

# Used Fuel Disposition Campaign

## *Stress Corrosion Cracking of SNF Interim Storage Canisters: Status of Mockup Residual Stress Measurements*

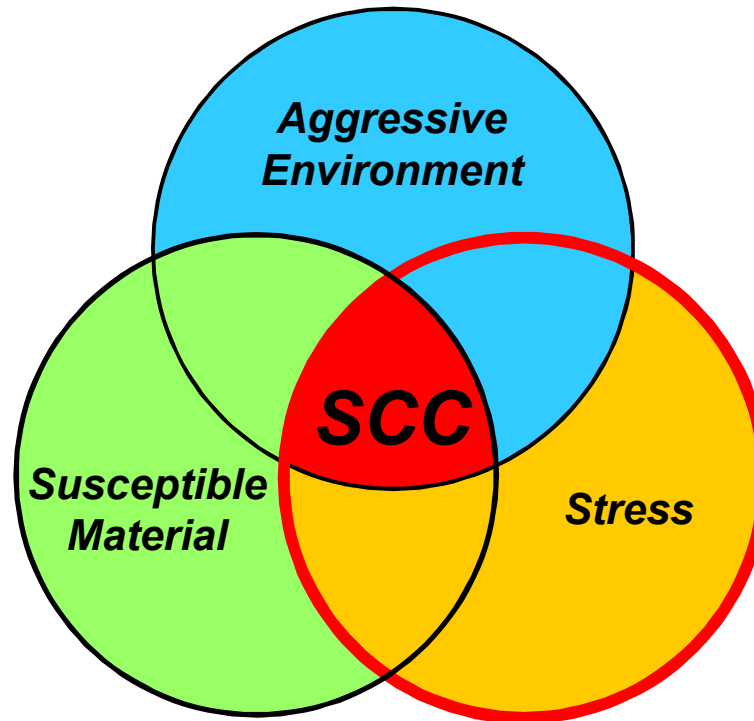
*David Enos and Charles Bryan  
Sandia National Laboratories*

*UFD Working Group Meeting  
June 8<sup>th</sup>, 2016  
Las Vegas, NV*

Used  
Fuel  
Disposition

## Degradation Mechanism of Concern: Stress Corrosion Cracking (SCC)

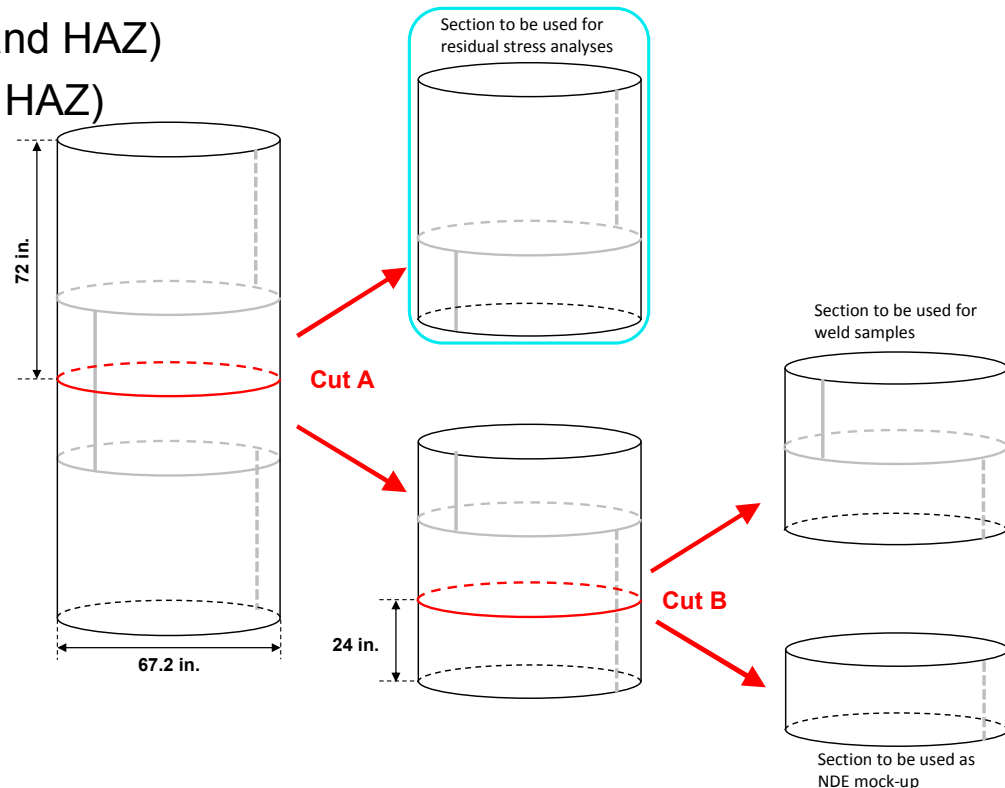
---



**Goal: Determine the nature of the residual stress state associated with the container and associated welds for a representative interim storage container.**

# Residual Stress Measurement

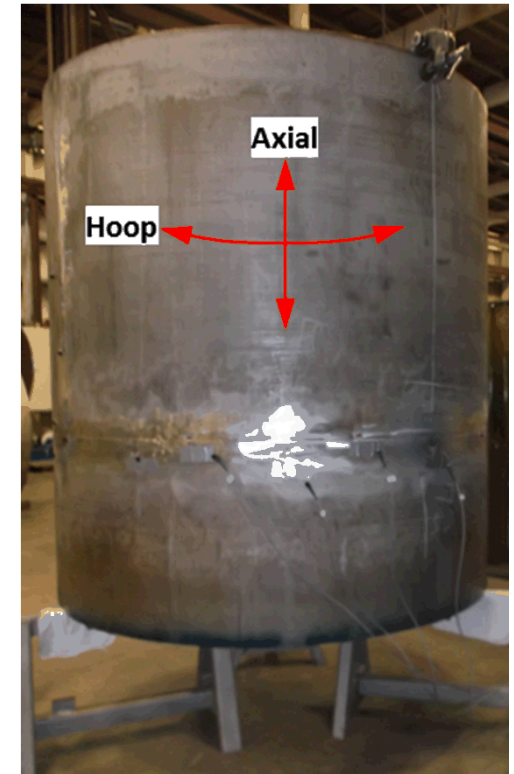
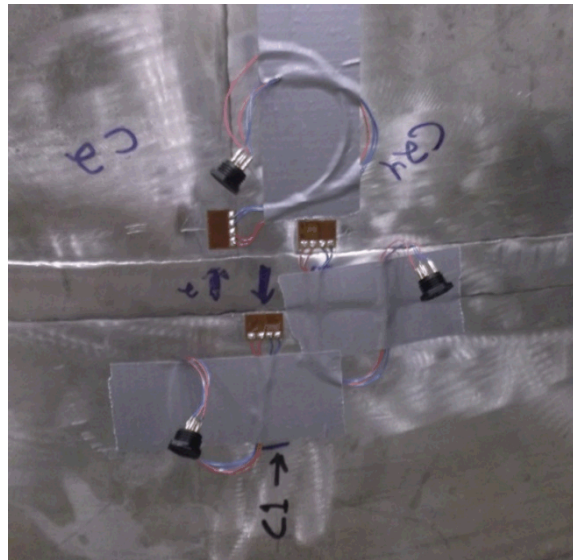
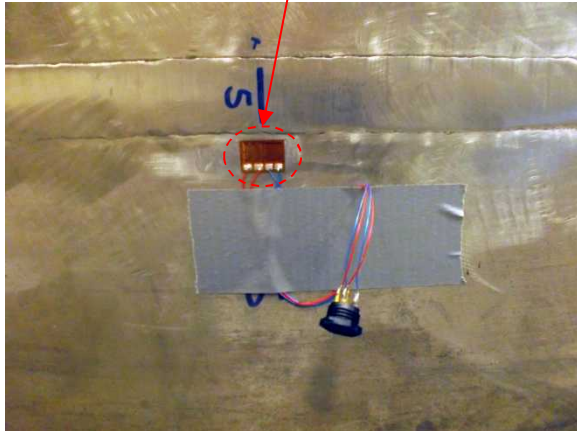
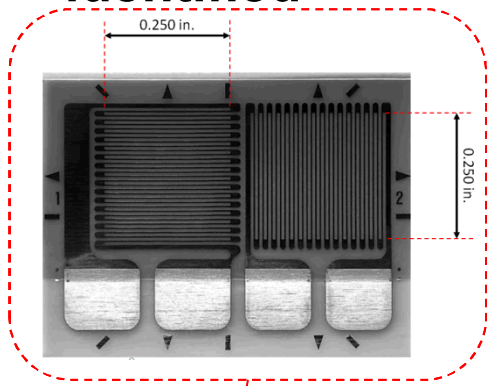
- **Goal:** Establish if there is sufficient through-wall tensile stresses to support SCC crack propagation
- Full-scale mockup container simulating a NUHOMS 24P container (produced at Ranor using procedures established for containers at Calvert Cliffs ISFSI)
- Series of key areas are being assessed
  - Base metal (far from welds)
  - Circumferential Weld (Centerline and HAZ)
  - Longitudinal Weld (Centerline and HAZ)
  - Weld Repair



