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Case History: Sudden Drop and Tilt of an Operating Coke Drum

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THE WORLD'S PREMIERE DELAYED COKING CONFERENCE
REFCOMM® GLOBAL
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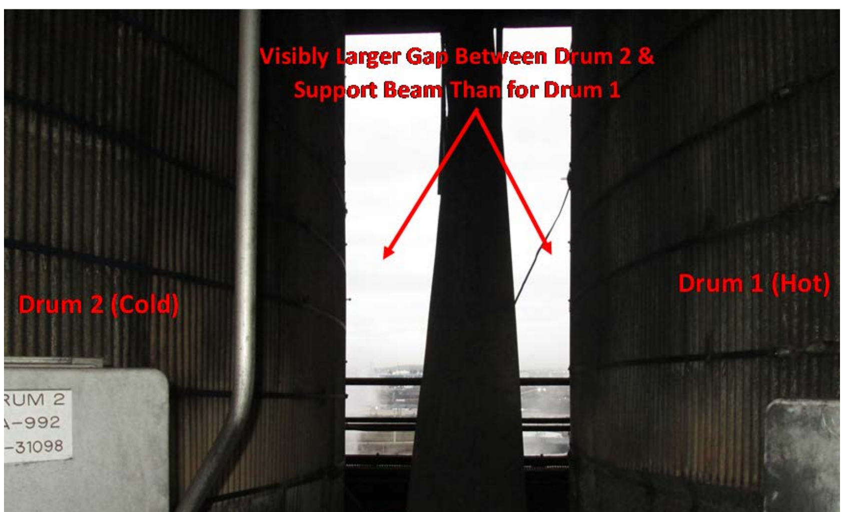
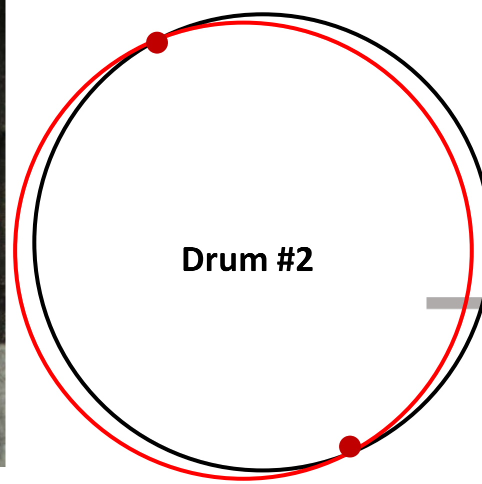
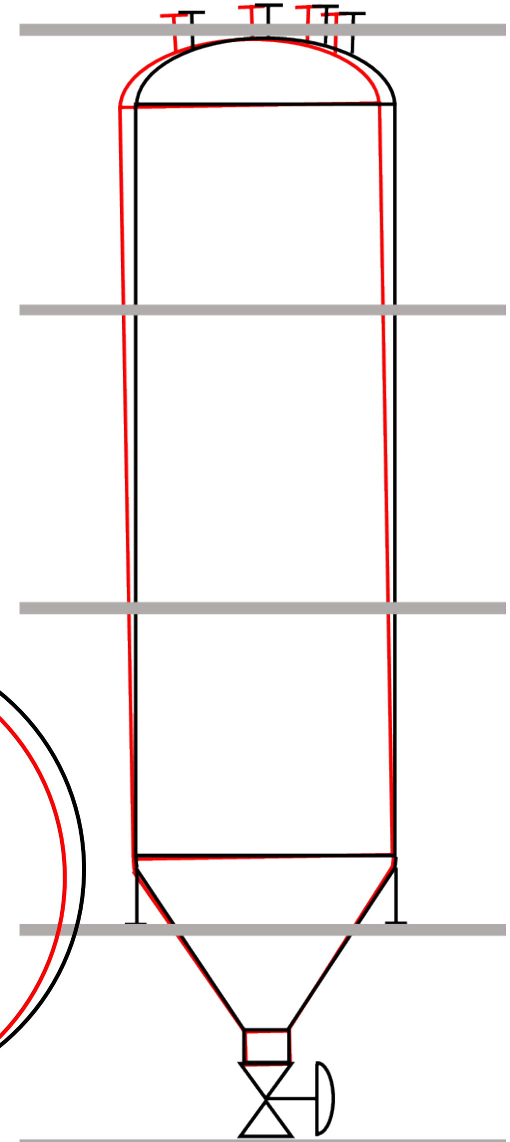
Event Description

- In early December 2018 coke drum suddenly moved while in operation
  - ≈ 4 million pounds full weight
  - Movement of ≈ 6” at outlet, drop of ≈ 2”
  - Visible rotation as well
- Drum successfully de-inventoried and brought off-line

