Used Fuel Disposition Campaign

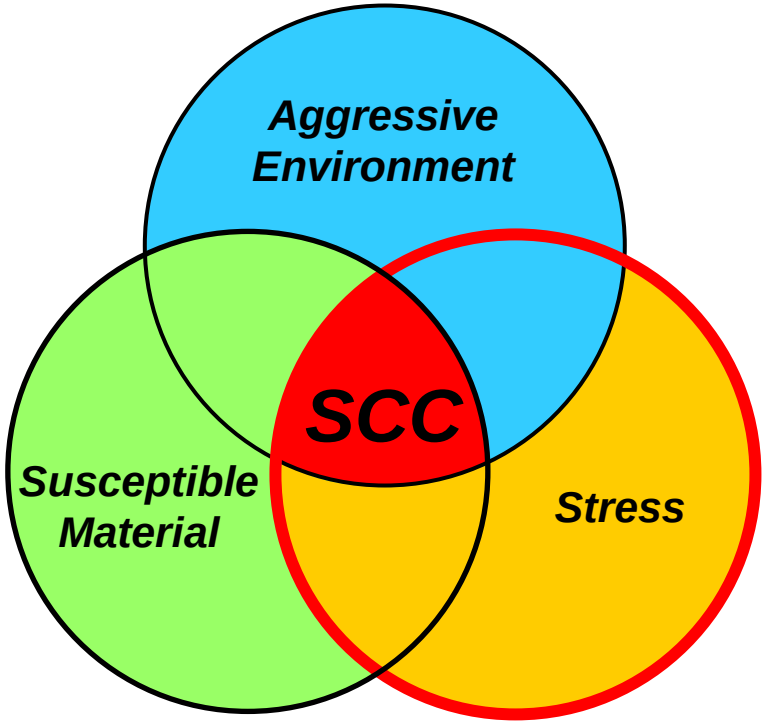
Stress Corrosion Cracking of SNF Interim Storage Canisters:
Status of Mockup Residual Stress Measurements

David Enos and Charles Bryan
Sandia National Laboratories

UFD Working Group Meeting
June 8th, 2016
Las Vegas, NV

Sandia National Laboratories is a multi program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2016-5496 PE.

Degradation Mechanism of Concern: Stress Corrosion Cracking (SCC)

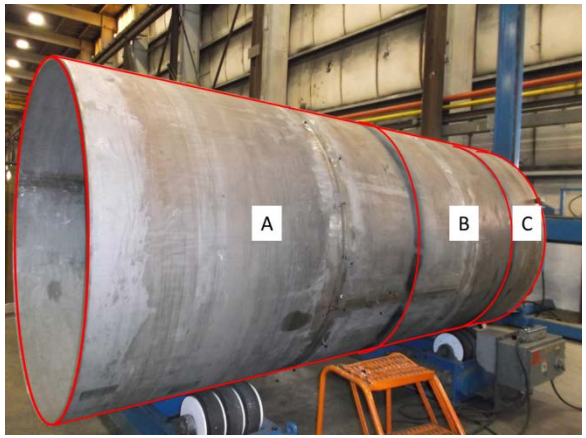


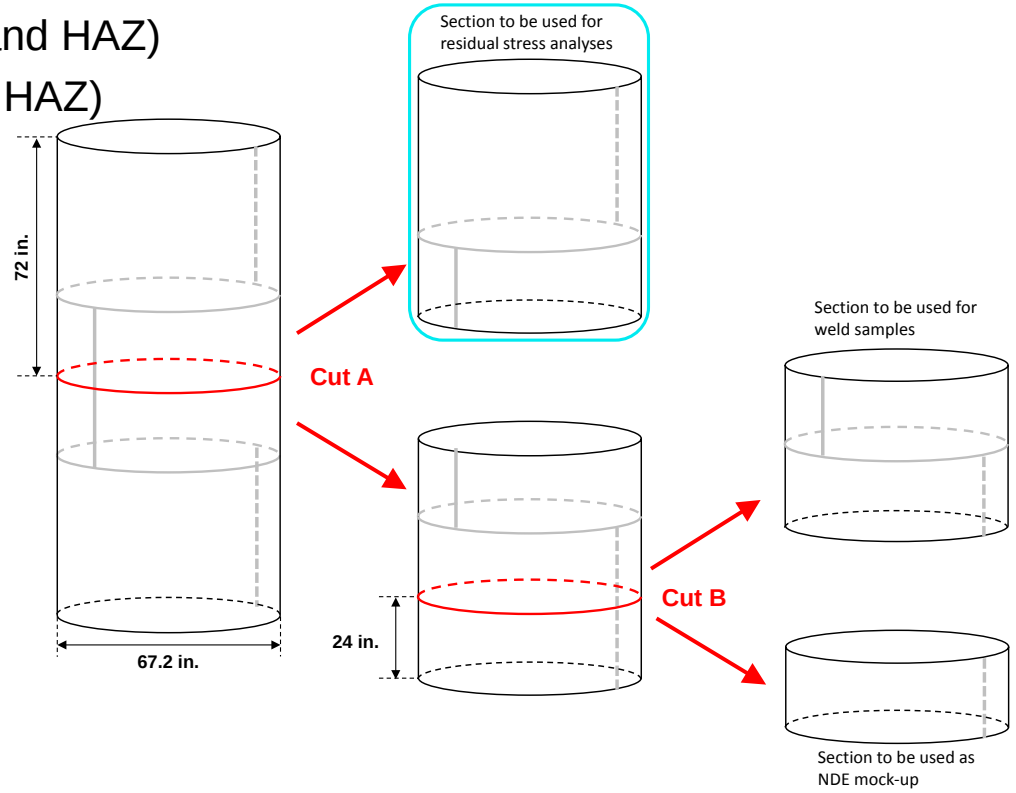
Goal: Determine the nature of the residual stress state associated with the container and associated welds for a representative interim storage container.

