Fast quench problems and how they damage coke drums

Coke Drum Reliability Workshop

Calgary • September 17, 2009

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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**

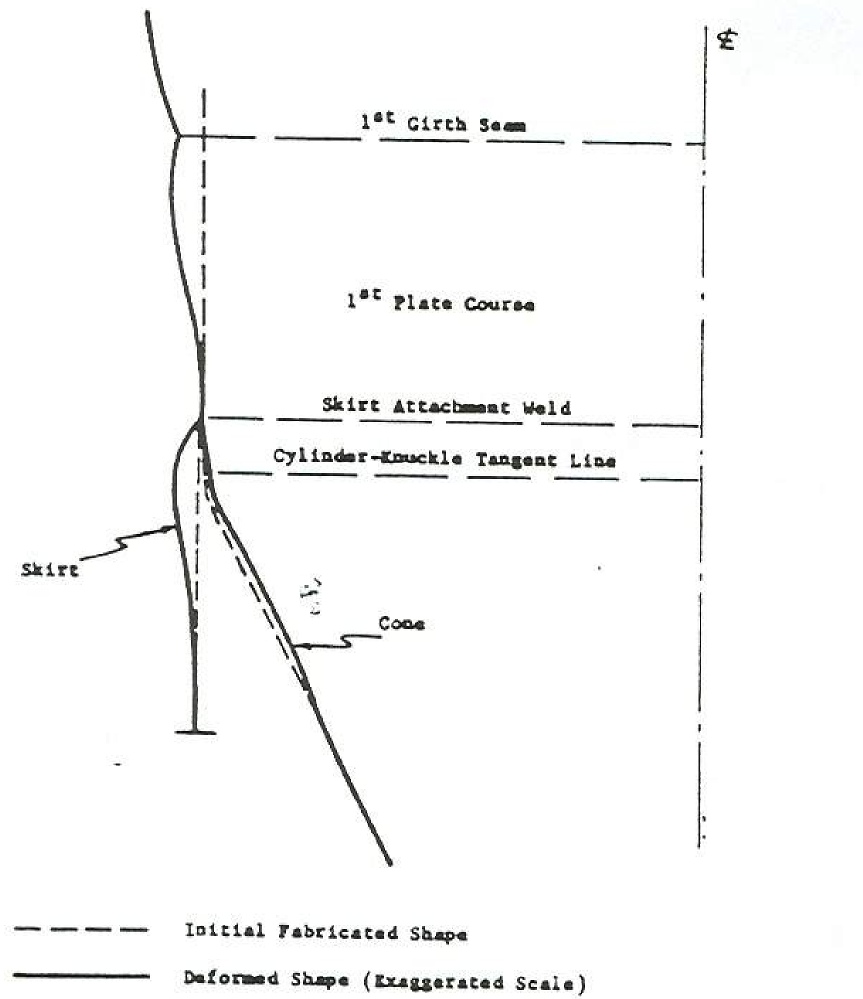

Fig. 7 Deformation pattern of vessels in heavily cyclic service

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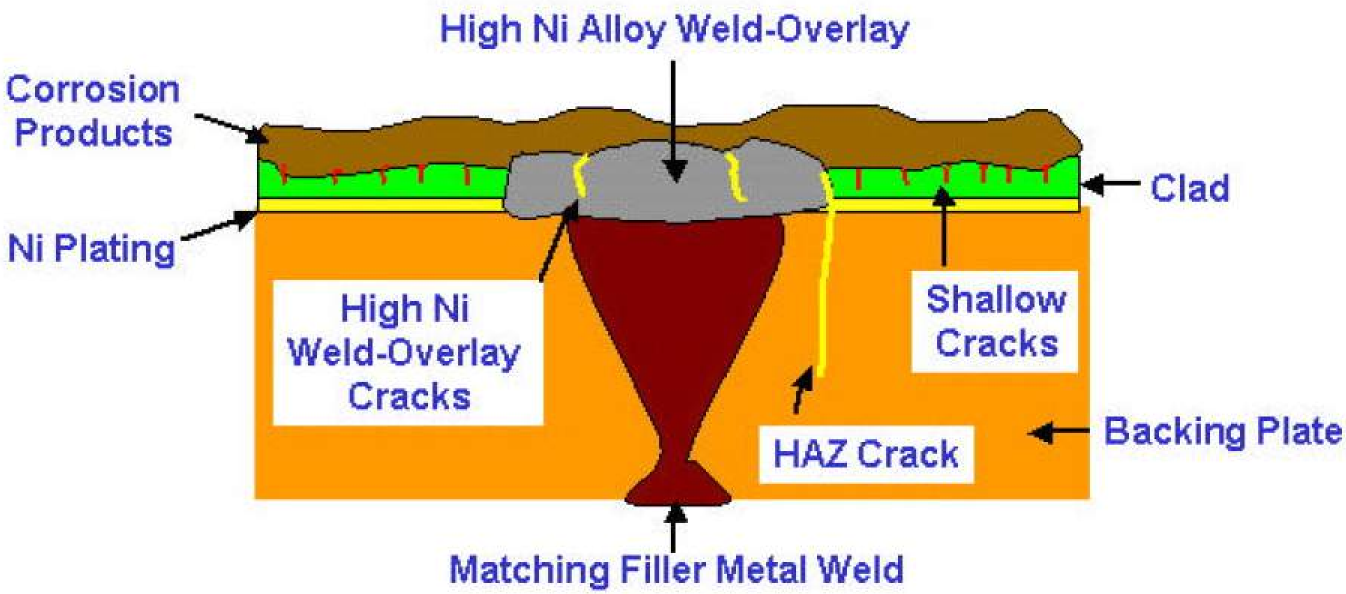
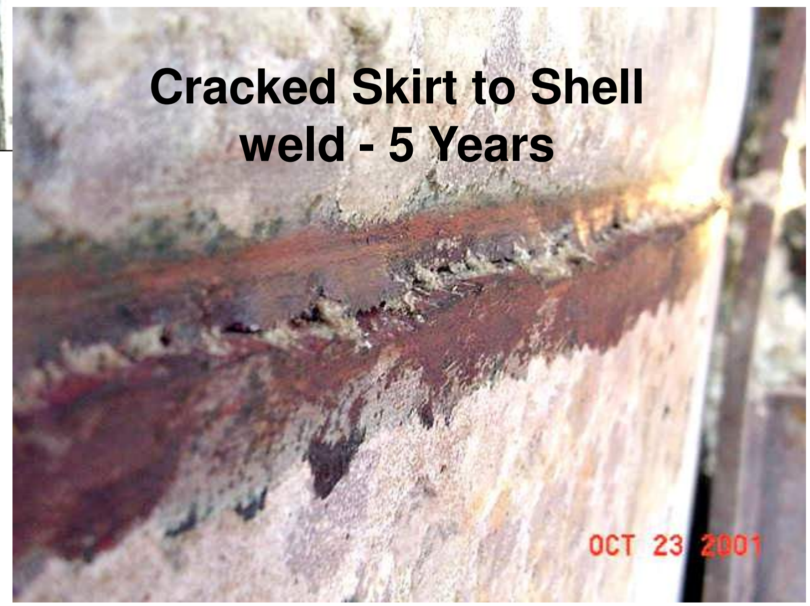
Problem Circ Weld Seam* Cracking Is Common

4. Crack Initiation and Propagation



* Joint detail may vary

Drum Cracking Examples



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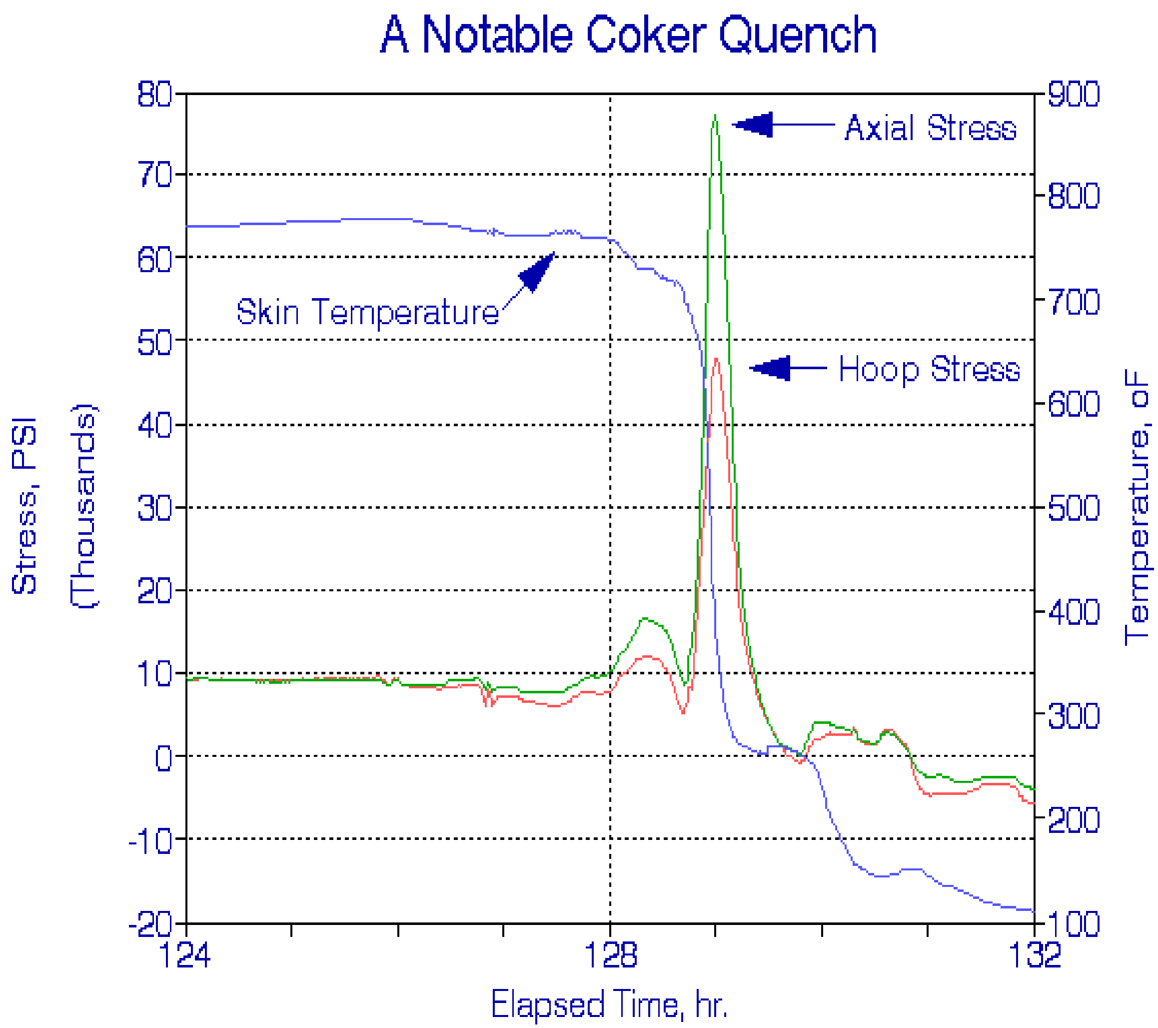
A NOTABLE QUENCH STRESS MEASURED ON SHELL O.D.



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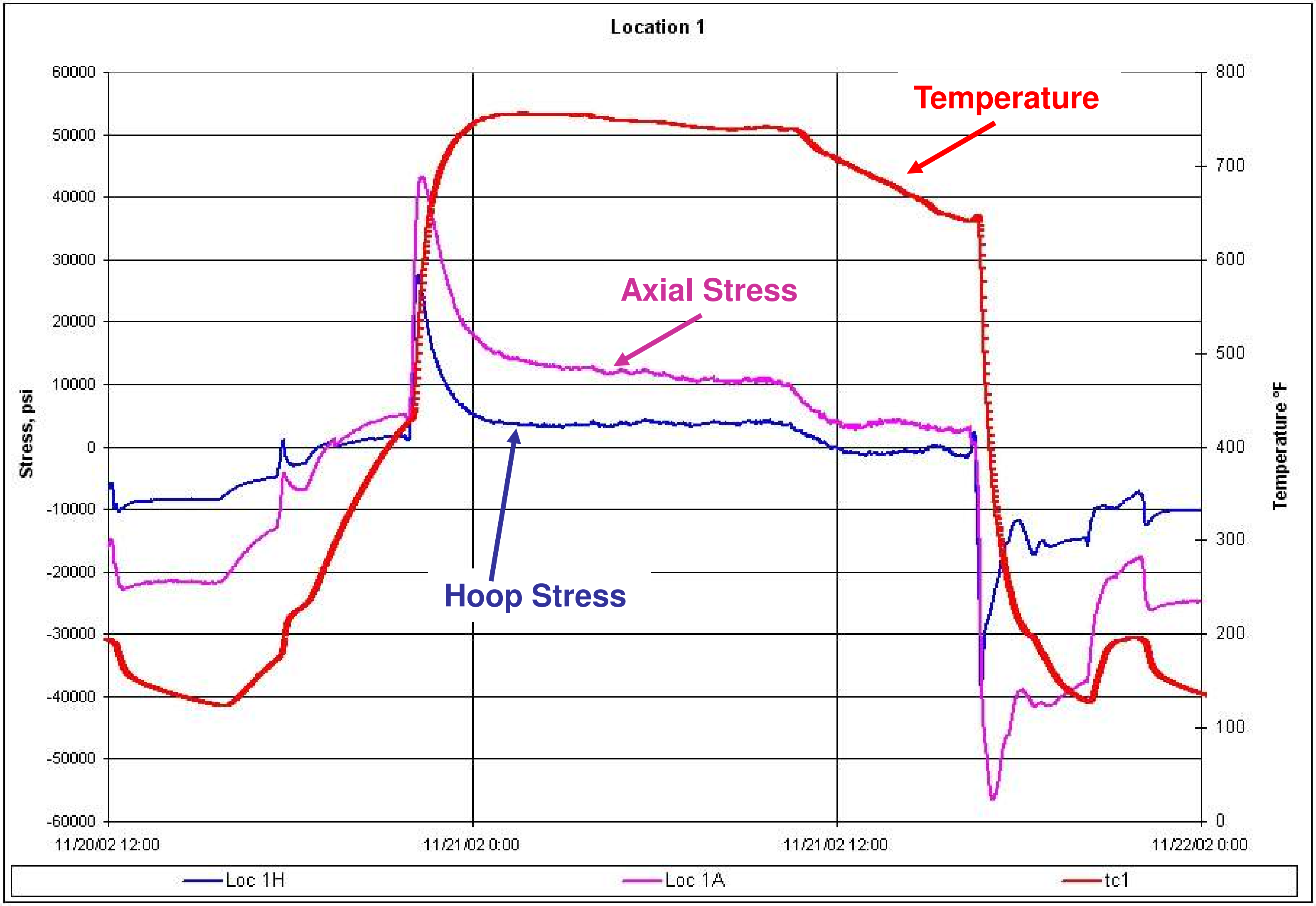
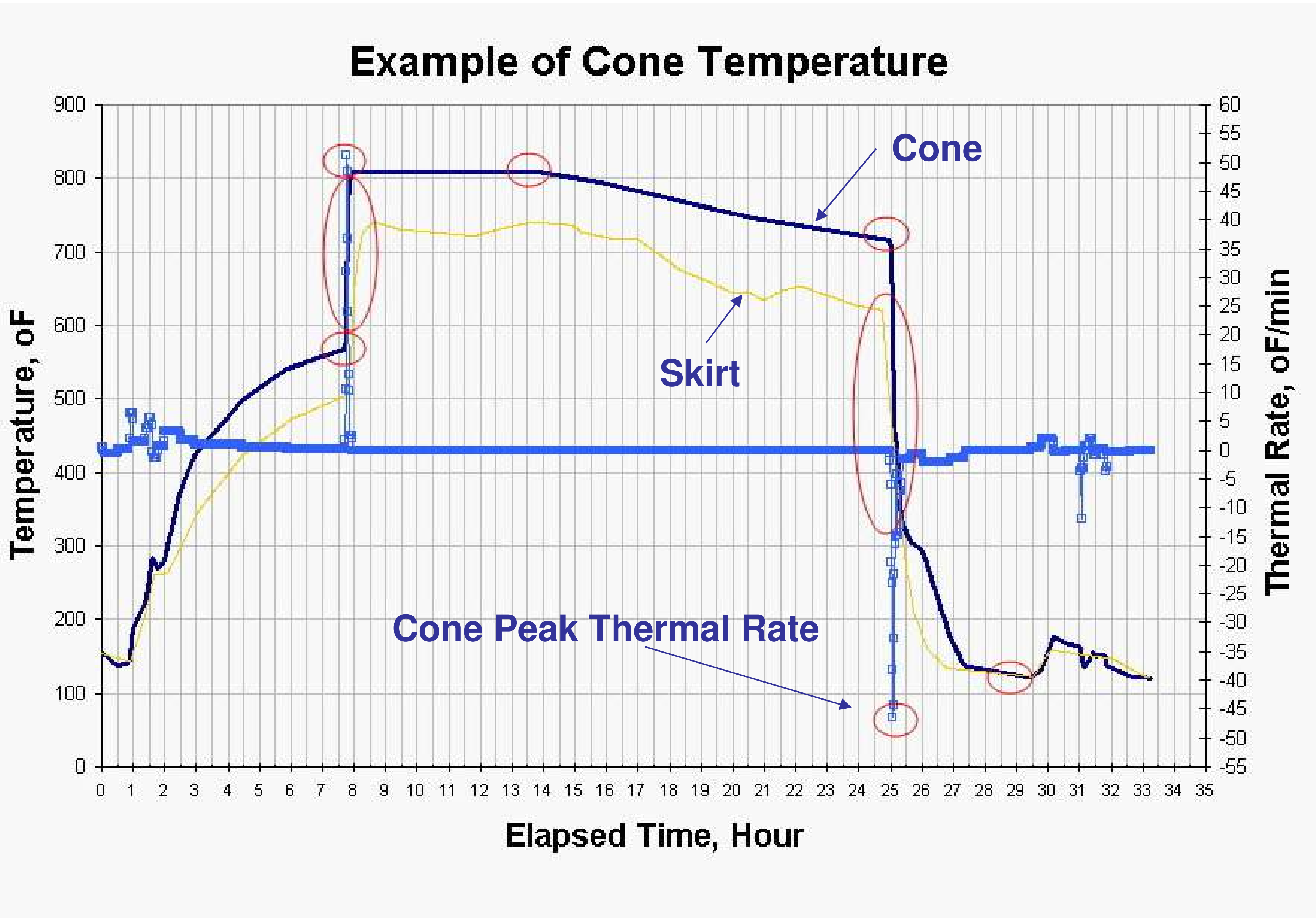
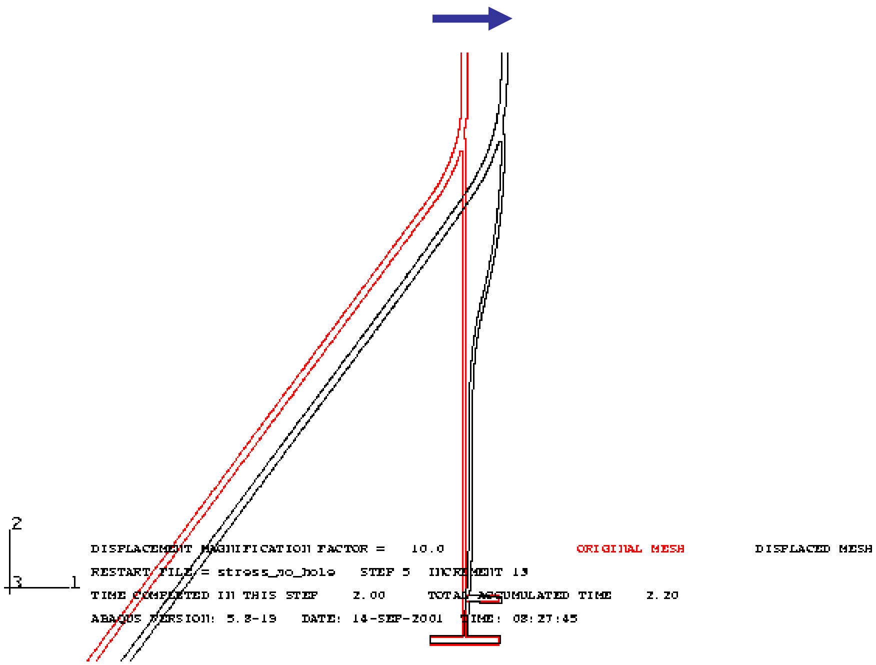
A Measured Cycle For In-Line Skirt Stress Response (OD)

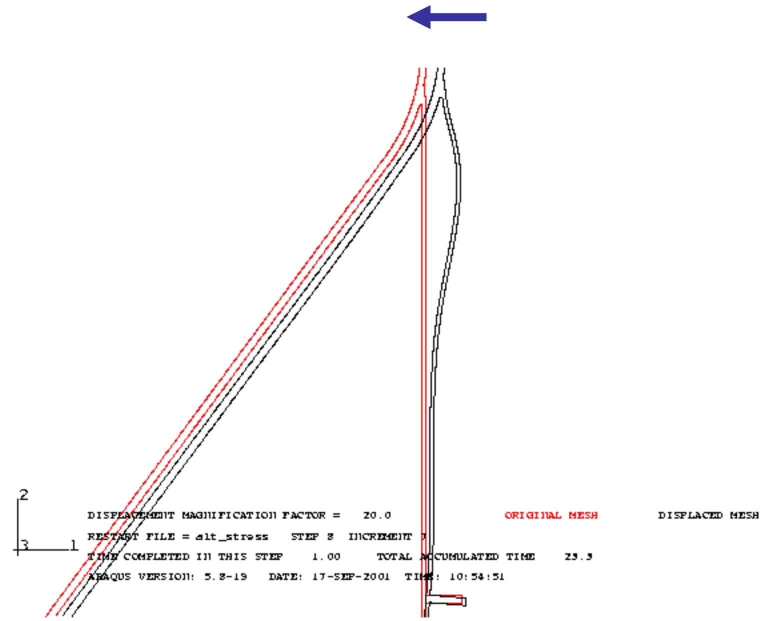



Example of Cone Temperature
Temperature, oF
Thermal Rate, oF/min
Elapsed Time, Hour
Cone
Skirt
Cone Peak Thermal Rate

