Coke Drum Reliability Workshop

Fast quench problems and how they damage coke drums

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Classic Drum Deformation For Low Alloy Drums

Weil and Murphy (Kellogg 1960, ASME)

- Permanent deformation pattern of vessels in cyclic service
- Skirt is attached to the cylinder by welding

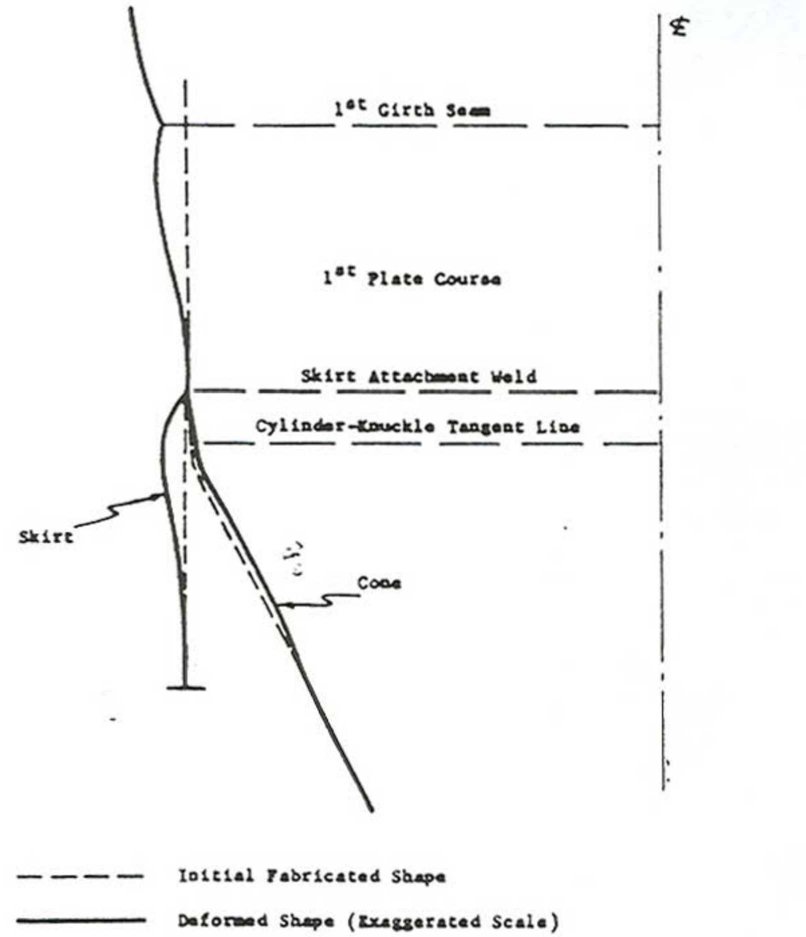


Fig. 7 Deformation pattern of vessels in heavily cyclic service

Typical* Butt Weld Detail

- Welds fail from Low Cycle Fatigue
- Crack initiates often at edges of weld cap interface to clad
- Crack grows through base metal to leak hot oil in Circ crack

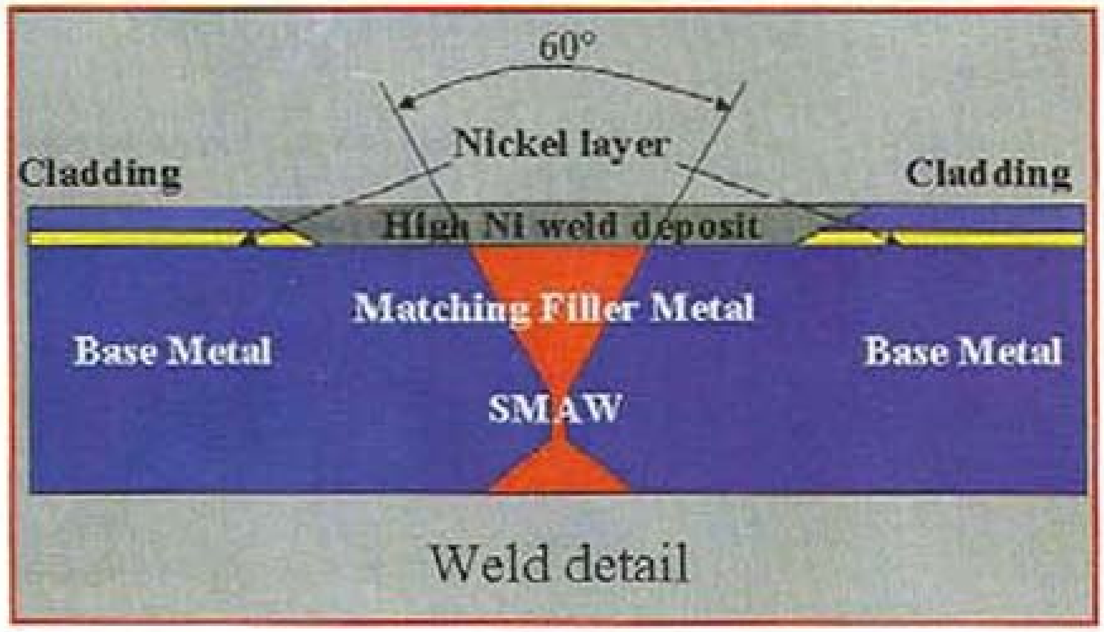
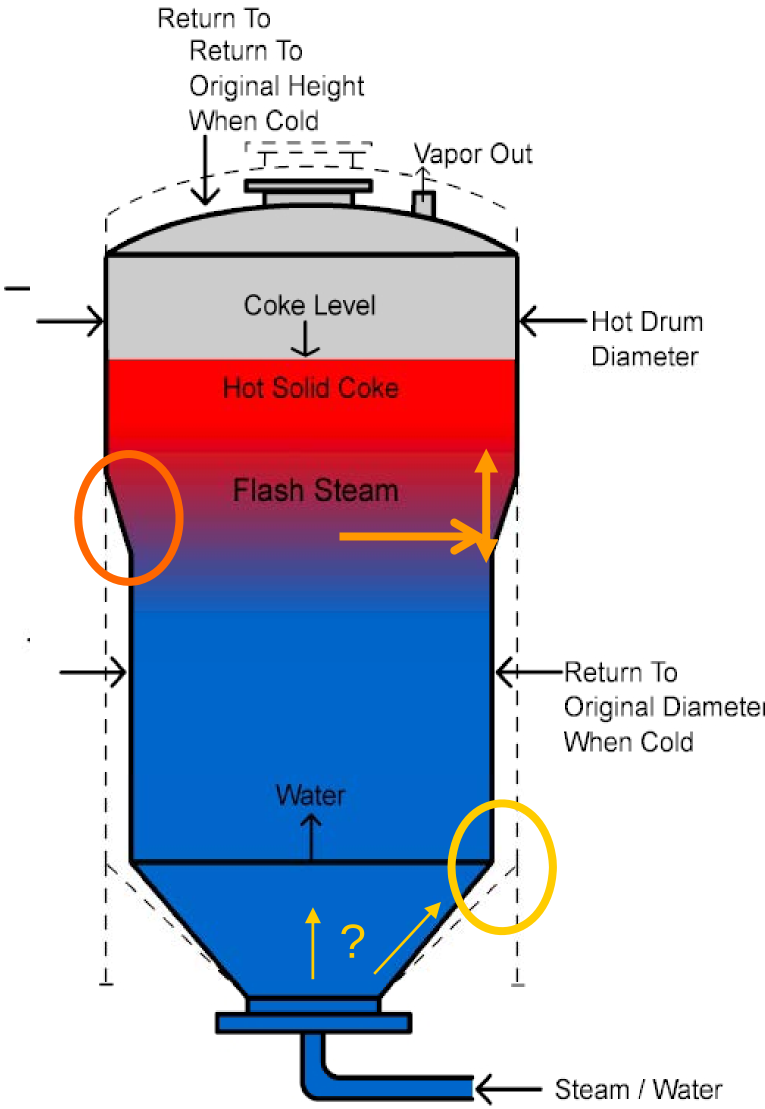


Fig. 3 — A typical weld detail.

*** Joint detail may vary**

Some Key Points of the Coking Cycle

- The drum grows larger and taller when it is hot –
- It is filled with a lot of hard material as the hydrocarbon cracks and releases vapor
- Some cokes will bond to the wall, and flow channels develop within the coke bed
- Hot oil is stopped (diverted to other drum)
- Steam is used to remove volatile vapor
- Water enters from bottom to cool the coke bed, becomes steam and flows up the center or outside along the walls
- The coke drum shrinks in diameter and height as it cools
- Eventually water can form and fills the drum
- *Which way does the water go?*



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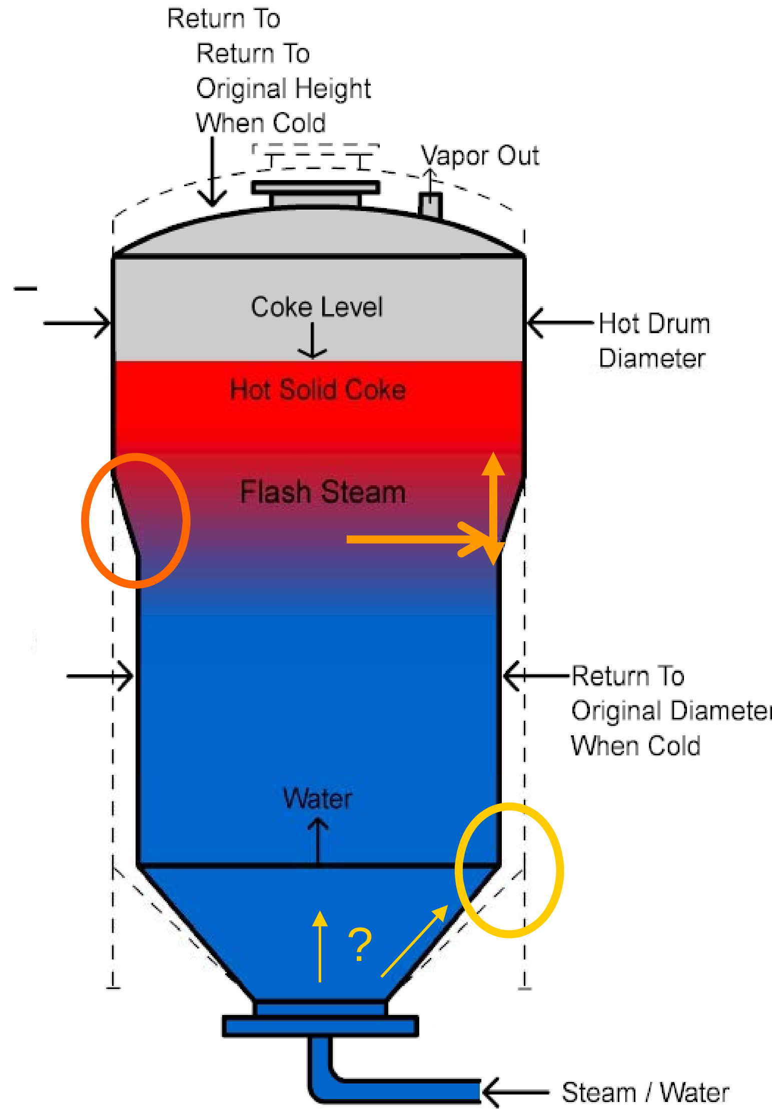
Discussion of the Flows during the Coking Cycle

- Traditional Analysis methods assume a uniform average flow of water upwards to remove heat from coke bed and shell at same time
- Coke bed formation determines path of least resistance for water flow
  - Flow channel area and friction
    - Plugging and channel collapse
  - Permeability
  - Porosity
  - Collapse strength of coke matrix
- Temperature measurements suggest fast quench with flow near wall is common
- This creates greater stress in **shell/cladding bond** and **skirt weld**
- This increases likelihood that hot zones remain in coke after quench