Used Fuel Disposition

Residual Stress Measurement

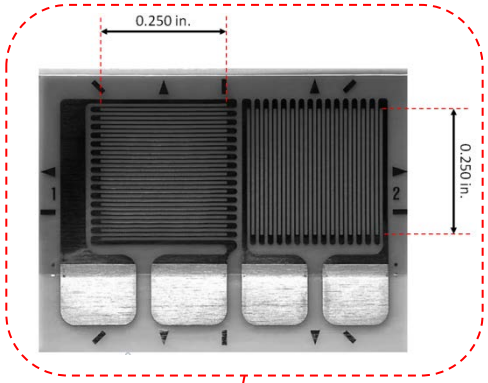
- **Goal: Establish if there is sufficient through-wall tensile stresses to support SCC crack propagation**
- **Full-scale mockup container simulating a NUHOMS 24P container (produced at Ranor using procedures established for containers at Calvert Cliffs ISFSI)**
- **Series of key areas are being assessed**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

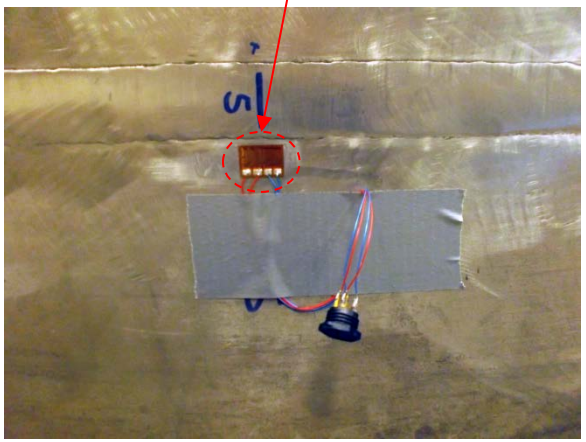