Used  
Fuel  
Disposition

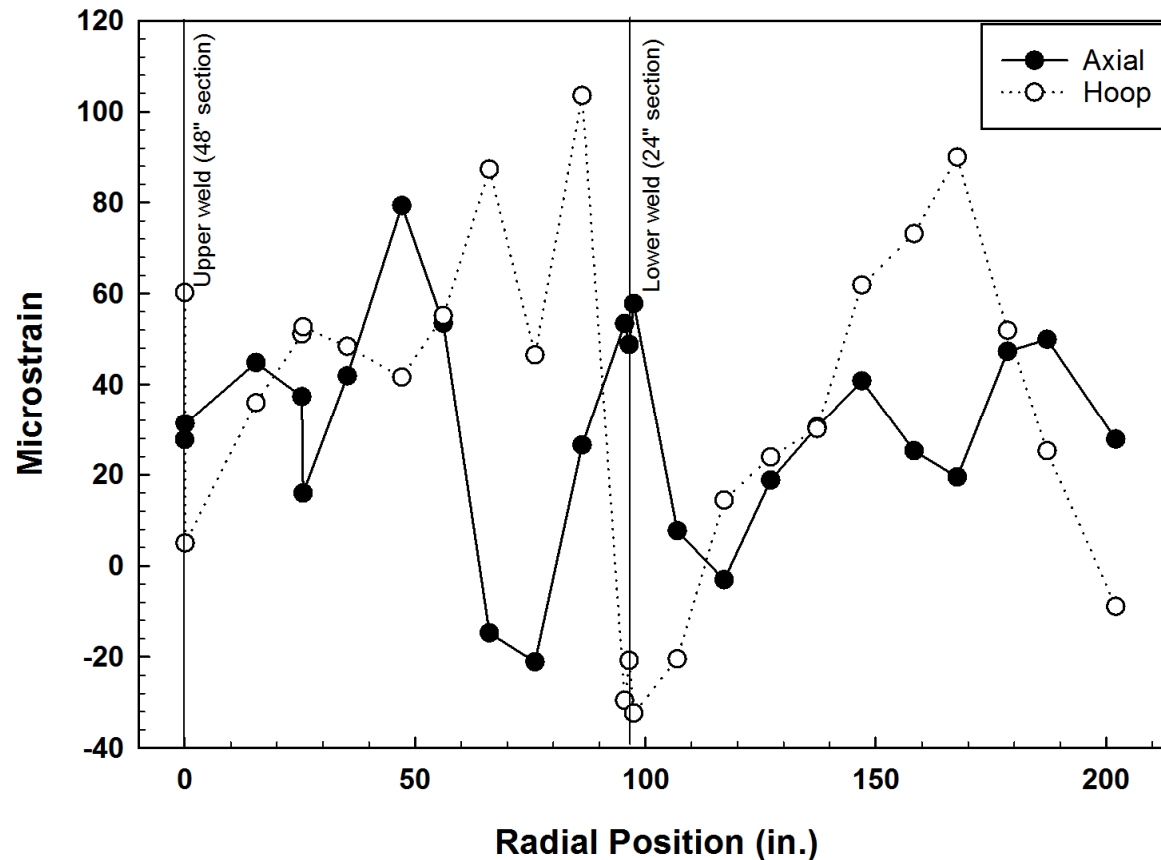
# Strain Gauge Positioning

- Gauges positioned such that one grid was parallel and one perpendicular to the weld
- Positioning required that a region with no heterogeneities be identified



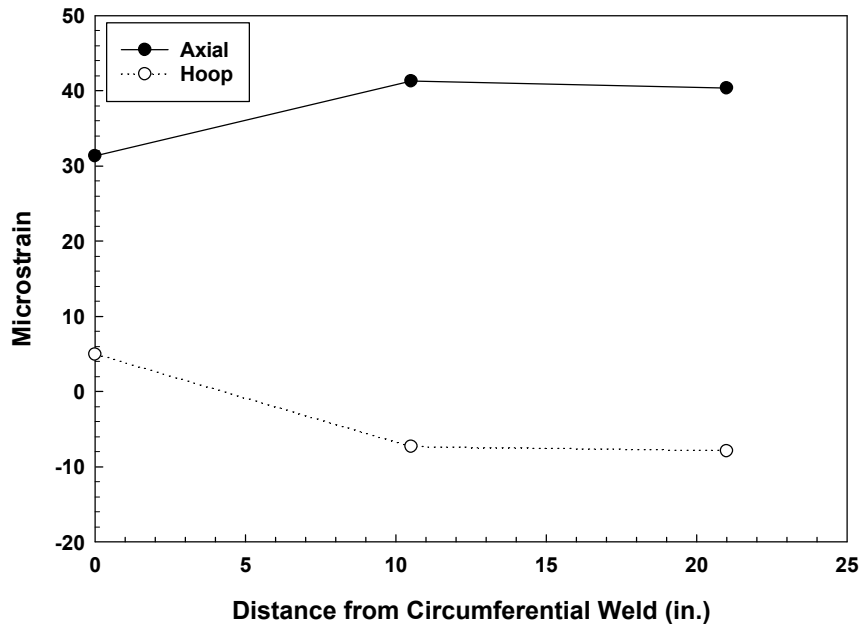
# Surface Strain Gauge Data: Circumferential Welds

- **Minimal impact of cutting operation on the circumferential weld**
  - Also assessed if measurements made on the upper vs. lower shell mattered (cut was on the lower shell)



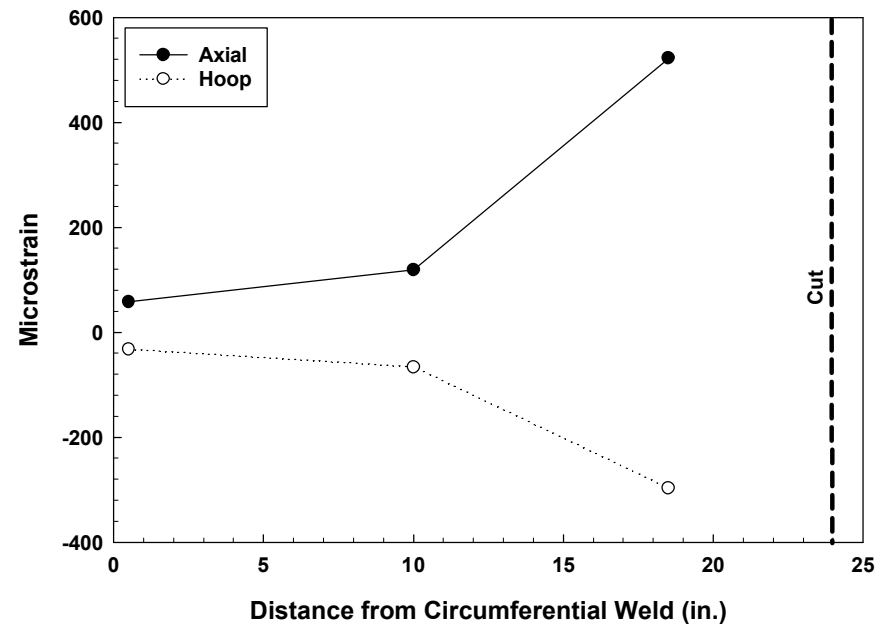
# Surface Strain Gauge Data: Longitudinal Welds

- Upper weld (shell which was not cut) not disturbed by the cutting operation



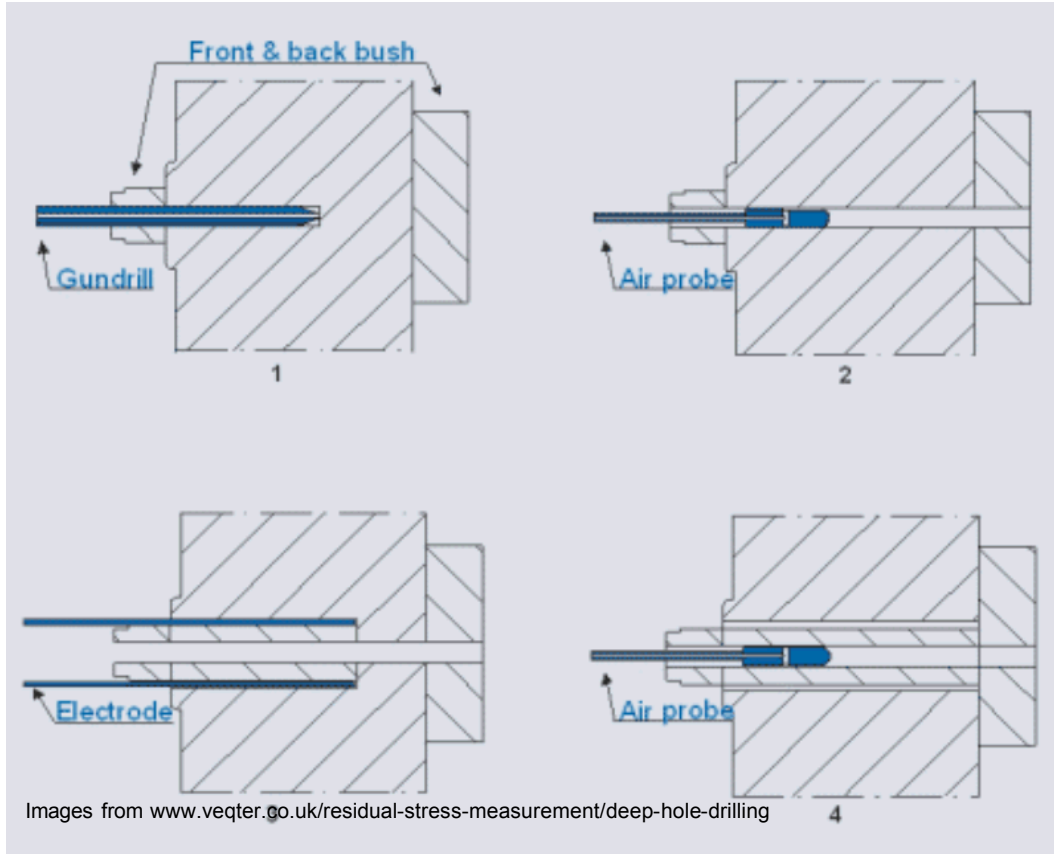
- Lower weld (shell which was cut) impacted by cut