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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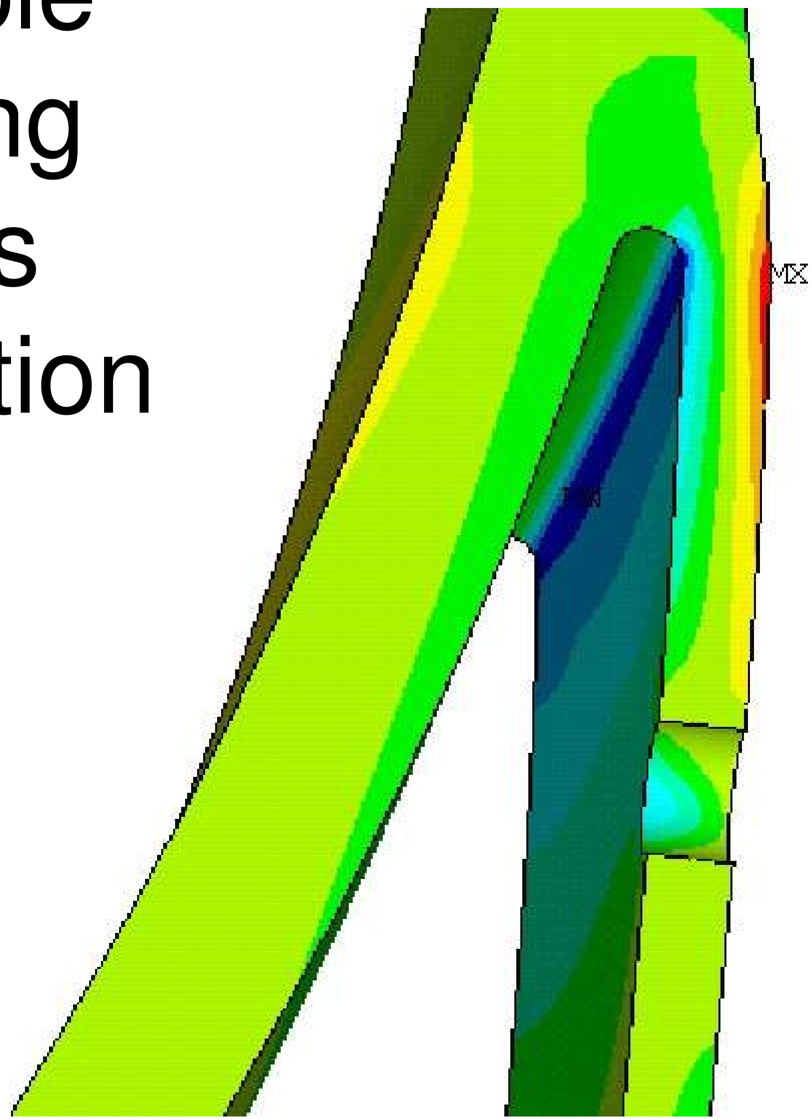
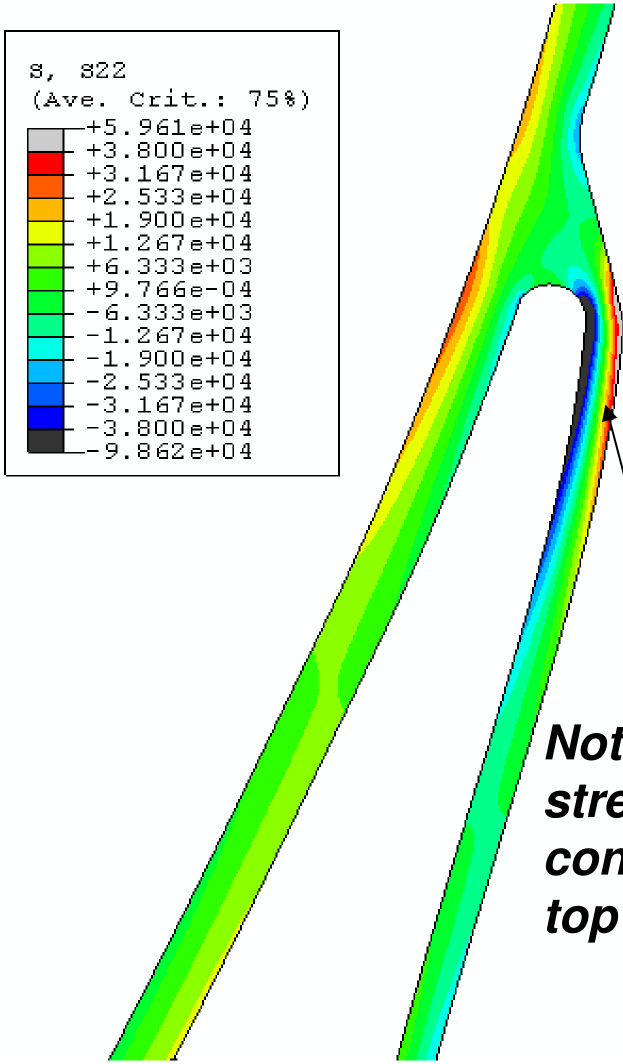
Example Bending Stress Distribution

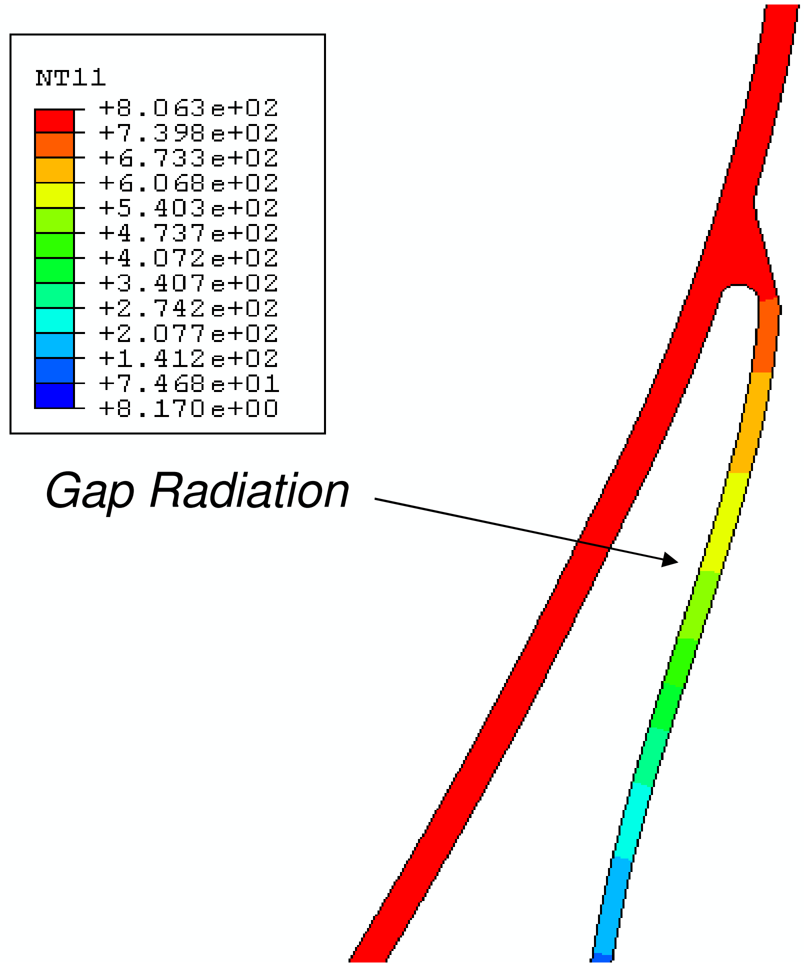


Example In-Line Skirt Axial Stress During the Fill Transient



Axial Bending Stress

Note high bending stresses as hotter cone PUSHES Skirt top Outward



Gap Radiation

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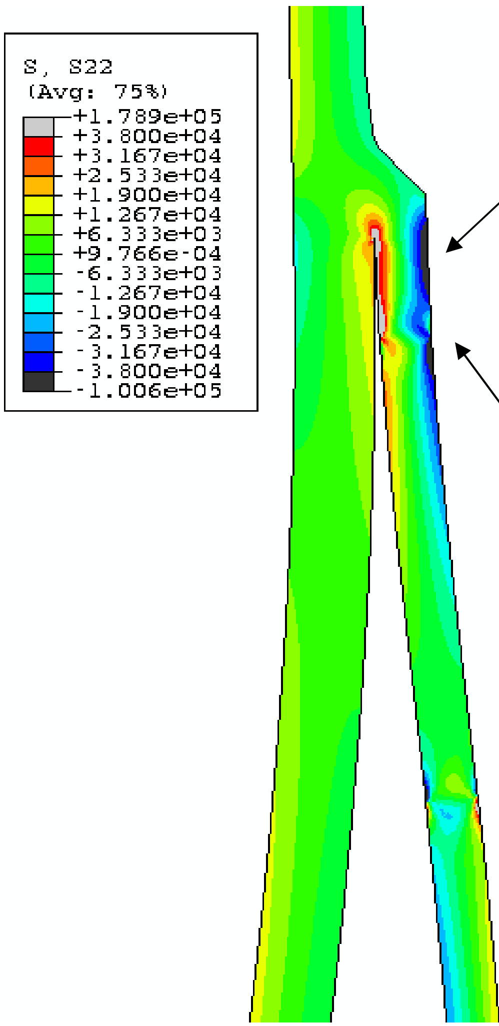
Example Tangent Mount Axial Stress During the Quench Transient

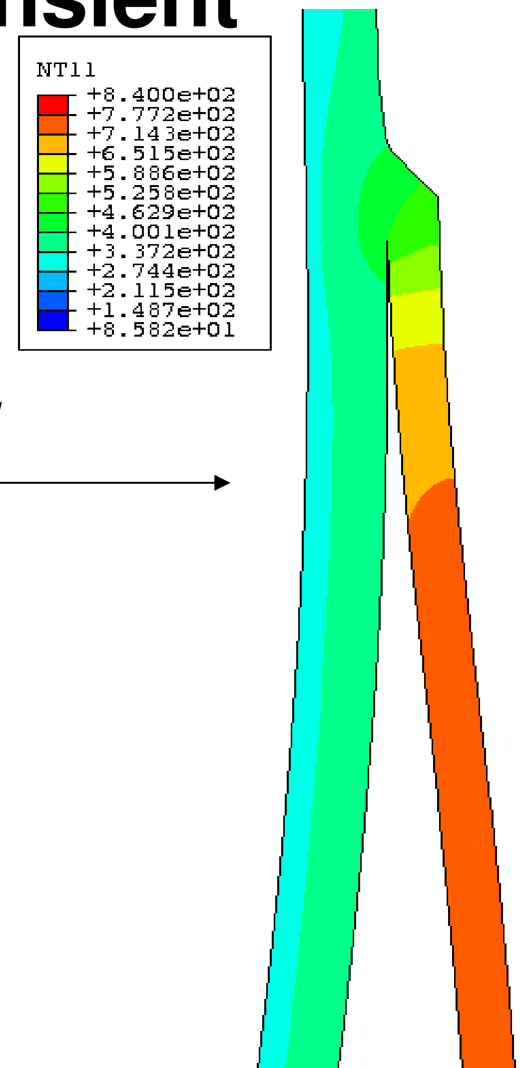


Axial Bending Stress

Gap Radiation,

Gap Conductance active when in contact

Note high bending stresses as cooler cone PULLS Skirt top Inward



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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 ***1228*** cycles was obtained.

Finite Element Model vs Reality

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

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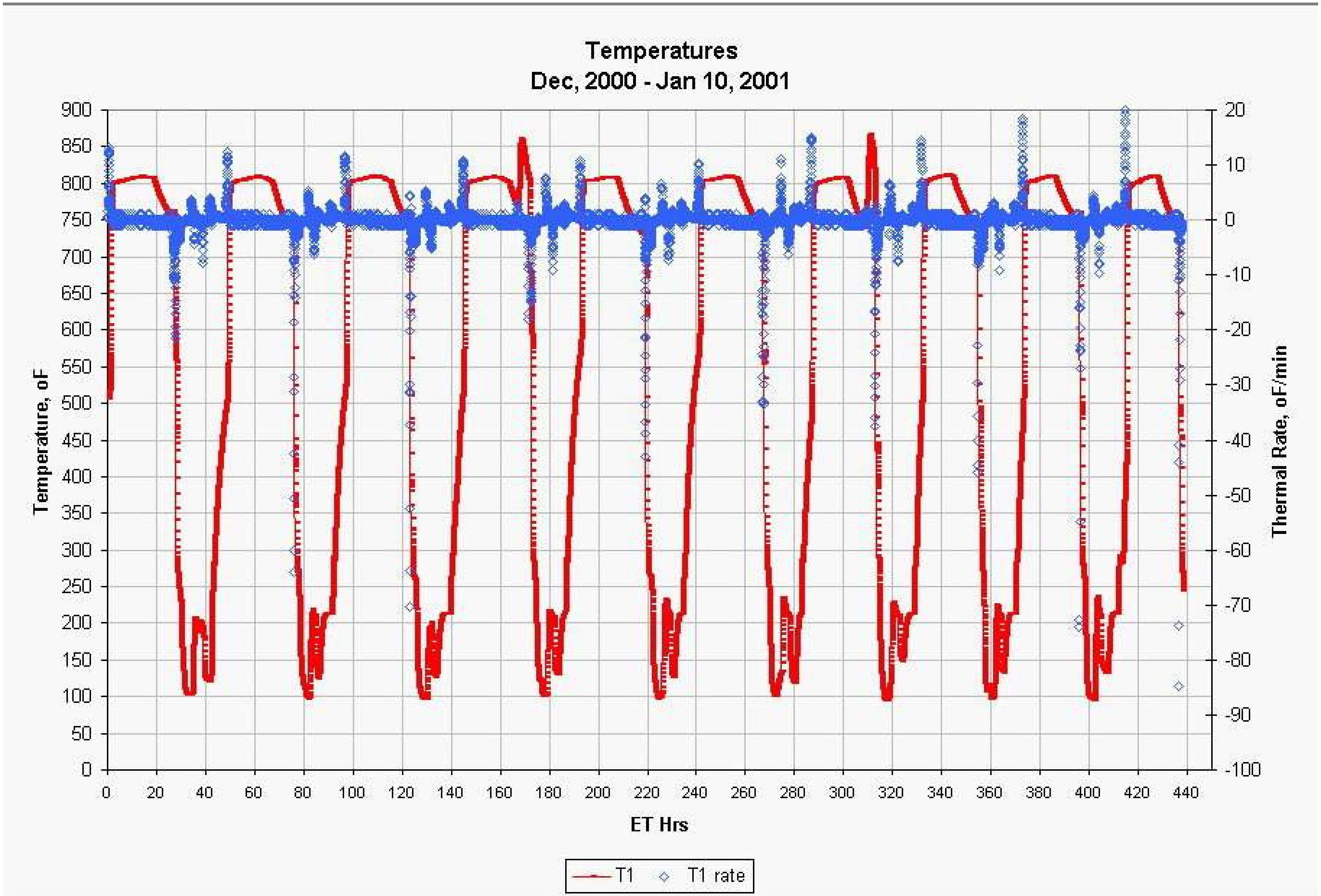
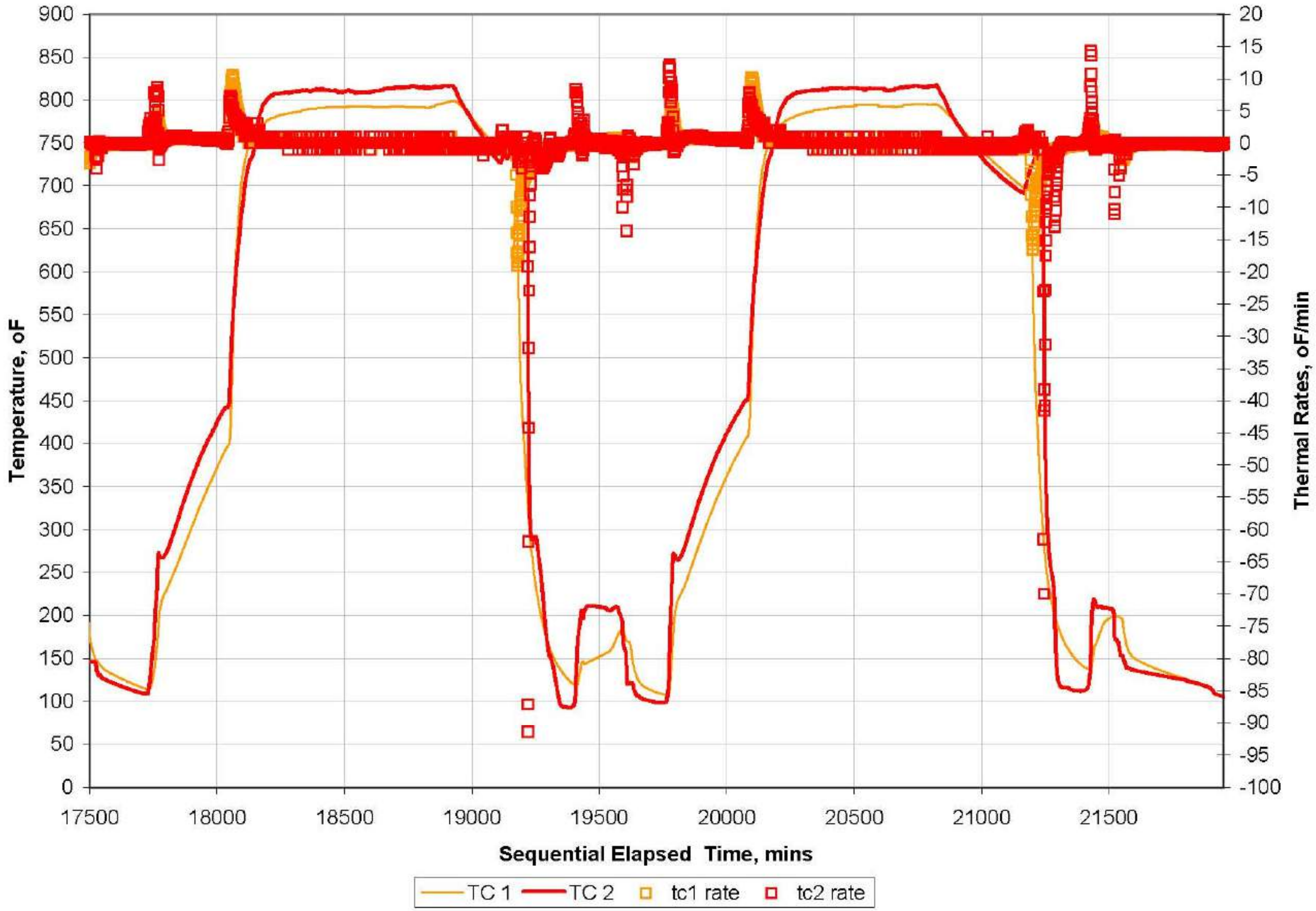
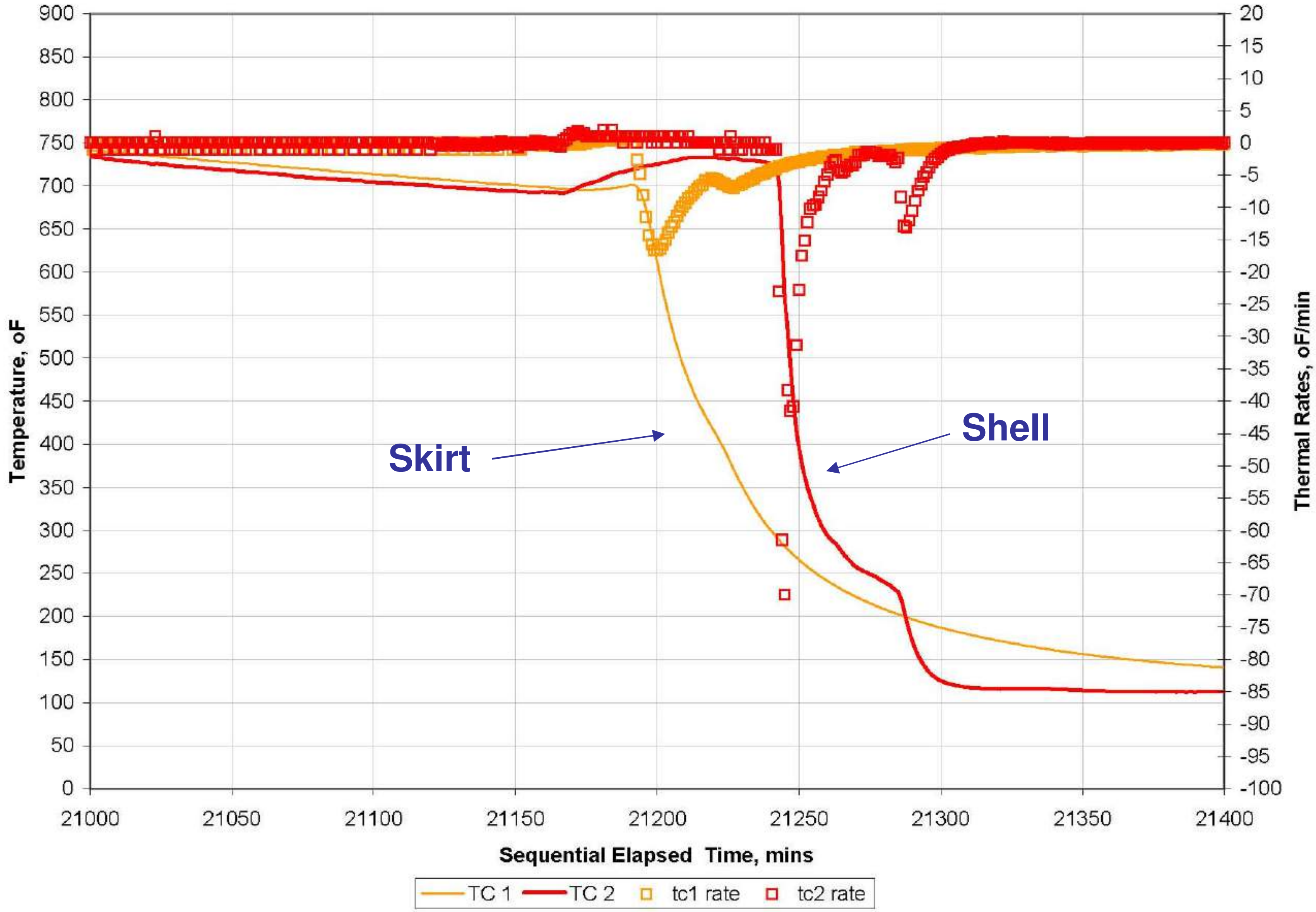
Thermal Cycles and Rates for Cone