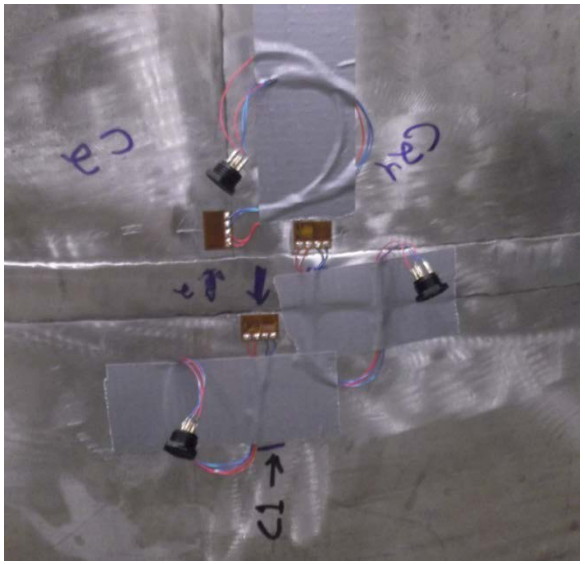


Strain Gauge Positioning

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

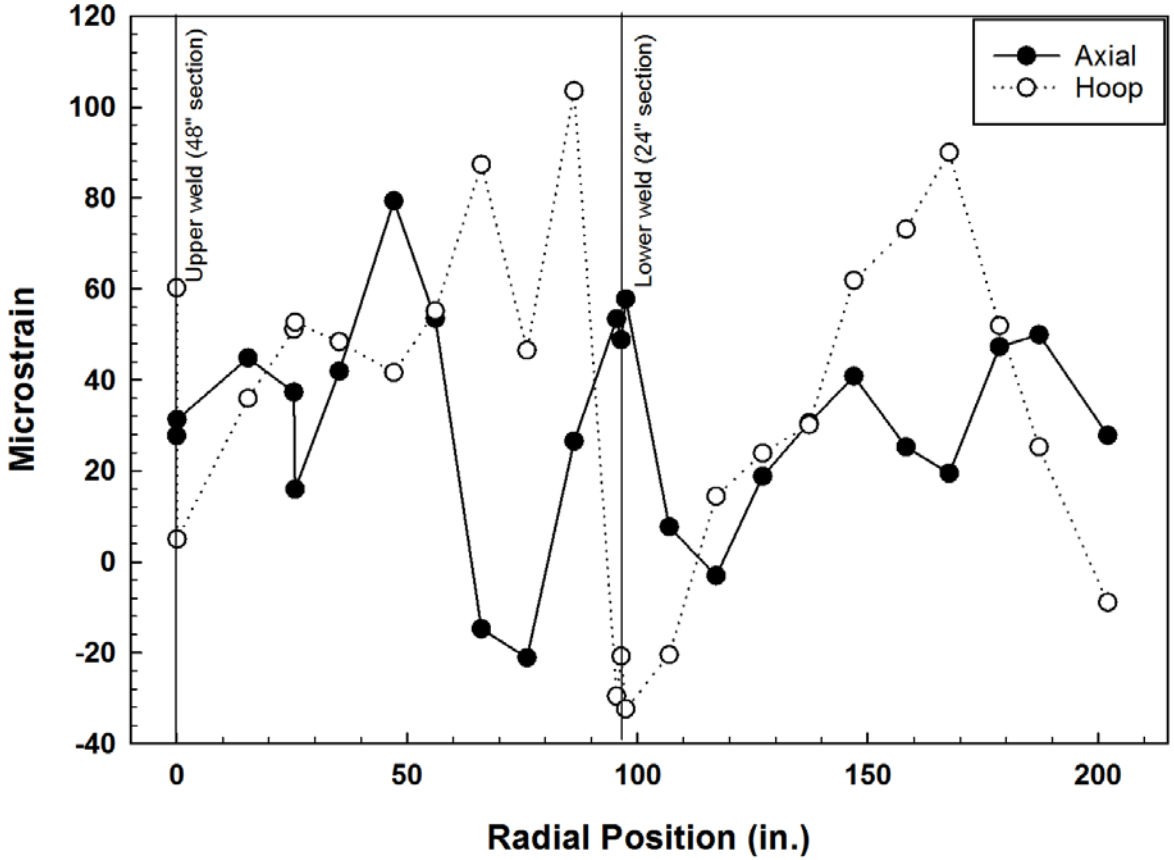






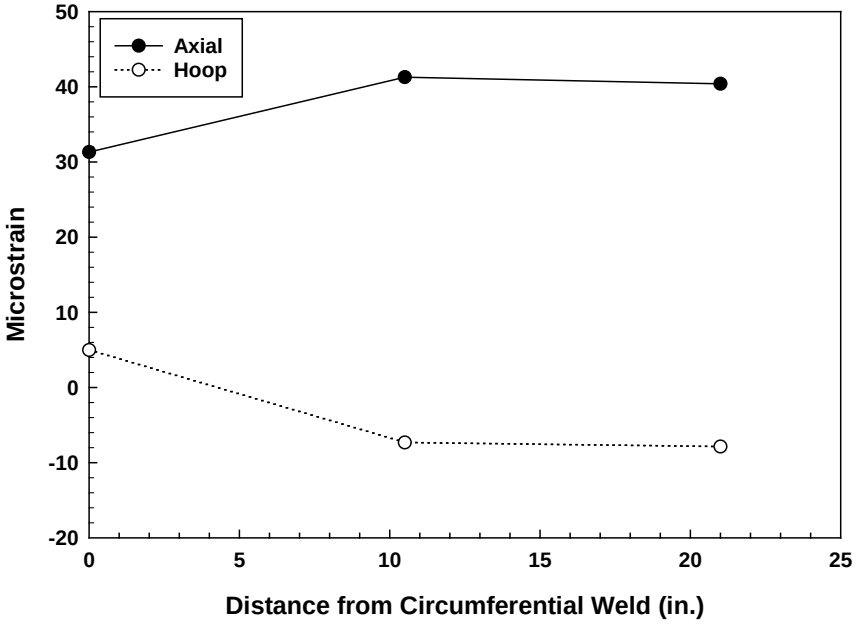
Surface Strain Gauge Data: Circumferential Welds

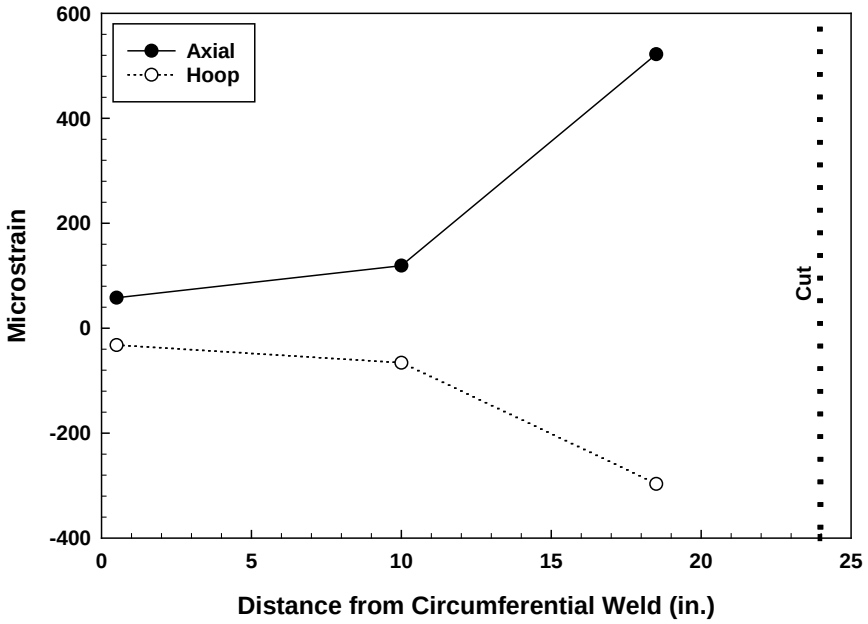
- **Minimal impact of cutting operation on the circumferential weld**
  - Also assessed if measurements made on the upper vs. lower shell mattered (cut was on the lower shell)