— Some deformation of the cylinder occurred near the cut, despite the high wall thickness



Used  
Fuel  
Disposition

# Deep Hole Drilling



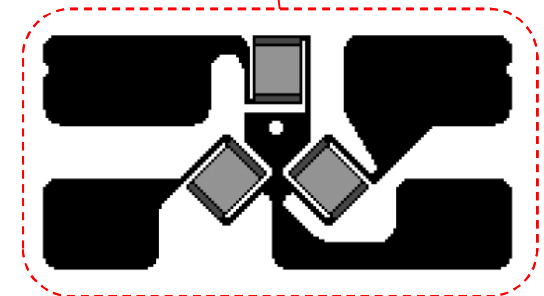
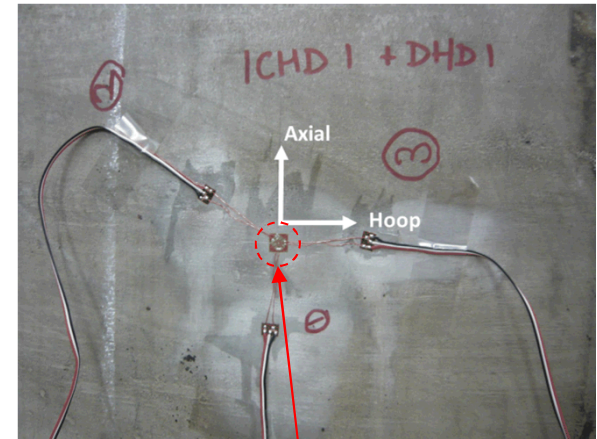
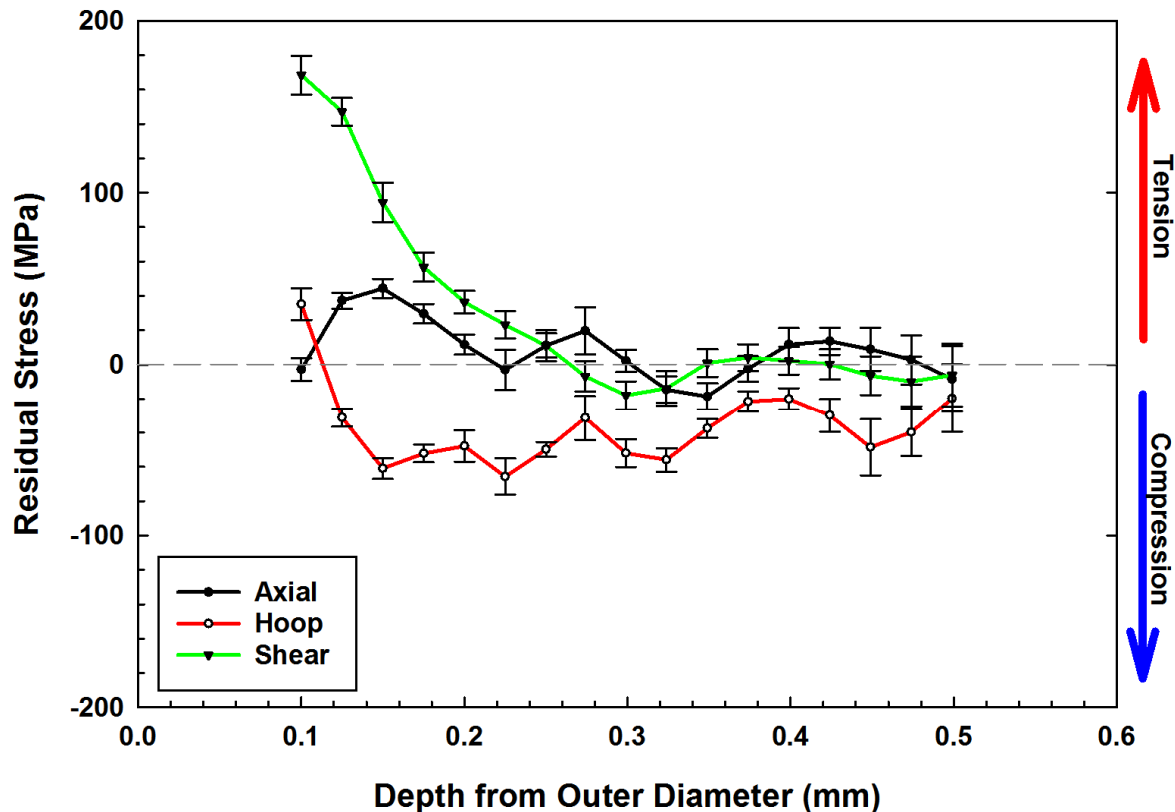
- Hole precisely drilled through region to be characterized
- Air probe used to measure the inner diameter of the hole as a function of position
- EDM used to cut core around the hole, relaxing the constraint placed by the surrounding material
- Air probe used to measure the resulting distortion of the hole inner diameter
- Stress state calculated from displacements
- Complicated when stresses are high (requires modified technique)

- Get one dimensional map of initial stress state without cutting up structure
- Semi-destructive, labor intensive (\$)

Used  
Fuel  
Disposition

# Near Surface Stresses Assessed Via Incremental Center Hole Drilling

- DHD is not able to resolve strains accurately very near the metal surface (first 0.5mm or so)
- iCHD used to make these measurements

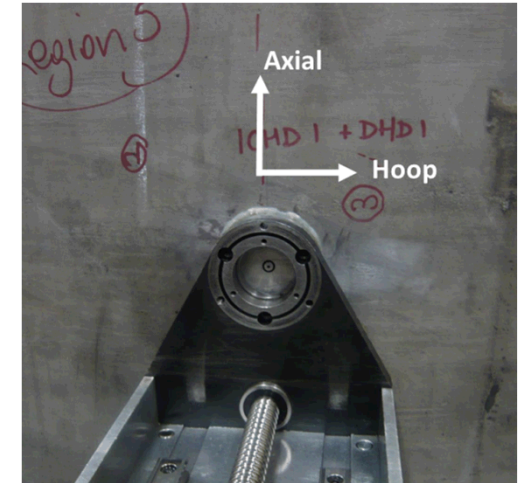
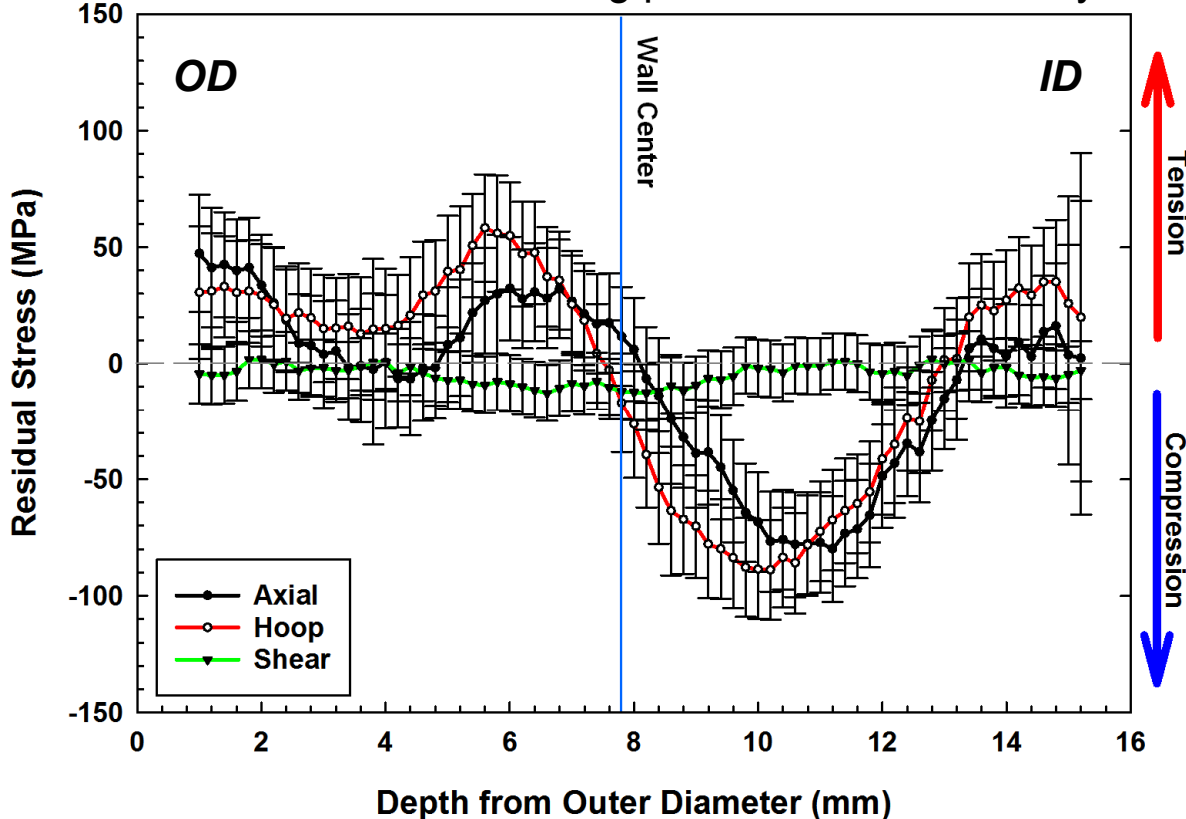