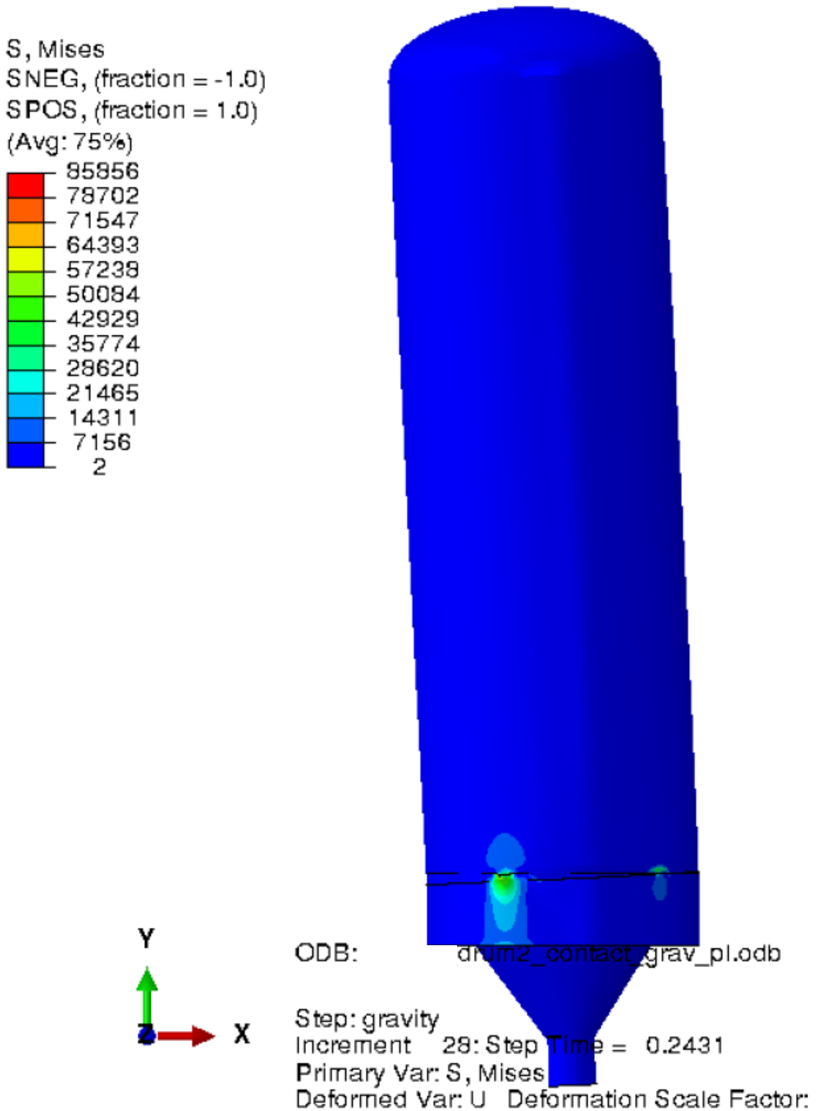






Overview

- This presentation documents
  - The initial response
  - Repair planning and execution
  - Detailed benchmark analysis for
    - Root cause
    - Current damage tracking
    - Future correction



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Drum Details

- 4 drum delayed coking unit, new drums in 2007
- Estimated 2,400 cycles at time of incident
- Drum and process details:
  - 29’ 8” ID (to clad), 1.25Cr, 410S clad
  - 1.393” uniform wall thickness, 0.110” thick clad (1.503” total)
  - In-line skirt, weld build-up internal radius, 1” thick, 91”long
  - Single side inlet nozzle (original DeltaValve)
  - Shot coke
  - 16-17 hour cycle
  - Automated quench, 200 GPM initial rate for 1 hour
  - Skirt temperature of 300°F-500°F at switch to feed

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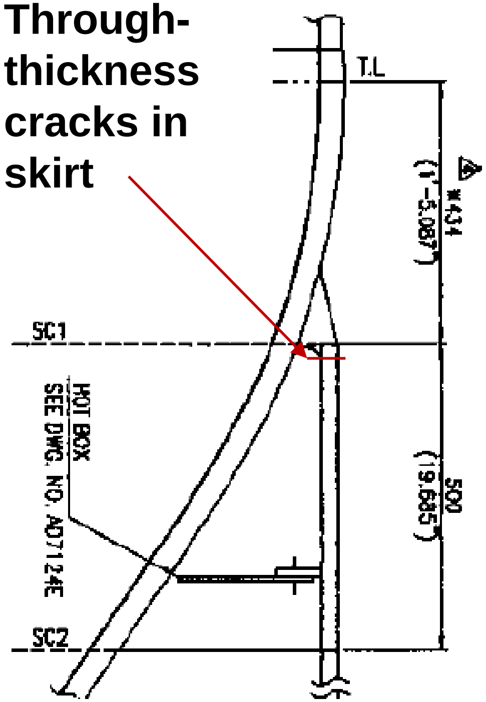
Condition Description

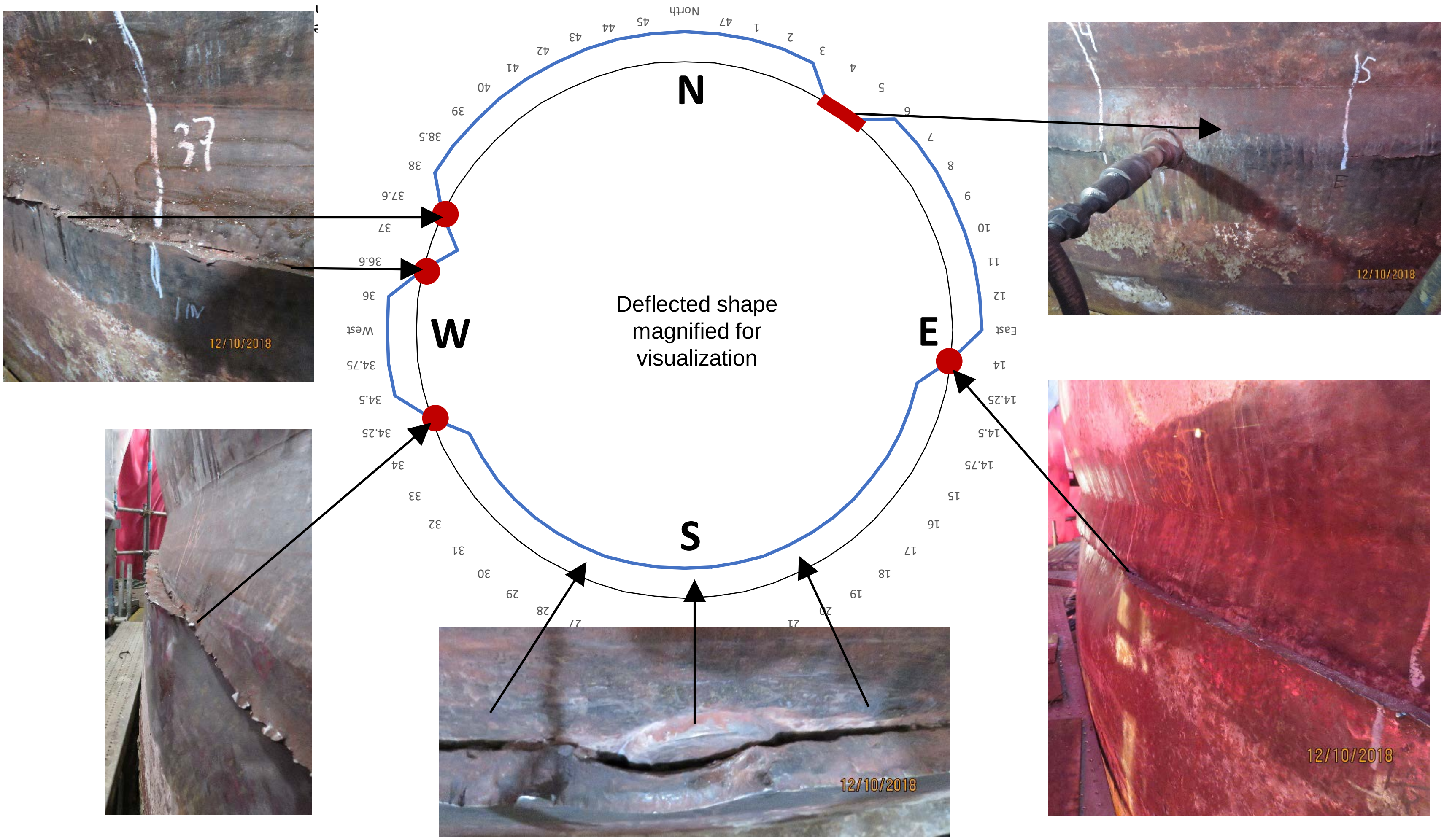
- When insulation removed found that skirt was fractured through thickness essentially all the way around
- Drum/upper skirt had dropped inside lower skirt on one side and lifted off on other
- Other 3 drums found to have same (non-displaced) cracking pattern, but not yet through-thickness all the way around