Surface Strain Gauge Data: Longitudinal Welds

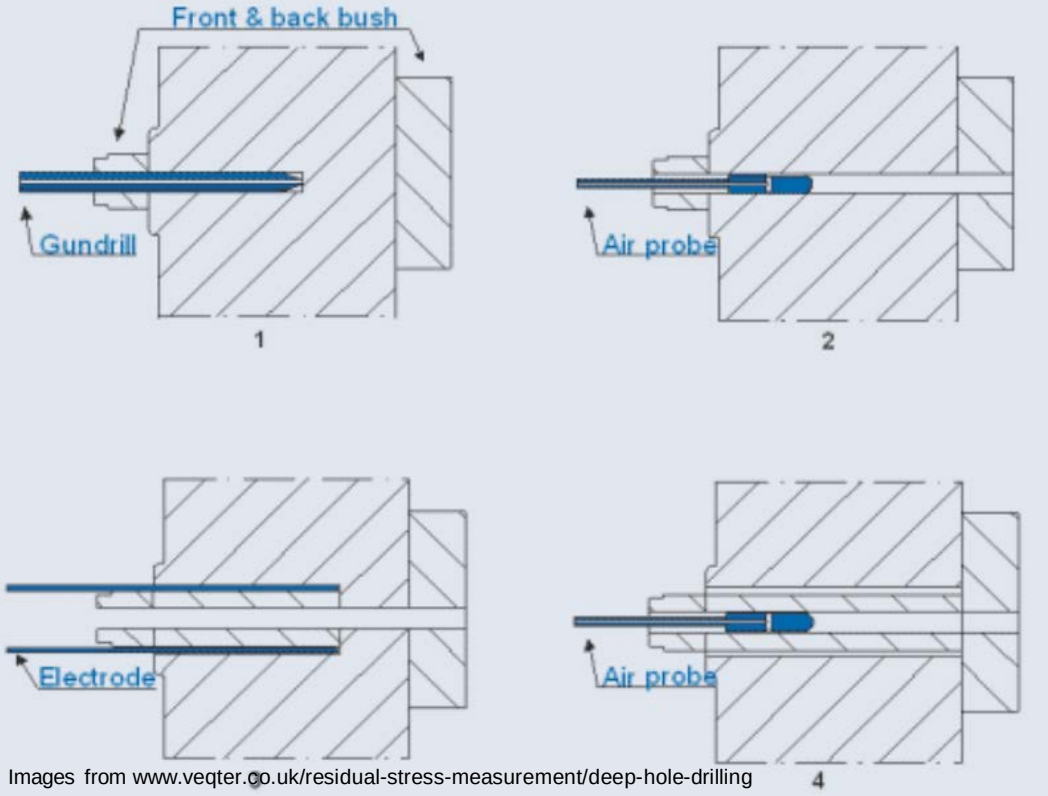
- **Upper weld (shell which was not cut) not disturbed by the cutting operation**
- **Lower weld (shell which was cut) impacted by cut**
  - Some deformation of the cylinder occurred near the cut, despite the high wall thickness





Used Fuel Disposition

Deep Hole Drilling



Images from www.veqter.co.uk/residual-stress-measurement/deep-hole-drilling

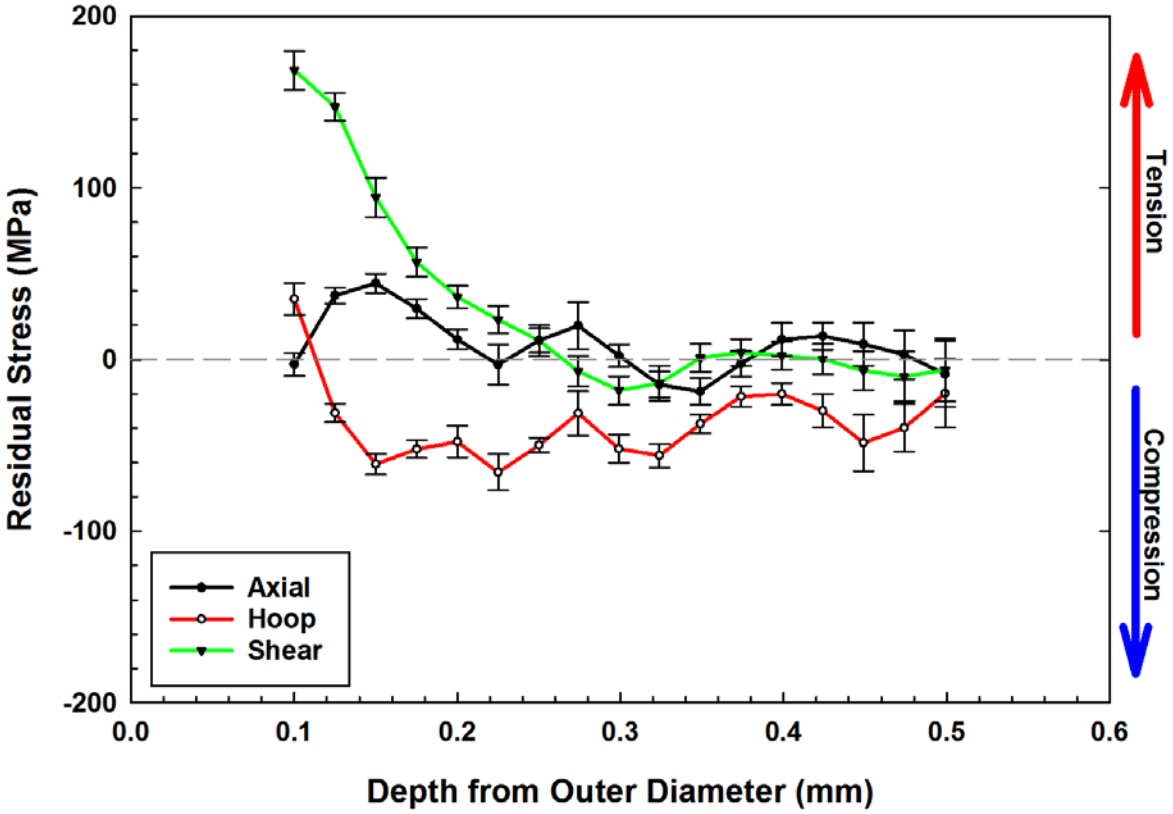
- Hole precisely drilled through region to be characterized
- Air probe used to measure the inner diameter of the hole as a function of position
- EDM used to cut core around the hole, relaxing the constraint placed by the surrounding material
- Air probe used to measure the resulting distortion of the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