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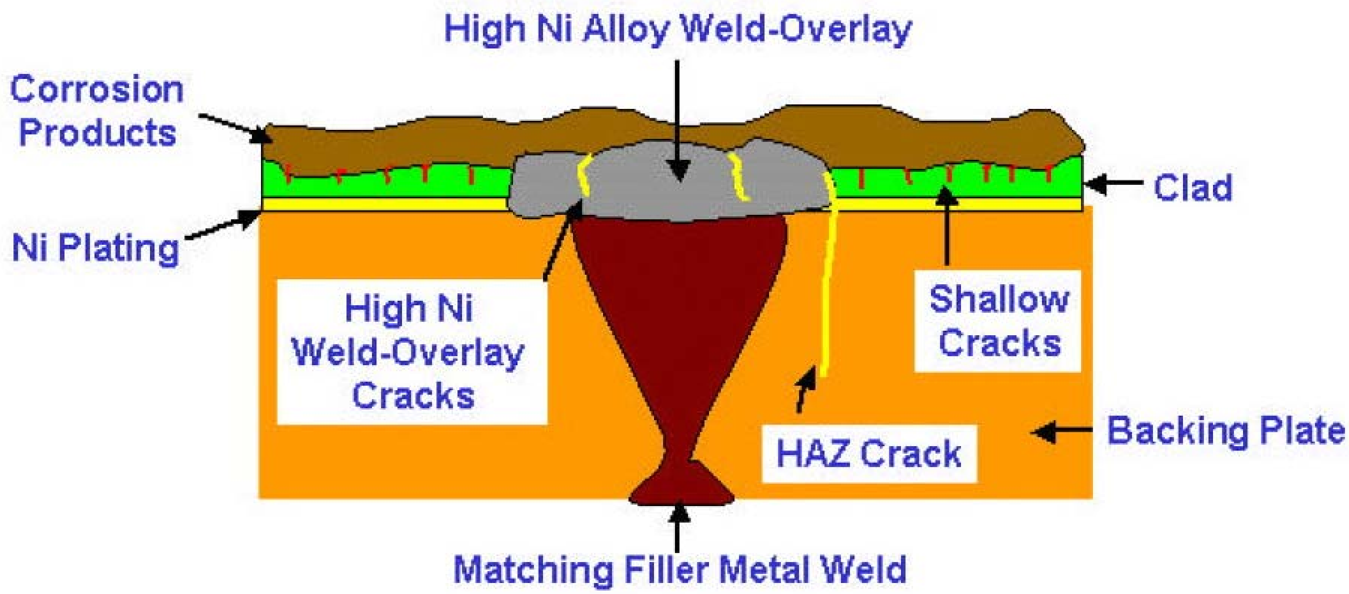
Problem Circ Weld Seam* Cracking Is Common

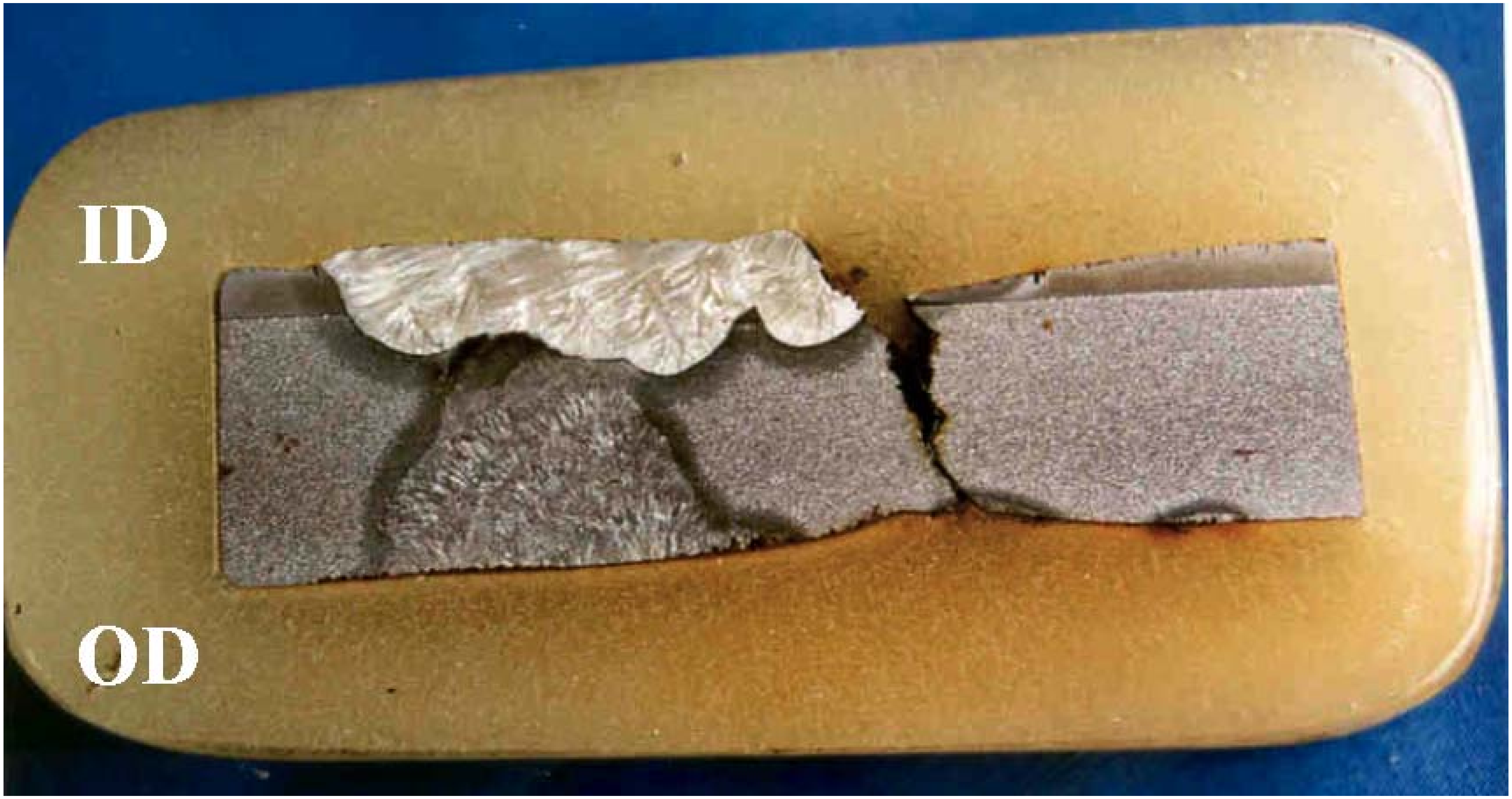
4. Crack Initiation and Propagation



PDVSA 2003 ASME Pressure Vessels & Piping Conference SHI Sumitomo Heavy Industries

* Joint detail may vary

Cracking from ID at Weld Cap to Clad Junction



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Drum Cracking Examples

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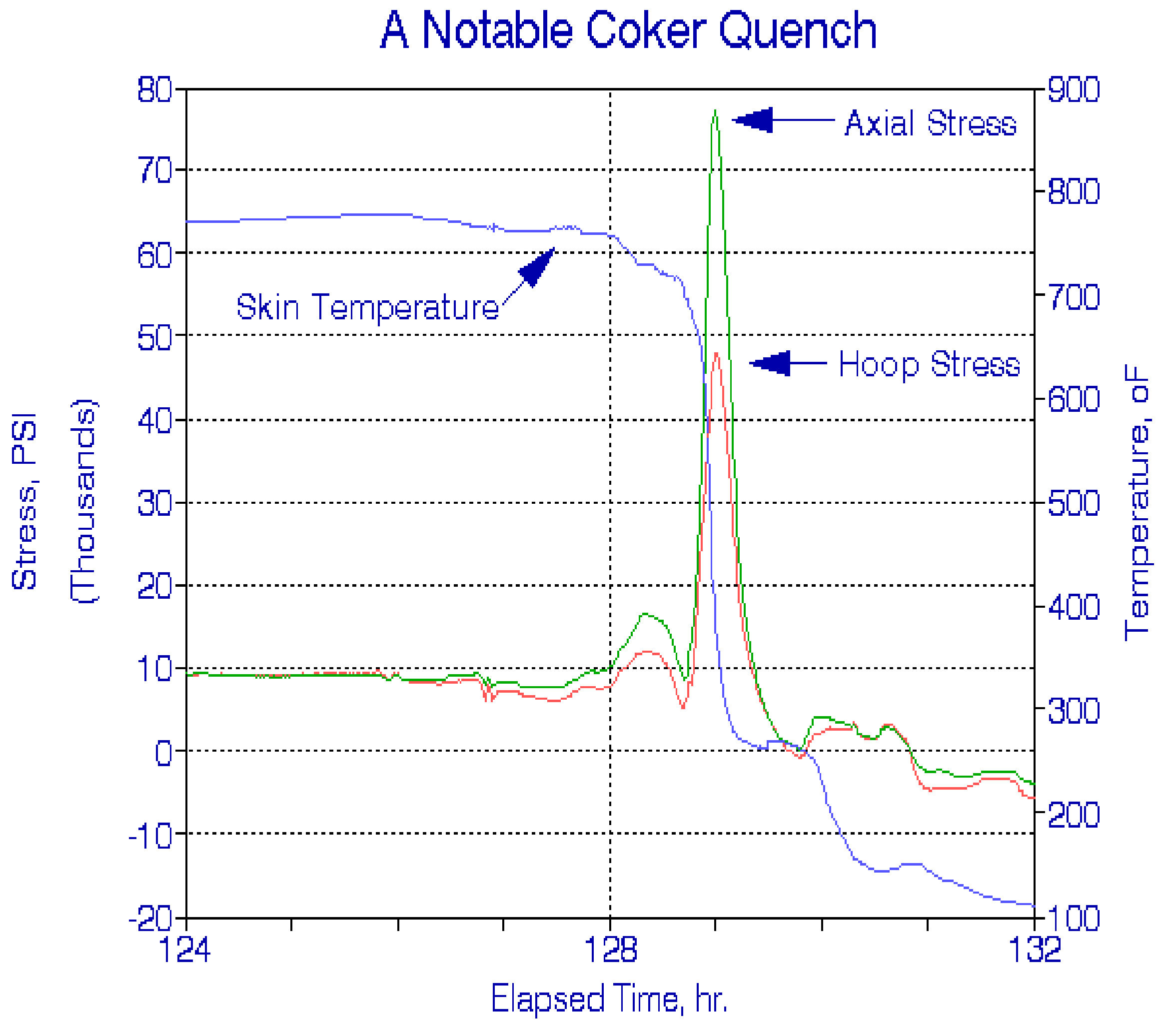
A NOTABLE QUENCH STRESS MEASURED ON SHELL O.D.