Through-thickness cracks in skirt



Skirt Condition

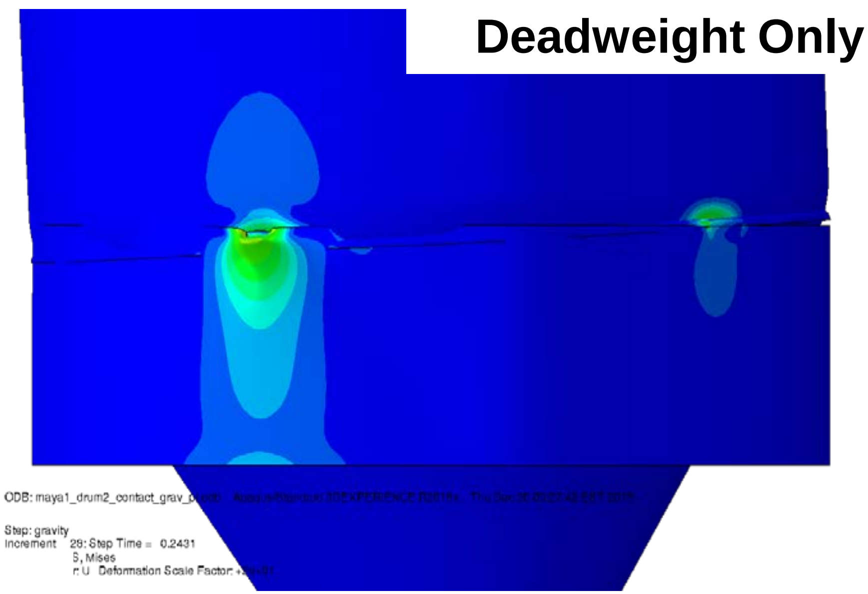
- No contact with (or support from) surrounding structure
- Minimal support from attached piping

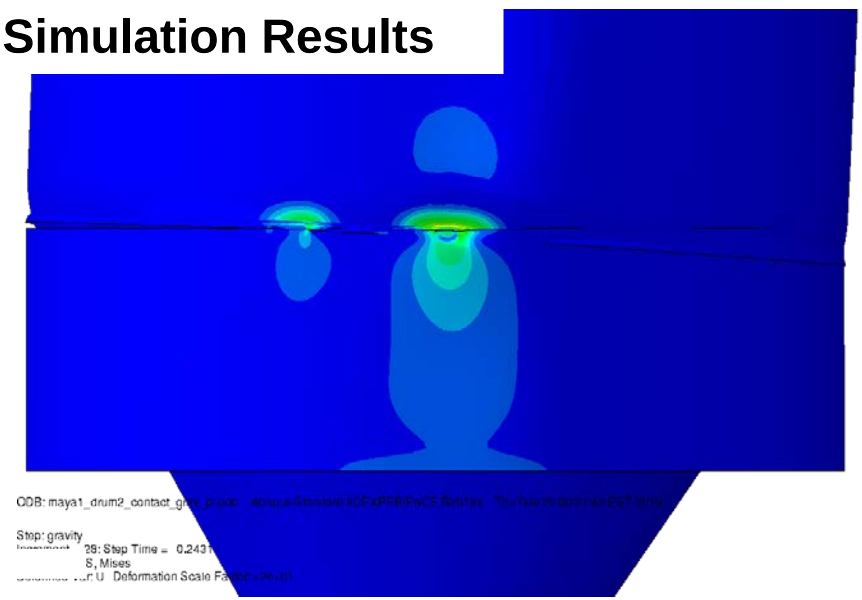


Stability

- Drum was displaced with over 4 million pounds and did not move while being emptied
  - Empty weight of 850,000 lbf
  - Gives a margin on deadweight of 4MM/0.85MM = 4.7
- Finite Element Analysis (FEA) used to look at wind load
  - Only 5 contact points, gives deadweight failure load of 2,100,000 lbf (so analysis is conservative by about 2x)
  - Wind velocity with actual deadweight solved for using same model: >140 mph

Deadweight Only Simulation Results





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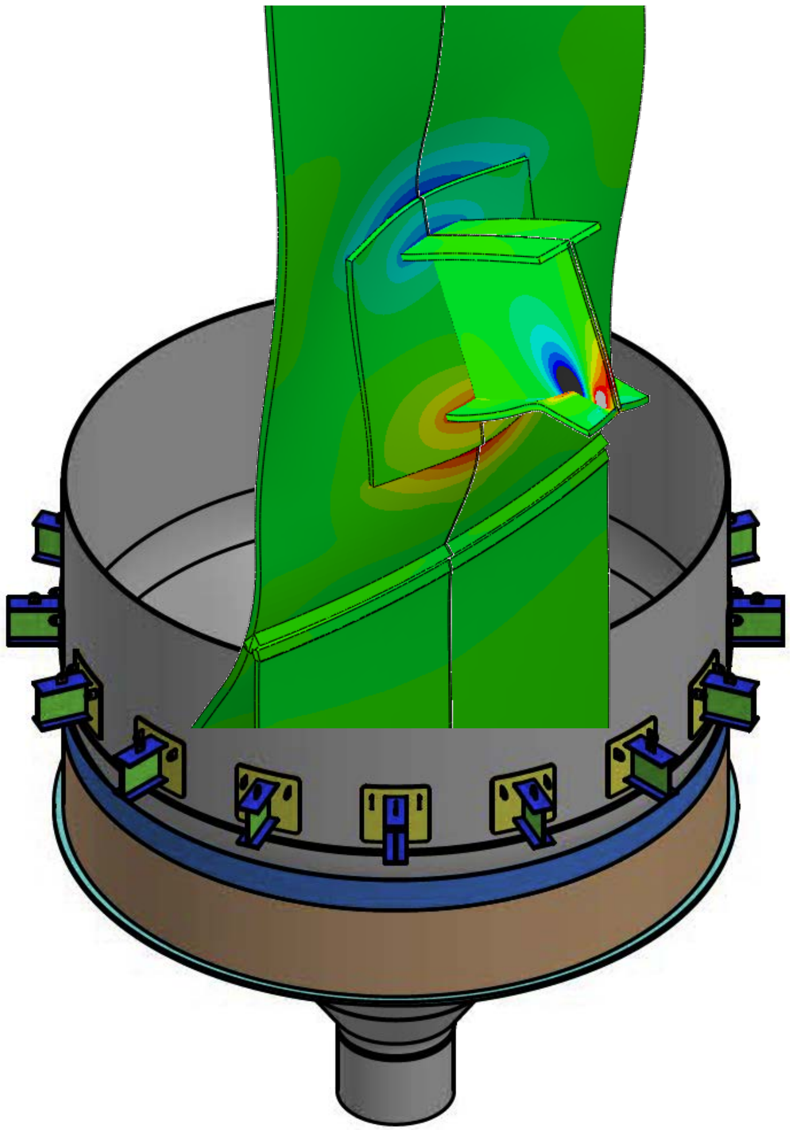
Remediation