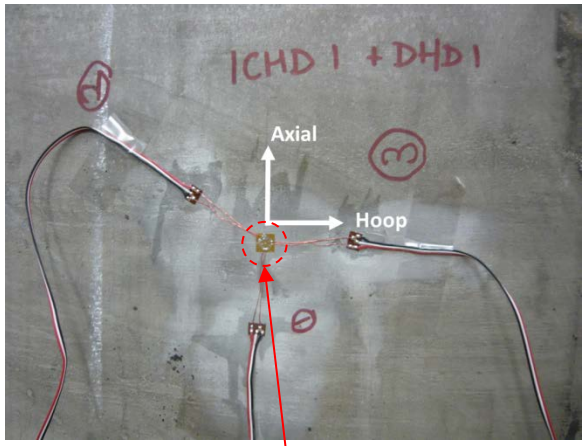
- Get one dimensional map of initial stress state without cutting up structure
- Semi-destructive, labor intensive ($)

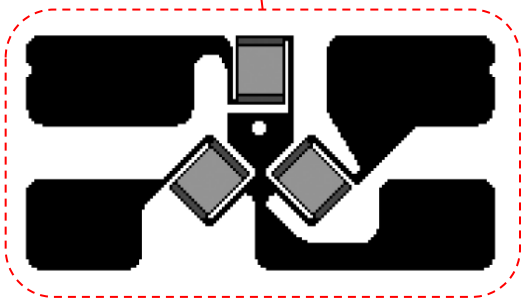
Used Fuel Disposition

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



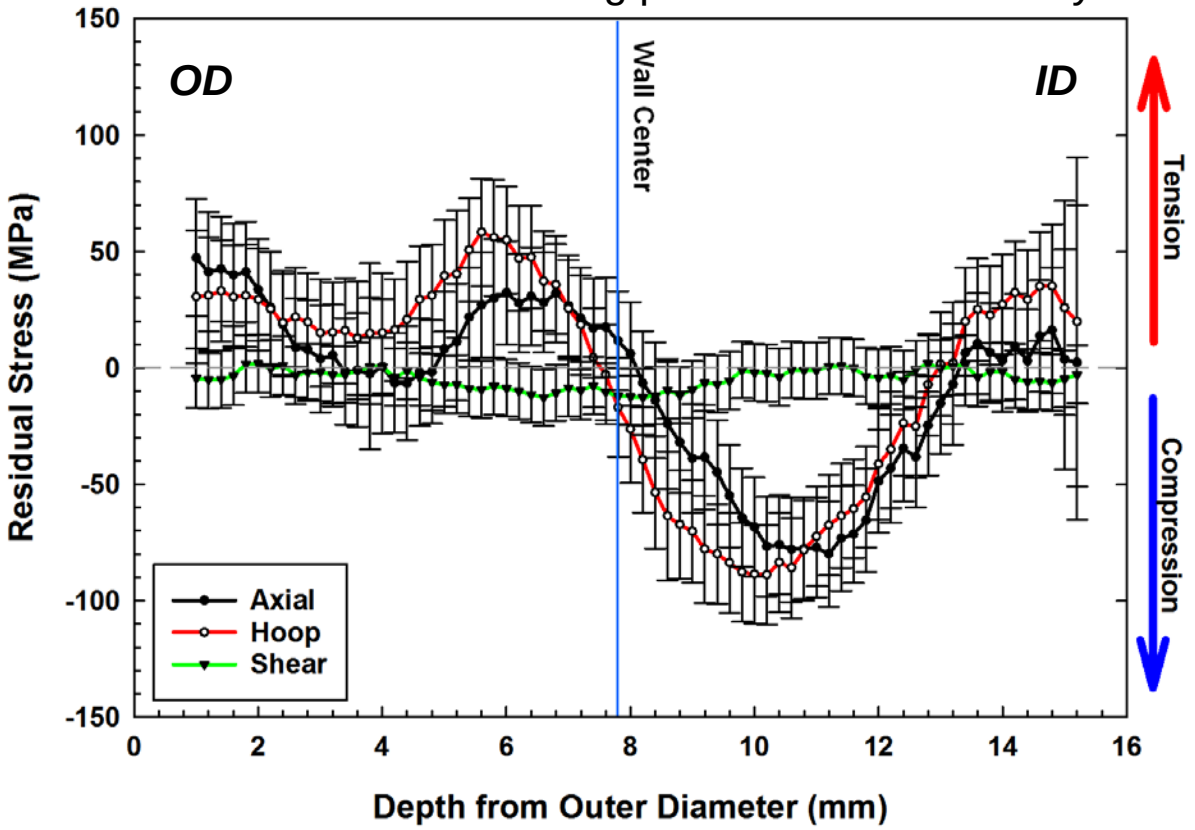