Thermal Cycles and Rates for Skirt and Shell



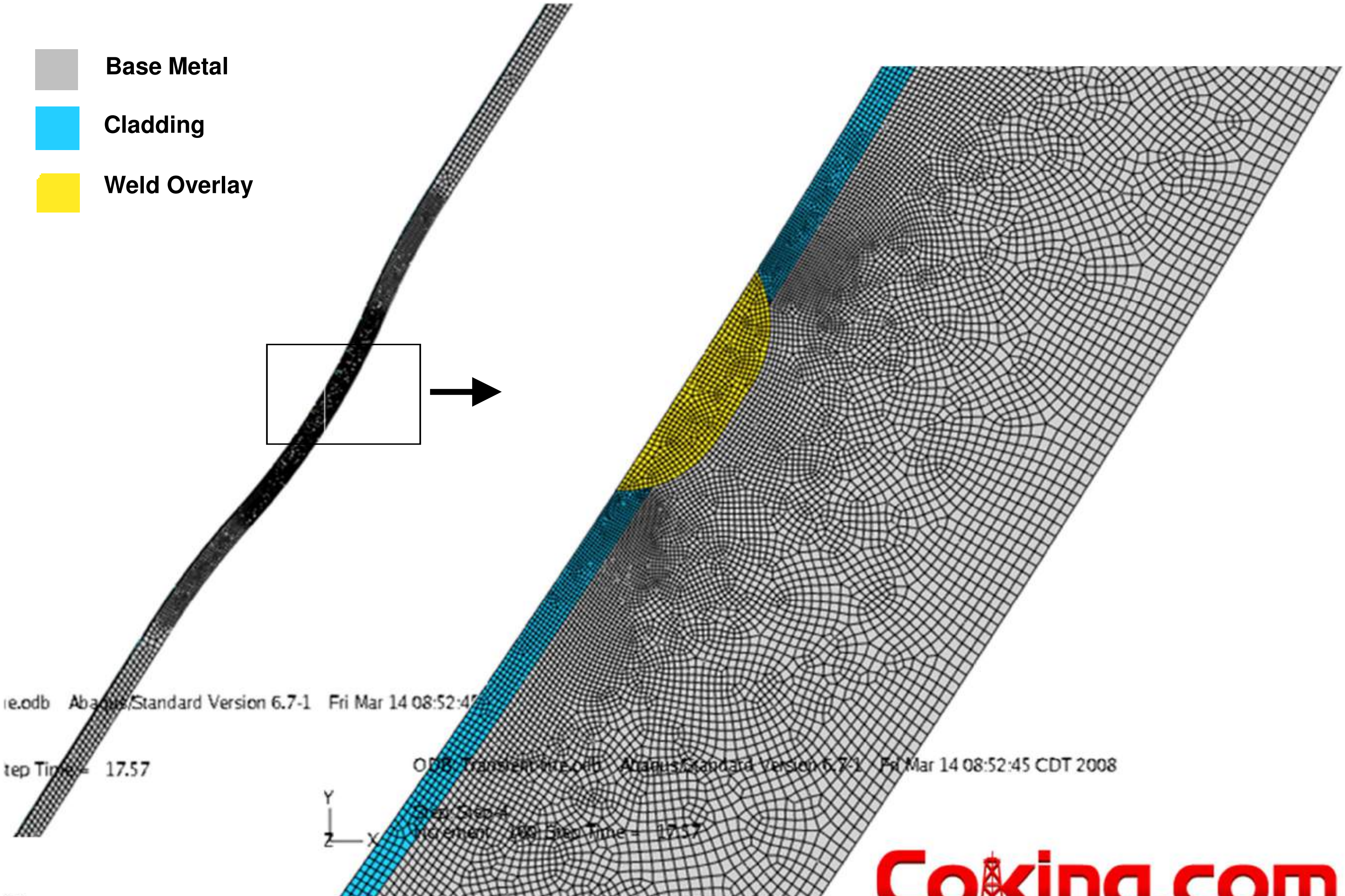
Thermal Quench and Rates for Skirt and Shell



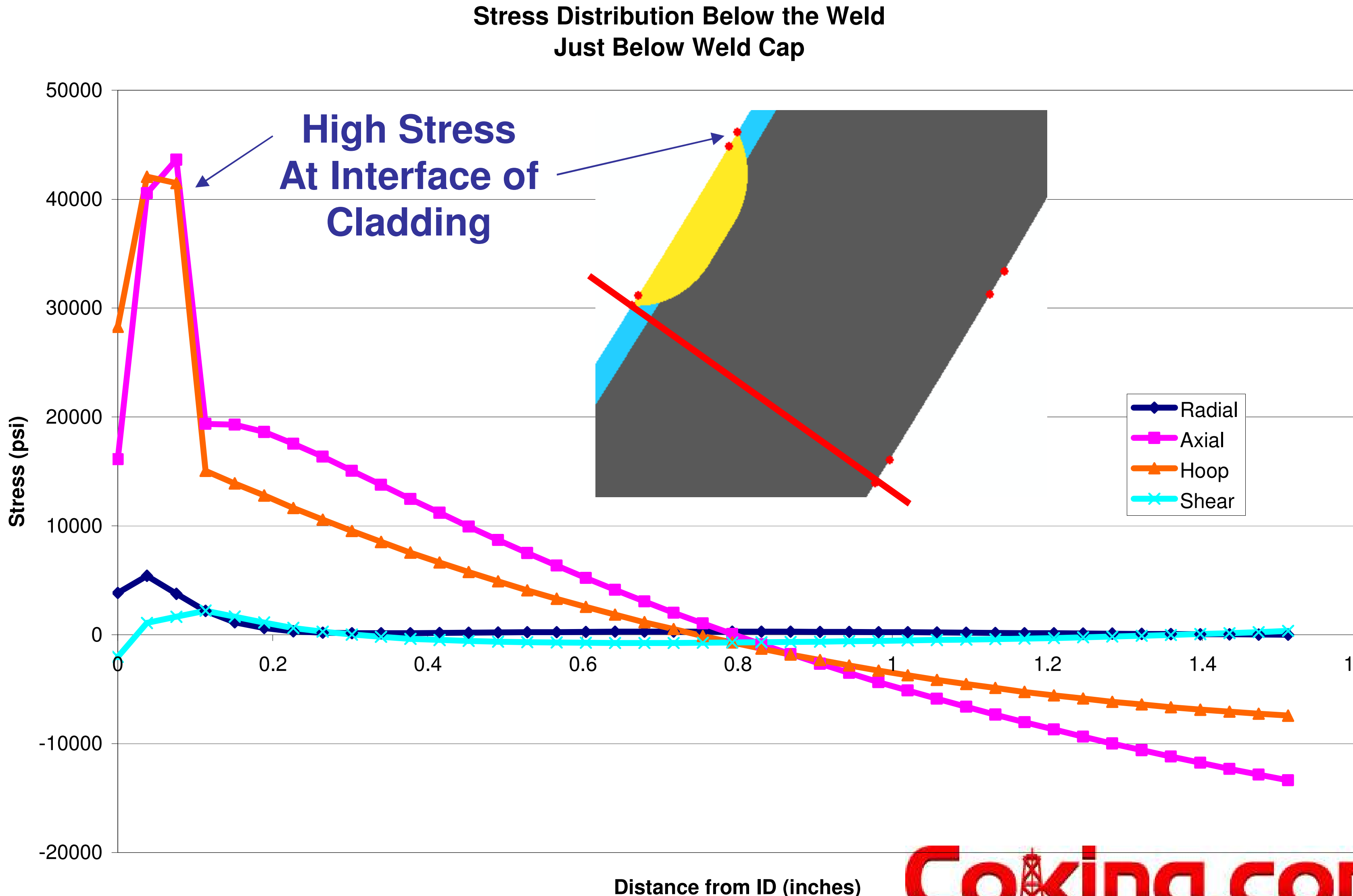
Does Fast Quench Shorten Cyclic Life ?

- 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



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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

What to do about Fast Quench ?

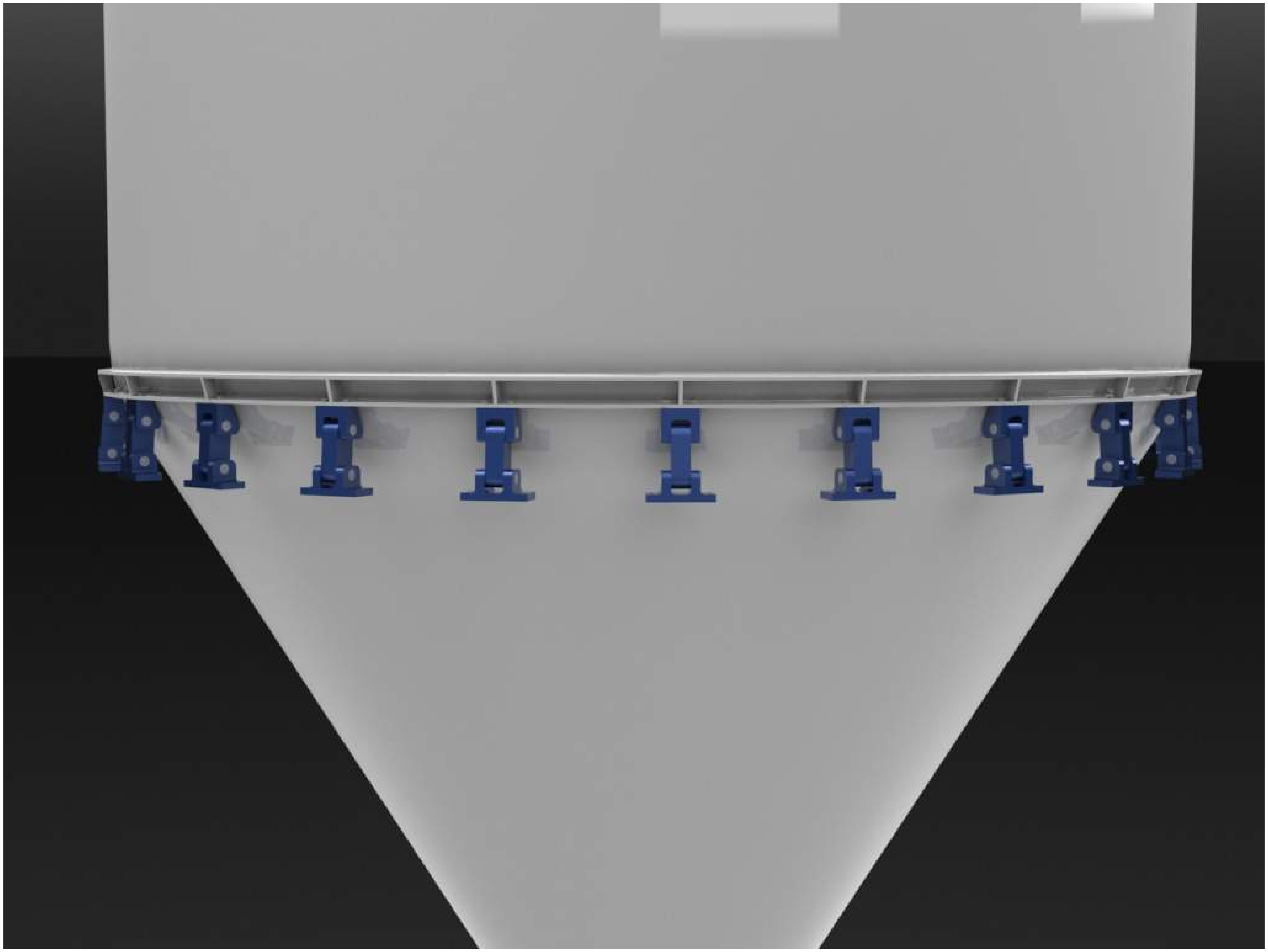
- Change the way you do it
- Use Sensor Measurements (TC and HTSG) to guide you
- Use your Process Technology experts to address the possible procedures and maintain production
- Change the way drums are made
- Or, be prepared for continued problems….

DeltaValve Listened

Feasibility Studies conducted by SES

- New Inlet Nozzle Concept
- New Skirt Concepts: The Next Generation

New Skirt Concept: The Next Generation



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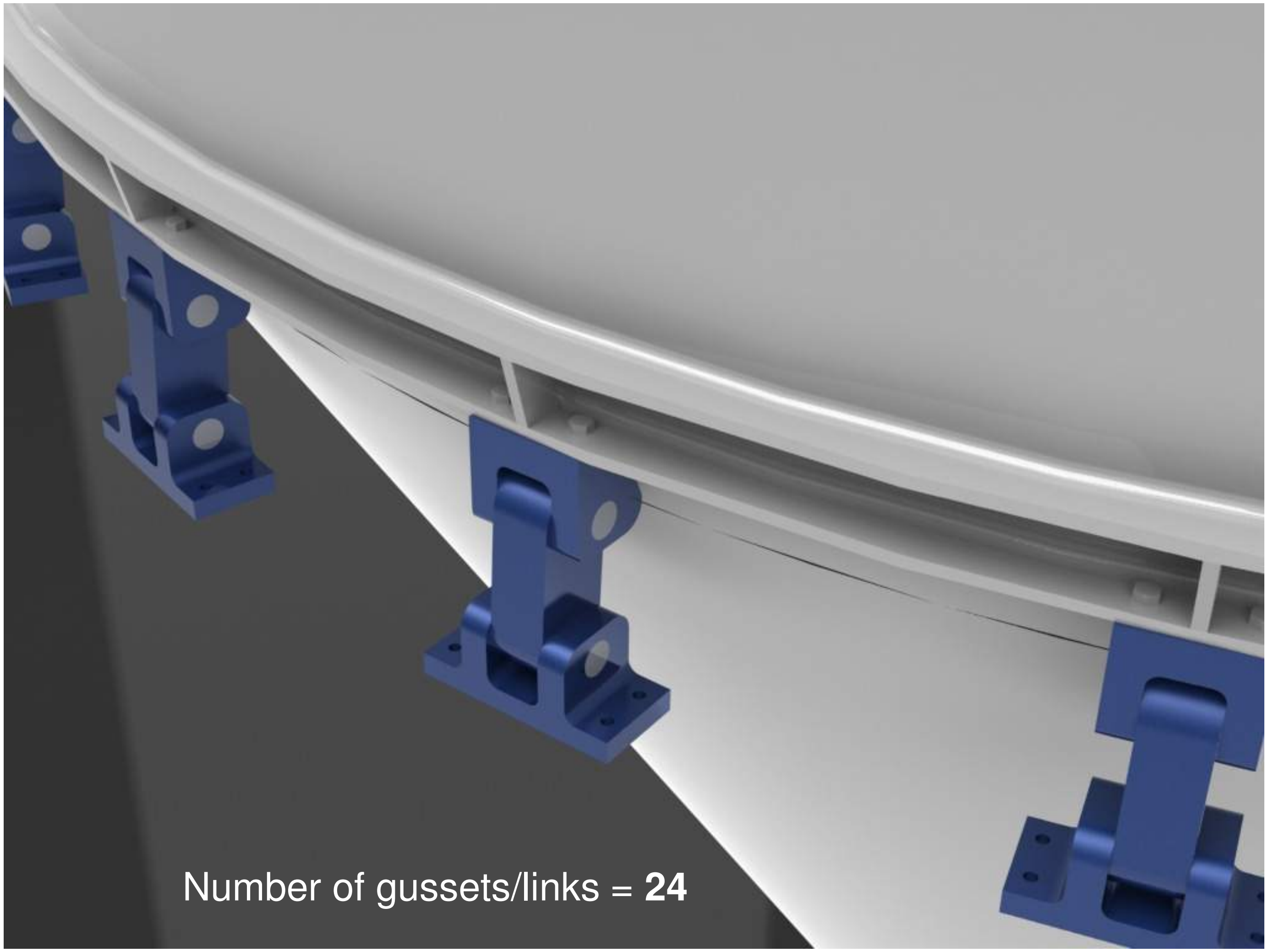
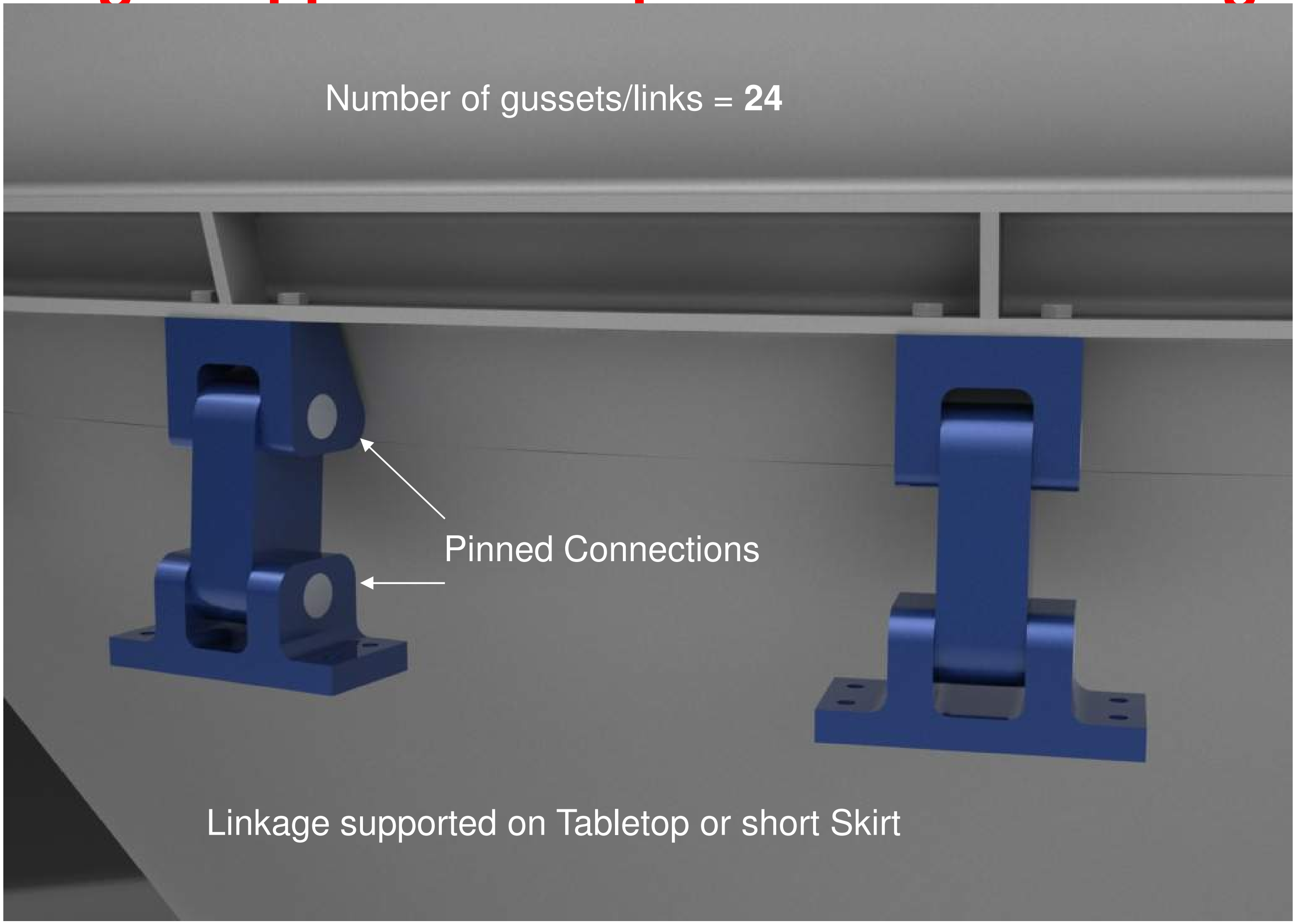
Linkage Support Concept – Continuous Rings



Linkage Support Concept – Continuous Rings



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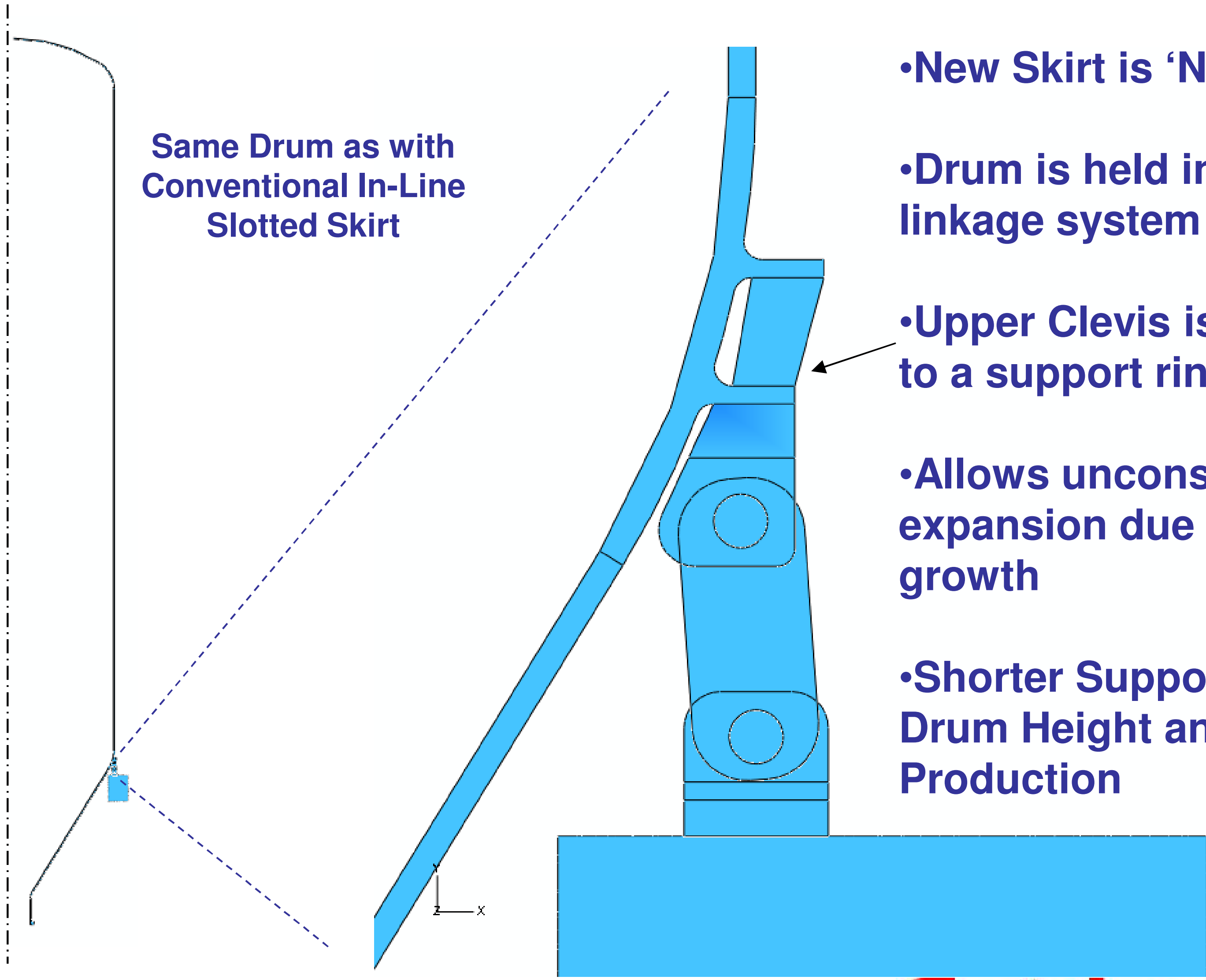
New Skirt Concept: The Next Generation



- New Skirt is 'No Skirt'
- Drum is held in place by a linkage system
- Upper Clevis is attached to a support ring
- Allows unconstrained expansion due to thermal growth
- Shorter Support = More Drum Height and Production