- Before skirt could be repaired it had to be lifted back into position
- Lift done from skirt-level deck
  - 16 lugs sized for lift using AISC and collapse analysis
  - Substantial impact factor
  - Tolerances and allowable offsets defined
  - Concrete deck qualified for loads
  - FEA and fracture mechanics performed for assumed existing ID flaws



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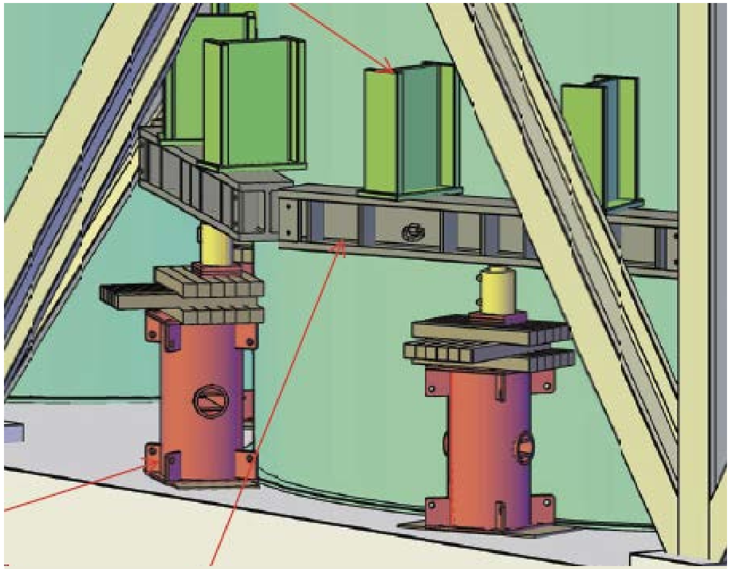
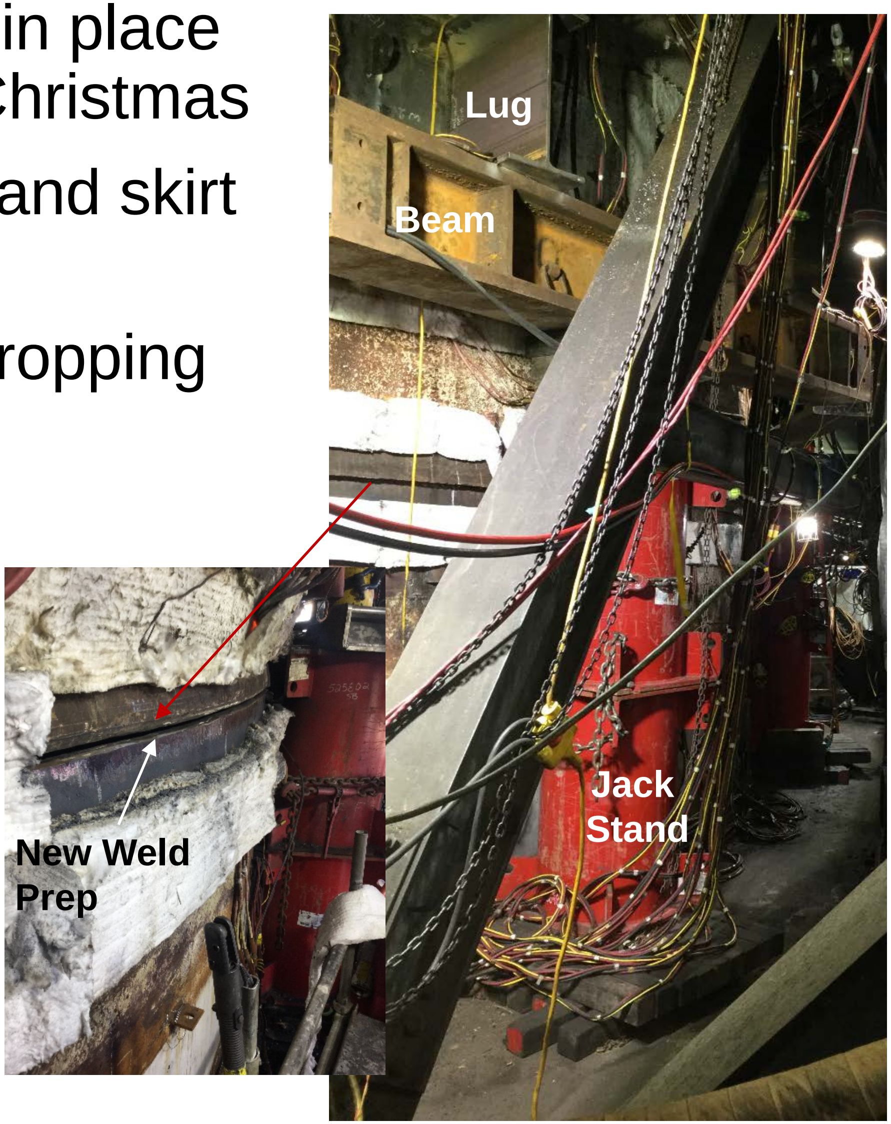
Lift

- Skirt successfully lifted back in place and re-stabilized right after Christmas
- Damaged material removed and skirt prepped for welding
- 3 weeks from drum initially dropping inside skirt



From initial lift plan courtesy of Mammoet



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Repair

- Some sections of skirt cut out and replaced, but most pulled back with key plates
- Crack was just low enough to allow internal radius to remain untouched when arc gouging out damaged material
- Repair welding completed round the clock with *zero* defects found using PAUT