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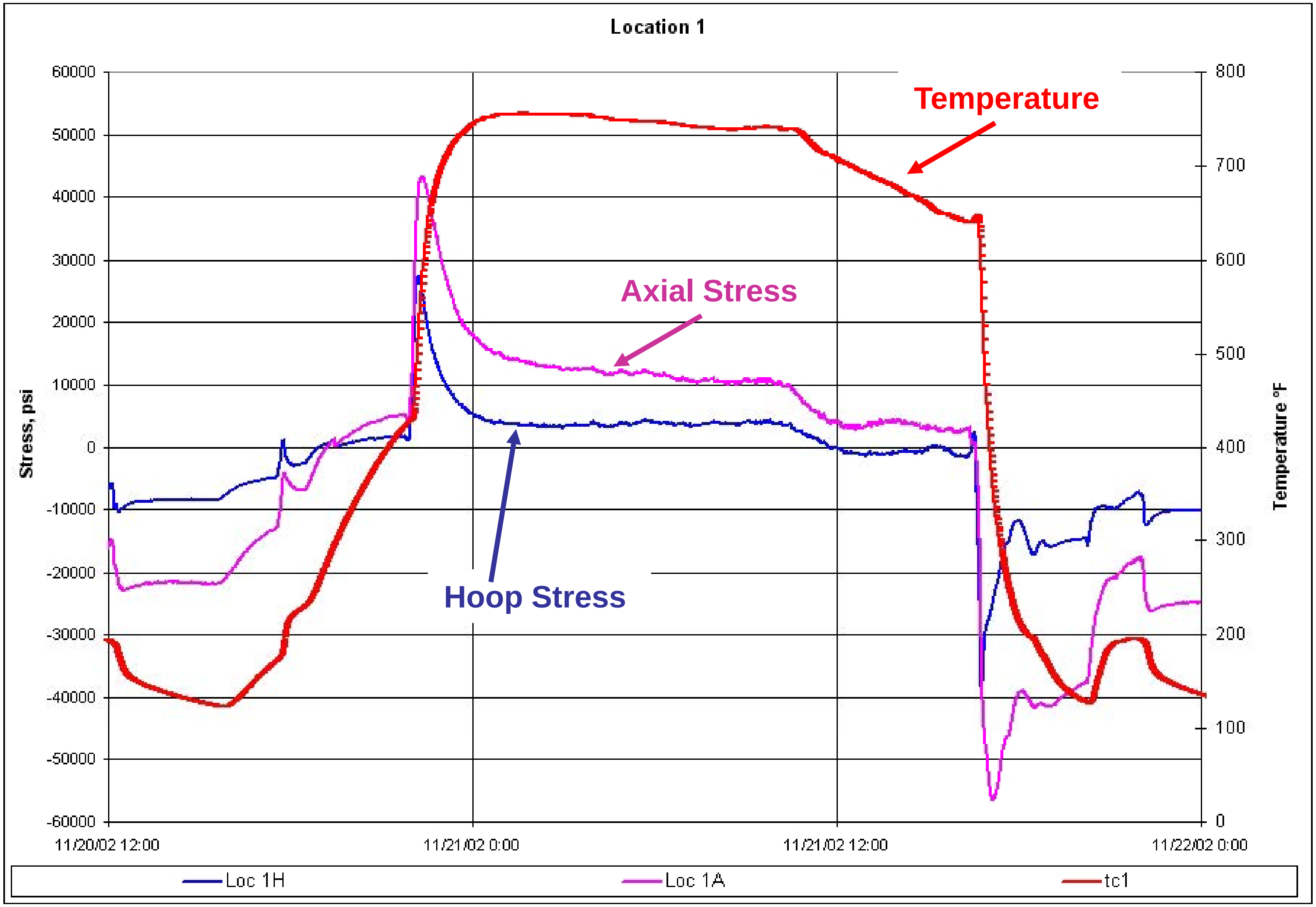
A Measured Cycle For In-Line Skirt Stress Response (OD)



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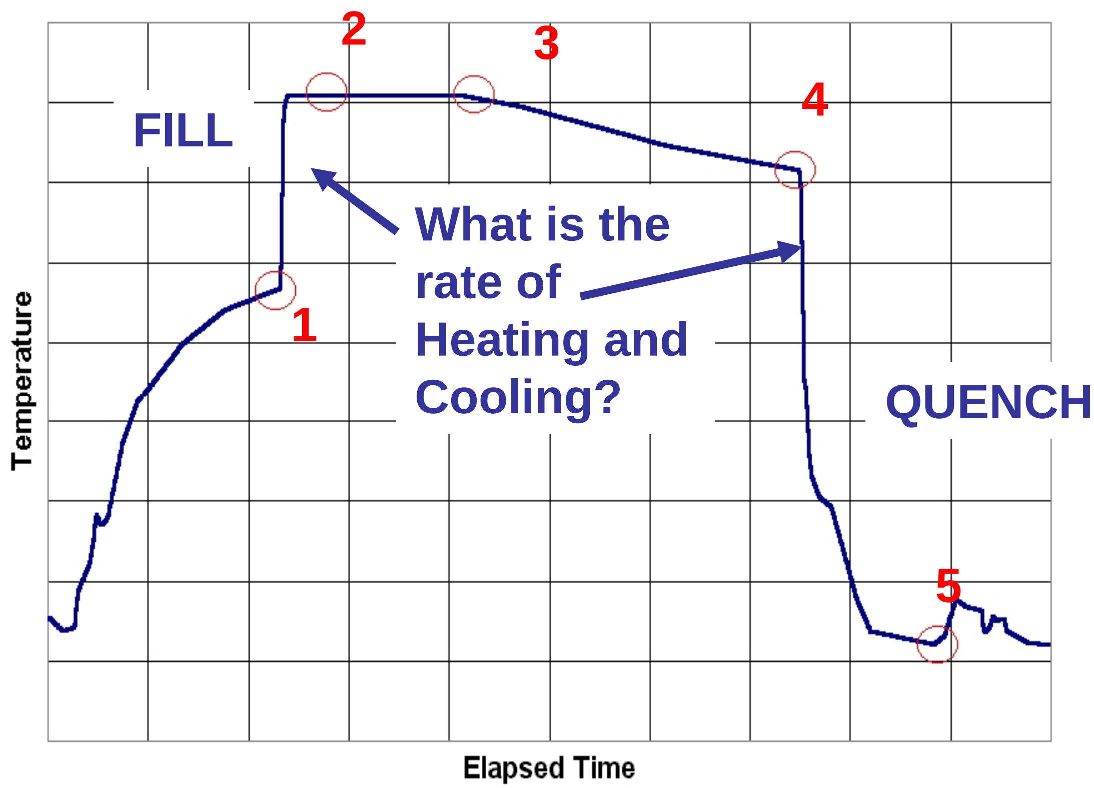
Skirt FE Analysis based on Measured Transients

Some Key points to describe the transient

1. Switch-In after Prewarm
2. Max temperature during Filling
3. Begin to cool from Coke Insulation Build-up
4. Begin Quench after Switch-Out and Steam Purge
5. Open drum, remove water and begin drilling



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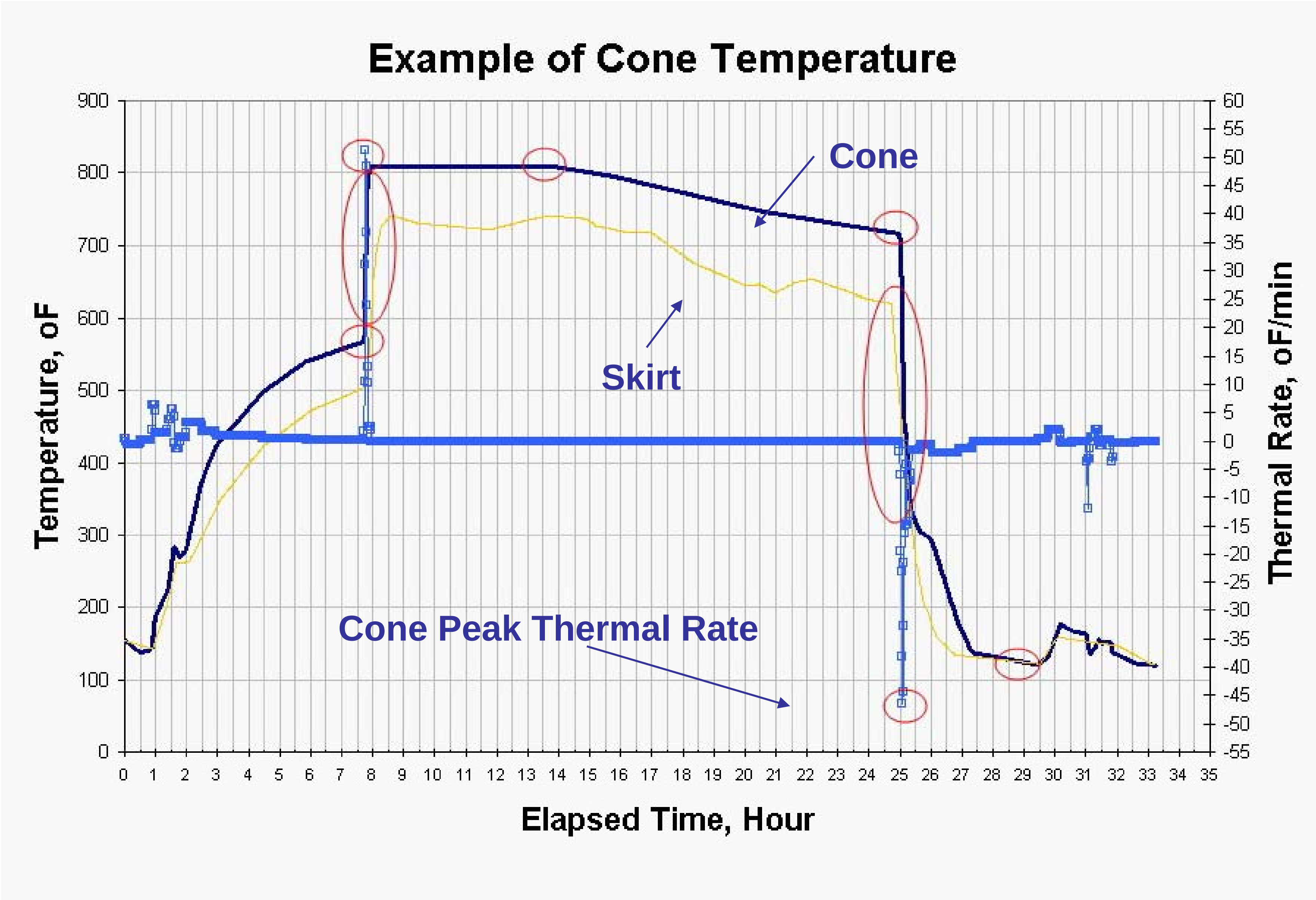
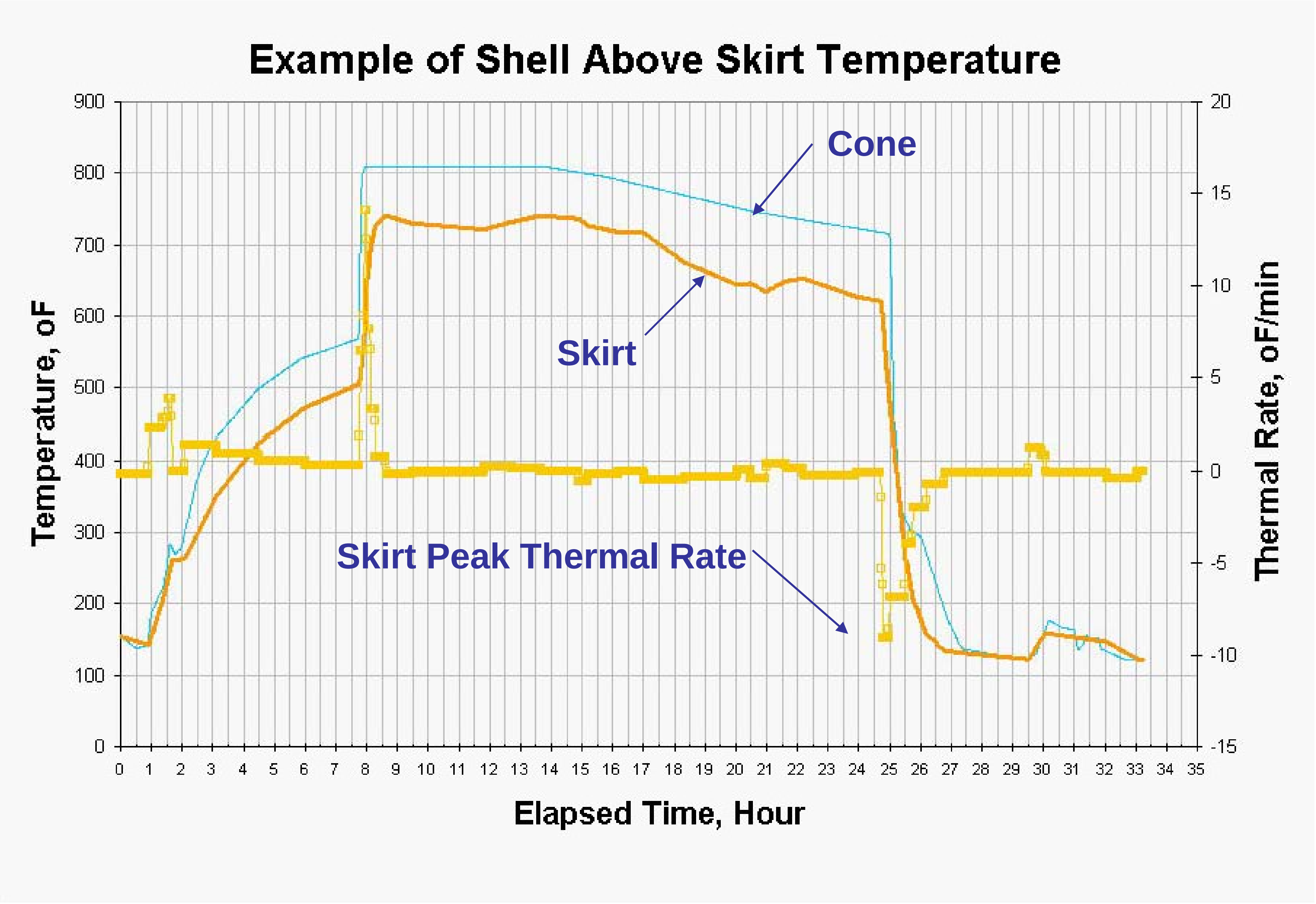
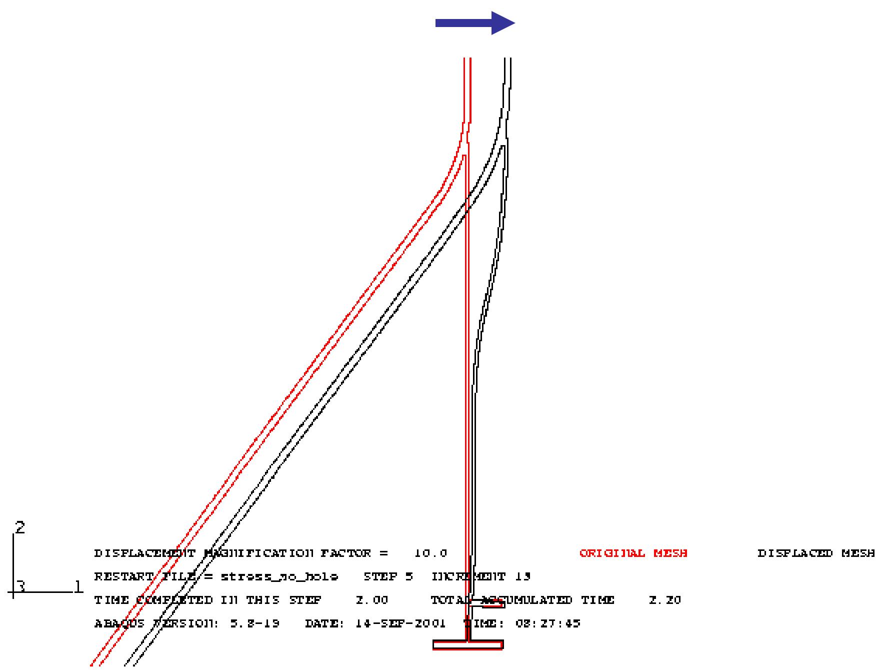


