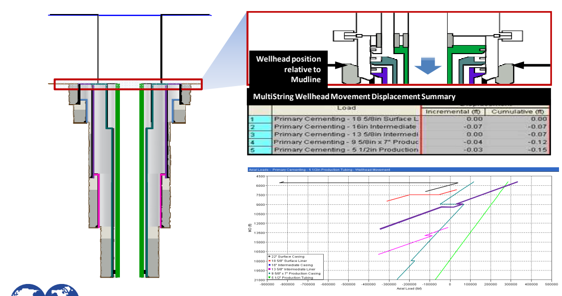
## Demonstration: What we Know

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|---|---|---|---|
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| 2 | Primary Cementing - 16in Intermediate | -0.07 | -0.07 |
| 3 | Primary Cementing - 13 5/8in Intermedi | 0.00 | -0.07 |
| 4 | Primary Cementing - 9 5/8in x 7" Produc | -0.04 | -0.12 |
| 5 | Primary Cementing - 5 1/2in Production | -0.03 | -0.15 |

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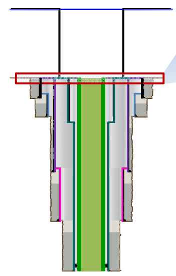
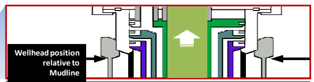
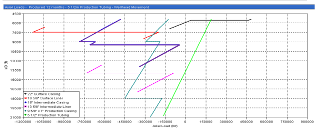
## Demonstration: What we Know






MultiString Wellhead Movement Displacement Summary

| | Load | Incremental (ft) | Cumulative (ft) |
|---|---|---|---|
| 1 | Primary Cementing - 18 5/8in Surface L | 0.00 | 0.00 |
| 2 | Primary Cementing - 16in Intermediate | -0.07 | -0.07 |
| 3 | Primary Cementing - 13 5/8in Intermedi | 0.00 | -0.07 |
| 4 | Primary Cementing - 9 5/8in x 7" Produc | -0.04 | -0.12 |
| 5 | Primary Cementing - 5 1/2in Production | -0.03 | -0.15 |
| 6 | Produce 1 year - 5 1/2in Production Tub | 0.41 | 0.26 |

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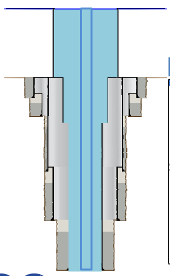
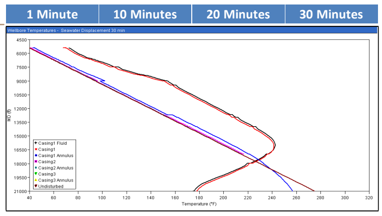
## Demonstration: What we Know



### Wellbore Temperatures
Tubingless Seawater Displacement

1 Minute | 10 Minutes | 20 Minutes | 30 Minutes



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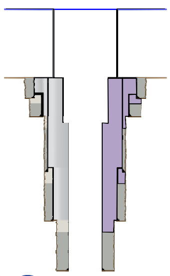
## Demonstration: What we Know



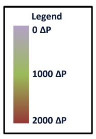
### Trap Annular Pressures
Tubingless Seawater Displacement

18 5/8" Surface Liner: **-6.0 ΔP**

16" Intermediate Casing: **-23.0 ΔP**

13 5/8" Intermediate: **-13.0 ΔP**

9 5/8" x 7" Production: **-166.0 ΔP**

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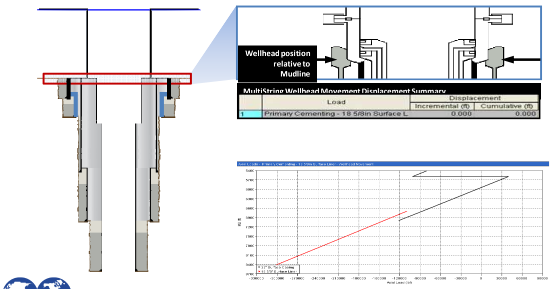
## Demonstration: What we Know




| | Load | Displacement Incremental (ft) | Displacement Cumulative (ft) |
|---|---|---|---|
| 1 | Primary Cementing - 18 5/8in Surface L | 0.000 | 0.000 |

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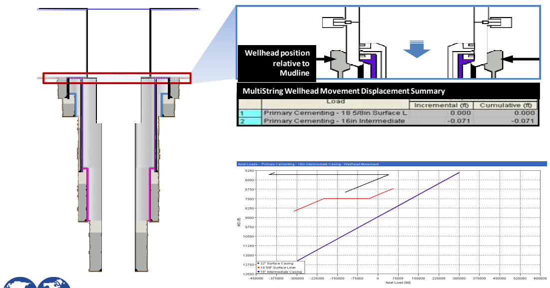
## Demonstration: What we Know




| | Load | Incremental (ft) | Cumulative (ft) |
|---|---|---|---|
| 1 | Primary Cementing - 18 5/8in Surface L | 0.000 | 0.000 |
| 2 | Primary Cementing - 16in Intermediate | -0.071 | -0.071 |