Used  
Fuel  
Disposition

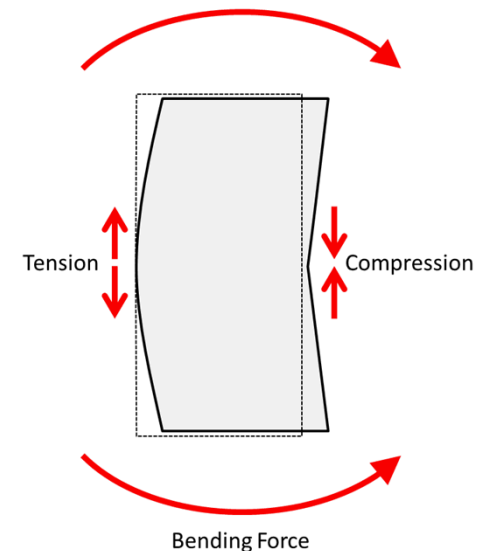
# Residual Stresses in the Base Metal Far from Welds

## ■ Stress state consistent with forming process

- Stresses on OD tensile
- Stresses in ID compressive
- Consistent with bending process used to form cylinder



Bending Force



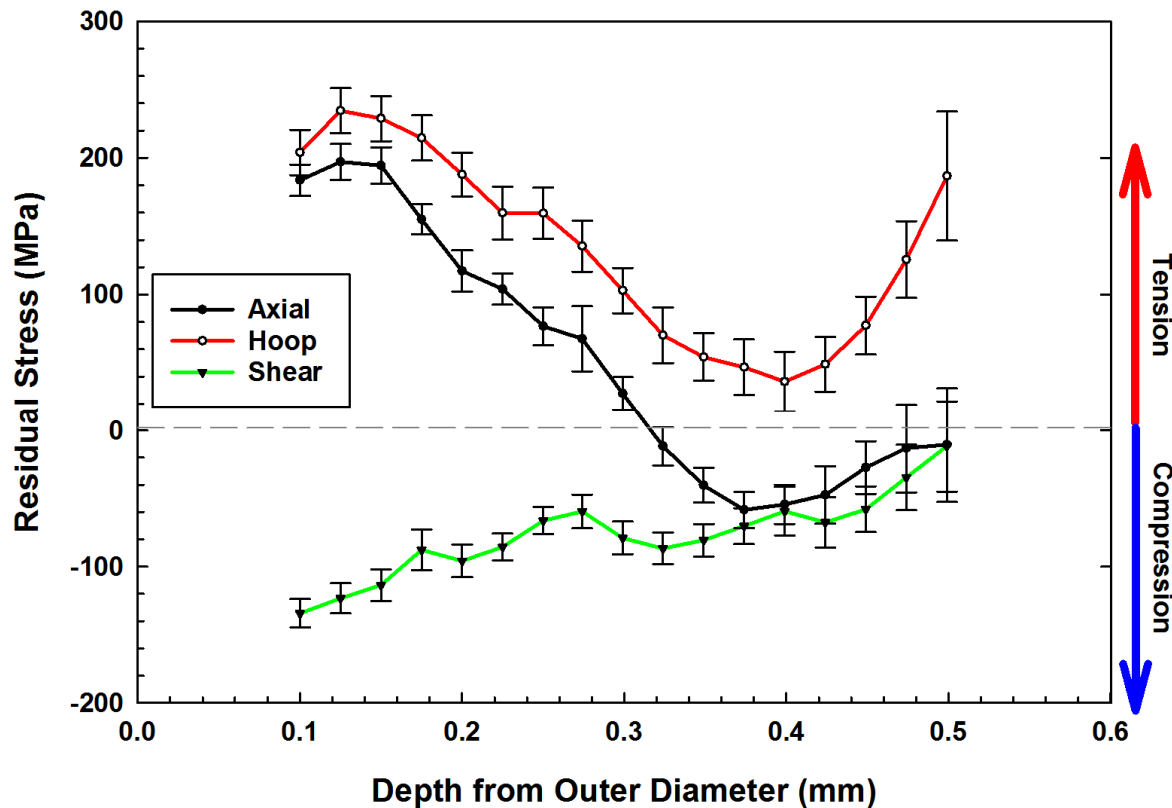
Bending Force

Note – locations where temporary supports have been welded and removed will be different...

Used  
Fuel  
Disposition

# Residual Stresses in Circumferential Weld (Centerline)

- iCHD used to assess stress state in region very close to the surface of the container (on the OD)

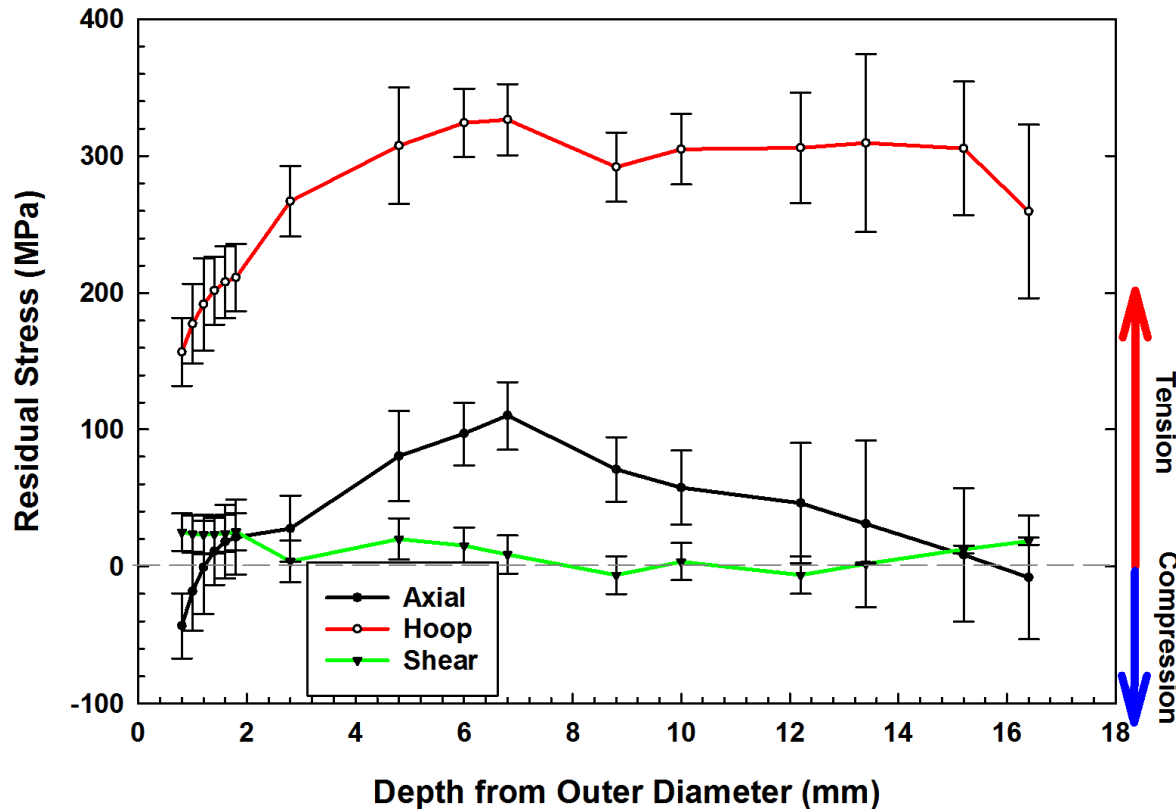


- Both axial and hoop stresses strongly tensile near surface
- iCHD measurements likely to exhibit some positional variability
  - Single test location
  - Consider qualitatively

Used  
Fuel  
Disposition

# Residual Stresses in Circumferential Weld (Centerline)

- Due to large stresses present in weld, material will yield as the core is cut for traditional DHD – as a result, incremental DHD measurements are made