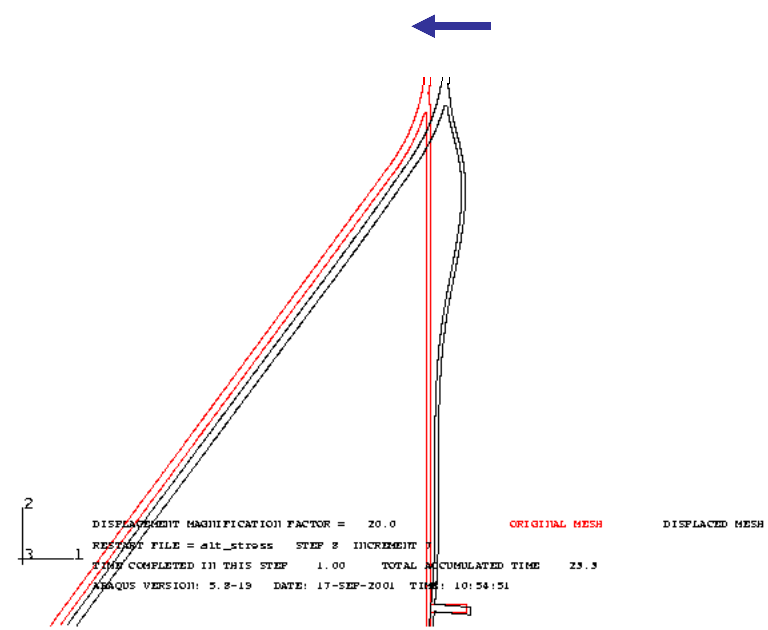
Example of Cone Temperature
Temperature, oF
900
800
700
600
500
400
300
200
100
0
Thermal Rate, oF/min
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
Elapsed Time, Hour
Cone
Skirt
Cone Peak Thermal Rate


Example of Shell Above Skirt Temperature
Cone
Skirt
Skirt Peak Thermal Rate
Temperature, oF
Thermal Rate, oF/min
Elapsed Time, Hour
900
800
700
600
500
400
300
200
100
0
20
15
10
5
0
-5
-10
-15
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

During Quench - Skirt is Pushed and then gets Pulled by Knuckle

DISPLACED SHAPE AT THE END OF FILL





DISPLACED SHAPE 1 HOUR INTO QUENCH

(MAXIMUM STRESS DURING QUENCH OCCURS HERE)

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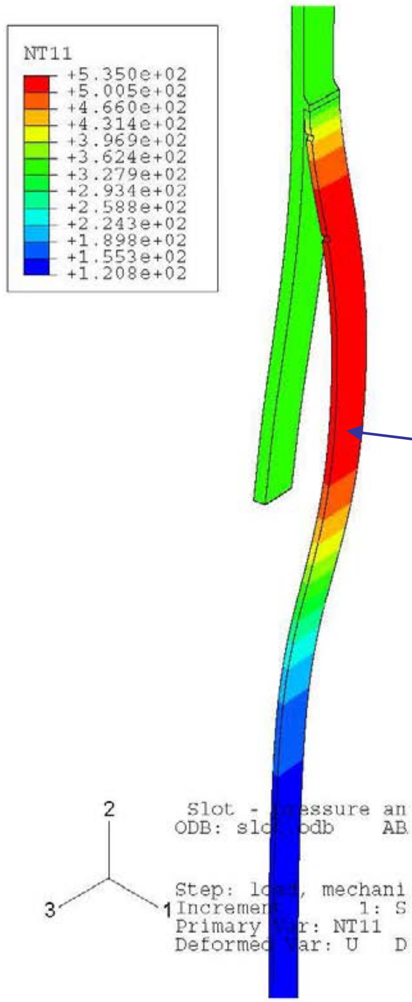
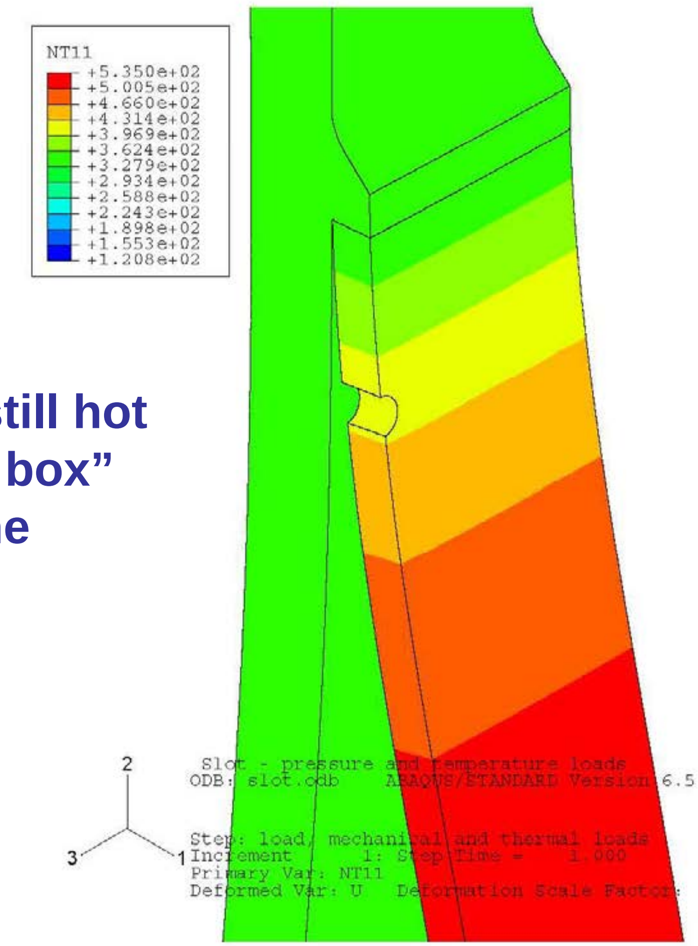
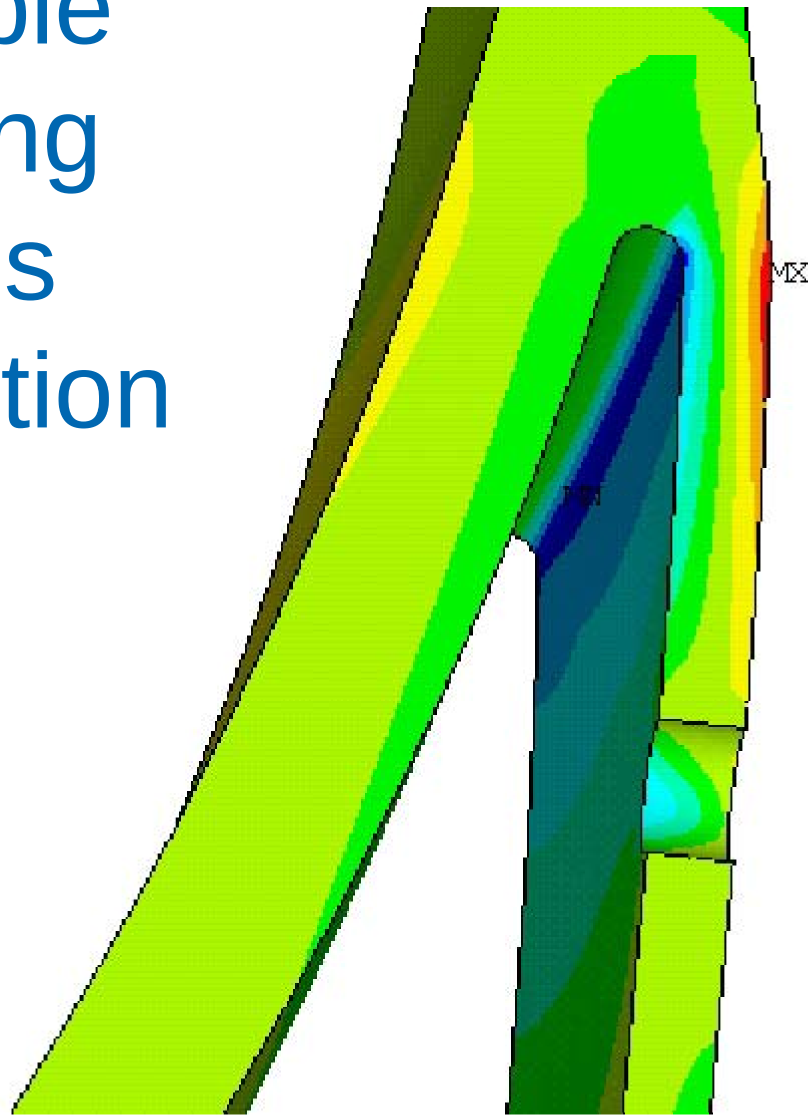
Example Temperature Distribution During Quench