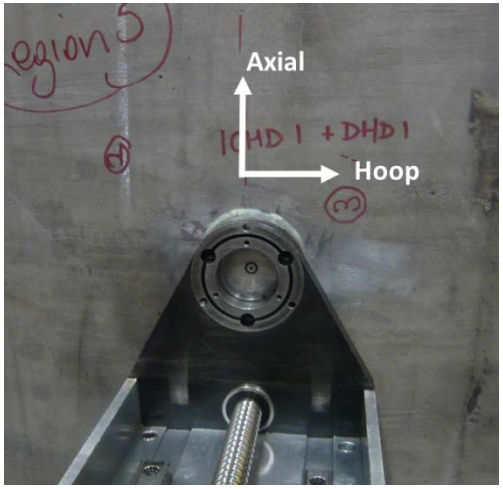


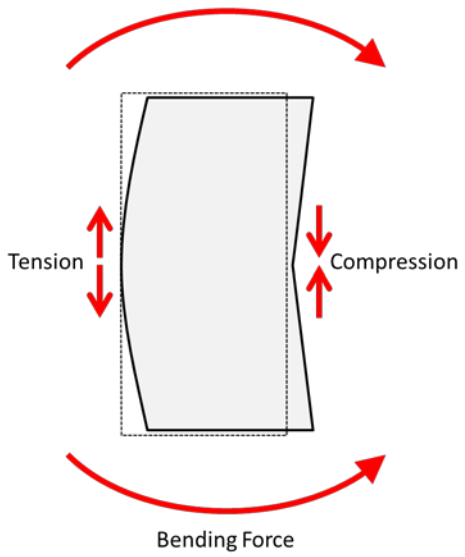
Used Fuel Disposition

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



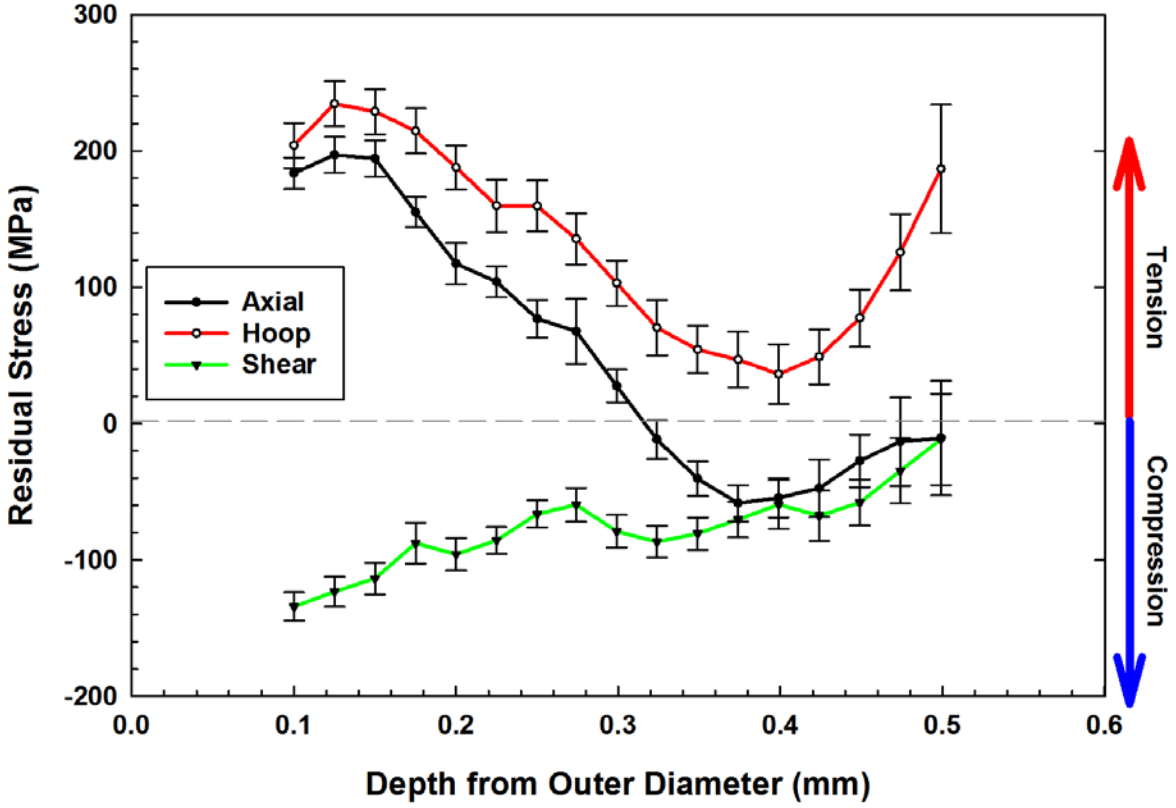




Note – locations where temporary supports have been welded and removed will be different…