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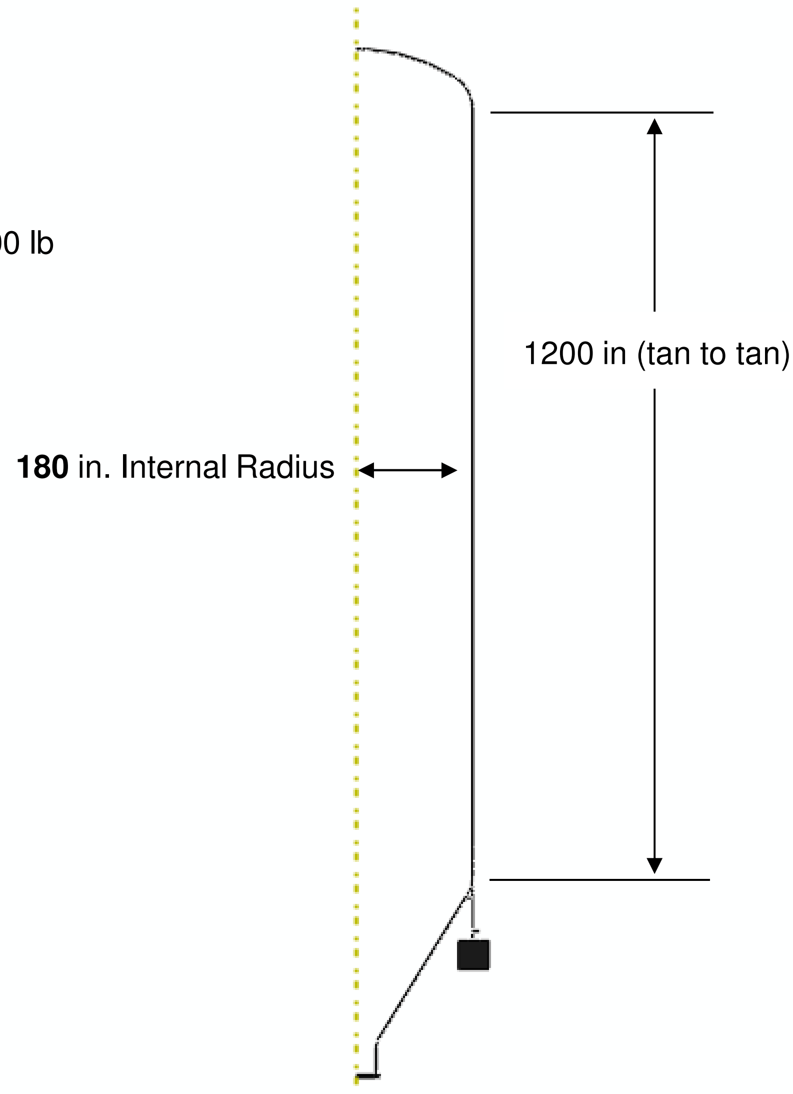
Typical Coke Drum Example for Comparison of Support Concepts

Supplied by DeltaValve

Drum Weight ~ 729,000 lb
Drum Diameter = **30** ft



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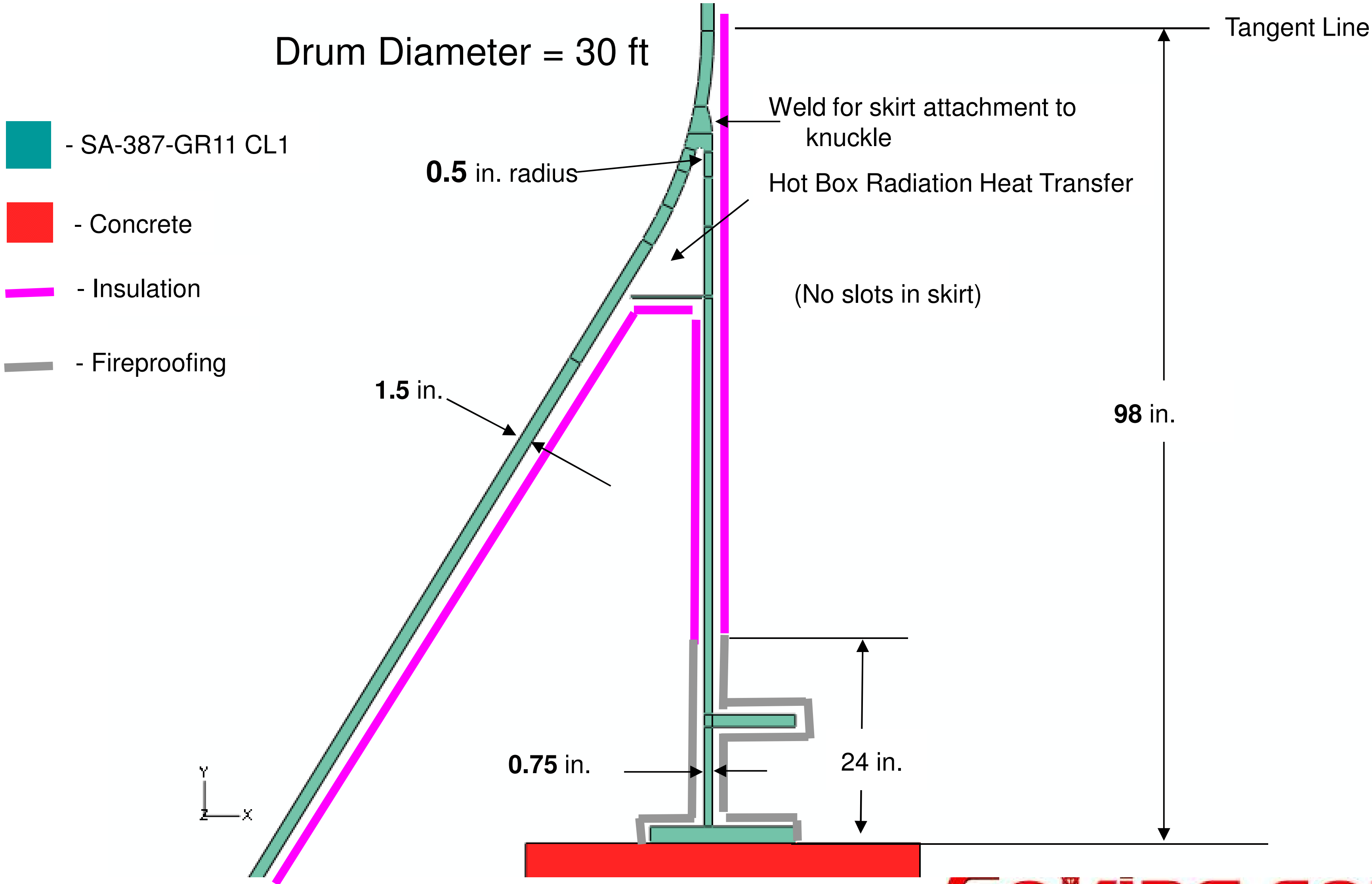
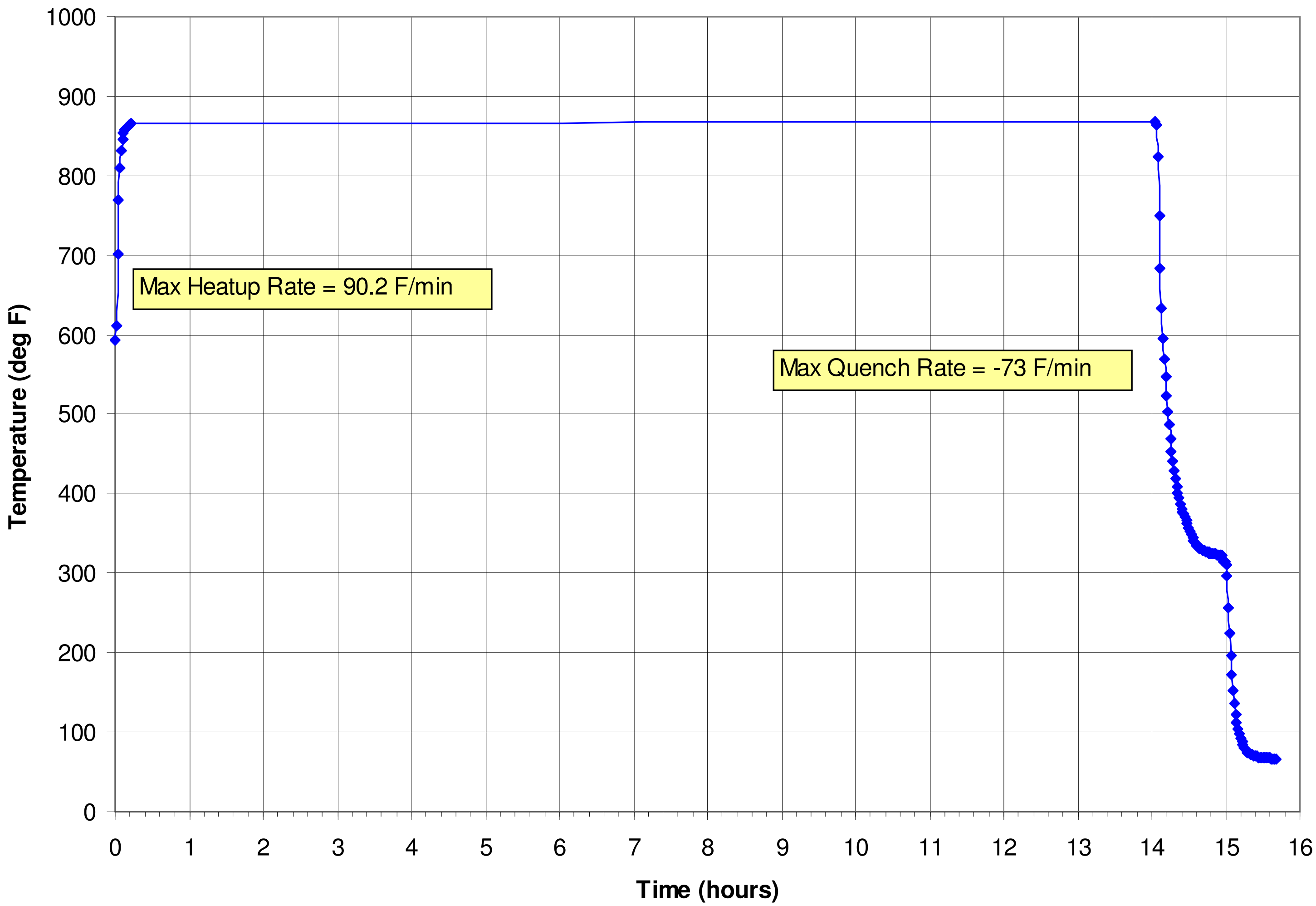
Compare Performance to Conventional In-Line Skirt

Supplied by DeltaValve



Severe Thermal Transient for FEA Model
measured by SES for DeltaValve



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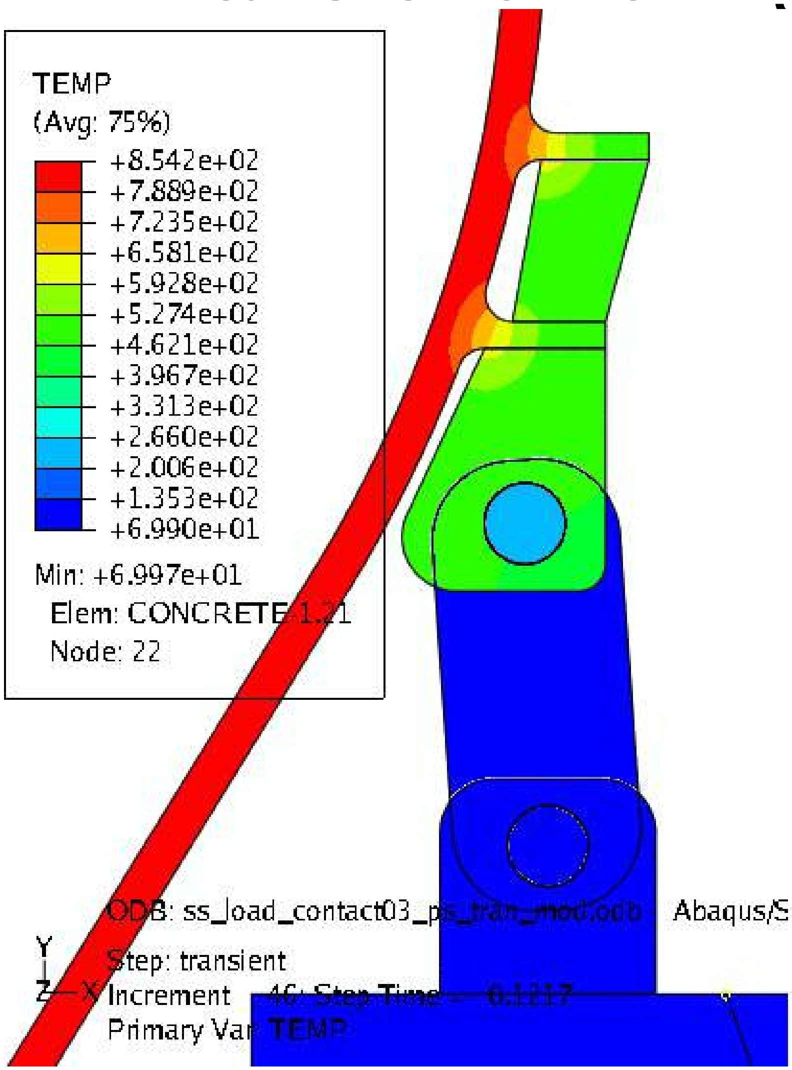
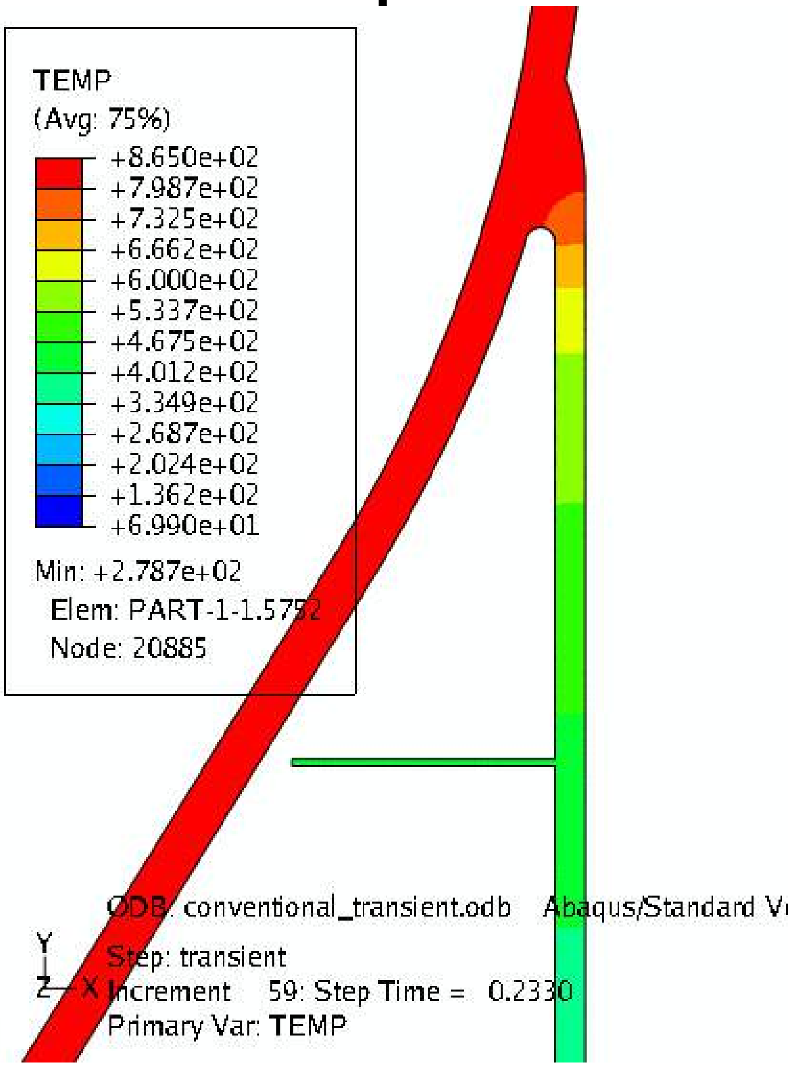
Transient During Fill Temperature





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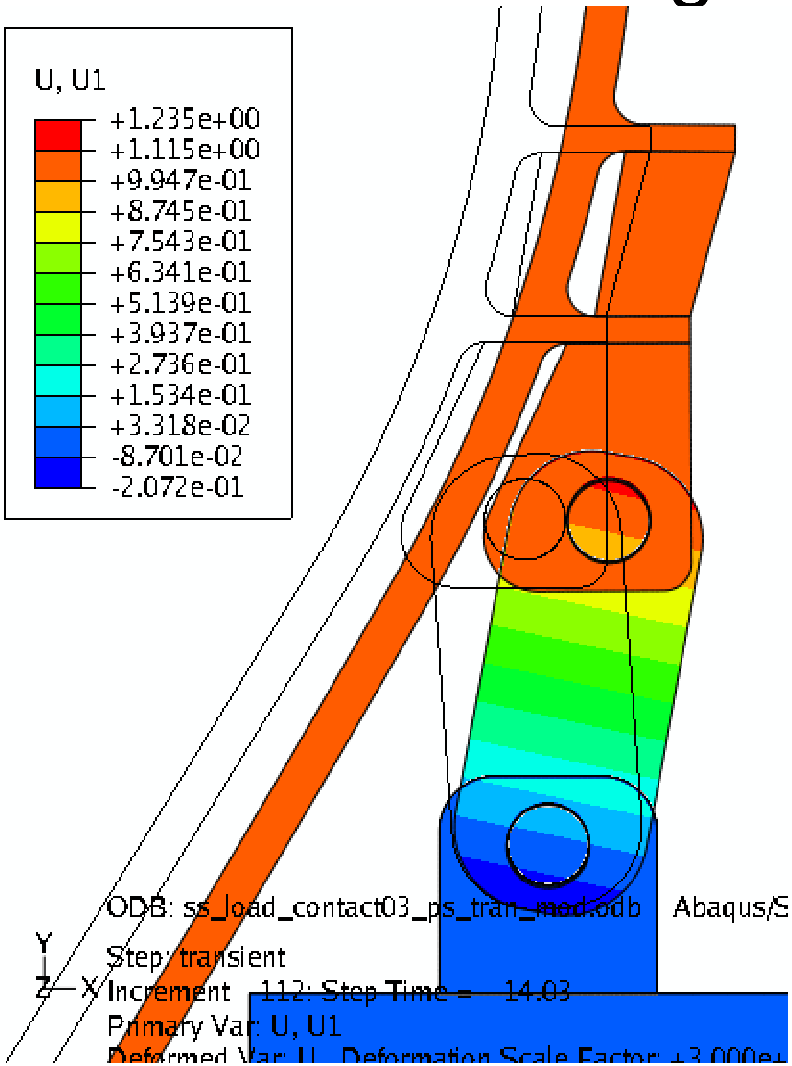
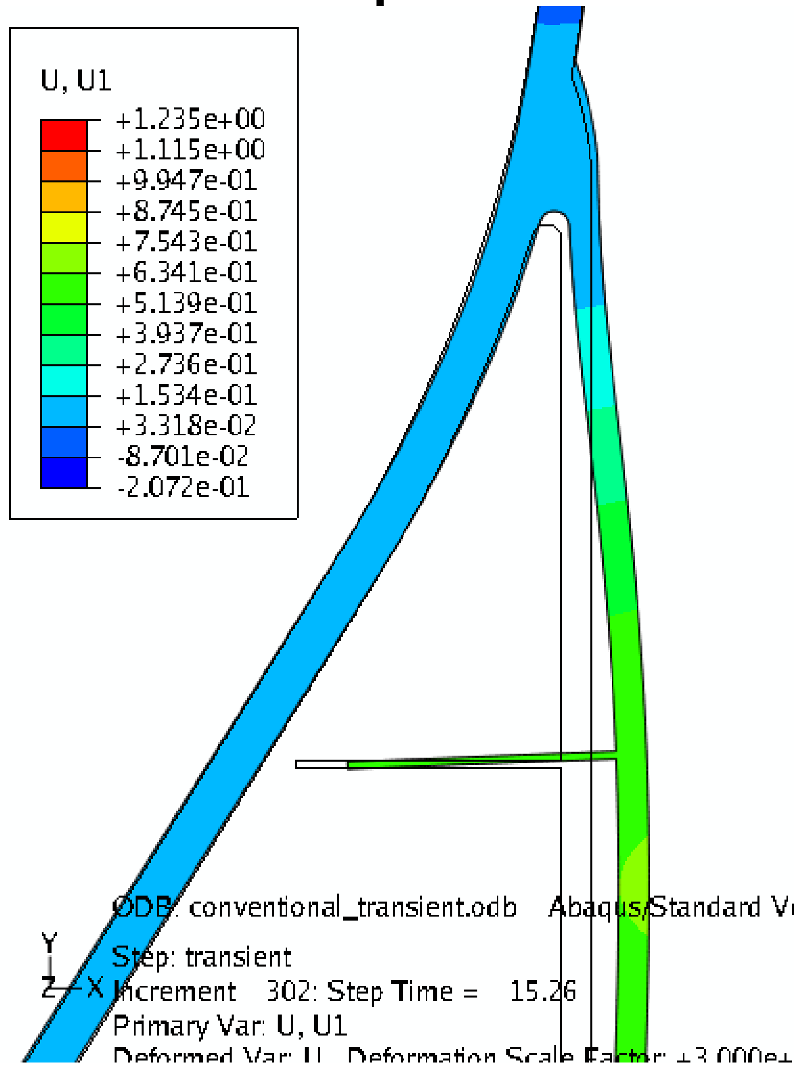
Transient During Quench Displacement





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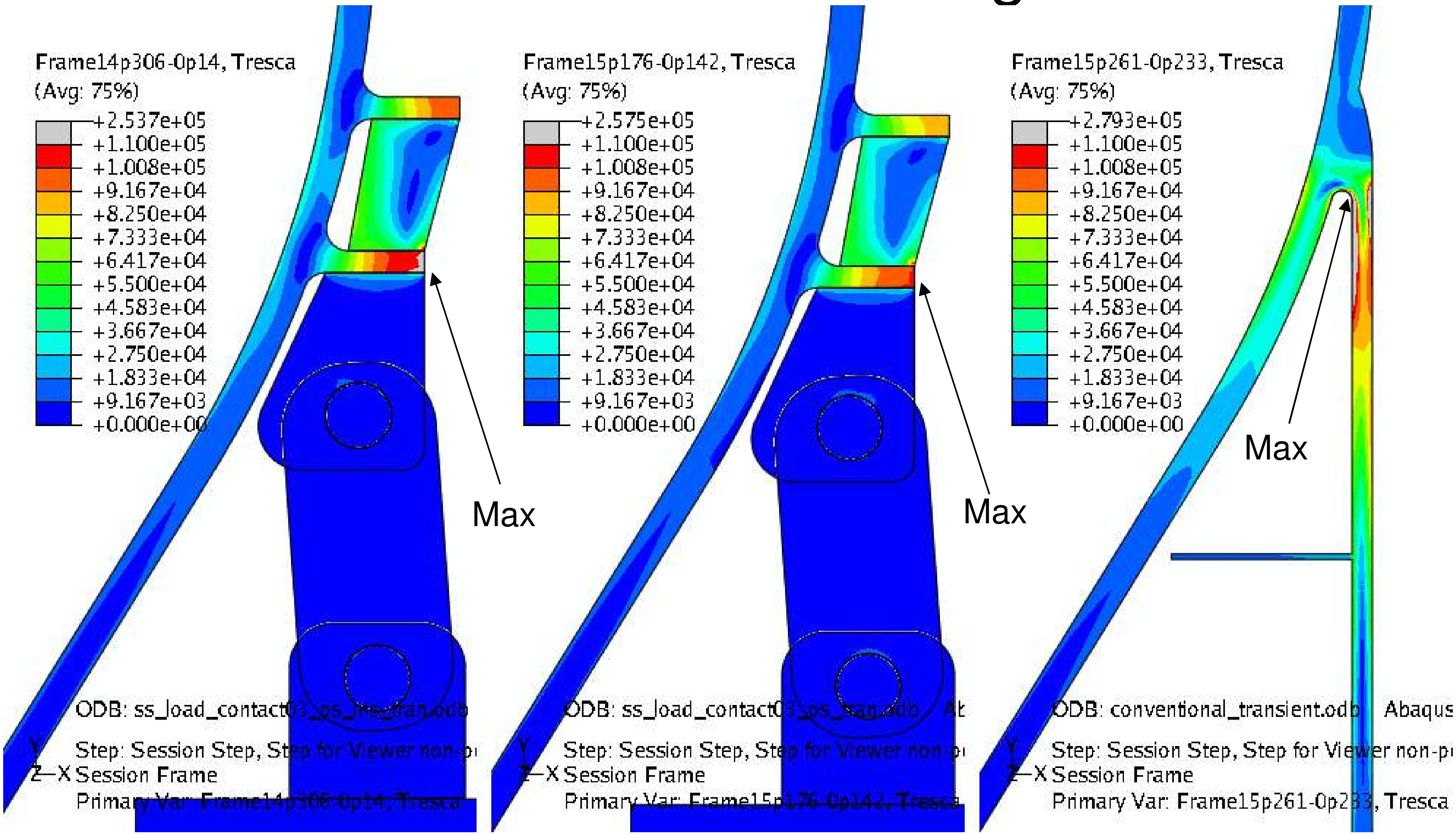
Tresca Stress Range