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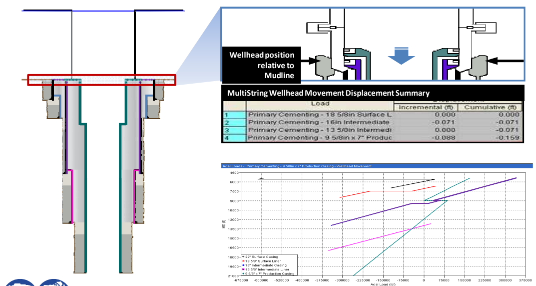
## Demonstration: What we Know




| | Load | Incremental (ft) | Cumulative (ft) |
|---|---|---|---|
| 1 | Primary Cementing - 18 5/8in Surface L | 0.000 | 0.000 |
| 2 | Primary Cementing - 16in Intermediate | -0.071 | -0.071 |
| 3 | Primary Cementing - 13 5/8in Intermedi | 0.000 | -0.071 |
| 4 | Primary Cementing - 9 5/8in x 7" Produc | -0.088 | -0.159 |

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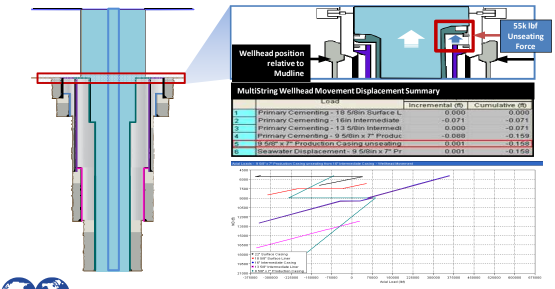
## Demonstration: What we Know

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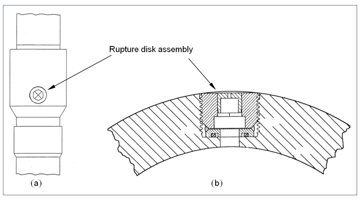
## Introduction of Rupture Disk

- One-time switch
- Open at specified differential pressure
- Able to burst and/or collapse

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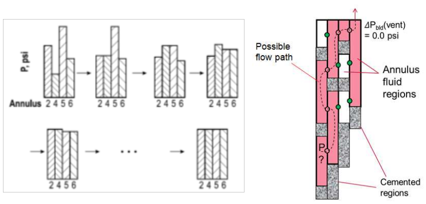
## Engineering Calculations

- Pair-by-pair pressure balancing
- Iteration to reach global equilibrium
- Region connection flagging based on graph theory

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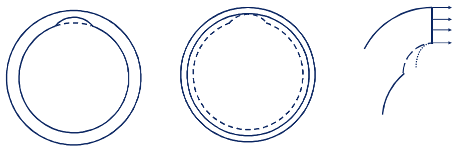
## Engineering Calculations

- What happens when inside and outside well engineering is coupled?
  - Absence of casing wear calculation will lead to overestimation of the well integrity
  - Wrong casing wear calculation will lead to underestimation of the well integrity



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## Poll Question

How Many of your Wells have faced **Annular Pressure Buildup** Challenges in their Lifecycle?

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*Well Integrity: Inside the Wellbore*

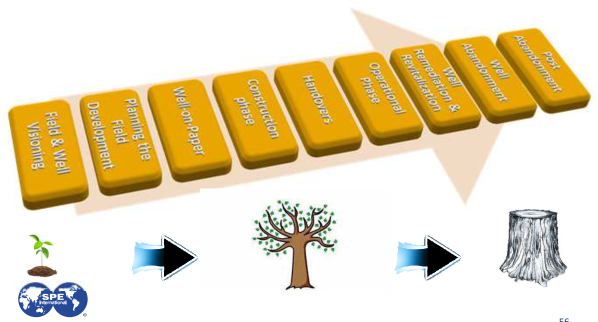
**Asset Integrity**

## Poll Question

Do you evaluate / consider **Asset Integrity** as part of Annual Review?