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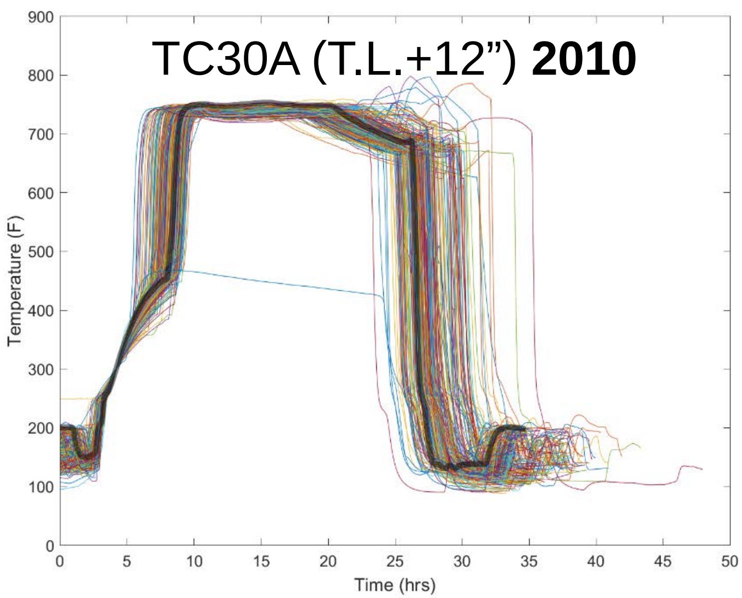
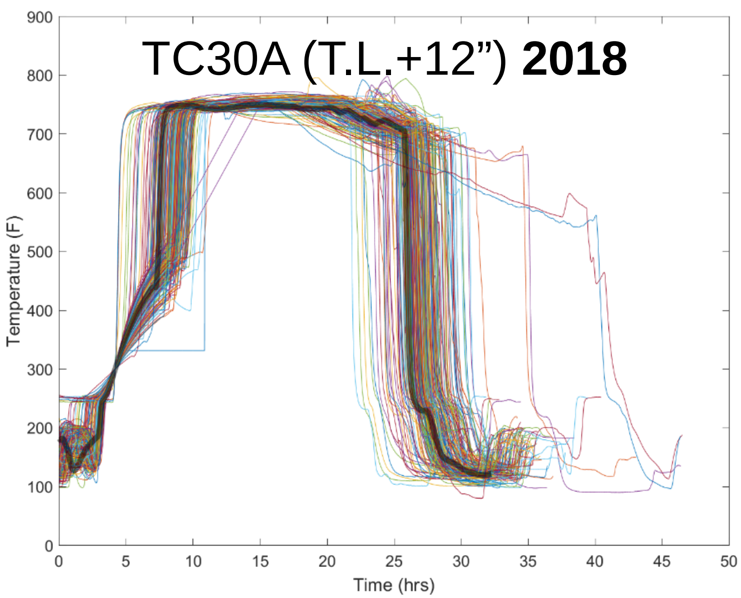
Root Cause

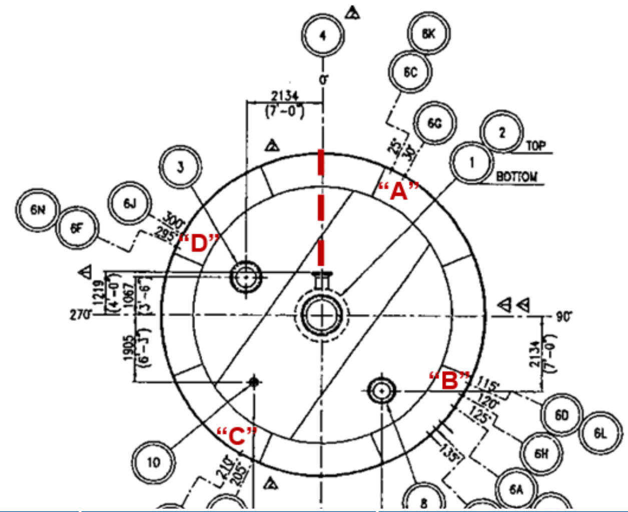
- Previous drums had actually suffered very similar cracking and skirt failure (1995 to 2007)
  - Operation was more severe at that time
  - Basic dimensions the same: diameter/skirt length = 4.6
  - Very stiff skirt . . .
- Health monitoring systems (HMS) exist on two drums
  - 3 complete years of data evaluated (2010, 2016, 2018) for both drums
  - ≈ 1300 cycles

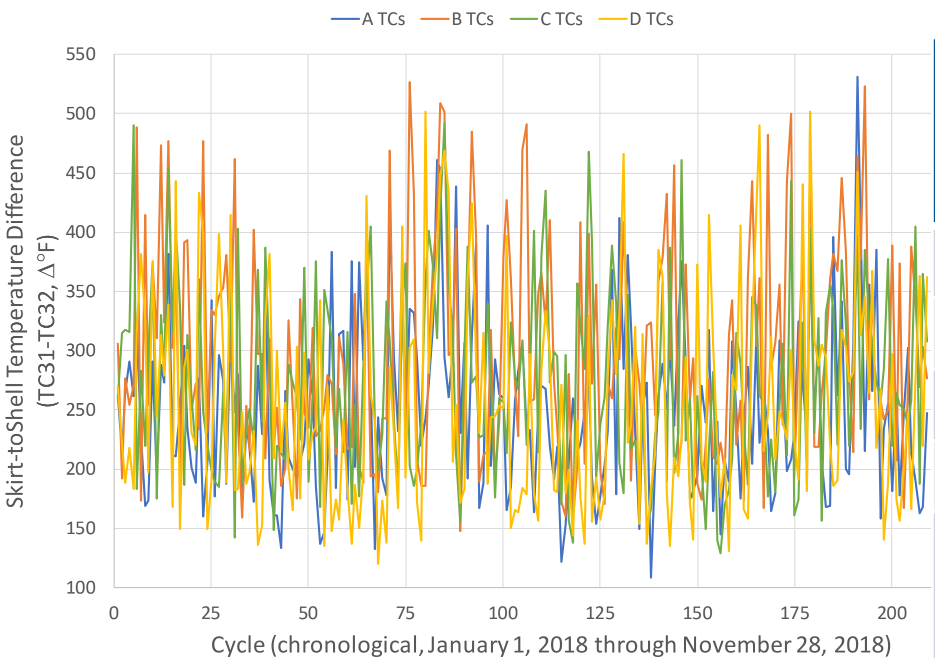




Drum-Skirt ΔT Data

- 2018 drum-skirt total ΔT (fill + quench) data shown below chronologically
- Worst location consistently moves around drum from cycle to cycle