Insulated Linked Support | Un-insulated Linked Support | Conventional Skirt

Low Cycle Fatigue Calculations

Stress Ranges interpreted for Design Cyclic Life

- **Conventional In-Line Skirt** (1/2” radius) at top of skirt on ID max stress range = 277,856 psi
  - Design Cycle life = **234** cycles
  - Note: a similar design was evaluated for client with measured but less sever Fill thermal rate and similar Quench rate. Total life predicted was 408 cycles

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Low Cycle Fatigue Calculations

Stress Ranges interpreted for Design Cyclic Life

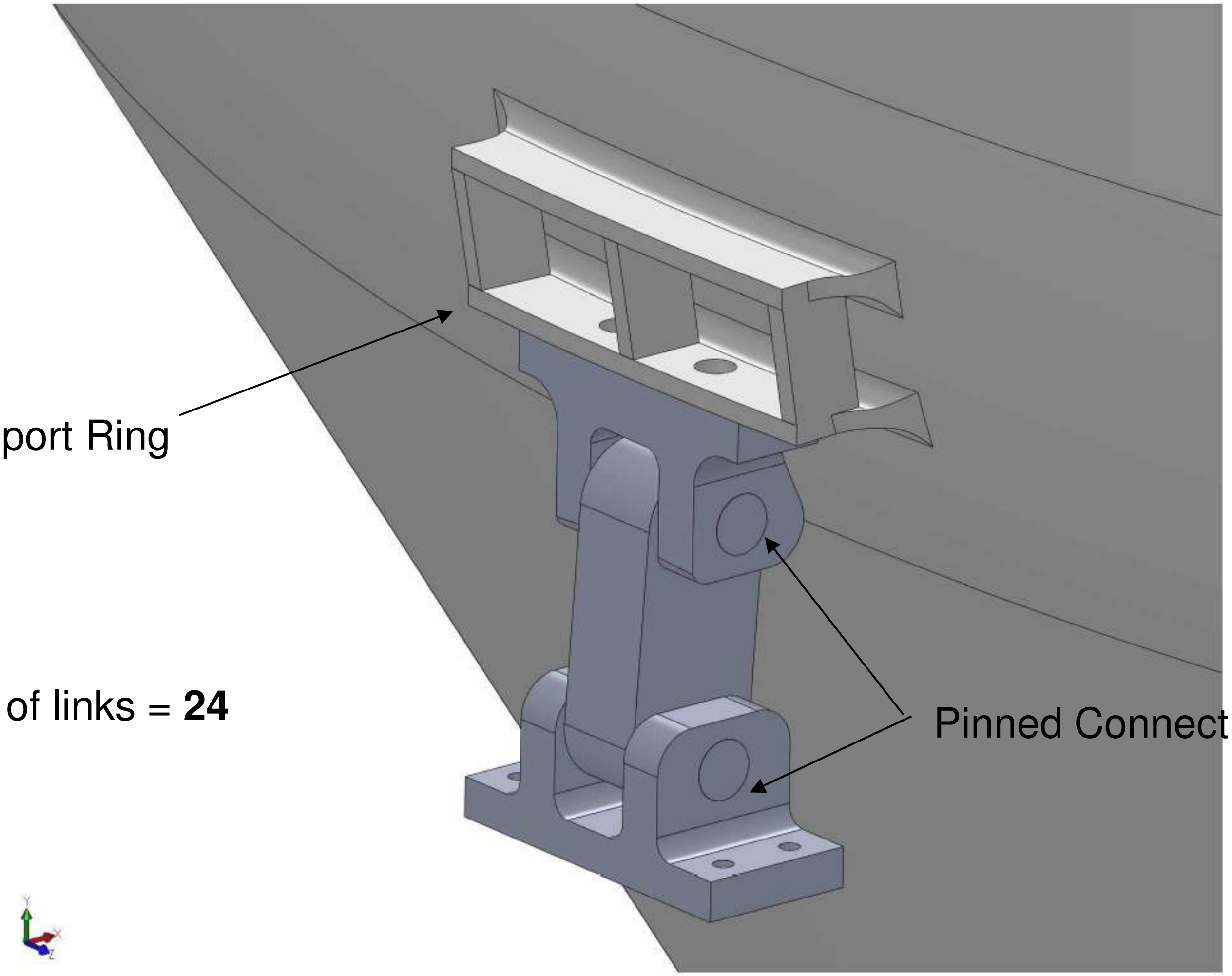
- **Continuous Ring Linked skirt** without insulation at bottom ring

  max stress range = 109,000 psi

  – Design Cycle life = **2,492** cycles

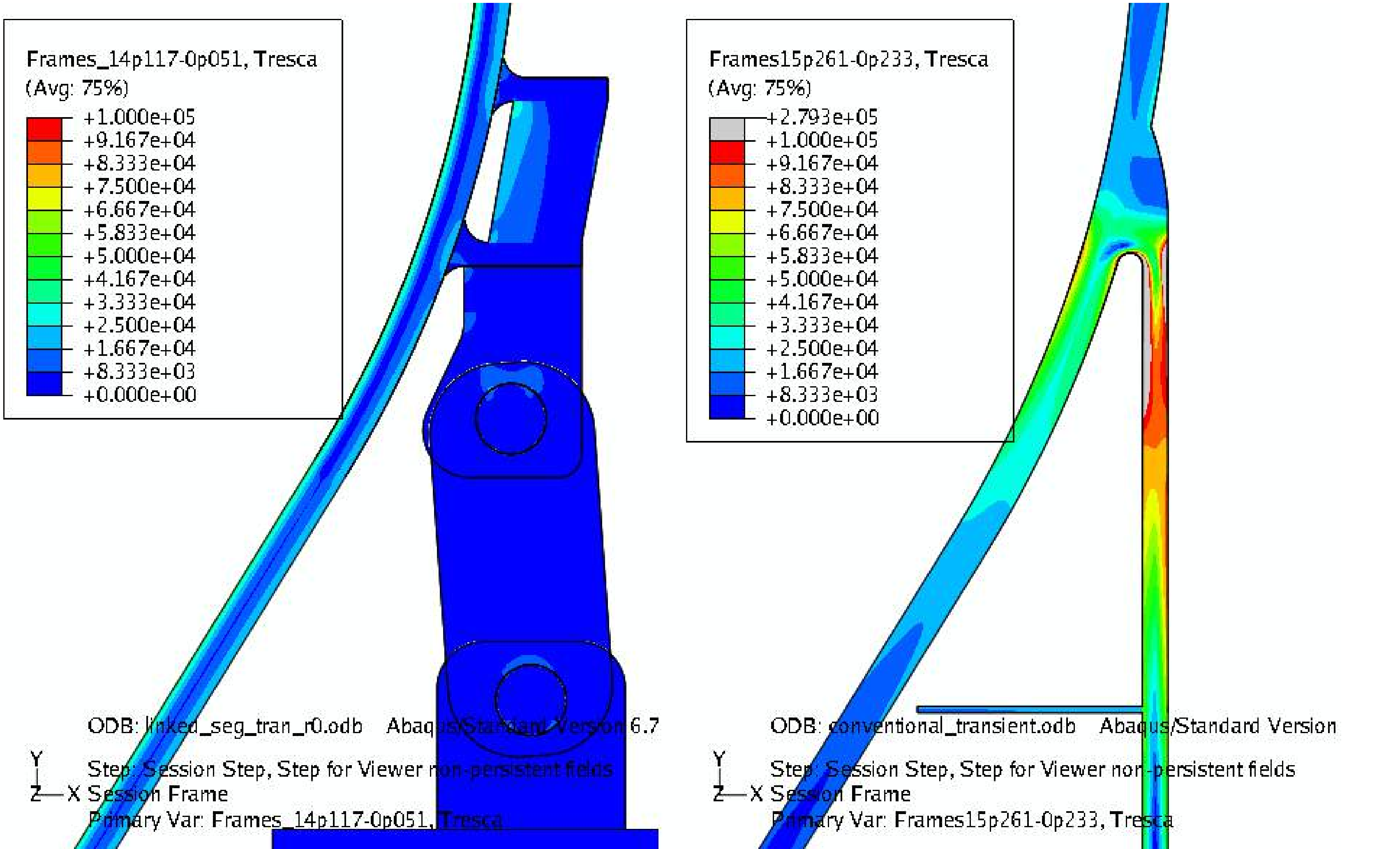
  – Note: limiting stress is thermal hoop stress at outside edge of ring

Segmented Linked Support Concept



Number of links = **24**

Tresca Stress Range (view 1)



Conventional Skirt

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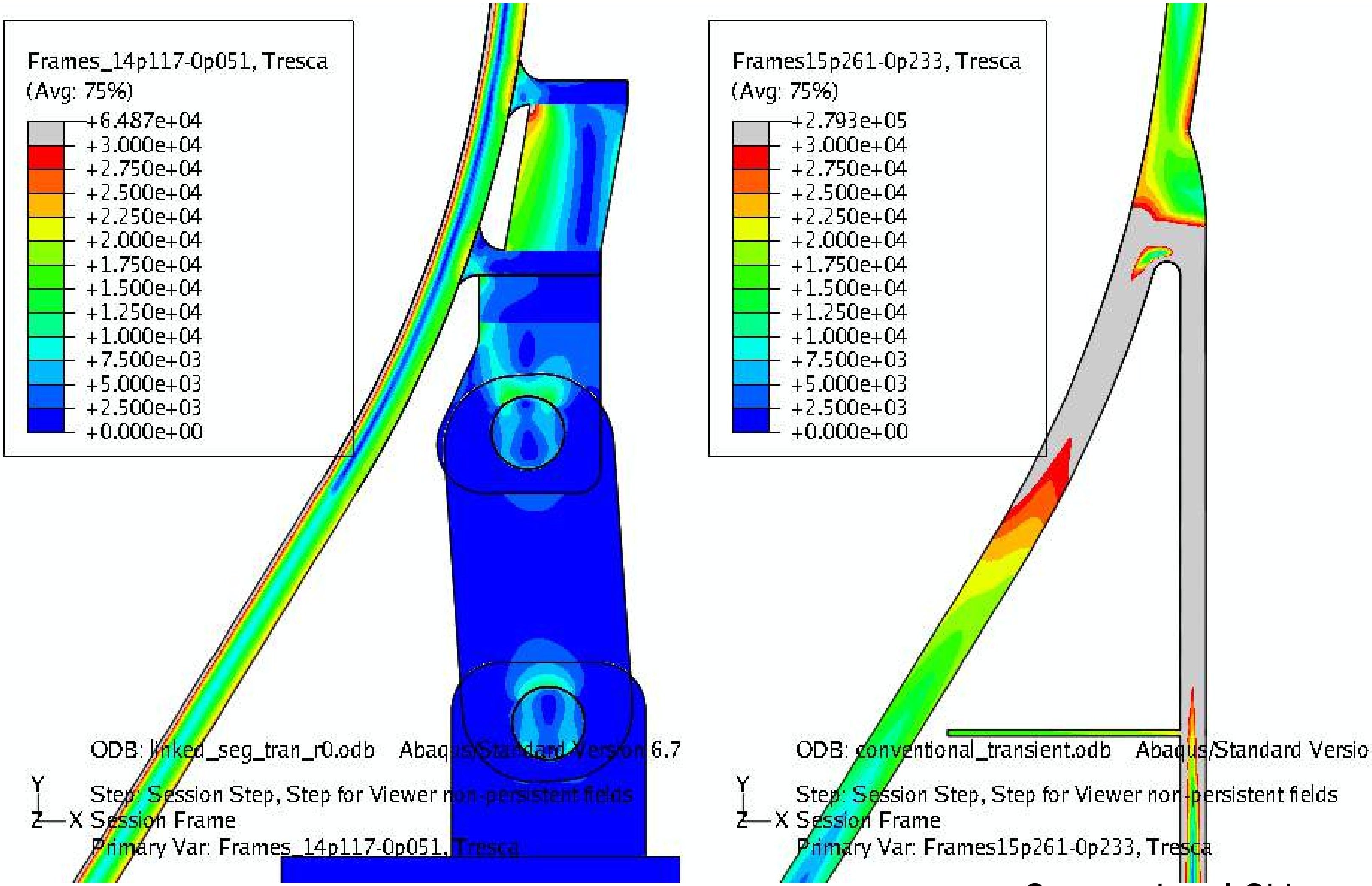
Tresca Stress Range (view 2)



Conventional Skirt

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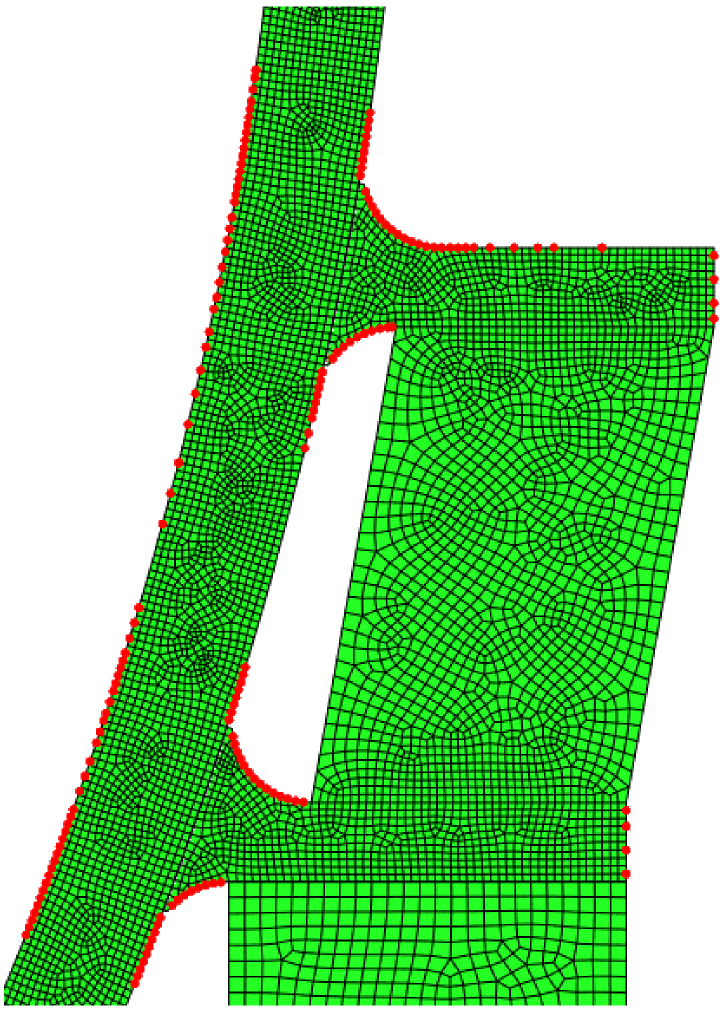
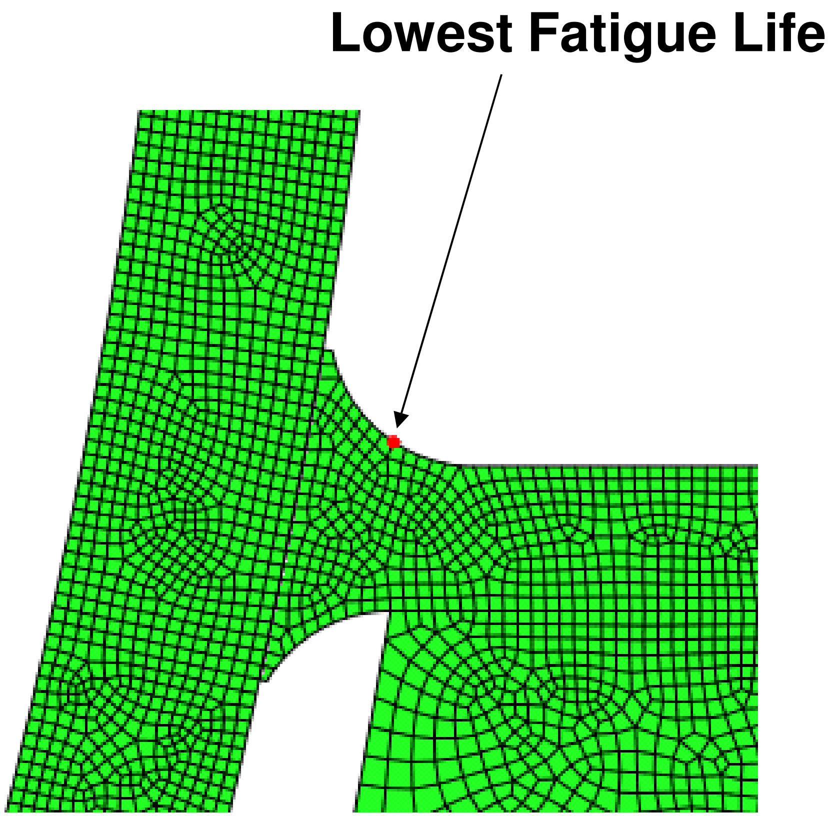
Fatigue Node Locations Selected – Segmented Linked Support





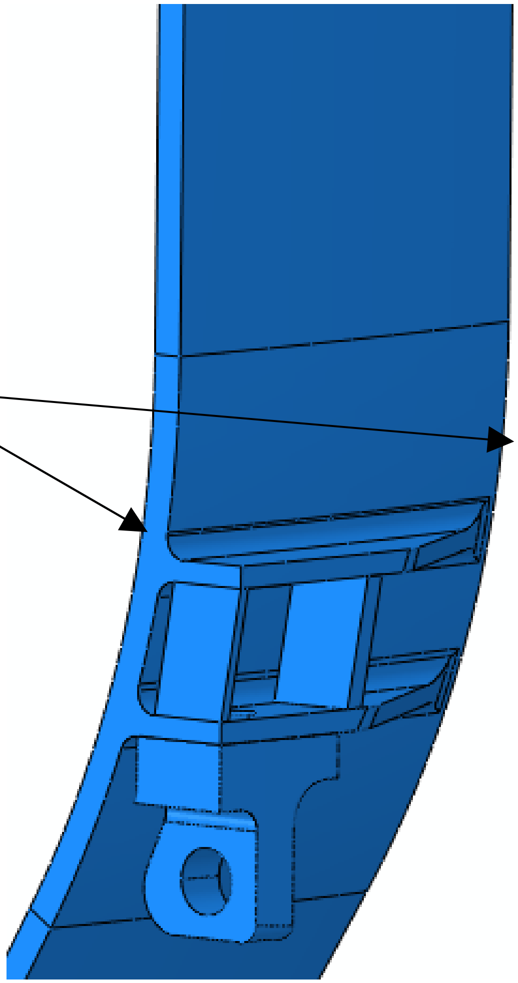
Low Cycle Fatigue Calculations

Stress Ranges interpreted for Design Cyclic Life
Axis-Symmetric Model

- **Segmented Ring Linked skirt** at bottom ring max stress range = 25,500 psi
  - Design Cycle life = ***40,600*** cycles

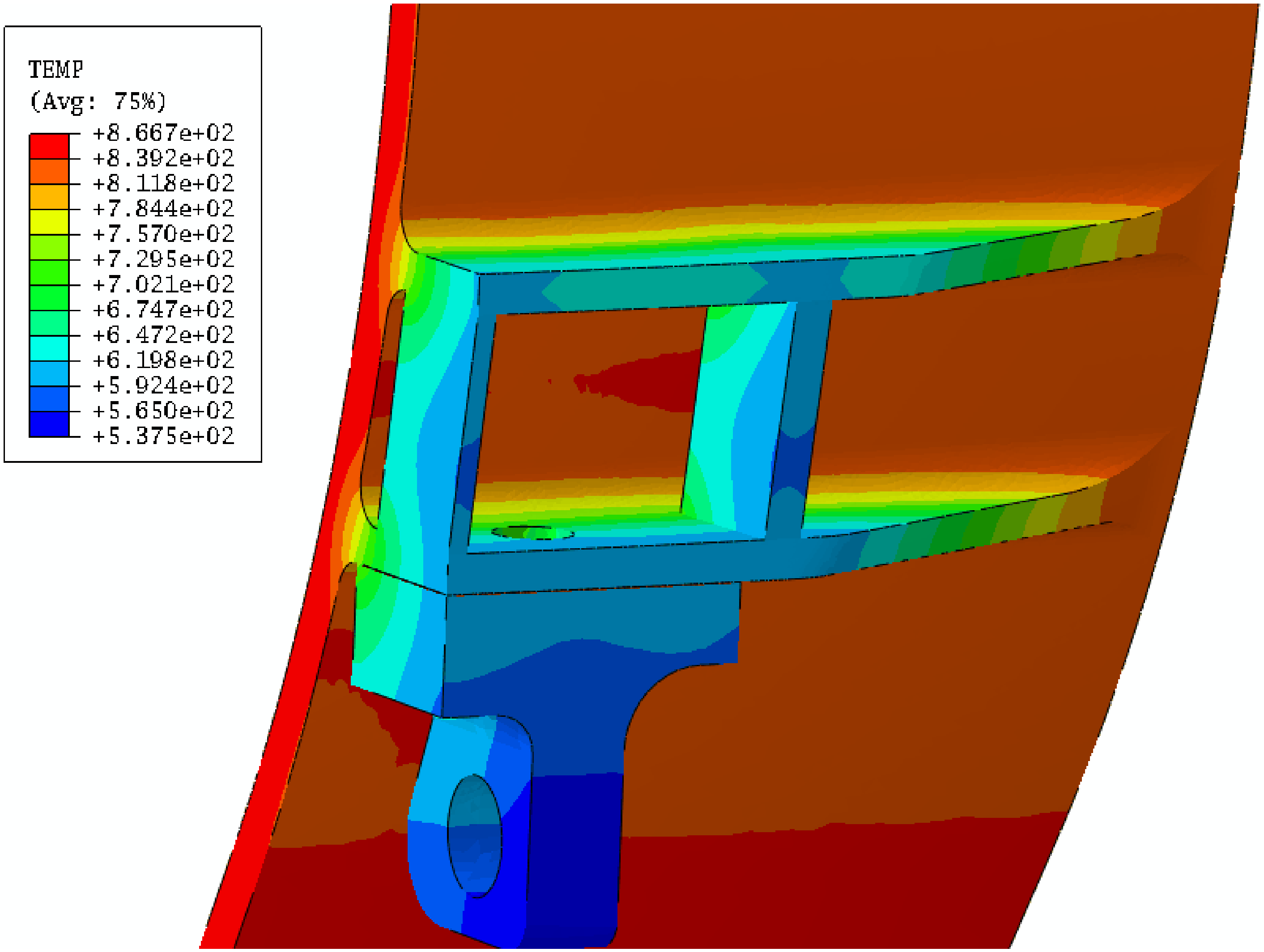
3D Model –
Segmented Linked Support

Symmetry Planes



Symmetry was used to reduce computation time

Coking Cycle – 867℉ – Temperature



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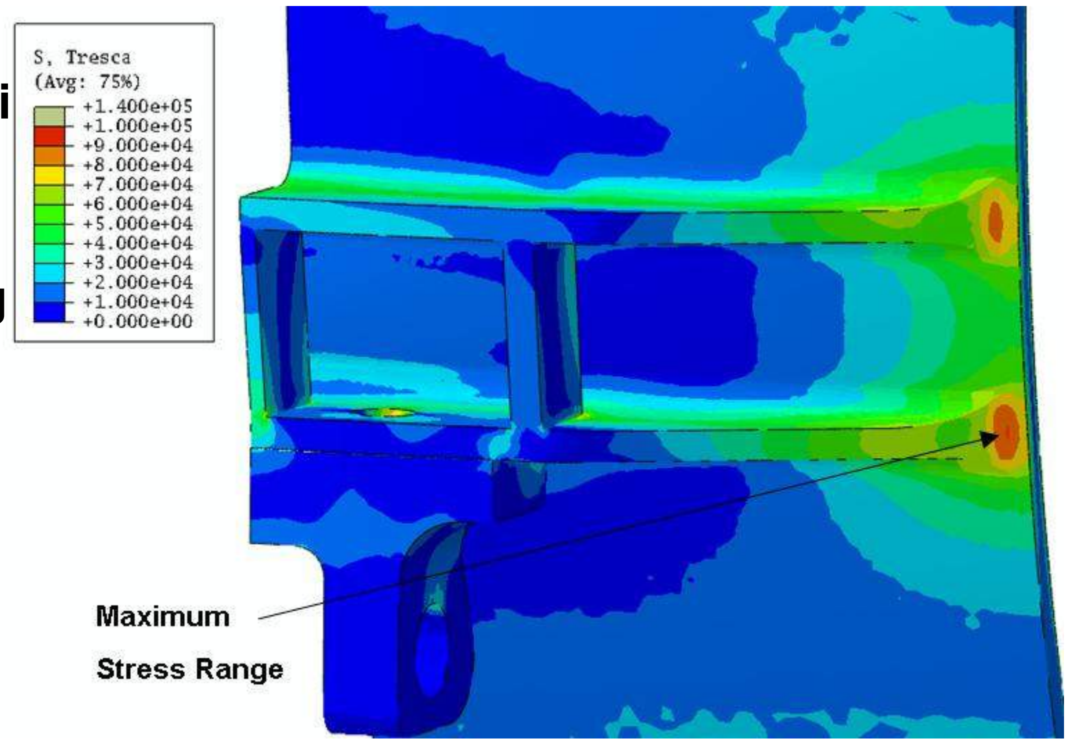
Fatigue Calculations 3D– Segmented Linked Support