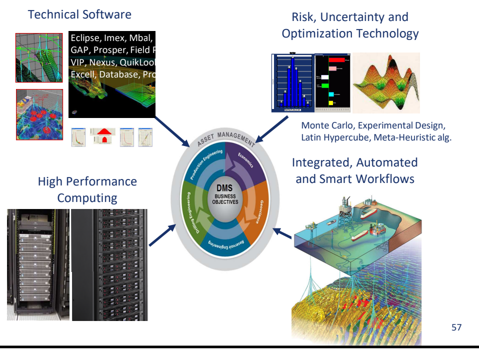


## Engineering is Beyond Well "Life Cycle"

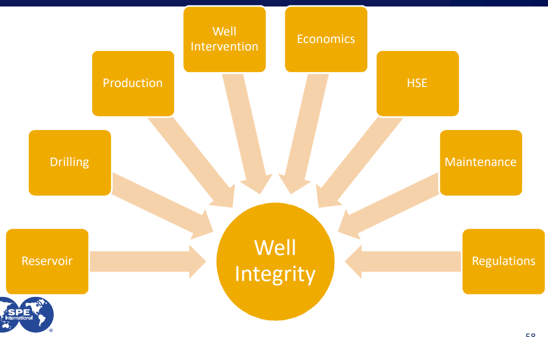





## 360˚ Engineering Convergence



## It Encompasses Many Engineering Domains

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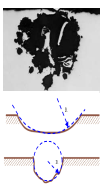
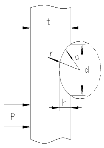
## Corrosion

- Like wear, corrosion can have a major detrimental effect on the mechanical integrity of tubular systems and must be included in the design premise.






$$K_{tg} = \frac{b^2 \cdot \gamma - (a-h) \cdot \sqrt{b^2 - (a-h)^2}}{b^2\gamma - a^2\beta - (a-h)^2(tg\,\gamma - tg\,\beta) + \frac{a^3(4m - 5mv + 3a^2n)}{(7-5v)}} \cdot \frac{27-15v}{14-10v}$$

***Sun and Samuel Model for Deration***

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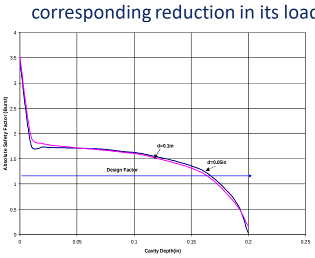
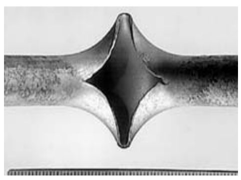
## Corrosion

- Metal loss reduces the wall thickness of the pipe and leads to a corresponding reduction in its load resistance.



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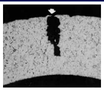
## Corrosion

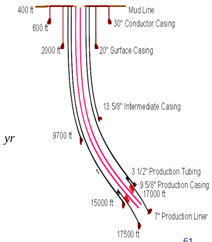
- Pipe can be so weakened that it can no longer withstand operating loads.
- The most severe forms of this type of corrosion are:
  - Sulfide-stress-corrosion cracking (SSCC)
  - Chloride-stress-corrosion cracking (SCC)
  - Hydrogen embrittlement.
- NORSOK Model

$$CR = Kf_{co_2}\left(\frac{S}{19}\right)^{0.146+0.0324\ \log\ f_{co_2}} f(pH)mm\ /\ yr$$

- De Ward Model

$$CR = F_k 10^{5.8-\frac{1710}{T}+0.67\ \log\ f_{co_2}}\ mm\ /\ yr$$



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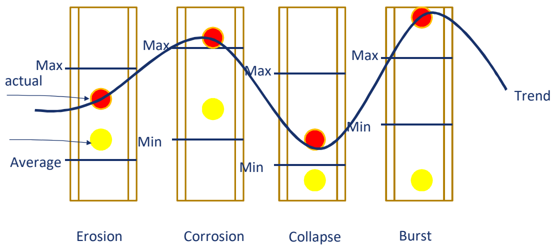
## Monitoring Dash Board

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## Erosion

- Corrosion – Chemical Process
- Erosion – Mechanical Process
- Erosivity:

$$ECR = C_o F_{sat}^{C} \times f_t \times f_{pH}\ mm\ /\ yr$$

- Customizable model

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## Risk of SSCC Increase With:

- Increasing $H_2S$ partial pressure
- Increasing material hardness (and consequently strength)
- Increasing tensile stress
- Increasing exposure time
- *Decreasing* pH of the environment
- *Decreasing* temperature

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## Material Selection for Sour Wells

- Different materials can be used at different depths in the wellbore based on a temperature profile
- The undisturbed temperature profile is often used because it represents a conservative estimate of the minimum steady-state temperature the pipe could experience while exposed to the sour environment.