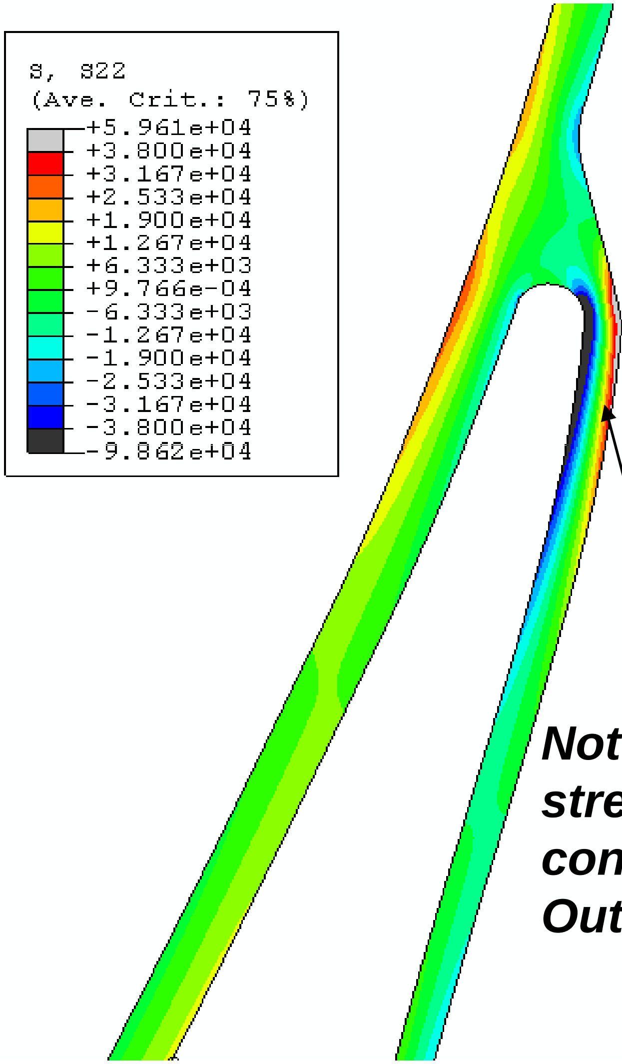
Skirt is still hot in “hot box” zone



Example Bending Stress Distribution

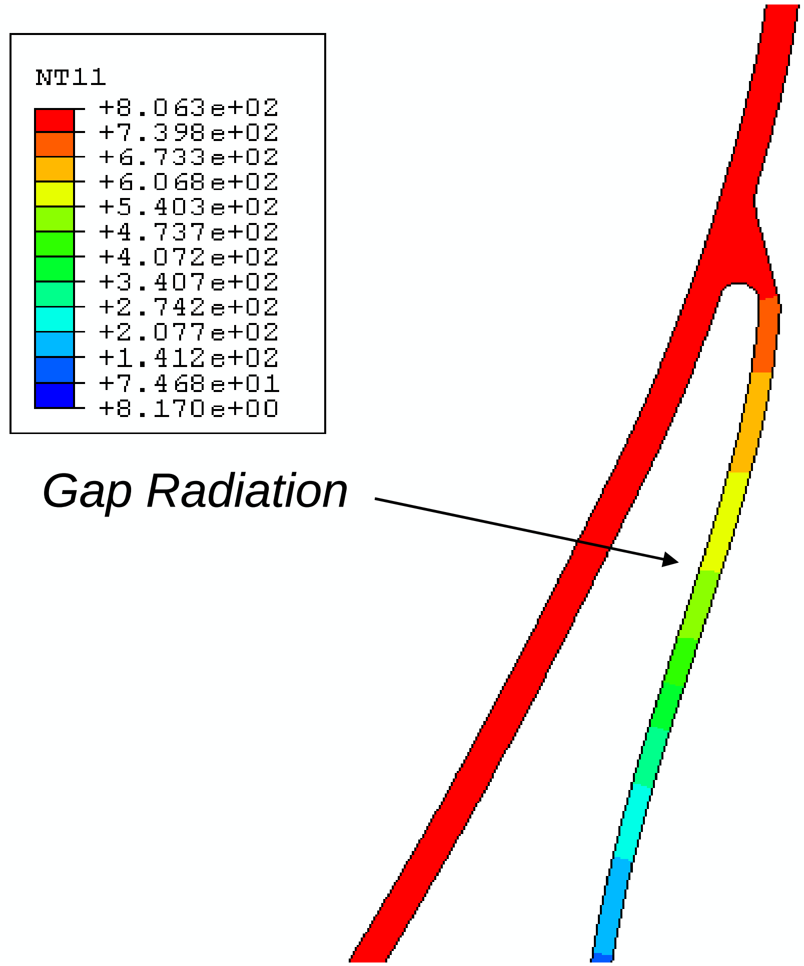


Example In-Line Skirt Axial Stress During the Fill Transient



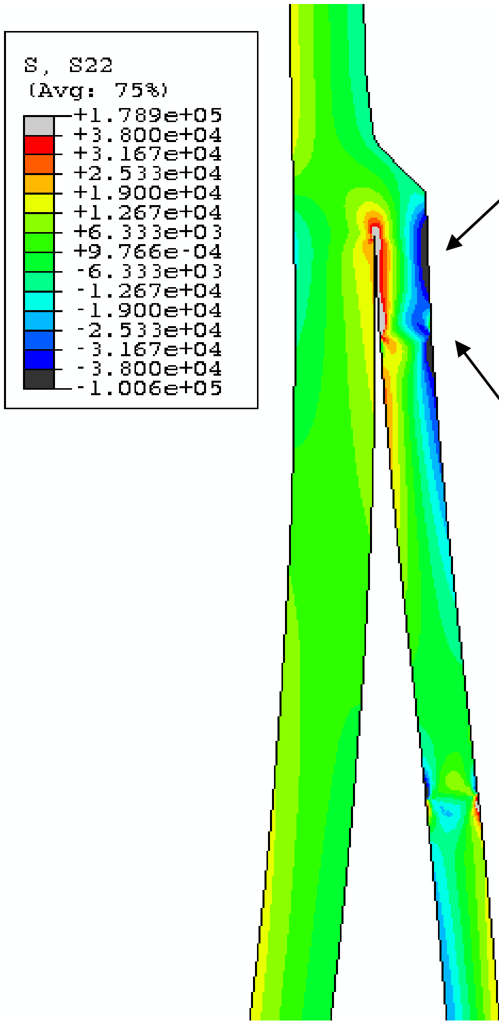
Axial Bending Stress

Note high bending stresses as hotter cone PUSHES Skirt Outward



Gap Radiation

Example Tangent Mount Axial Stress During the Quench Transient

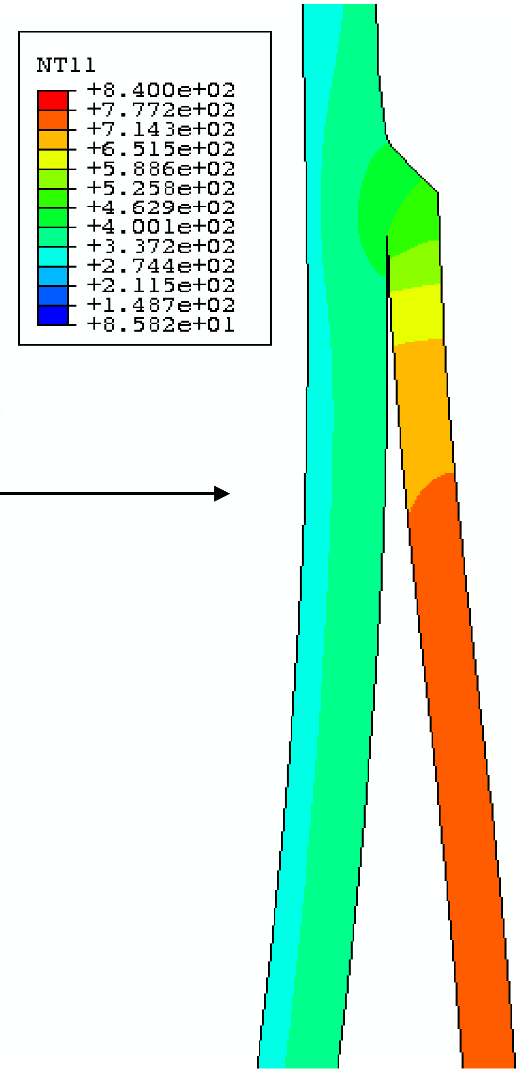


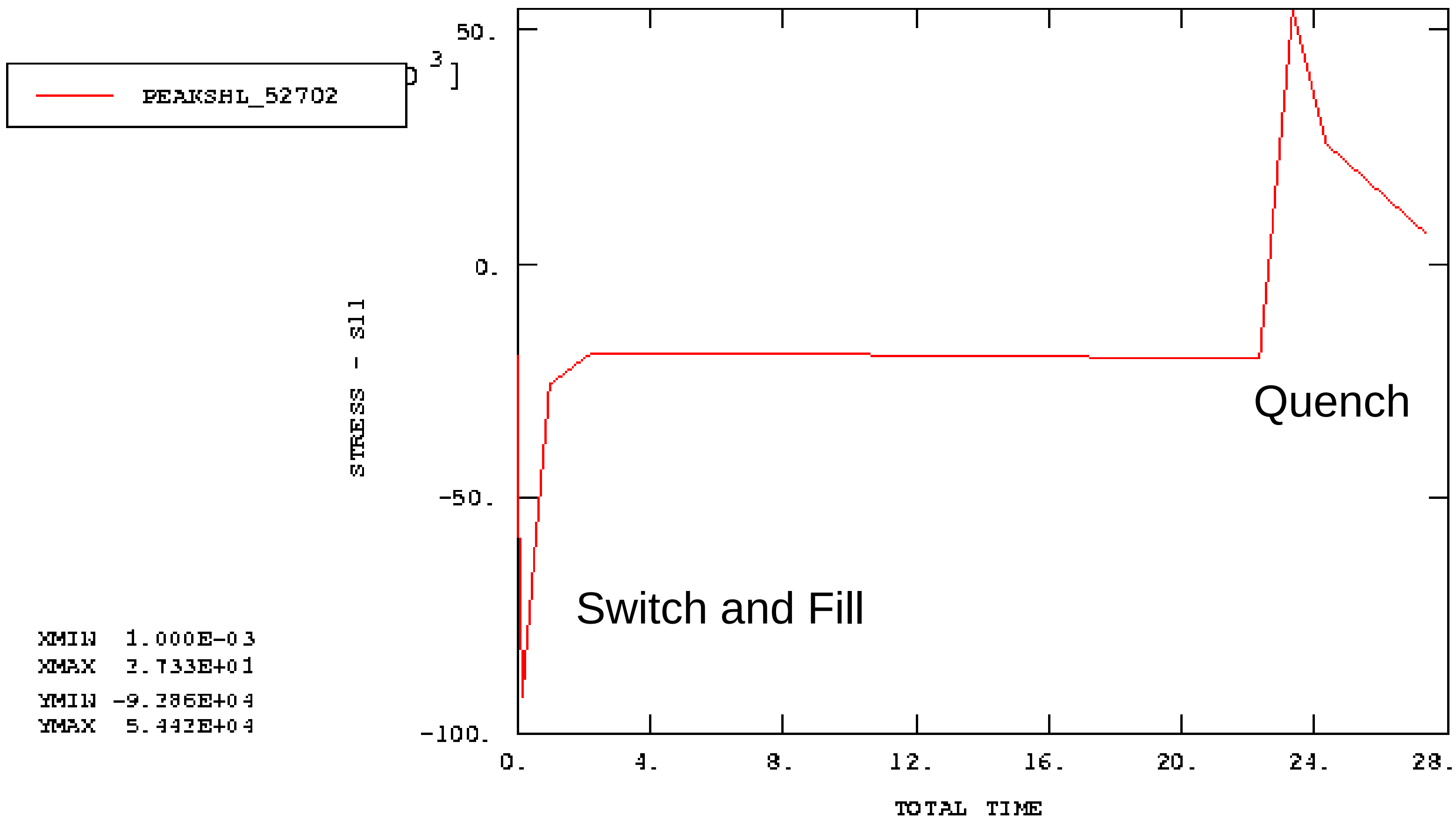
Axial Bending Stress

Note high bending stresses as cooler cone PULLS Skirt Inward

Gap Radiation,

Gap Conductance active when in contact