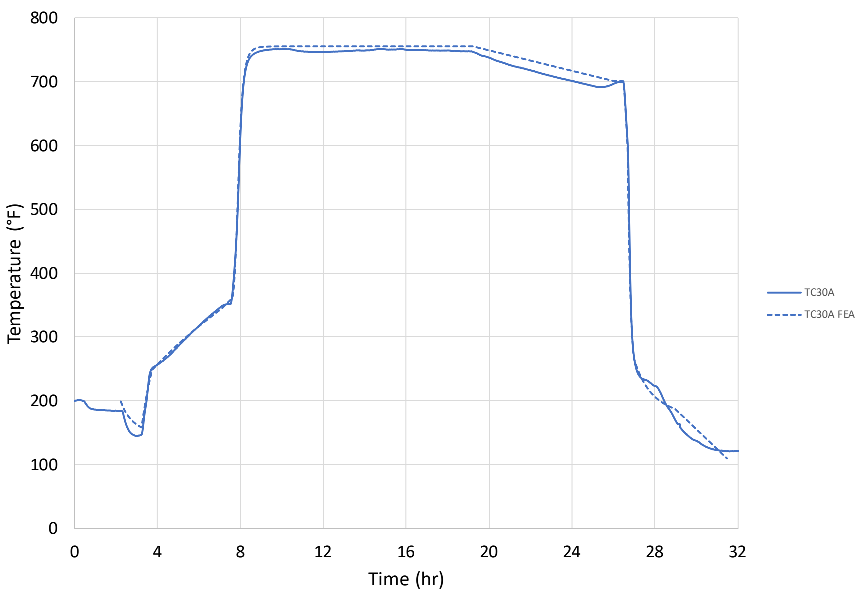


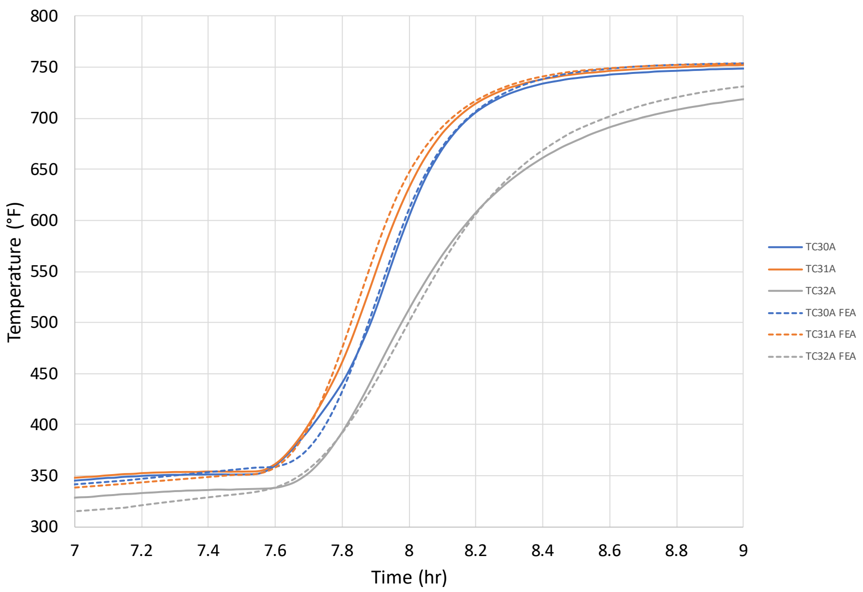
Location of Max. ΔT Range	Number of Occurrences	Average Range of ΔT** (Δ°F)
A	41	320
B	71	377
C	57	338
D	40	358

* Range of ΔT is difference between TC31 and TC32 at given orientation for both fill and quench (summed)
** average of all occurrences when location/orientation is overall maximum

FEA – Thermal Calibration

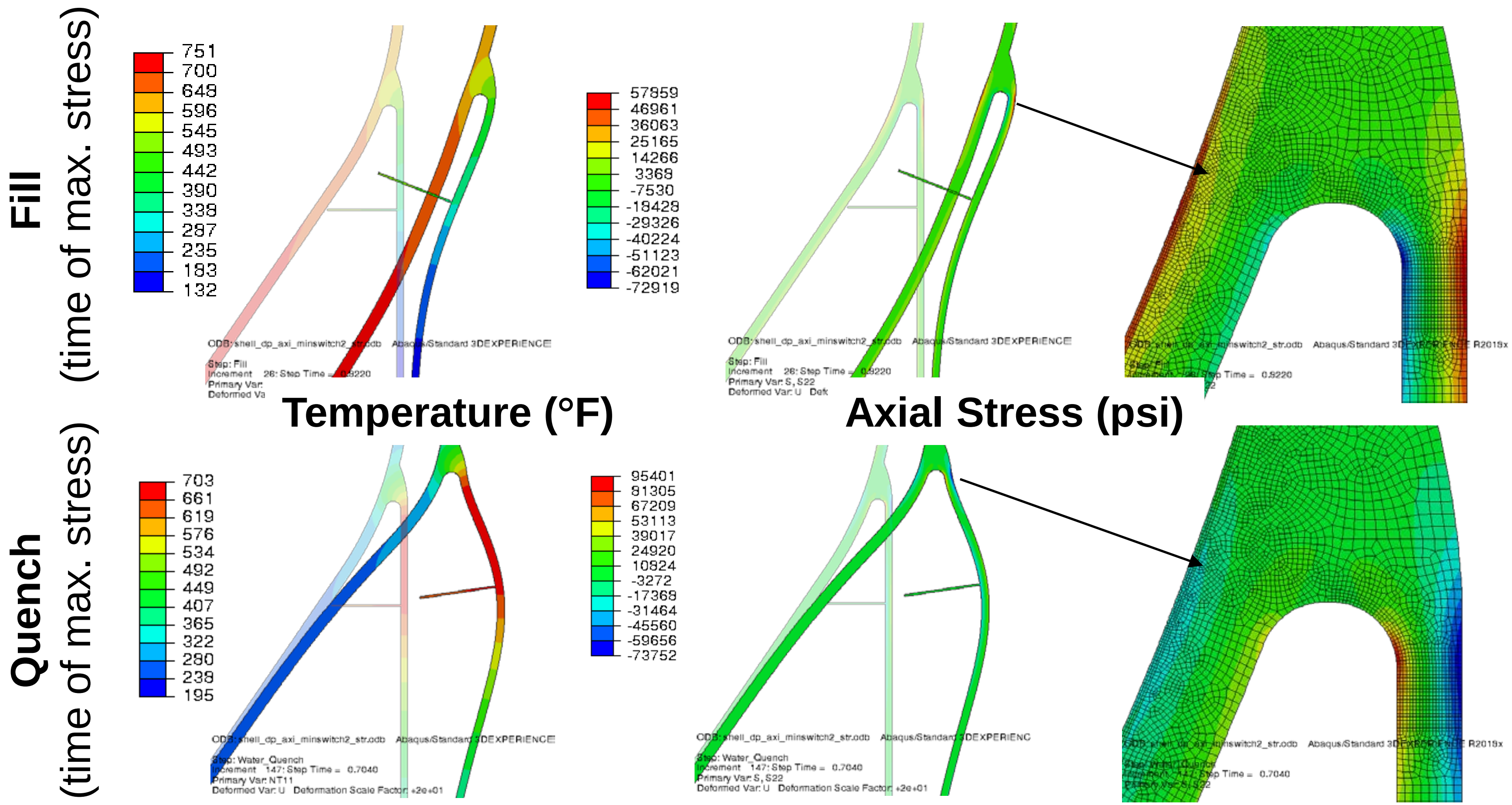
- Moving liquid level used for fill and quench, flow rate tuned to match TC data
- Hot box radiation included, heat transfer coefficients tuned (within physically reasonable bounds) as well