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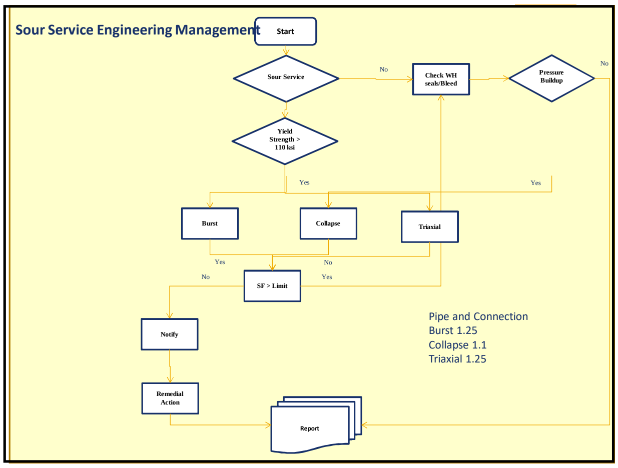
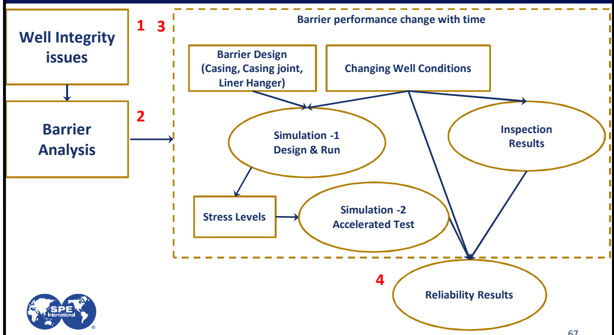


## How is this Done?

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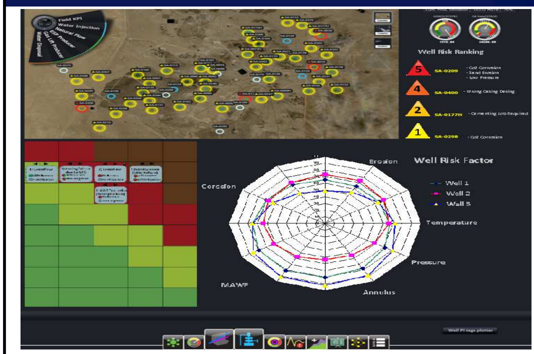
## Risk Analysis

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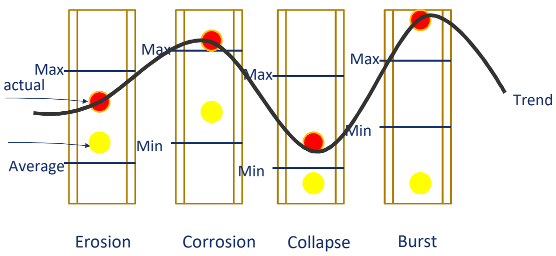
## Inspection Dashboard

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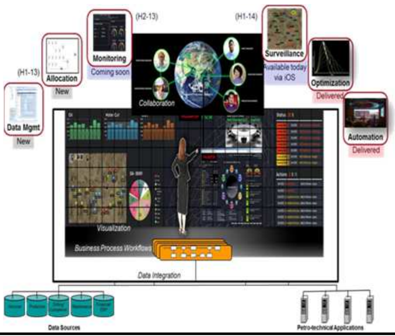
## Digital Oilfield Integrity: A Comprehensive Strategy

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## Engineering Calculations

- What happens when inside, outside and beyond the well engineering is coupled?
  - Absence of casing wear calculation will lead to overestimation of the well integrity
  - Wrong casing wear calculation will lead to underestimation of the well integrity
  - Wrong annular pressure build up calculation will lead to overestimation of casing design

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## Poll Question

Do you think you need to concentrate more on **Asset Integrity** to manage your assets well?

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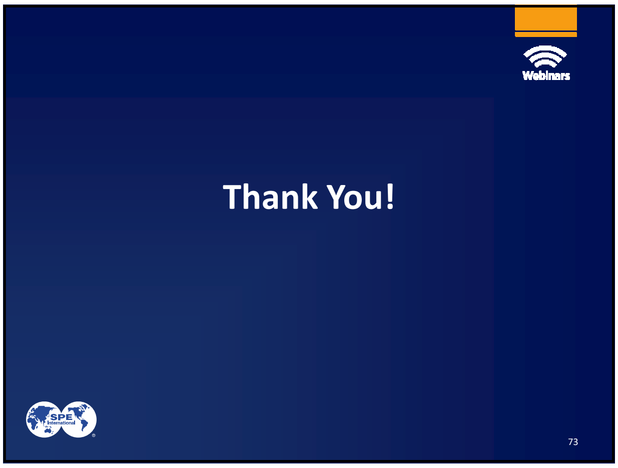
Webinars
Thank You!
SPE
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