FEA : Axial Stress transient at the top of the skirt ID is function of SCF at inside radius

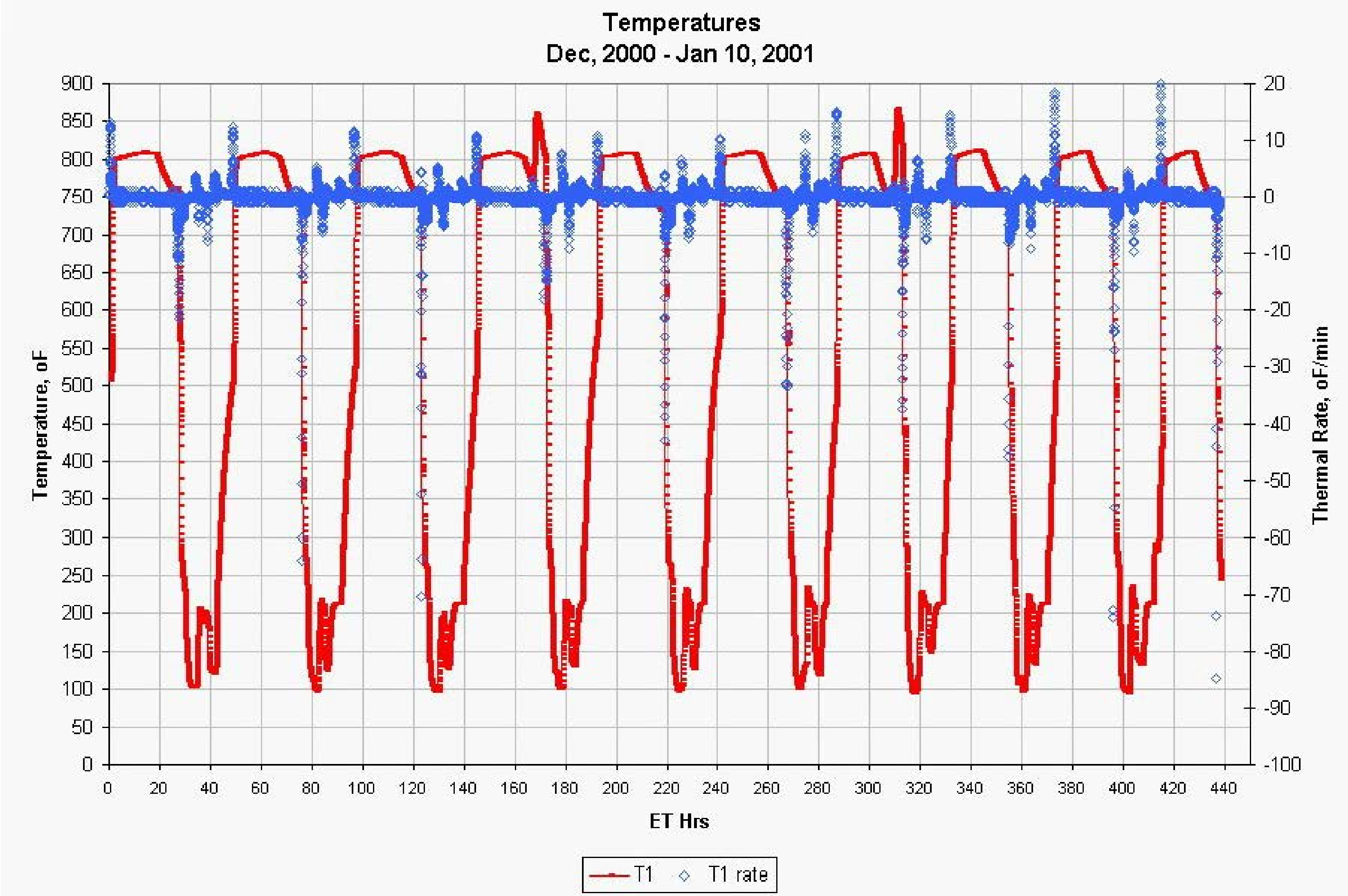
FATIGUE LIFE CALCULATION FOR A SKIRT IS MORE ACCURATE USING MEASURED THERMAL TRANSIENT

- Design (by others) predicted 152 years
- SES Transient analysis performed prior to T/A
- Maximum stress intensity range during transient = 143,430 psi
- Using ASME code Section VIII Division 2 fatigue design Table 5-110.1, UTS < 80 ksi, a fatigue life of ***<u>1228</u>*** cycles was obtained.

Finite Element Model vs Reality

After 5 years (~<u>1369</u> cycles) cracks were discovered in all 4 drum skirts (no slots) prior to T/A