Stress Analysis Results (Min. Switch)

- Stresses are very large for worst case analyzed
- Stress range of ≈175 ksi



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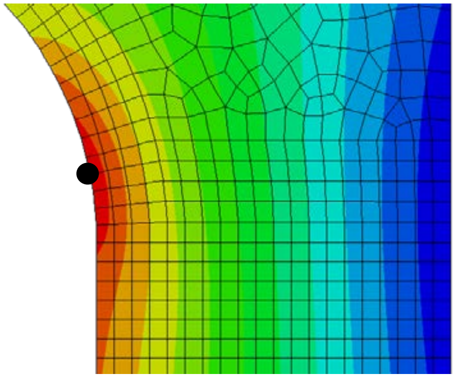
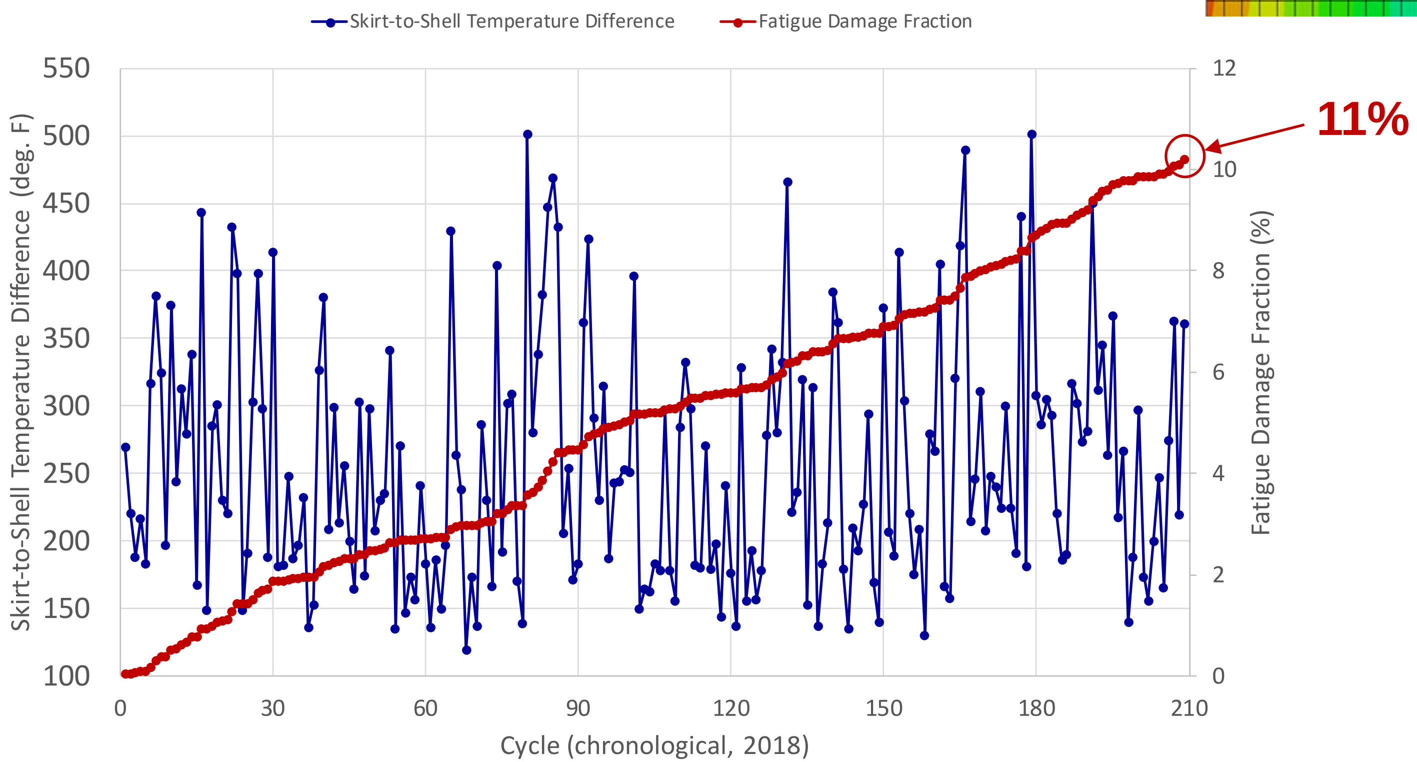
Fatigue Analysis Results

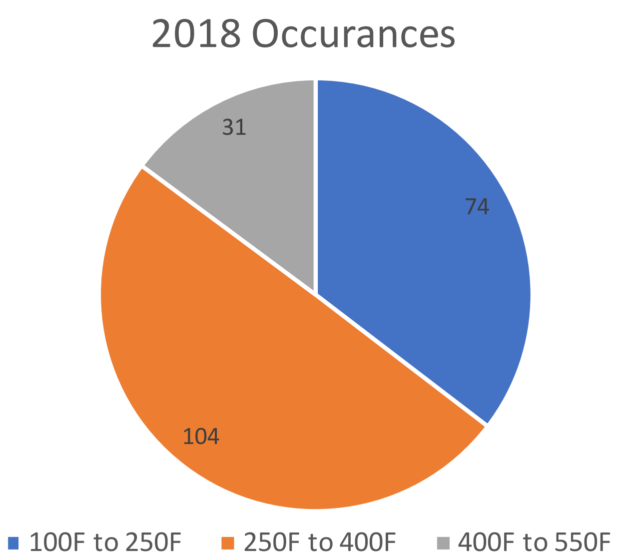
- **11%** damage for 1 full year (228 cycles)
- 100% damage in **9 years** (2049 cycles)
- **1.4 years** to grow crack through skirt wall
- **10.4 years** predicted for failure vs. 10-11 years actual