Residual Stresses in Circumferential Weld (Centerline)

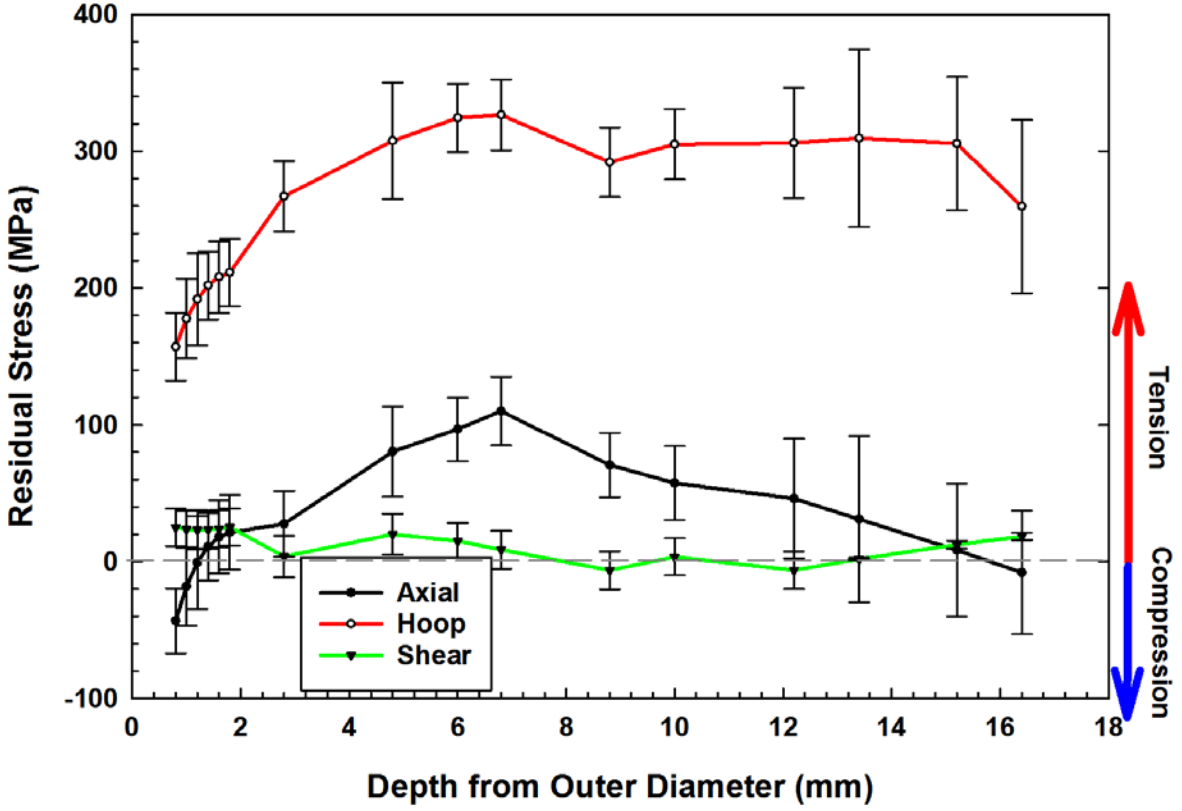
- iCHD used to assess stress state in region very close to the surface of the container (on the OD)



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

Residual Stresses in Circumferential Weld (Centerline)