Thermal Cycles and Rates for Cone



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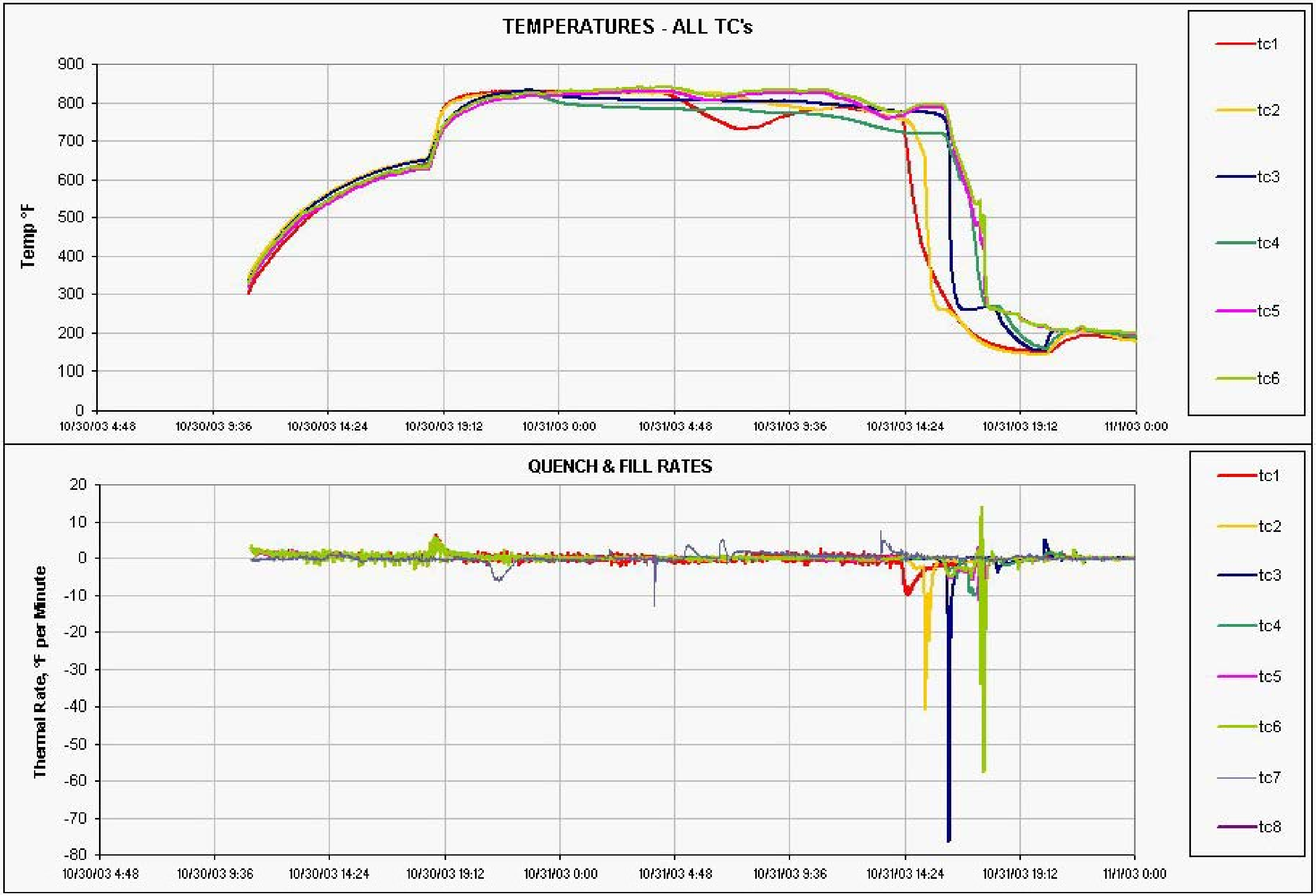
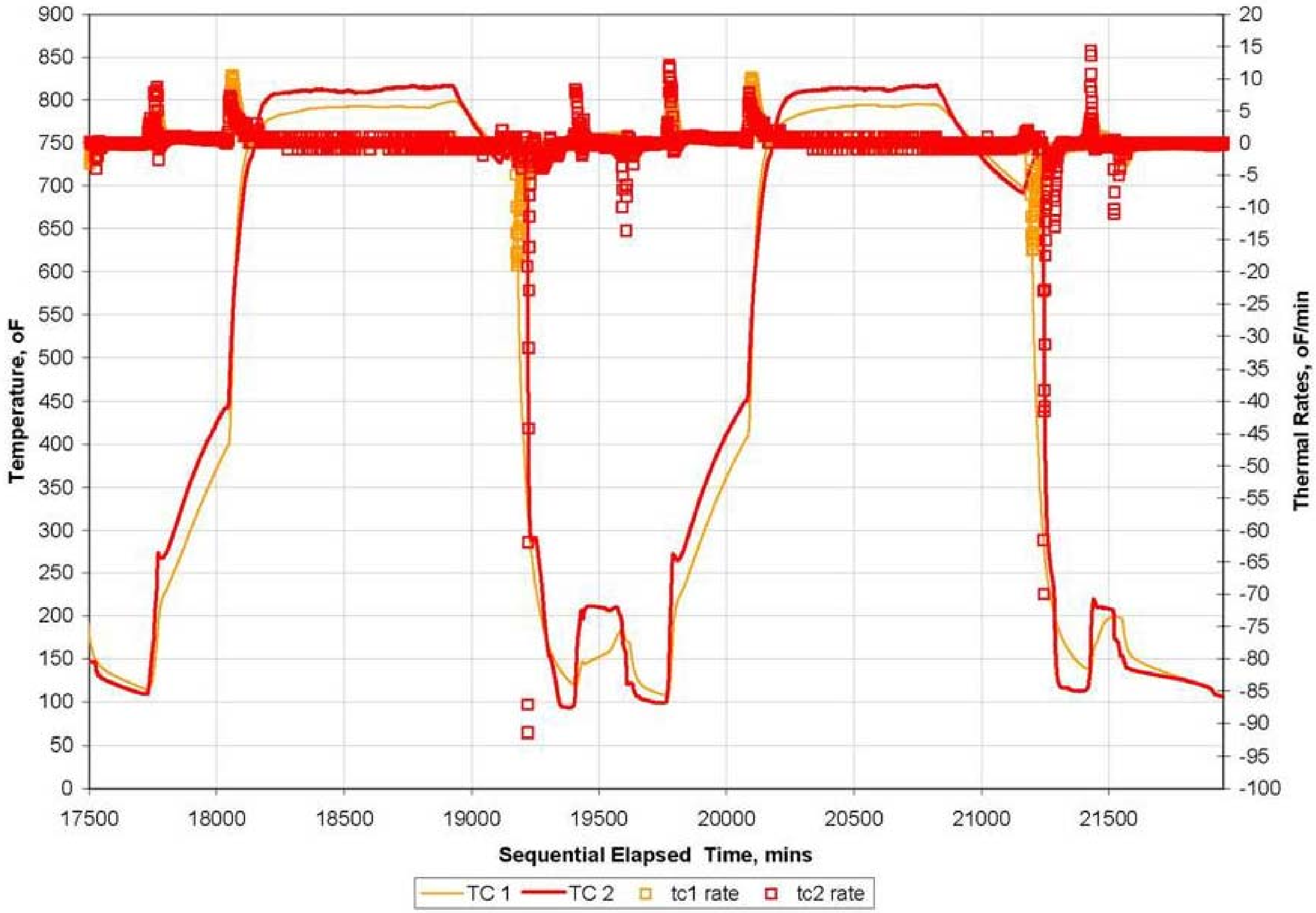
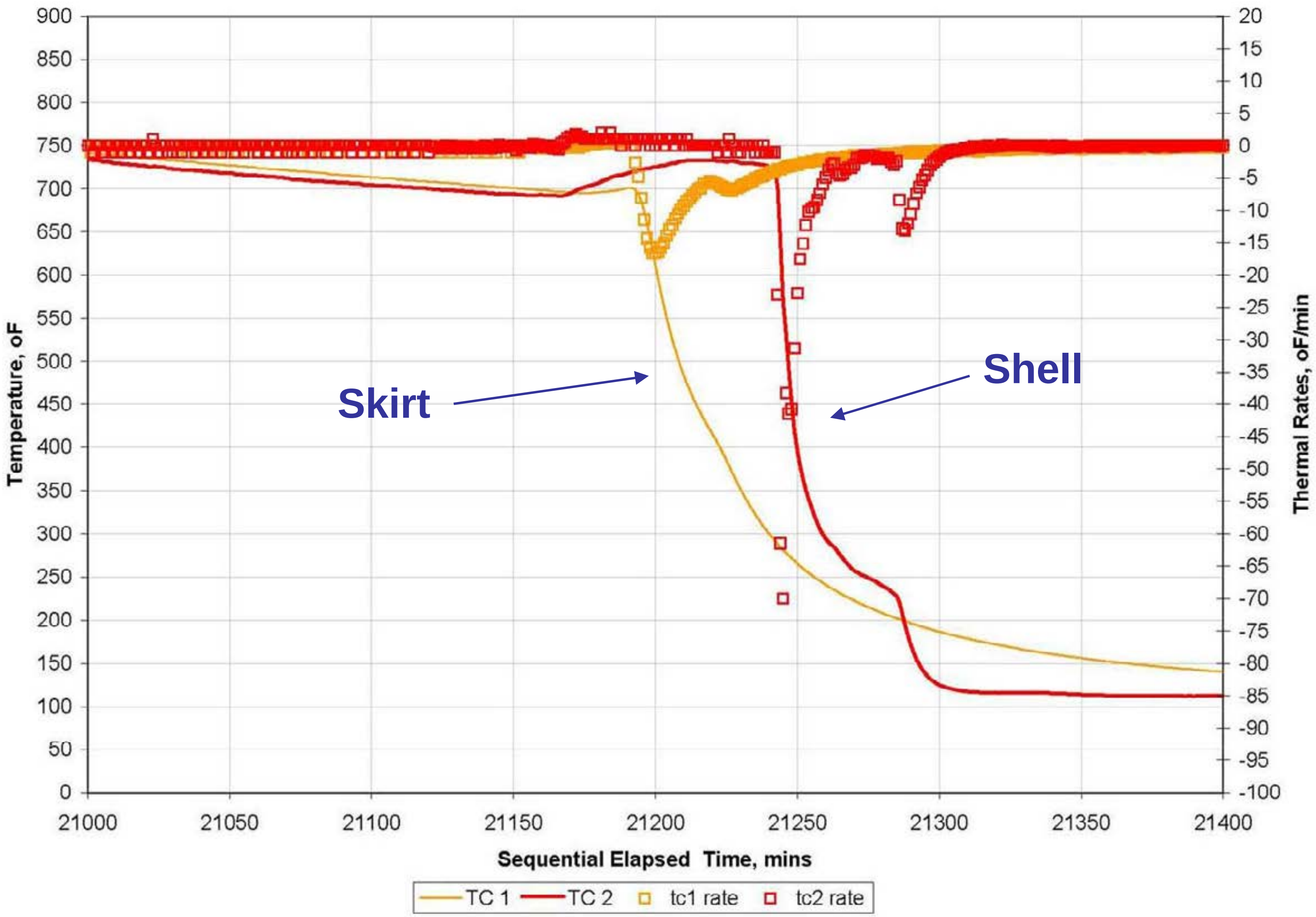
Thermal Cycles and Rates for Skirt and Shell



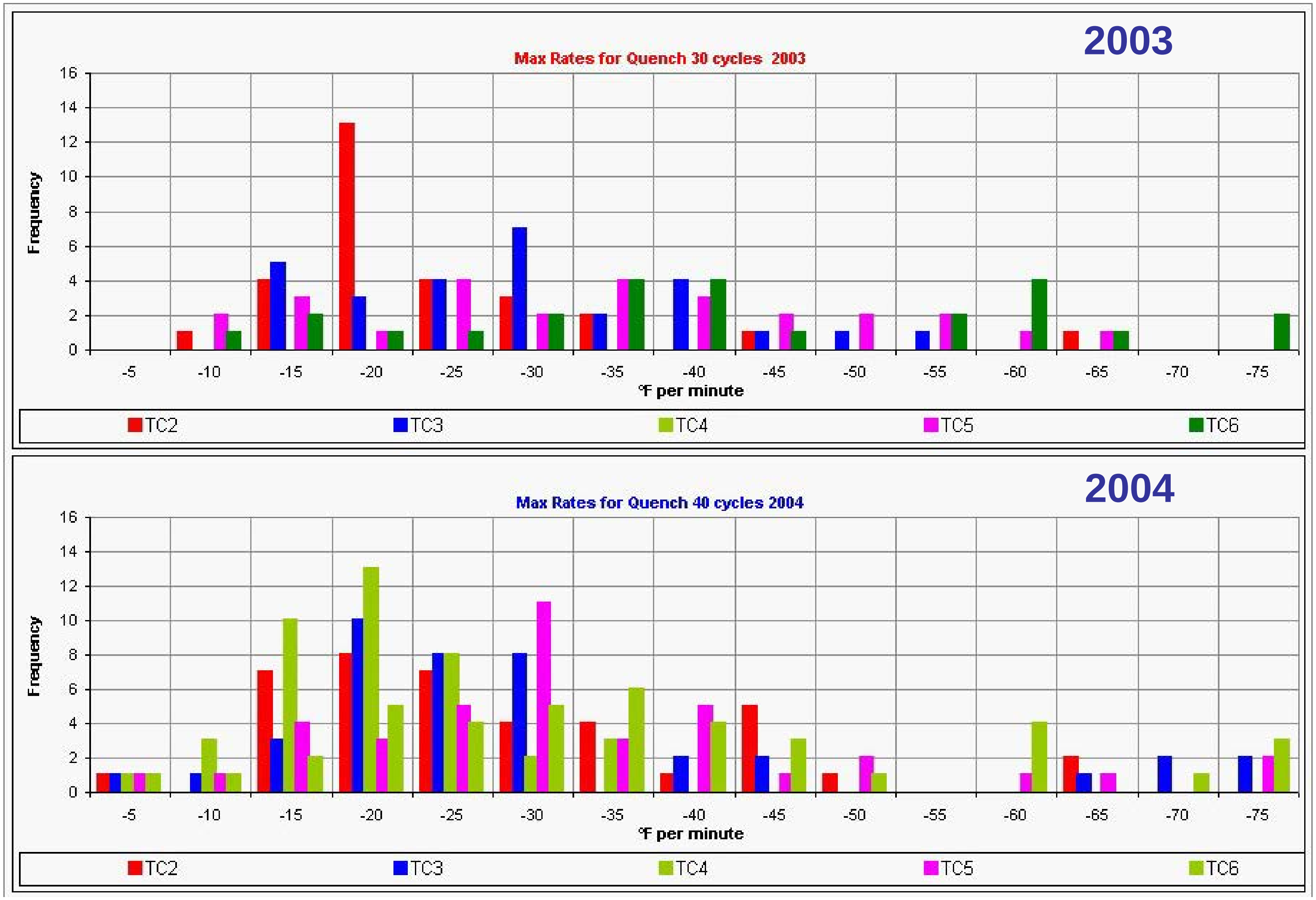
Thermal Cycles and Rates for Skirt and Shell