- **Tresca Stress range = 90.9 ksi**
- **Alternating Stress Intensity (Salt) = Equivalent Alternating Stress Intensity (Seq) = 45.4 ksi**
- **Allowable Alternating Stress Value (Sa) (E = 27.4 psi at 500°F) = 49.7 ksi**
- **Minimum Fatigue life = 4,453 cycles**



Fatigue Results Summary

- Summary of fatigue results – estimated fatigue life for feasibility study
  - Segmented Linked Support: **4,453** cycles
  - Continuous Linked Support: **2,492** cycles
  - Conventional Skirt: **207** cycles

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Stress Engineering Services

DV Project Team +

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Harbi Portal
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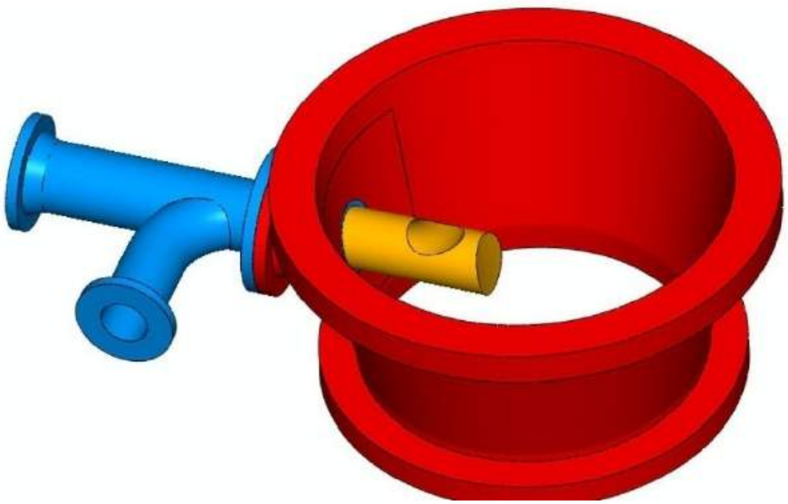
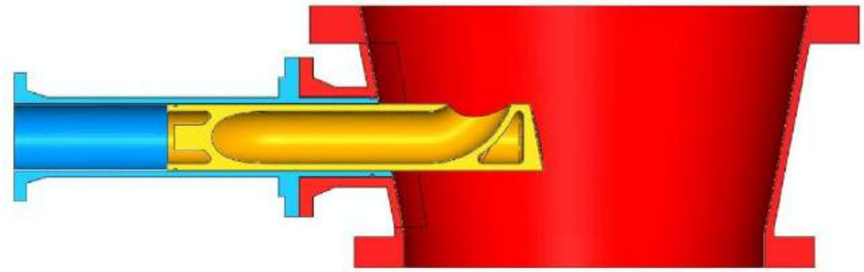
Mac Samman
Julian Bedoya

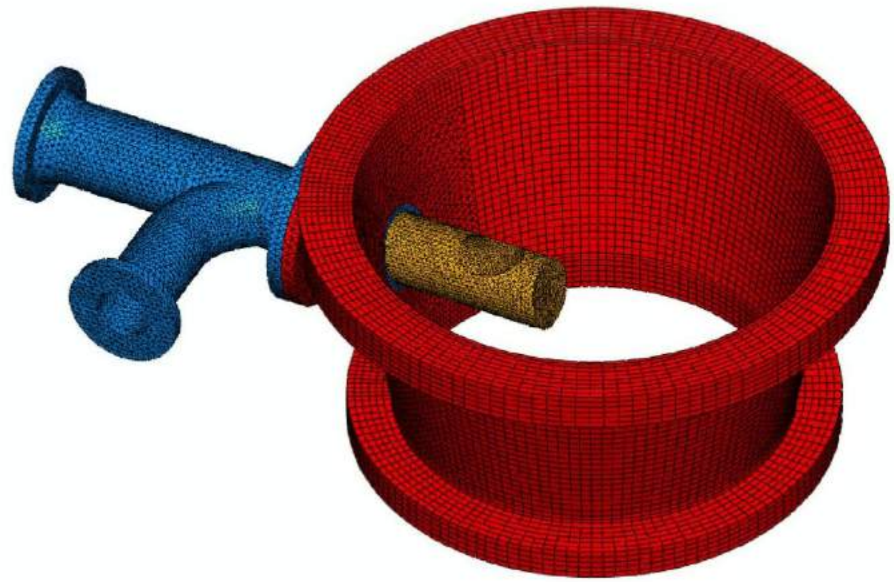
Design Analysis Insert Nozzle

- Apply thermal design transient to insert nozzle
- Evaluate thermal expansions and deformations for seal design
- Evaluate Low Cycle Fatigue Life





Geometry of Original Concept Imported from DV Solid Works Model into ABAQUS FEM



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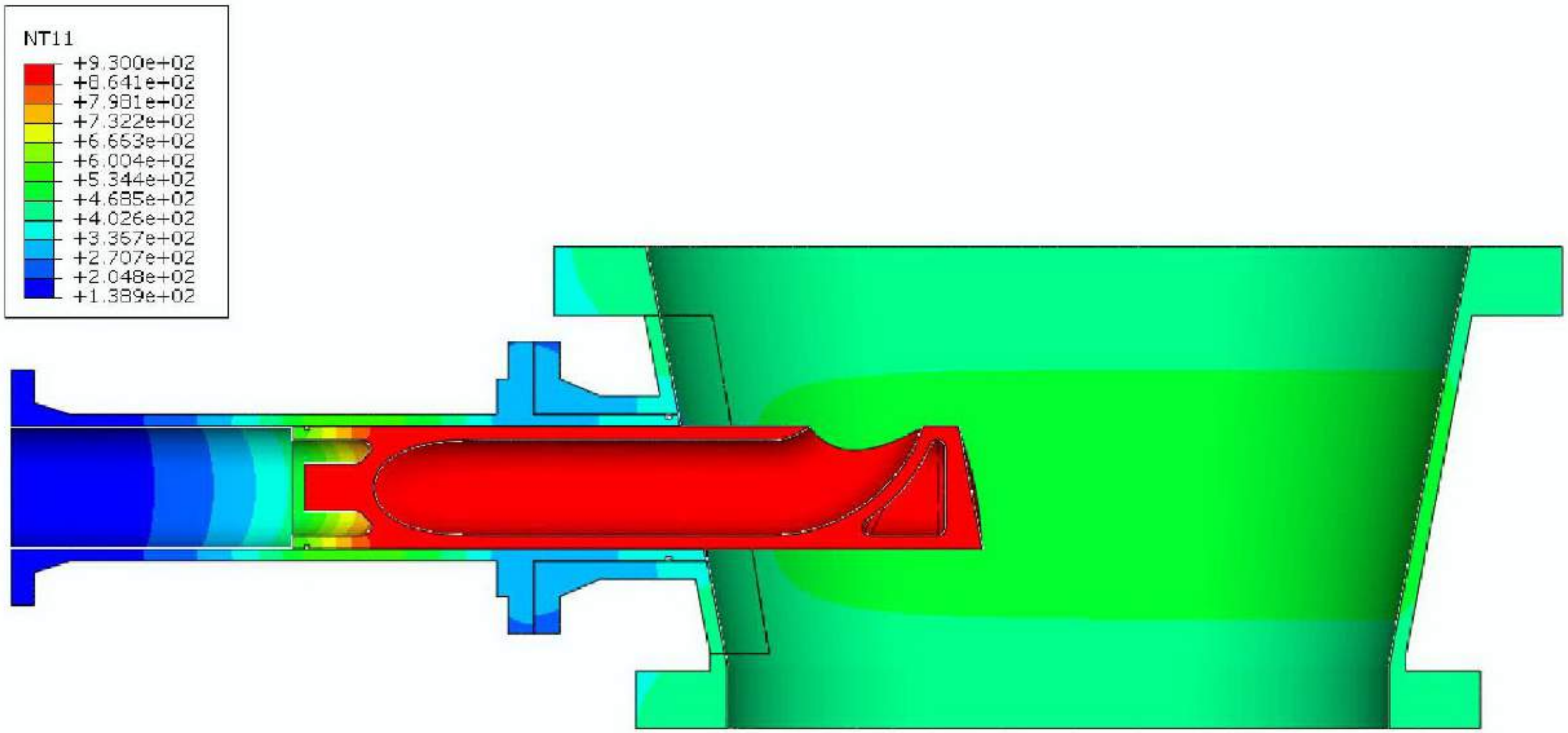
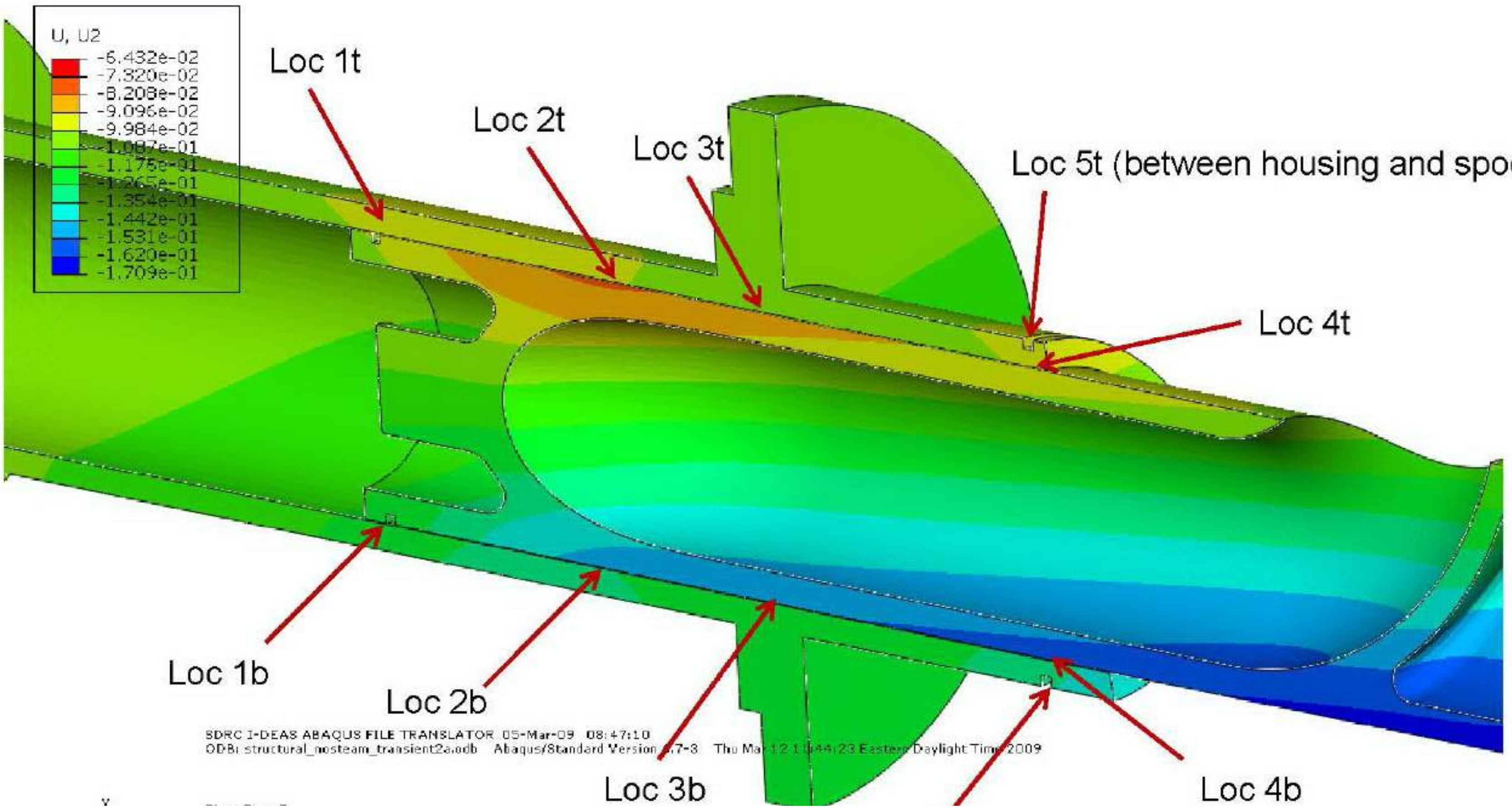
Temperature at End of Fill, Cross Section



Locations to Track Thermal Expansion



Drum Flow Analysis using CFD

- Simulate flow patterns for initial condition into empty drum
- Compare
  - Convention bottom center feed
  - Modern Horizontal Inlet feed
    - Straight Side Entry
    - Elbow Side Entry
  - New Generation Insert Nozzle feed

Analysis Method – Flow Rates

Condition #1 (data gathered from literature)

- The flow rate into the coke drum depends on the process cycle time and refinery throughput. The flow rate through the drum is estimated.

- *Analysis is carried out using an inflow velocity of **17 m/s** (55 ft/sec) in the feed pipe**.***

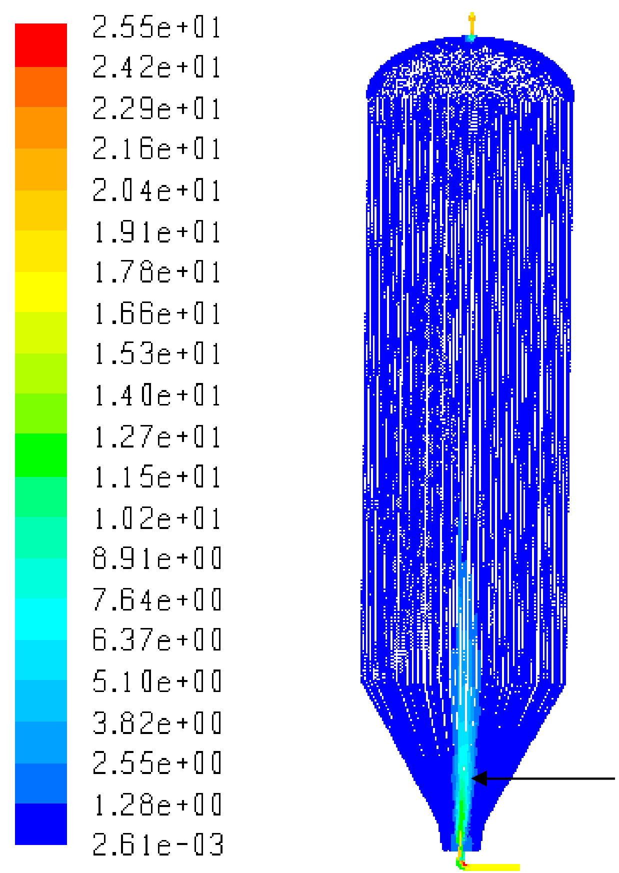
Condition #2 (data gathered from plant simulation by Sim Romero of KBC AT)

- Flow rate into drum 421880 lb/hr (~53. Kg/sec or ~2.24 m3/sec).

- This corresponds to an inflow velocity of **62.4 m/s** in the feed pipe.

Results
Traditional Bottom Center Feed Nozzle

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum



Velocity (m/s) (on Plane 1)

A close examination of the simulations indicate unsteady flow behavior in the coke drum for the simulated conditions. This aspect is investigated by examining the flow distribution at various time instants.

Centered flow is observed when a centrally located traditional nozzle is used

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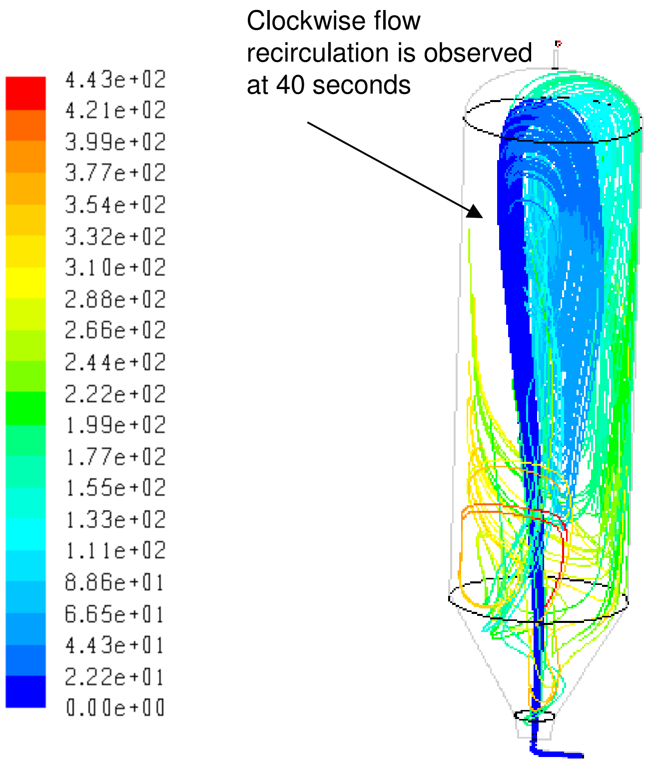
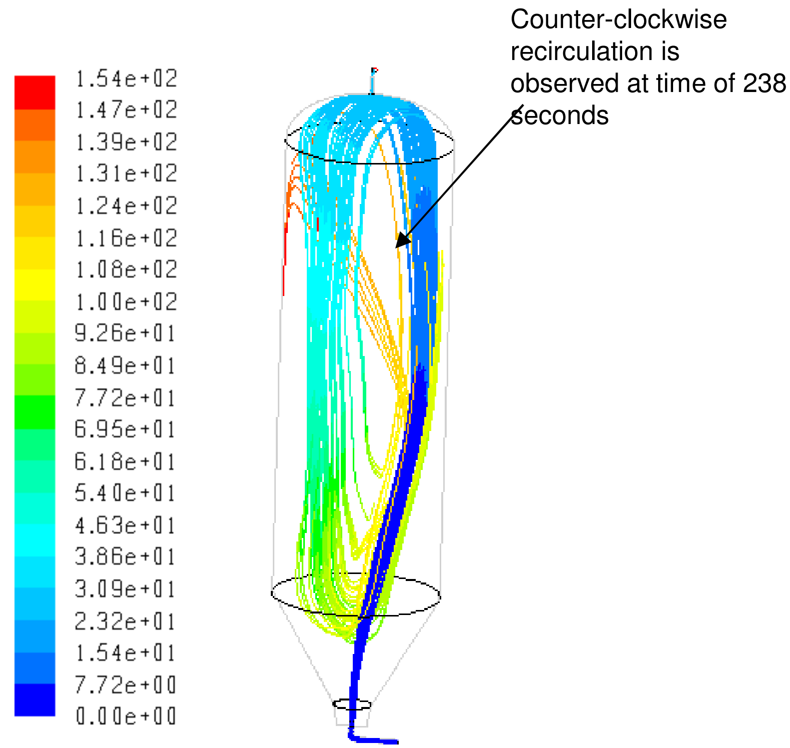
Results – Traditional Bottom Center Feed Nozzle

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum





Flow path lines colored with residence time (seconds)

Flow at the top reverses direction with time.

It must be noted that the main focus of this study is to compare the overall flow behavior associated with the traditional nozzle to that of the new concept nozzle designs. Investigation of unsteady flow behavior investigation is not the primary focus.