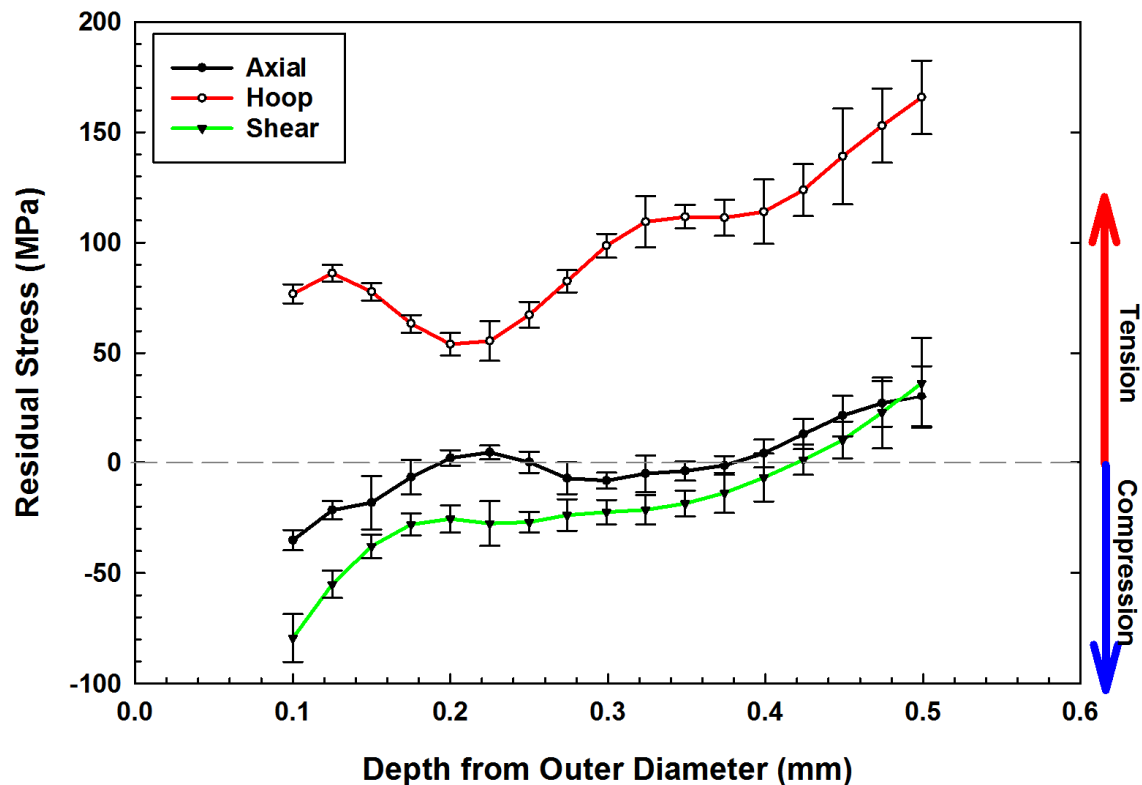


- DHD near surface, iDHD in bulk
- Hoop stress strongly tensile through wall
- Axial stress compressive at surfaces, tensile through bulk
- Single measurement location

Used  
Fuel  
Disposition

# Residual Stresses in Circumferential Weld (HAZ)

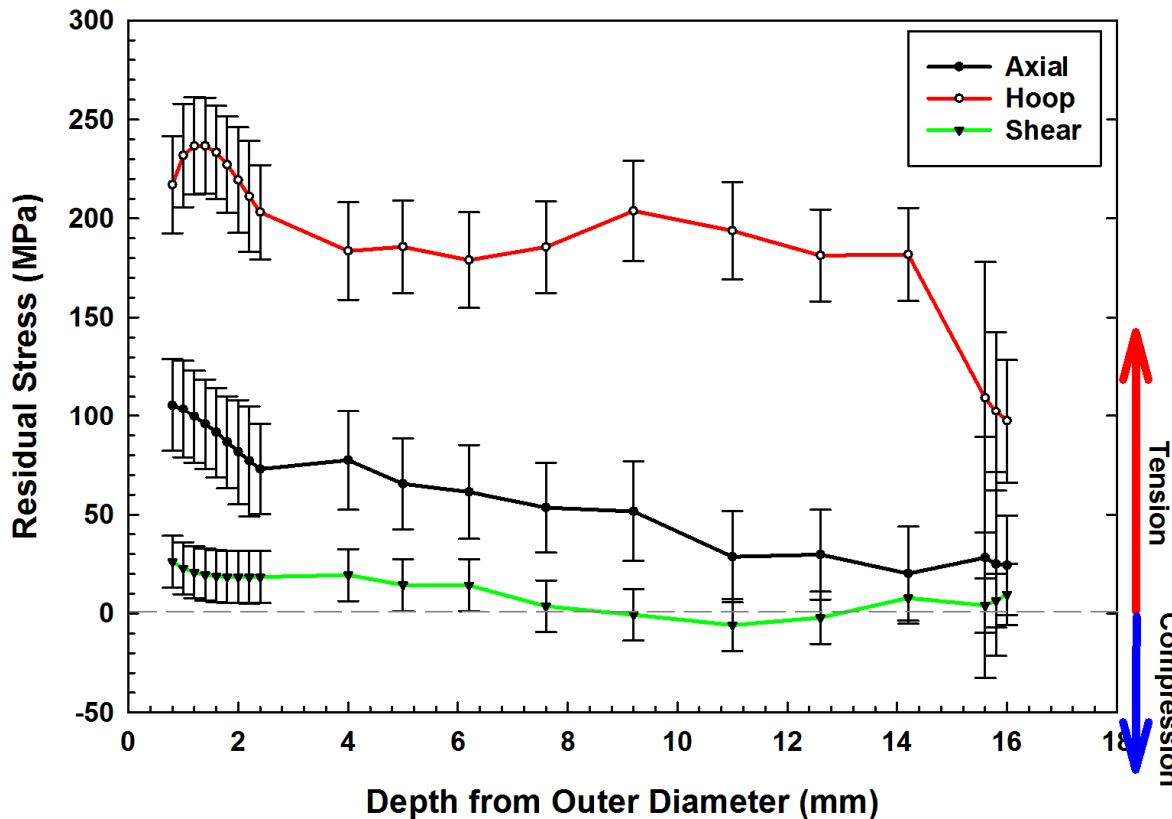
- Looking at 4mm from weld toe
- iCHD used to assess stress state in region very close to the surface of the container (on the OD)



- Hoop stress tensile at surface, increasing with depth
- Axial stress low and slightly compressive, becoming tensile with depth
- iCHD measurements likely to exhibit some positional variability
  - Single test location
  - Consider qualitatively

# Residual Stresses in Circumferential Weld (HAZ)

- Due to large stresses present in weld, material will yield as the core is cut for traditional DHD – as a result, incremental DHD measurements are made

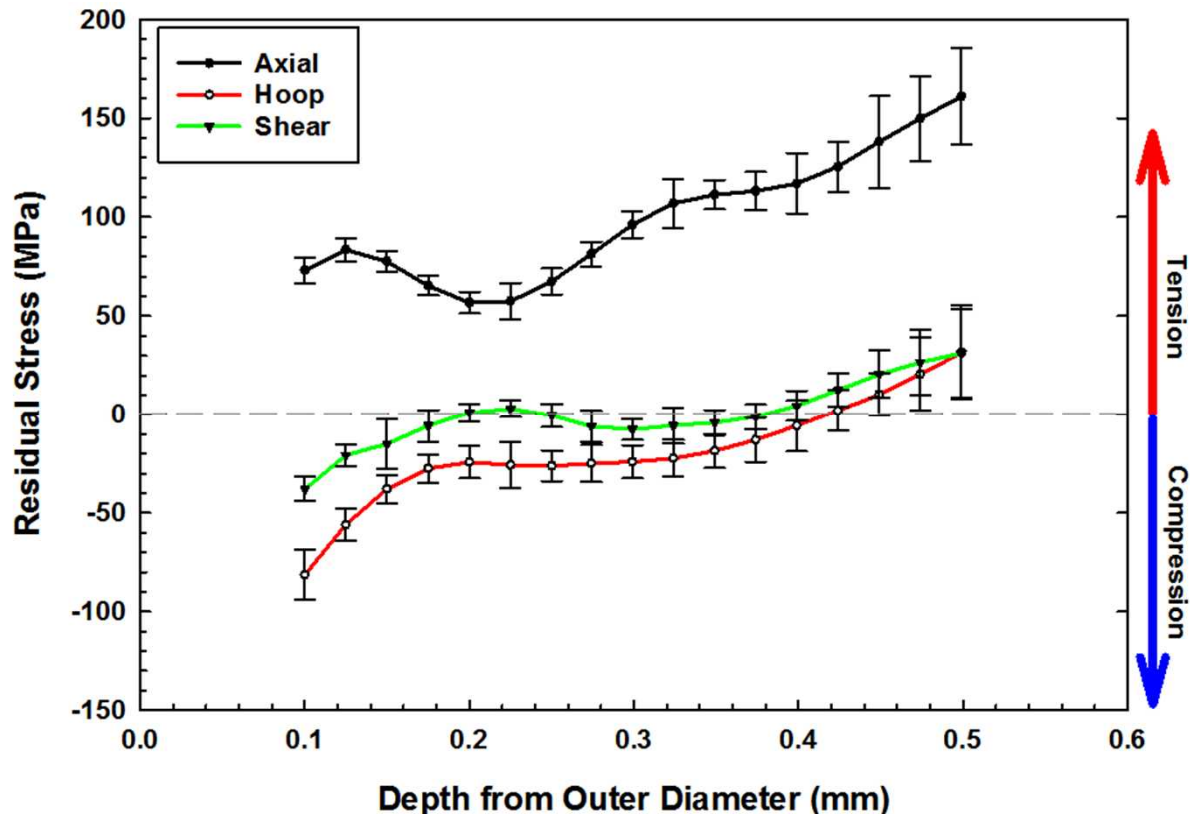


- DHD near surface, iDHD in bulk
- Hoop stress strongly tensile through wall
- Axial stress lower in magnitude, but tensile through thickness
- Single measurement location