Thermal Quench and Rates for Skirt and Shell



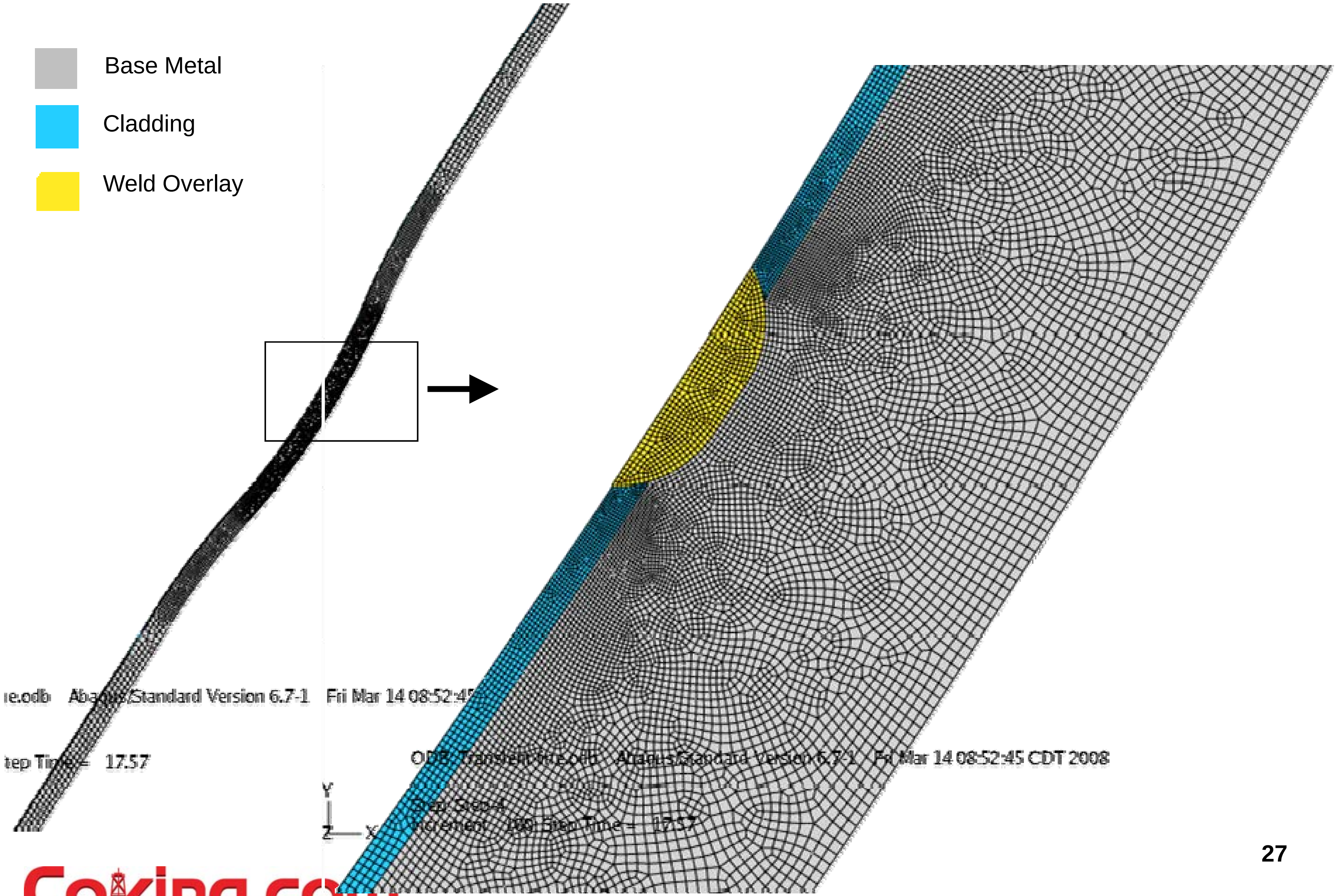
Thermal Rate Histogram for Shell



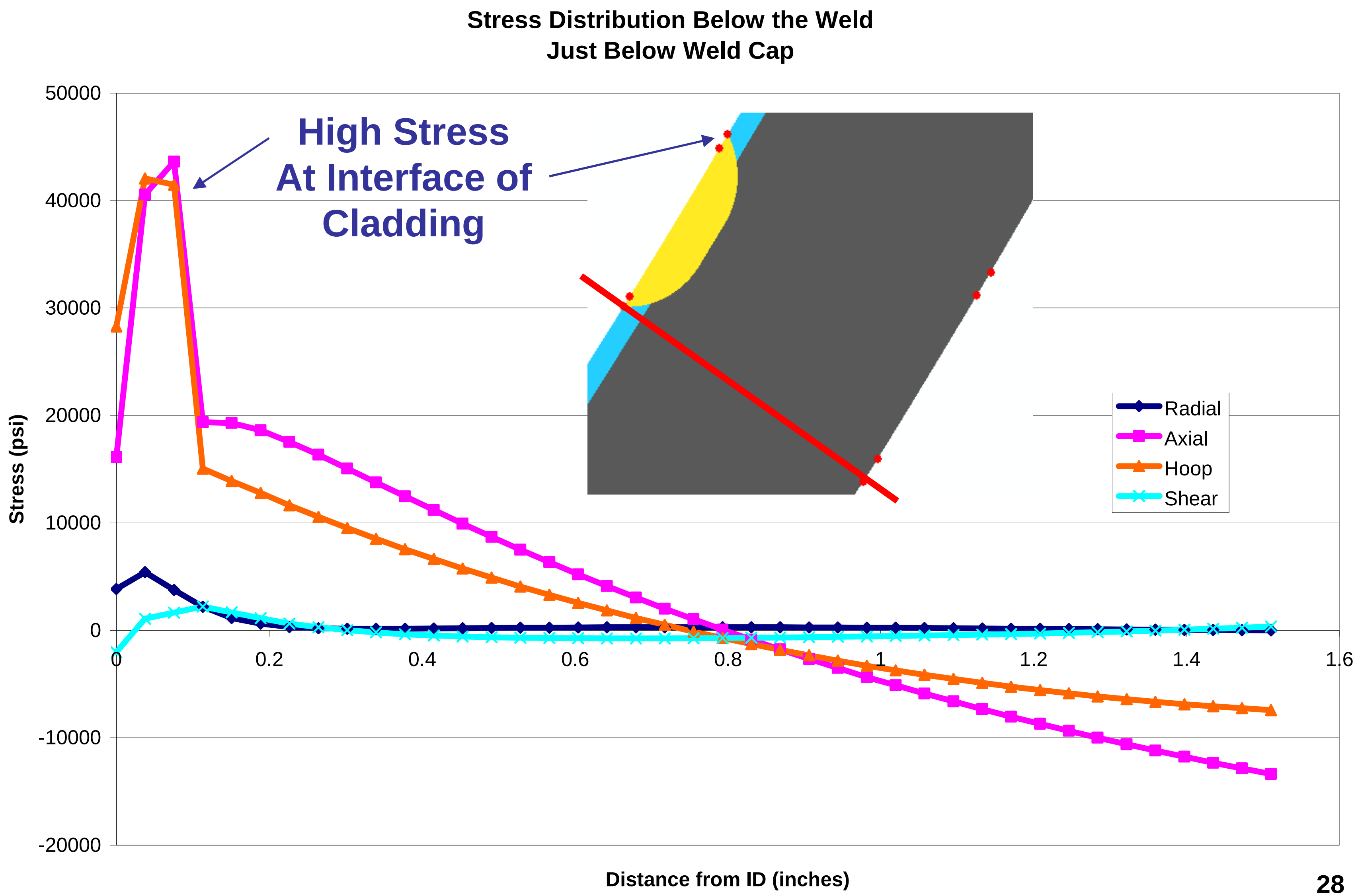
Does Fast Quench Shorten Cyclic Life ?

- Where Does Fast Quench Hurt?
  - Skirt Attachment Weld
  - Shell Circ Seams
  - Cone Circ Seams
- Why Does Fast Quench Hurt?
  - Constraint created by components at different temperatures (i.e. thermal expansions)
  - Different Material Properties (Yield, Expansion, Conductivity, Diffusivity)

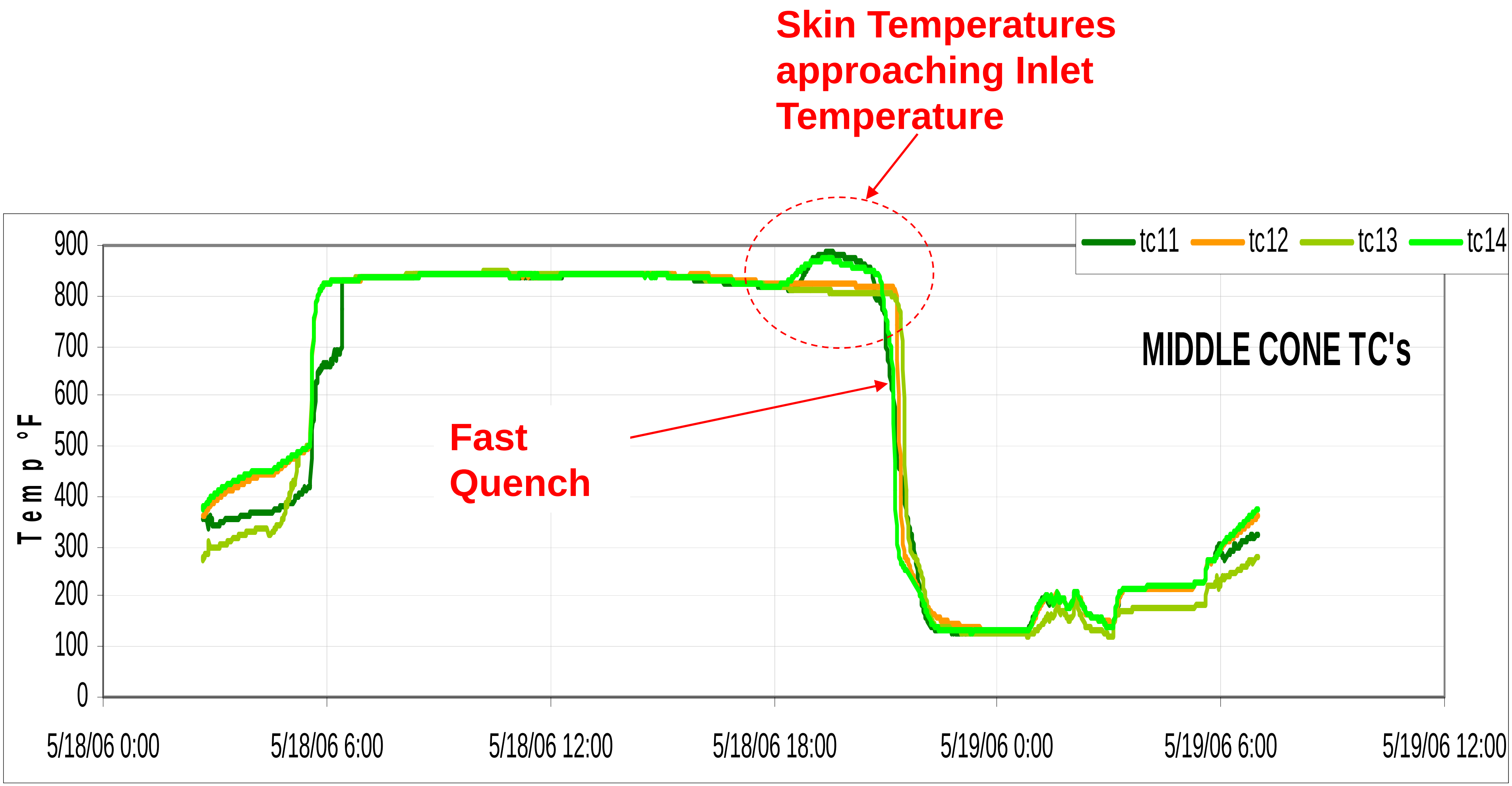
FEA Transient Analysis for ID Circ Seam



Stress Distribution Across Weld During Quench for Linear Elastic Fracture Mechanics Evaluation



Example of Measured Cone Temperatures



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Fast Quench Issues

- ***Traditional Analysis*** methods assume a ***uniform average flow*** of water upwards to remove heat from coke bed and shell at same time, or ***up thru central primary flow channel***.
- Coke bed formation determines path of least resistance for water flow
  - Flow channel area and friction
    - Plugging and channel collapse creates new flow paths
  - Permeability
  - Porosity
  - Collapse strength of coke matrix
- Temperature measurements suggest fast quench with flow near wall is common
  - **Generally random and not necessarily aligned with Inlet Nozzle**
- This creates greater stress in **shell/cladding bond** and **skirt weld**
  - **Creates greater stress at circ seams tri-metal junction**
- This increases likelihood that **hot zones remain** in coke bed after quench

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What to do about Fast Quench ?

- Change the way you do it
- Use Sensor Measurements (TC and HTSG) to guide you
- Use your Process Technology experts to address the possible procedures and maintain production
- Change the way drums are made
- Or, be prepared for continued problems….