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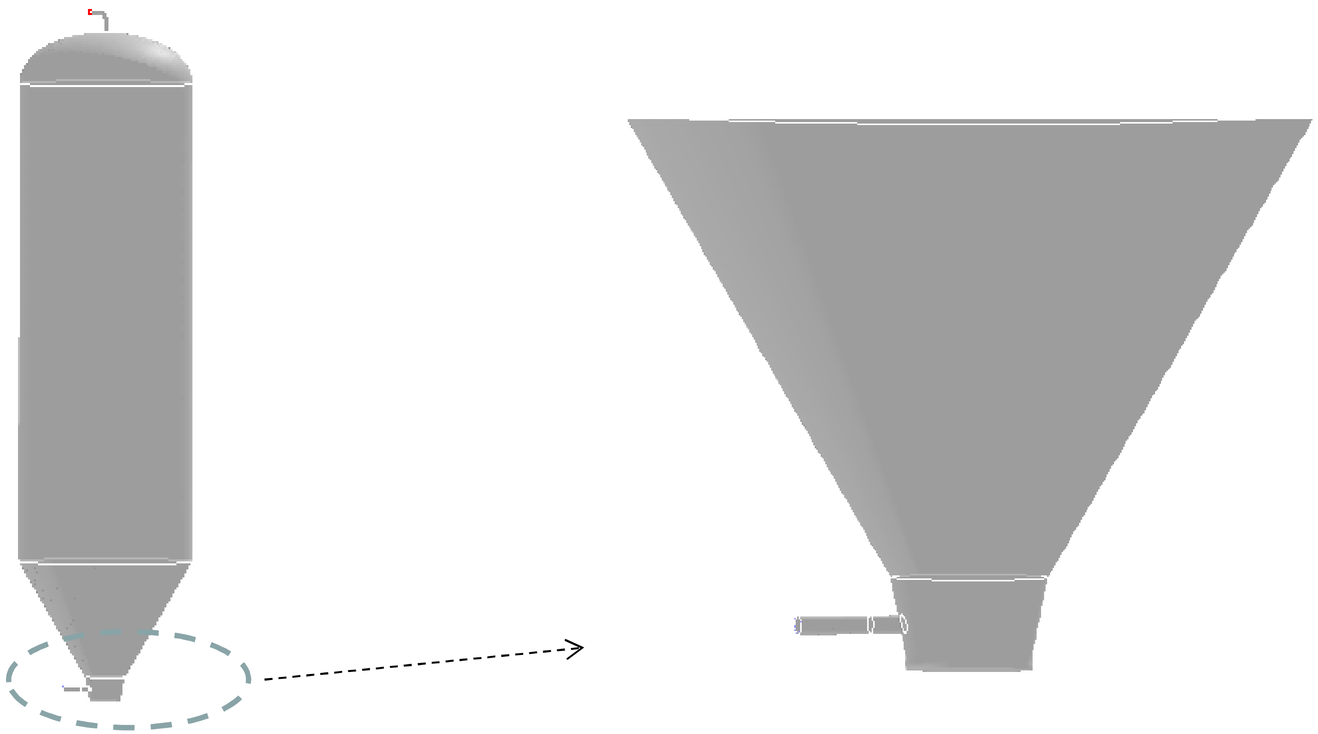
Analysis Method
Flow Geometry (Straight Side-Entry Nozzle)

The nozzle is placed in a representative coke drum.



Close up of straight side-entry inlet feed nozzle and spool region

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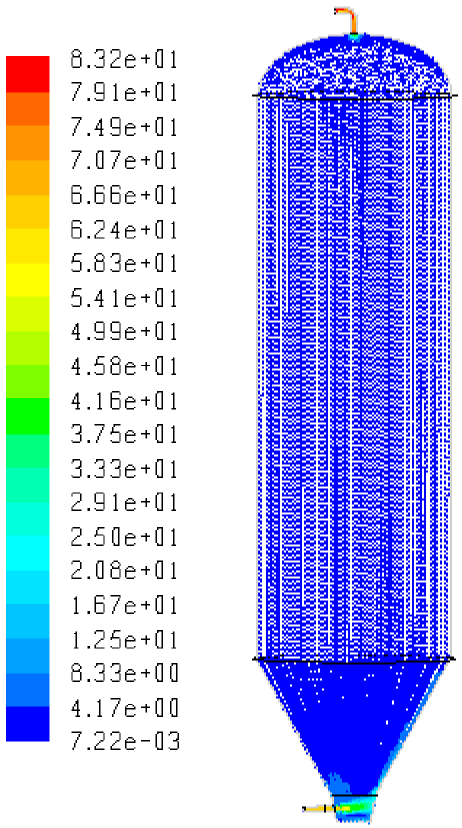
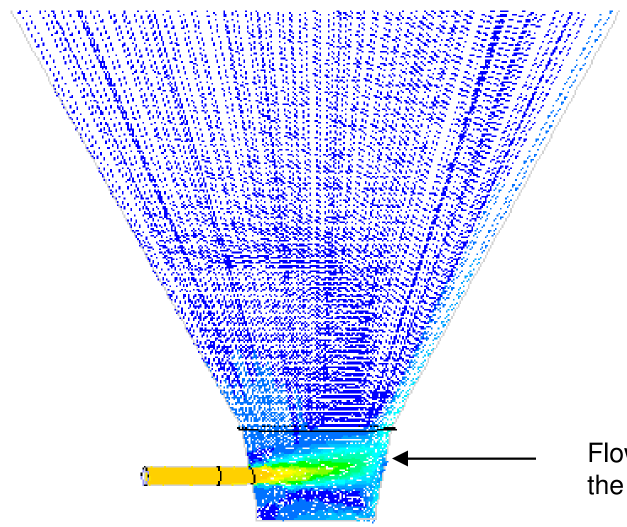
Results – Straight Side-entry Nozzle, Flow Condition #2

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum





Velocity (m/s) (on Plane 1)

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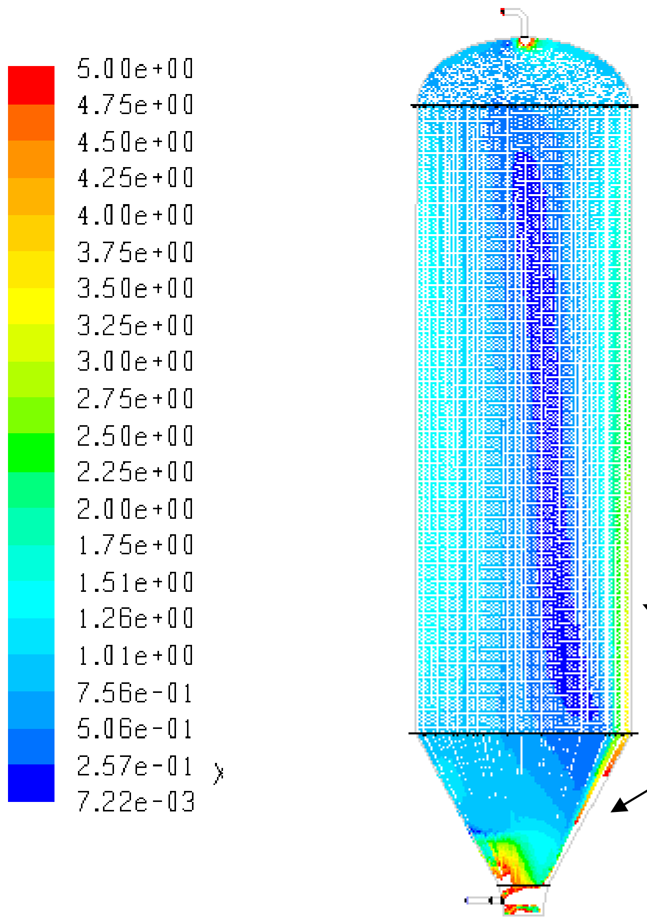
Results – Straight Side-entry Nozzle, Flow Condition #2

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum



Slight unsteadiness is observed in the flow in the upper portion of the drum. This aspect is not explored in detail as the overall flow pattern inside the drum is almost unchanged.

Flow velocity along the wall is 5m/s or higher

Velocity (m/s) (on Plane 1)

Red color denotes velocity of **5 m/s** . The white region next to red denotes velocity higher than **5 m/s**

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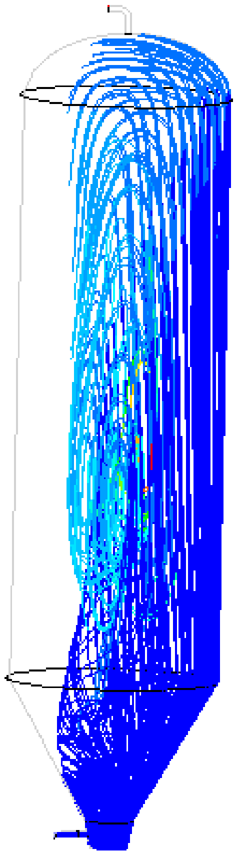
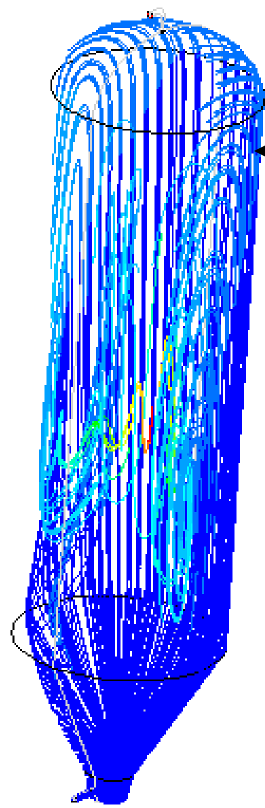
Results – Straight Side-entry Nozzle, Flow Condition #2

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum



Path lines of flow originating at the inlet



Alternate view

Rising flow

The analysis and path lines shows that the flow impinges upon the drum wall. The impingement causes the flow to disperse partially around the circumference of the drum; the flow then rises vertically upwards along the walls of the drum.

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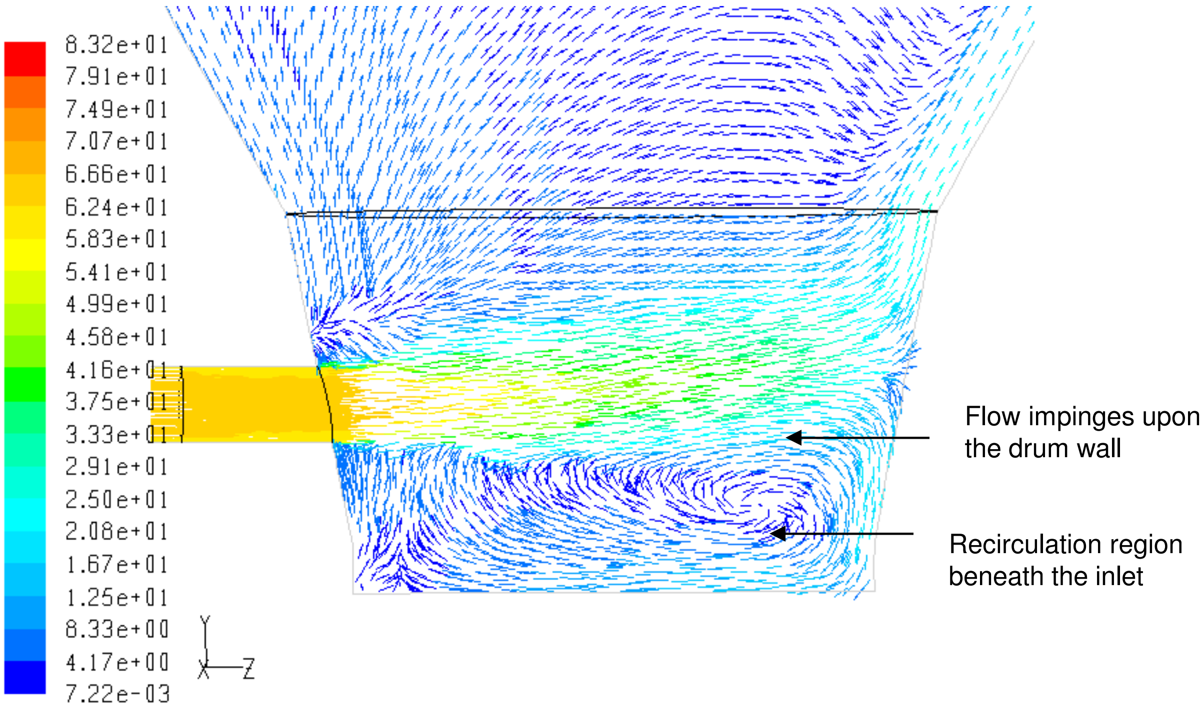
Results – Straight Side-entry Nozzle, Flow Condition #2

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum



Close up view of flow in the inlet region

Velocity (m/s) (on Plane 1)

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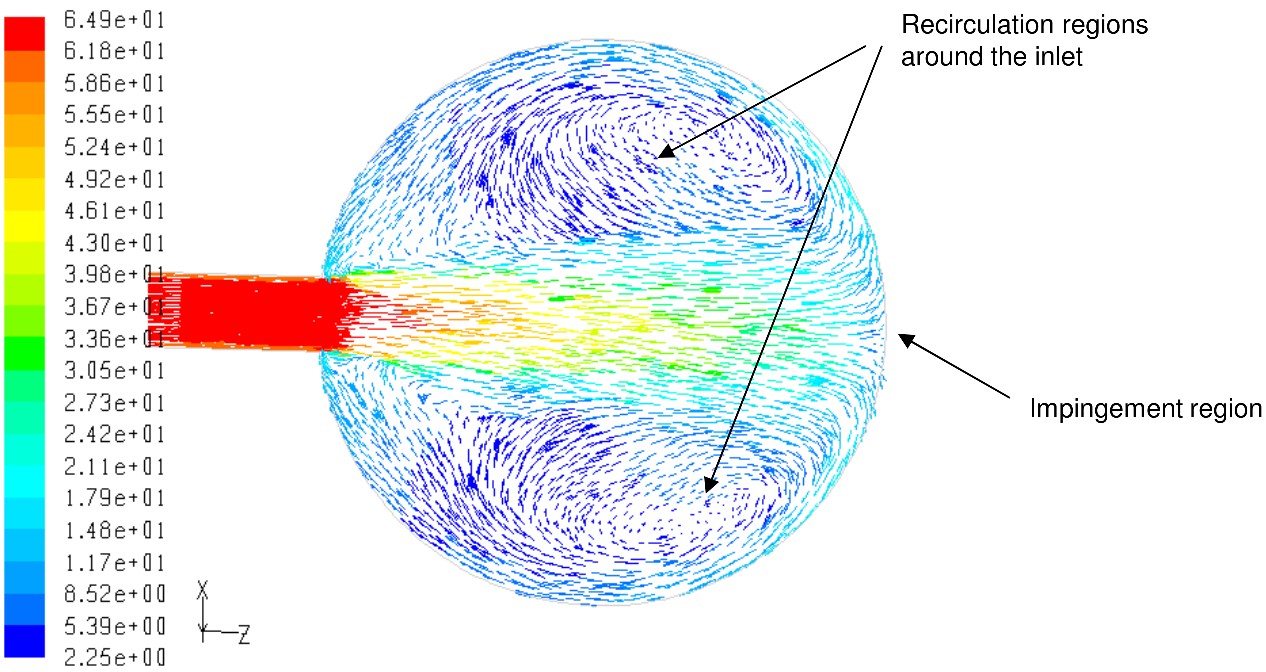
Results – Straight Side-entry Nozzle, Flow Condition #2

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum



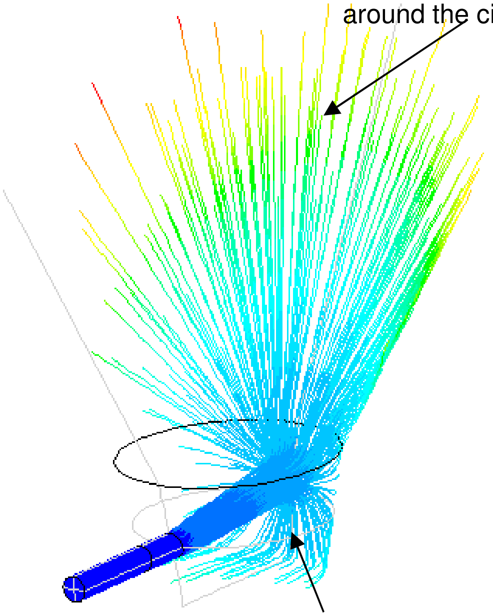
Close up view of flow in the inlet region

Velocity (m/s) (on horizontal plane through the inlet; viewed from above)

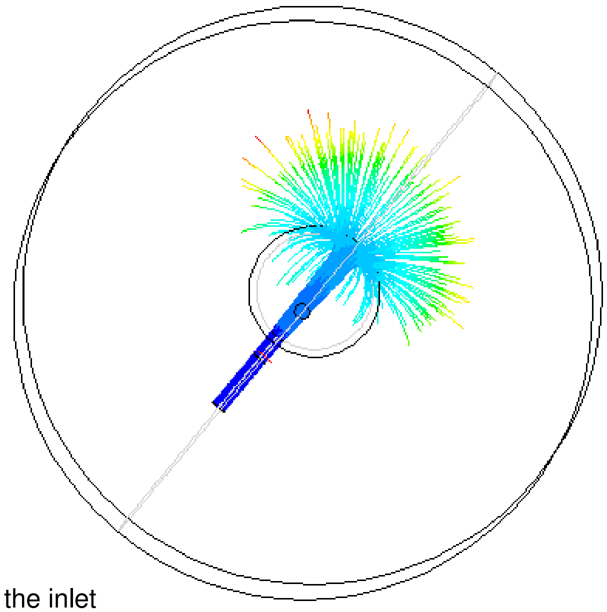
Results – Straight Side-entry Nozzle, Flow Condition #2

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum

Upon impingement flow spreads upwards and around the circumferential direction on the wall



Some flow is also directed beneath the inlet



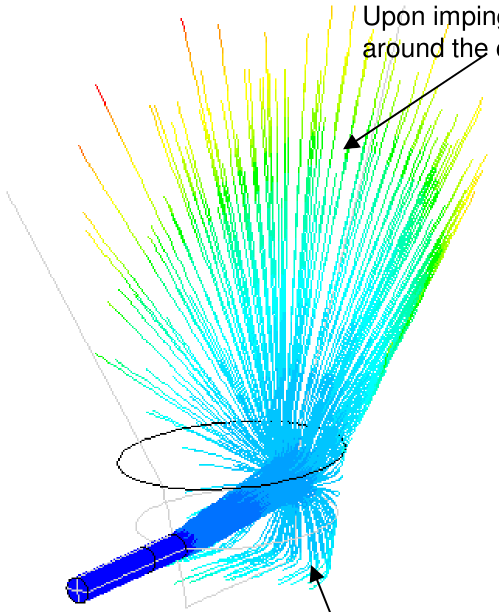
View from above

Path lines of flow originating at the inlet

Results – Straight Side-entry Nozzle, Flow Condition #2

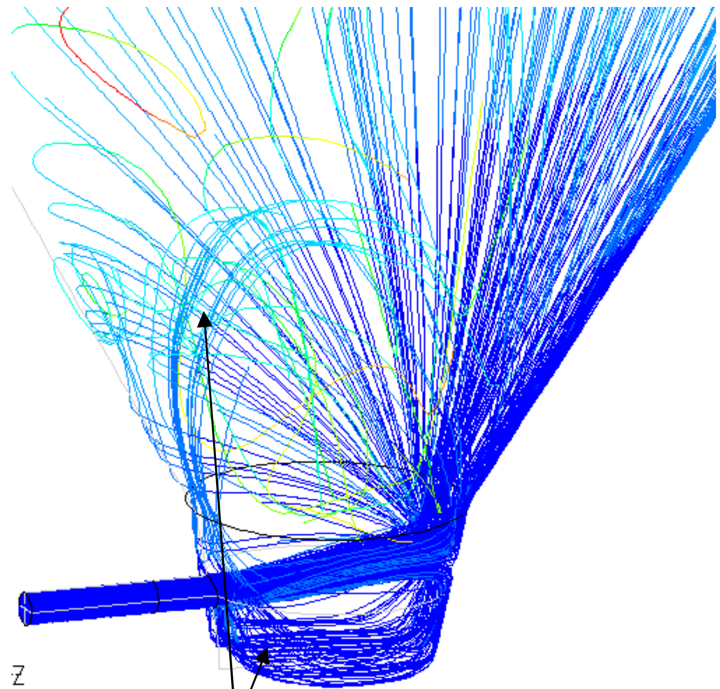
The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum

Upon impingement flow spreads upwards and around the circumferential direction on the wall



Some flow is also directed beneath the inlet

Path lines of flow originating at the inlet



Flow that is directed beneath the inlet rises and loops around to join the upward flow on the wall at the wall of the drum

This looping generates a high three-dimensional and complex flow pattern

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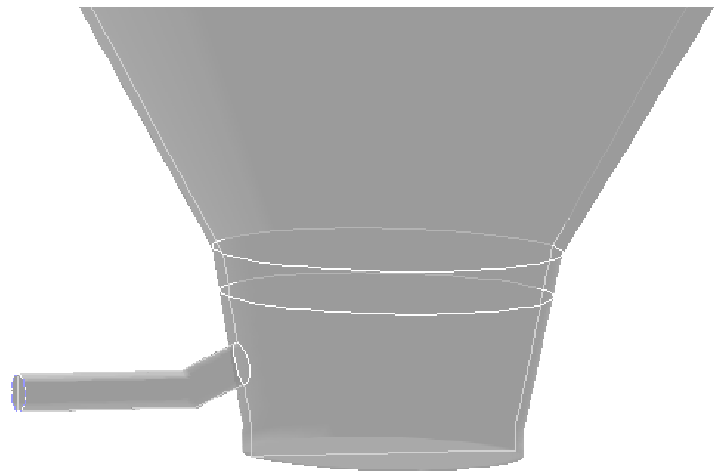
Analysis Method

Flow Geometry (side-entry elbow nozzle)

The elbow style nozzle is placed in a representative coke drum.



Close up of side-entry inlet feed nozzle and spool region

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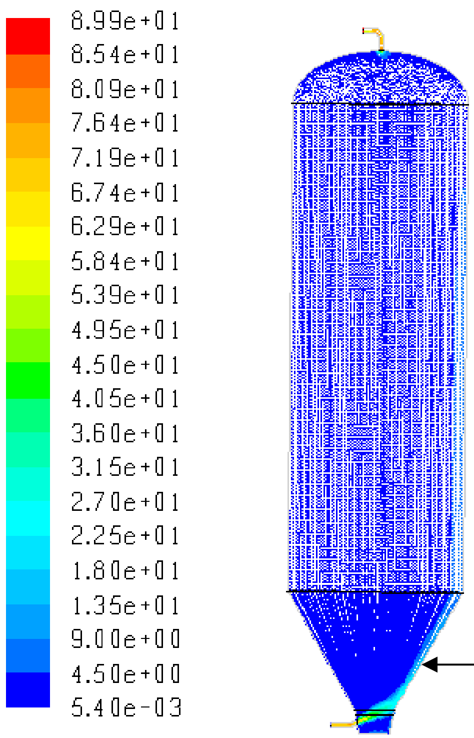
Results – Side-entry Elbow Nozzle, Flow Condition #2

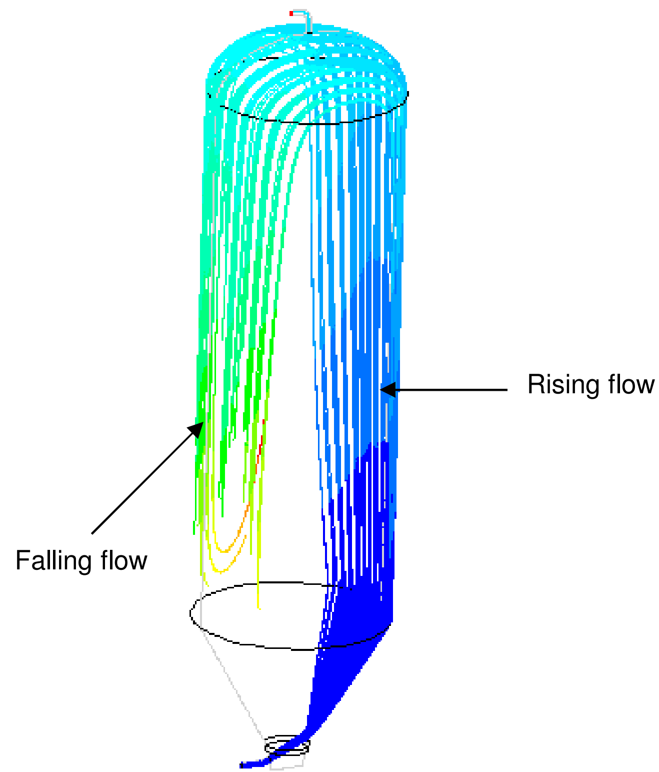
The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum



Flow is impinges upon the drum wall

Velocity (m/s) (on Plane 1)

A close examination of the simulations indicate unsteady flow behavior in the coke drum for the simulated conditions. This aspect is investigated by examining the flow distribution at various time instants.