Used  
Fuel  
Disposition

# Residual Stresses in Longitudinal Weld (Centerline)

- iCHD used to assess stress state in region very close to the surface of the container (on the OD)

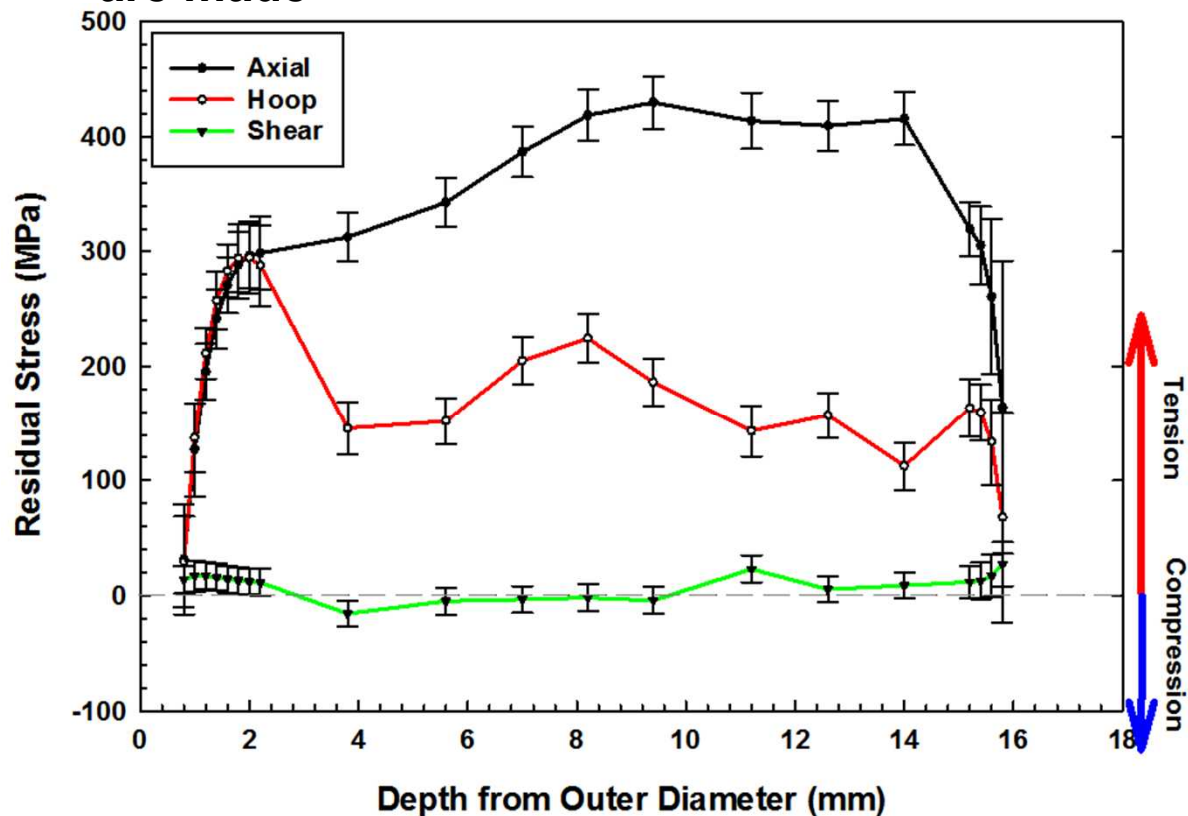


- Axial stresses strongly tensile near surface
- iCHD measurements likely to exhibit some positional variability
  - Single test location
  - Consider qualitatively

Used  
Fuel  
Disposition

# Residual Stresses in Longitudinal Weld (Centerline)

- Due to large stresses present in weld, material will yield as the core is cut for traditional DHD – as a result, incremental DHD measurements are made

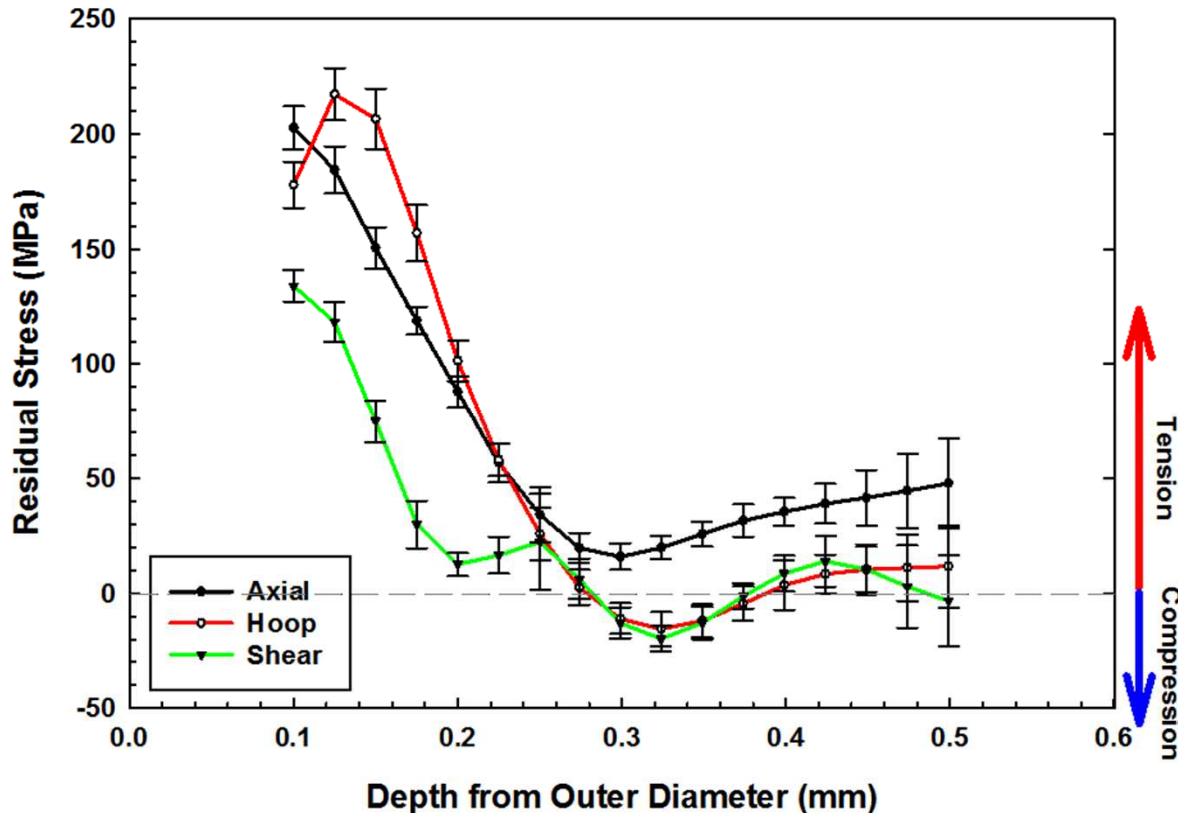


- DHD near surface, iDHD in bulk
- Axial stress strongly tensile through wall
- Hoop stress lower in magnitude, but tensile through thickness
- Single measurement location

Used  
Fuel  
Disposition

# Residual Stresses in Longitudinal Weld (HAZ)

- Looking at 4mm from weld toe
- iCHD used to assess stress state in region very close to the surface of the container (on the OD)

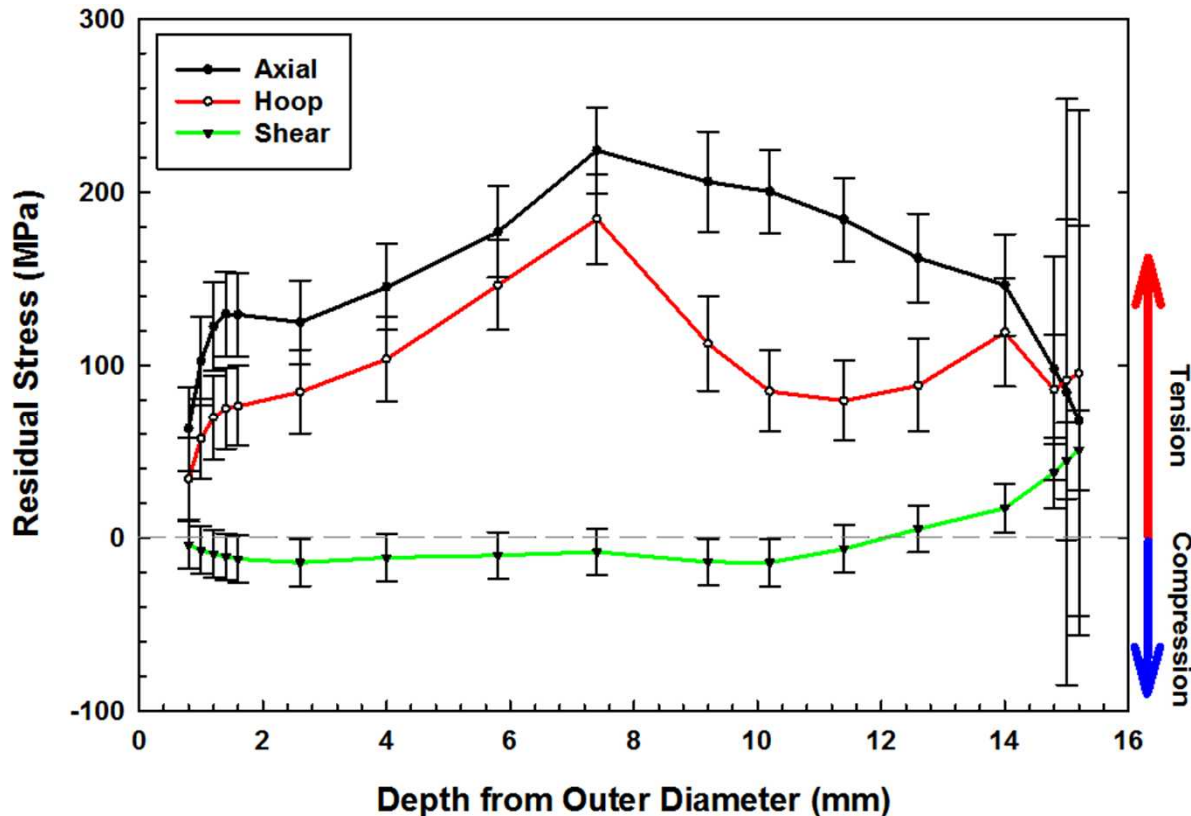


- Both Axial and Hoop stress tensile at surface, decreasing with depth
- iCHD measurements likely to exhibit some positional variability
  - Single test location
  - Consider qualitatively