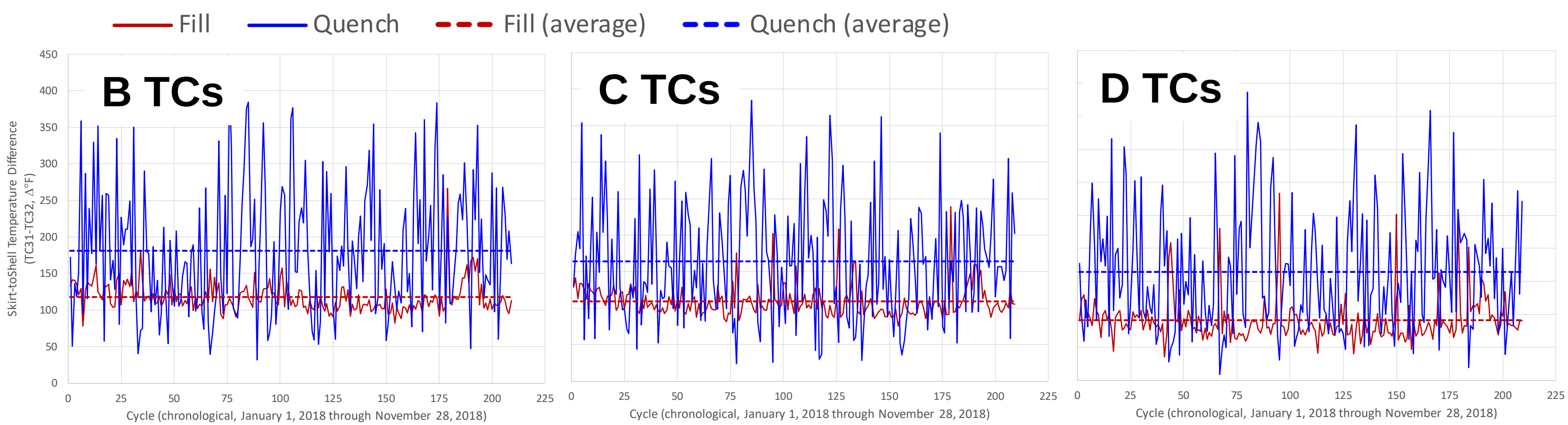




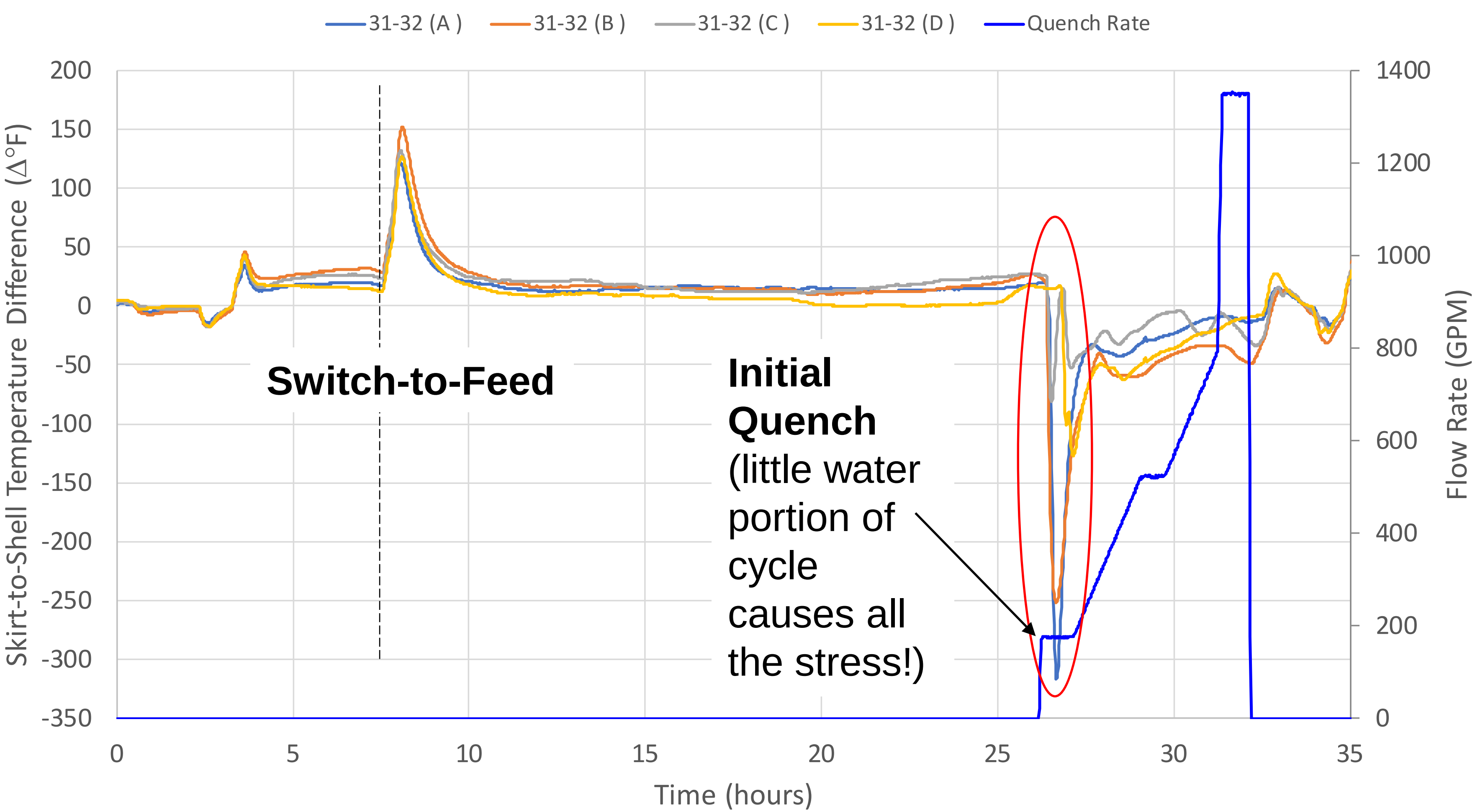
Drum-Skirt ΔT (Again . . .)

- **Fill** and **Quench** ΔT's separated below
- Most of variation and largest magnitudes comes during quench
- Quench is larger contributor to fatigue by about a factor of 3 to 1 here





Quench Rate Importance



Discussion

- Skirt design (length) is very important to reliability
- Calibrated analysis successfully used
- Health monitoring system was critical:
  - To reconstruct what happened – daily operation and impact on damage was clear
  - Can now be used to track damage on a daily basis
  - And is invaluable for measuring effect of future operating changes
- Effort is now moving to life management and extension, considering not just the skirt but the drum condition as well

THANK YOU!