Path lines depicting the rising and falling flow inside the drum

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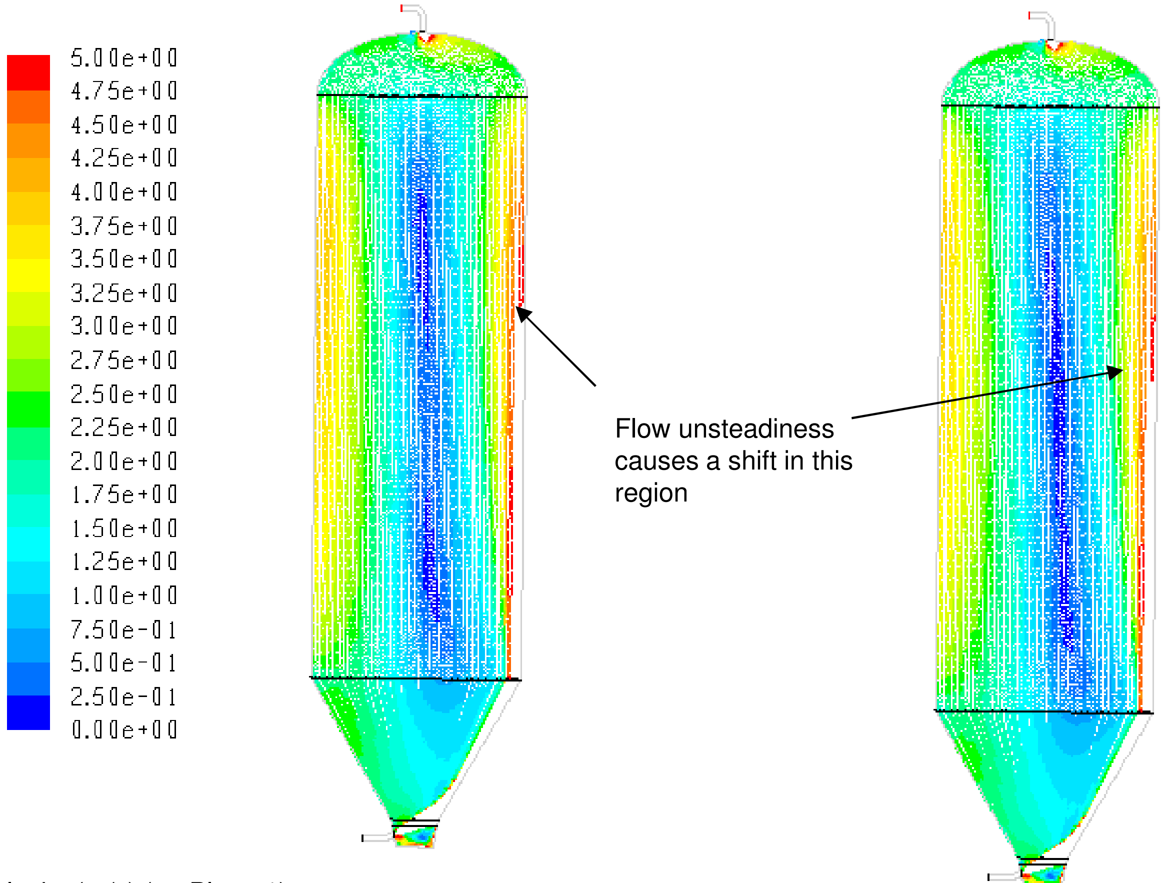
Results – Side-entry Elbow Nozzle, Flow Condition #2

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum



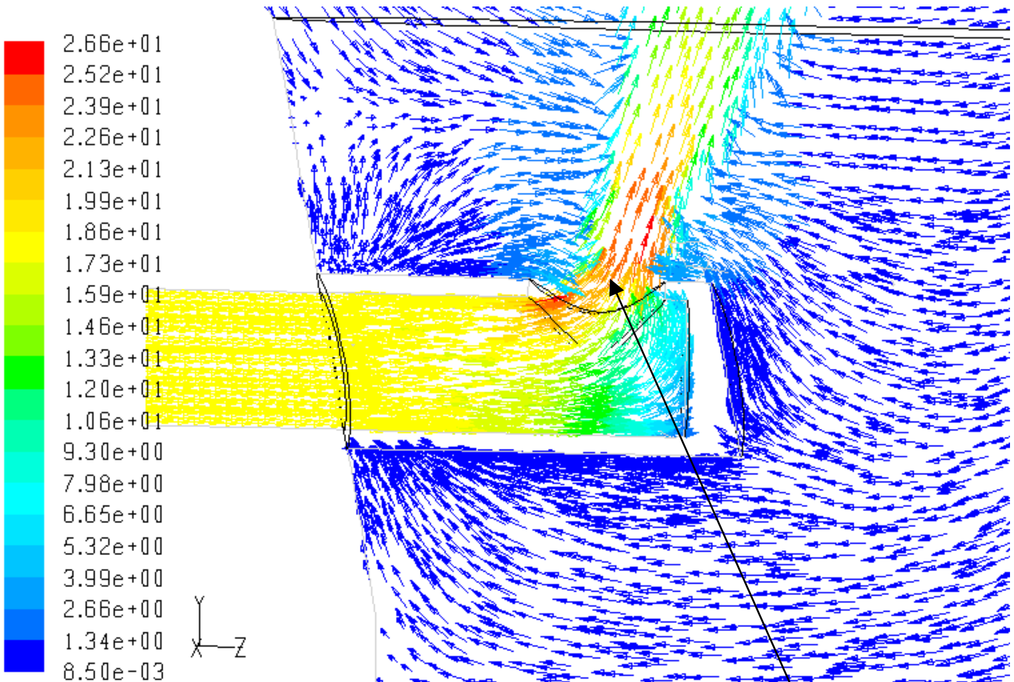
Velocity (m/s) (on Plane 1)

*Note: red color denotes speed of **5 m/s** and the white color adjacent to red denotes regions that are higher than **5 m/s***

Flow unsteadiness in the upper region of the drum is observed.

Results – New Concept Nozzle (Design modification 1)

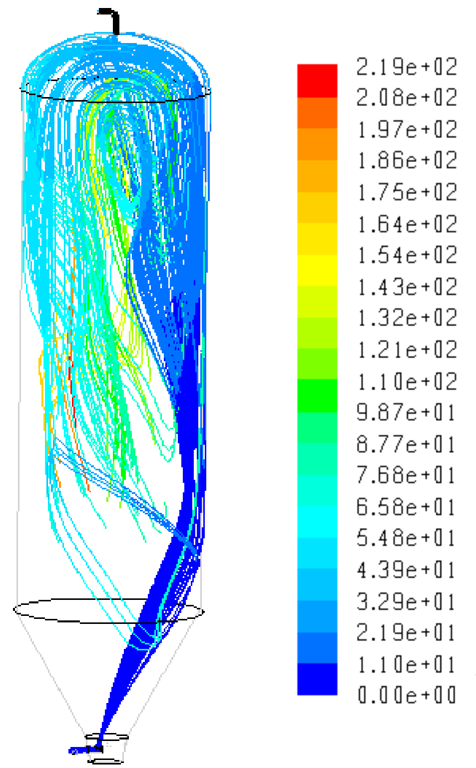
The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum



Velocity (m/s)

Flow leaves the nozzle at an angle

Close up of flow at the nozzle



Flow path lines colored with residence time (seconds)

Unsteady flow behavior at the top of the drum is observed.
However, the unsteadiness is quite weak and is not explored in any detail

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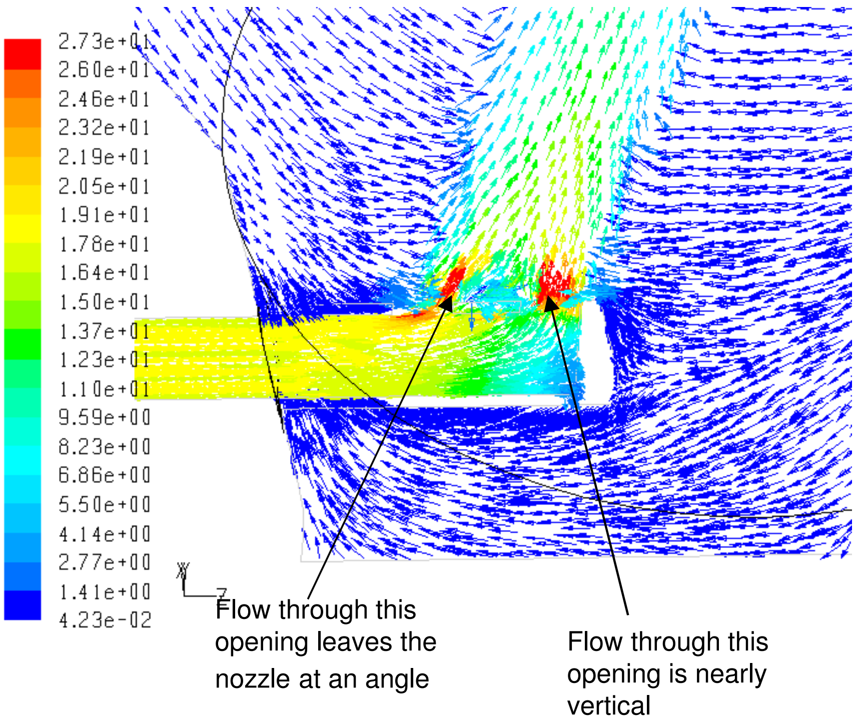
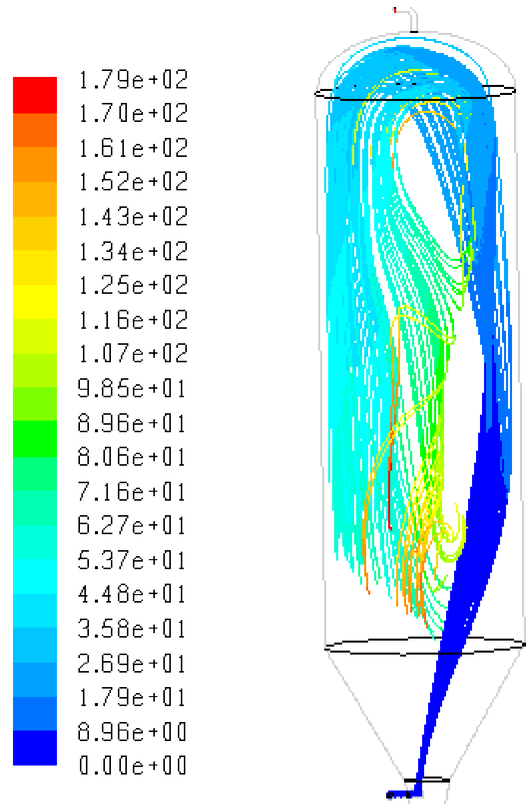
Results – New Concept Nozzle (Design modification 2)

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum



Close up of flow at the nozzle



Flow path lines colored with residence time (seconds)

Unsteady flow behavior at the top of the drum is observed.
However, the unsteadiness is quite weak and is not explored in any detail

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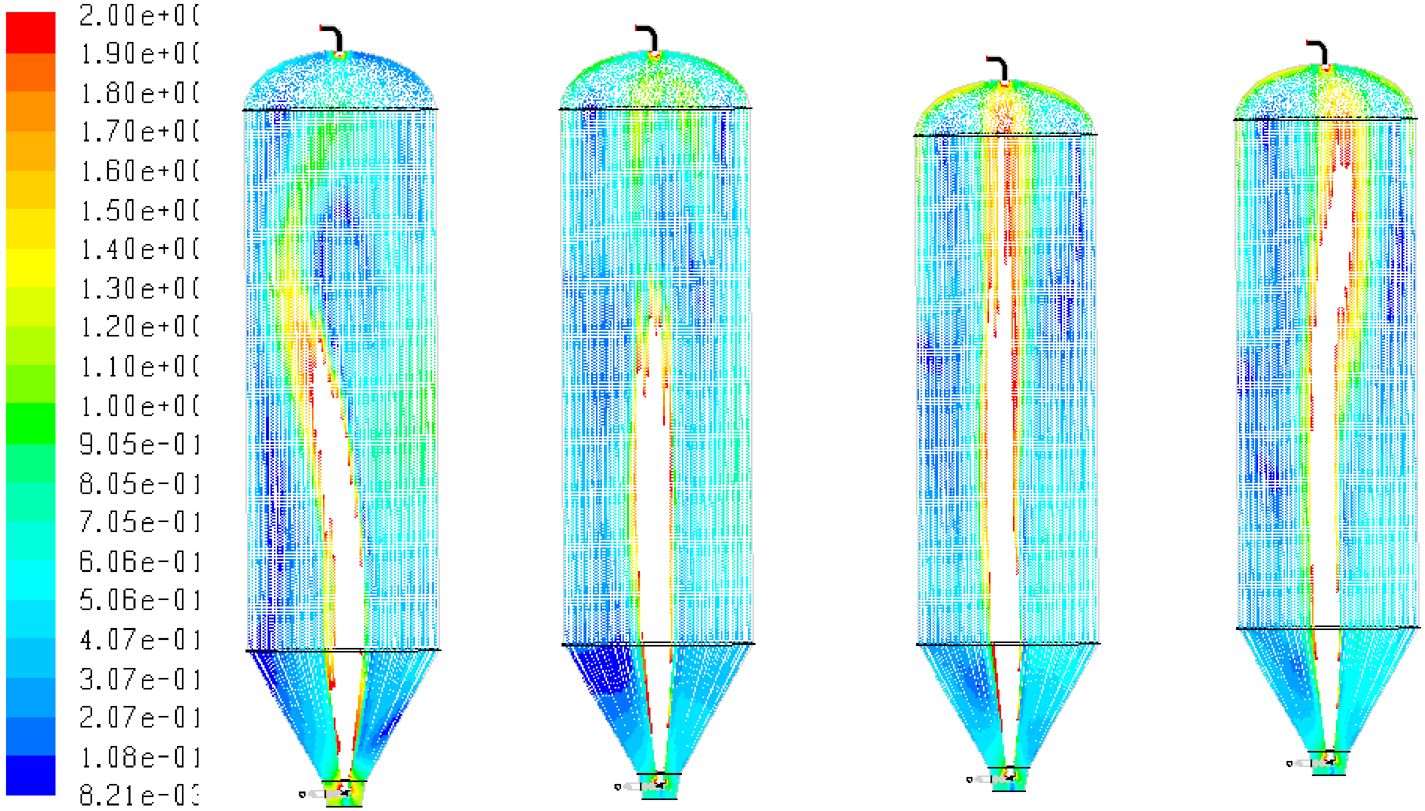
Results – Centered Insert Nozzle (Flow Condition #1)

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum

Unsteady flow inside the drum is observed (similar to the traditional nozzle)



Velocity (m/s)

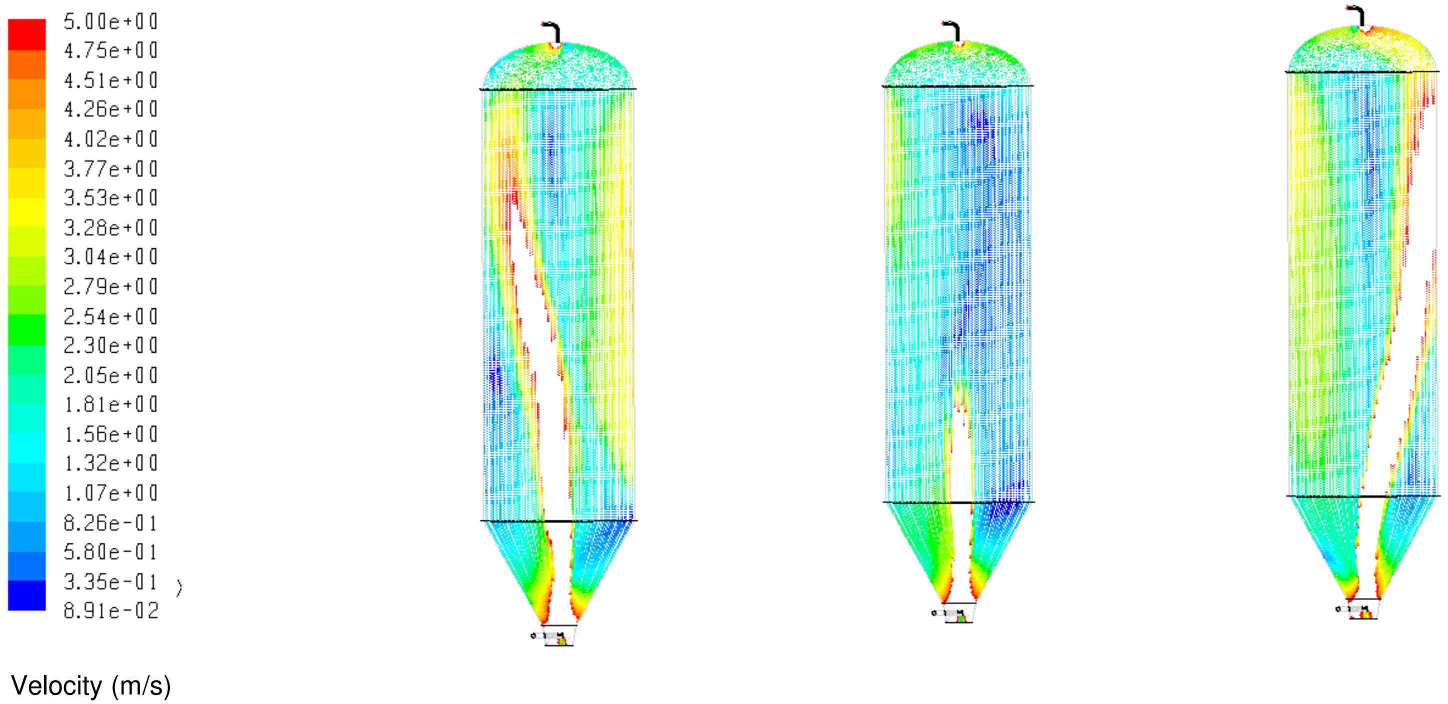
Flow distribution at different time instants depicting the unsteady plume

Red color denotes speed of 2 m/s; the white color adjacent to red denotes speed higher than 2 m/s

Results – Centered Insert Nozzle (Flow Condition #2)

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum

Unsteady flow inside the drum is observed (similar to the traditional nozzle)



Flow distribution at different time instants depicting the unsteady plume

Red color denotes speed of **5 m/s;** the white color adjacent to red denotes speed higher than **5 m/s**

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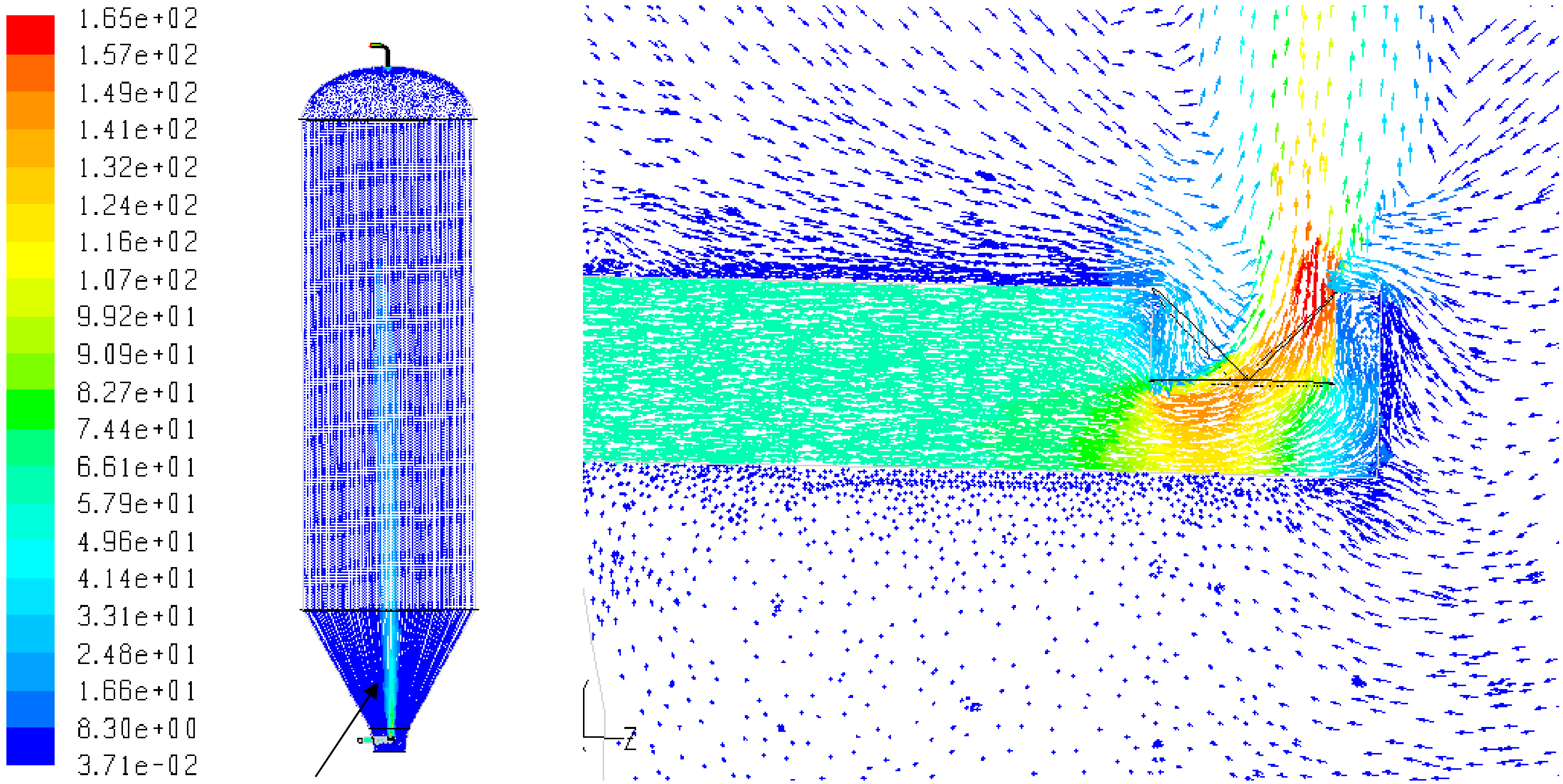
Results – Centered Insert Nozzle (Flow Condition #2)

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum



Velocity (m/s)

Vertically directed flow at the center of the drum is generated by the inlet

Close up of inlet region

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