Used  
Fuel  
Disposition

# Residual Stresses in Longitudinal Weld (HAZ)

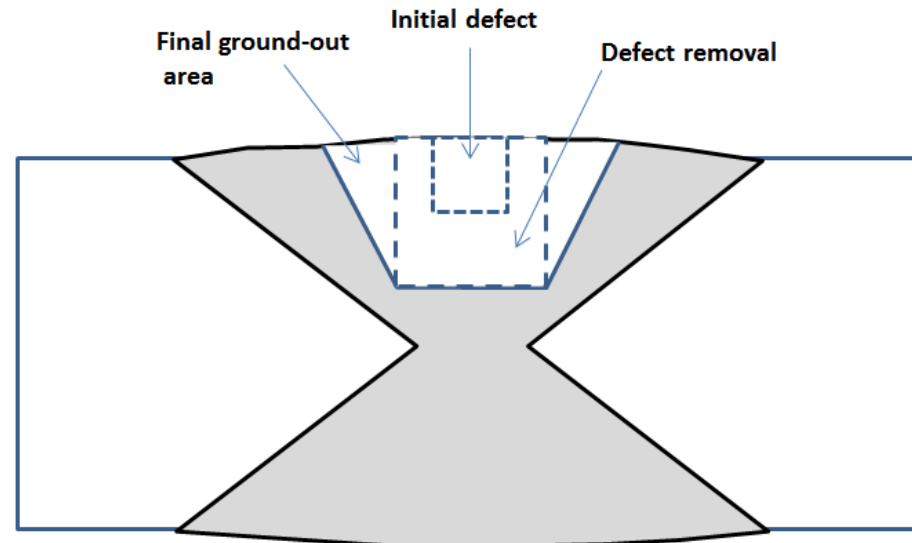
- Due to large stresses present in weld, material will yield as the core is cut for traditional DHD – as a result, incremental DHD measurements are made



- DHD near surface, iDHD in bulk
- Axial stress strongly tensile through wall
- Hoop stress lower in magnitude, but tensile through thickness
- Single measurement location

# Weld Repairs on Circumferential Welds

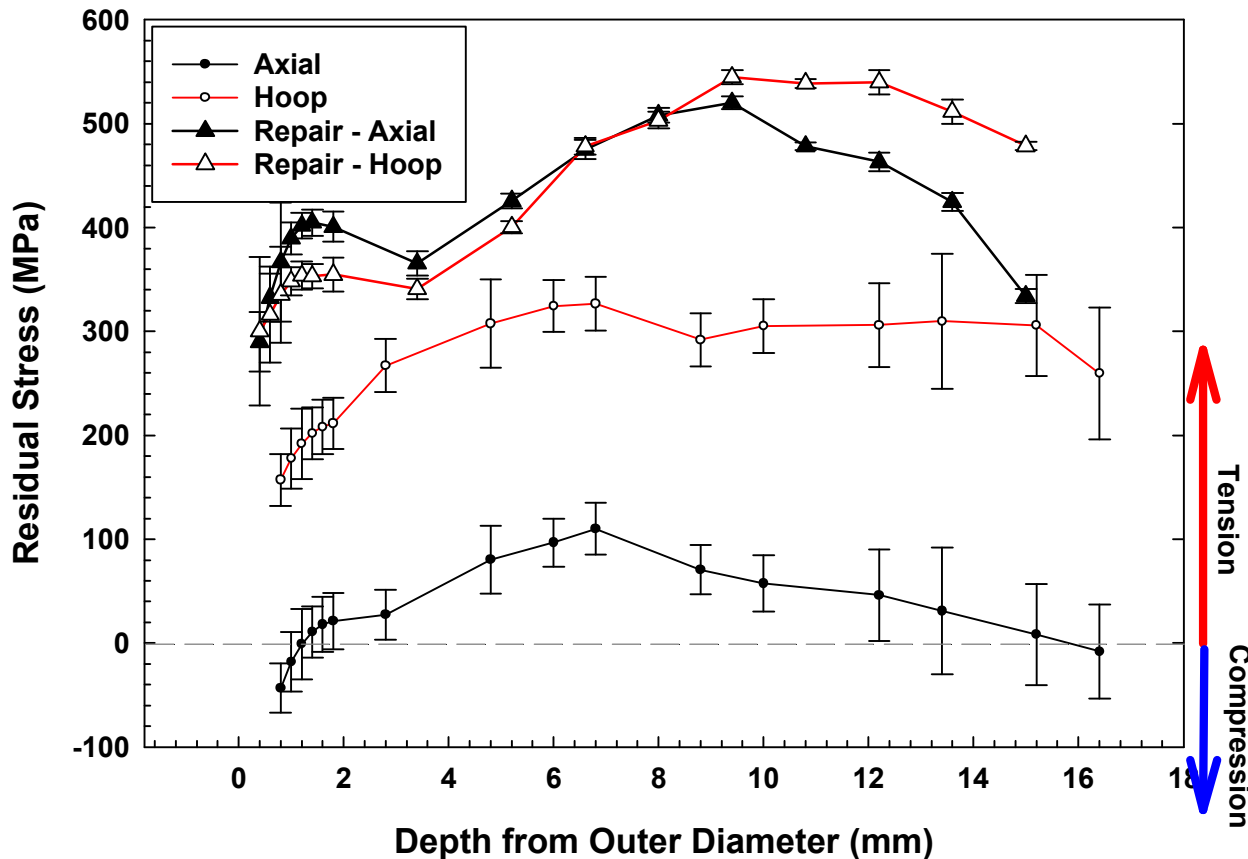
- Welds were fabricated via submerged arc welding using a well defined protocol/schedule – very low defect density
- Manufacturer (Ranor) created a repair typical for this type of weld (simulating a local defect due to entrained slag at a weld stop/start point, etc.)
- mock defect into the container by drilling a 1/8" diameter hole partially into the center of the weld root. They then went back and “removed” that defect, by drilling out additional material using a 1/4" drill, after which they ground the edges of the site such that the opening of the hole was approximately 0.5" wide. Repair completed via TIG.



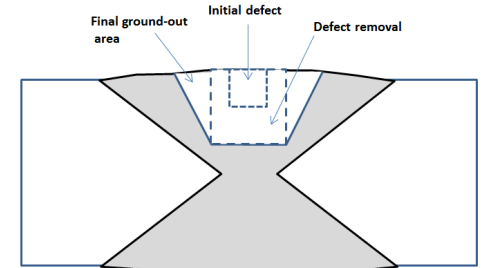
Used  
Fuel  
Disposition

# Residual Stresses in Repair: Circumferential Weld (Centerline)

- Dramatic increase in magnitude of stresses, particularly in the axial direction, when a repair is made

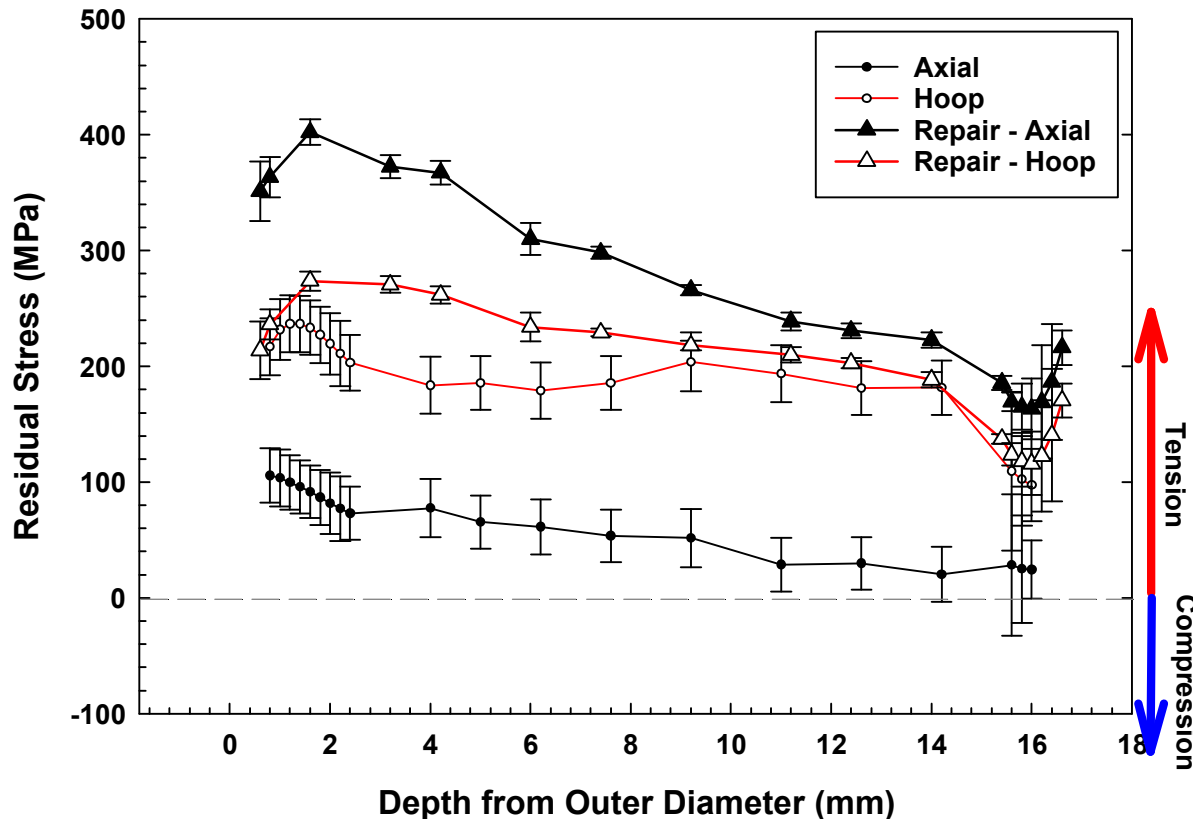


- *DHD near surface, iDHD in bulk*
- *Both axial and hoop stresses dramatically increased in weld repair*

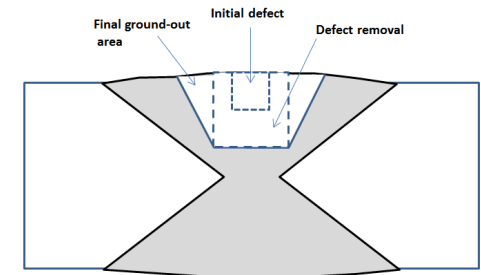


# Residual Stresses in Repair: Circumferential Weld (HAZ)

- Dramatic increase in magnitude of stresses, particularly in the axial direction, when a repair is made



- 4mm from weld toe
- DHD near surface, iDHD in bulk
- Hoop stress increased in region of weld repair
- Axial stress dramatically increased in weld repair
- Less significant increase in hoop stress at ID, but axial stress is elevated

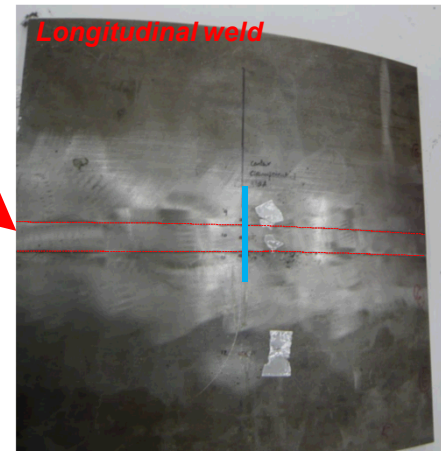
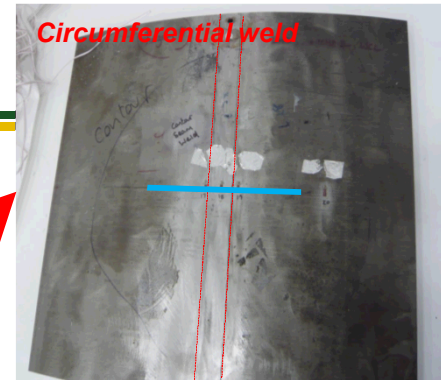


# Used Fuel Disposition

## Sectioning of the Mock-Up

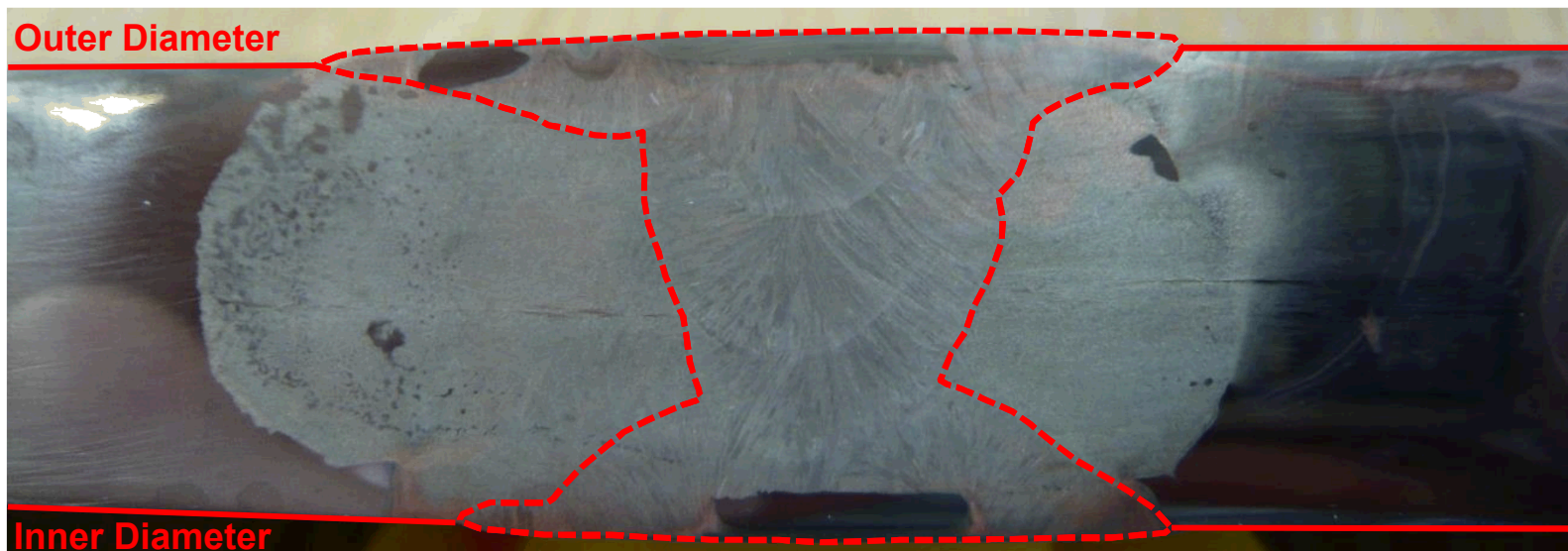
### ■ Mockup sectioned for contour measurements.

- Provide map of residual stresses
- EDM cutting complete, Measurement in progress

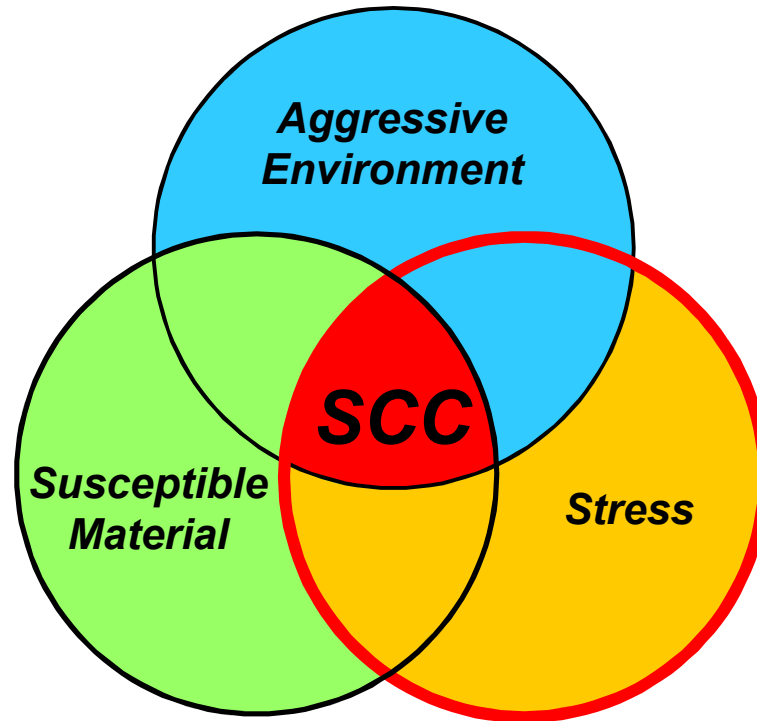


## Circumferential Weld Cross Section

- Deep hole drilling measurements seem to indicate misalignment of weld
- X-ray inspection and cross section reveal well formed weld, but cross section suggests surface passes may be yielding the perceived misalignment



## Conclusions and Future Direction



- Tensile stress exists through thickness at both longitudinal and circumferential welds
- Weld repairs exacerbate the stresses observed
- Contour measurements remain to be completed, as well as an evaluation of the magnitude of the plastic strain along the weld fusion zone