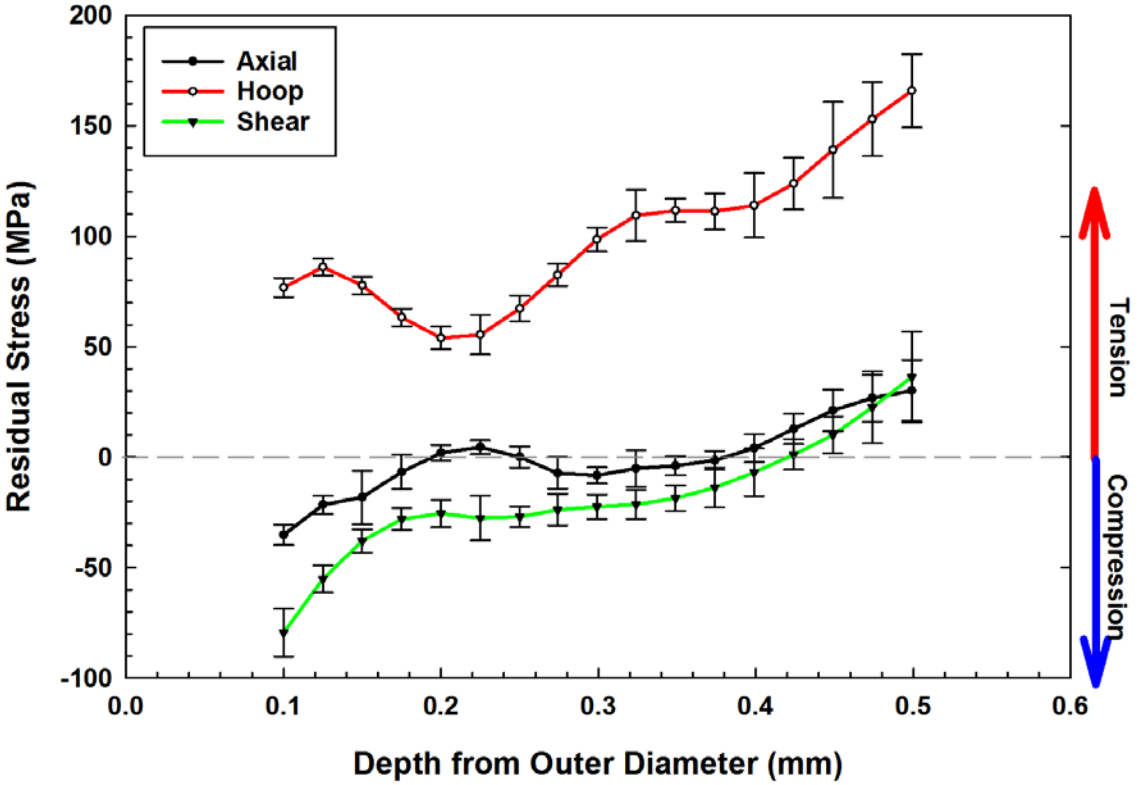
- Due to large stresses present in weld, material will yield as the core is cut for traditional DHD – as a result, incremental DHD measurements are made



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

Residual Stresses in Circumferential Weld (HAZ)

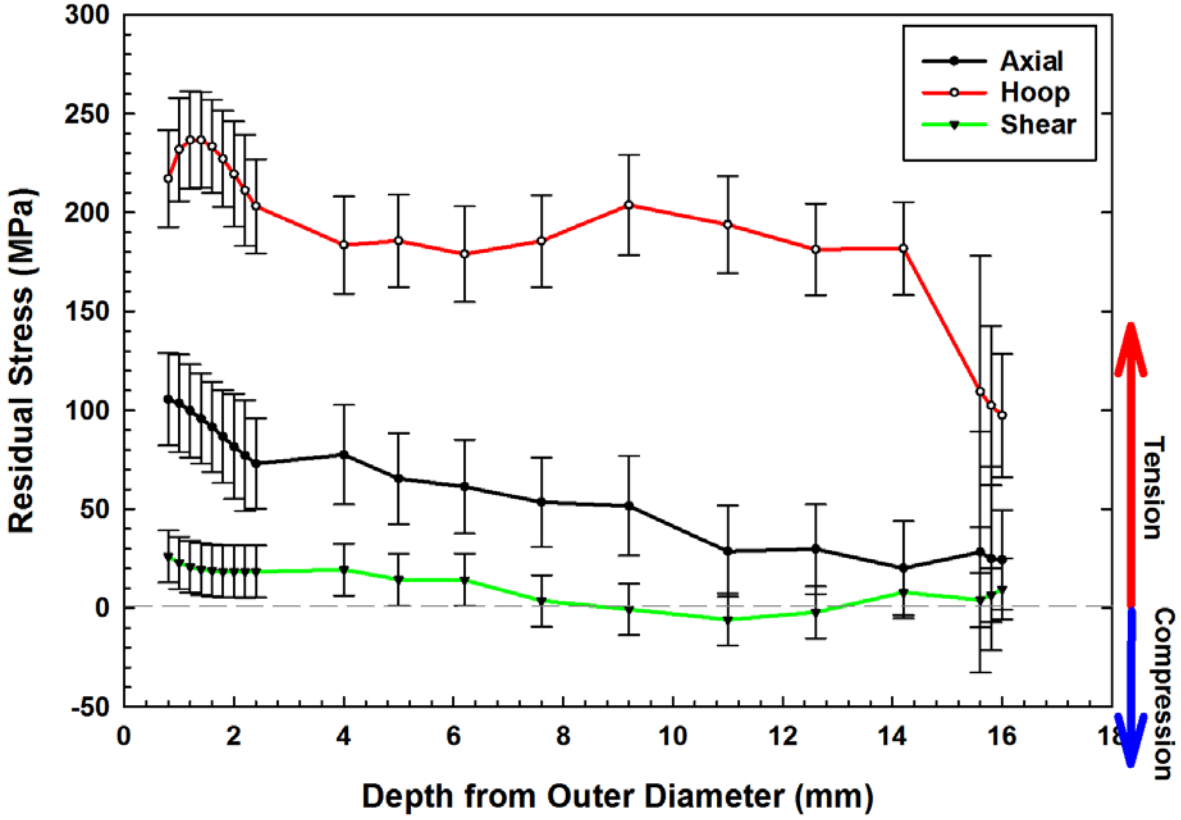
- Looking at 4mm from weld toe
- iCHD used to assess stress state in region very close to the surface of the container (on the OD)



- 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)

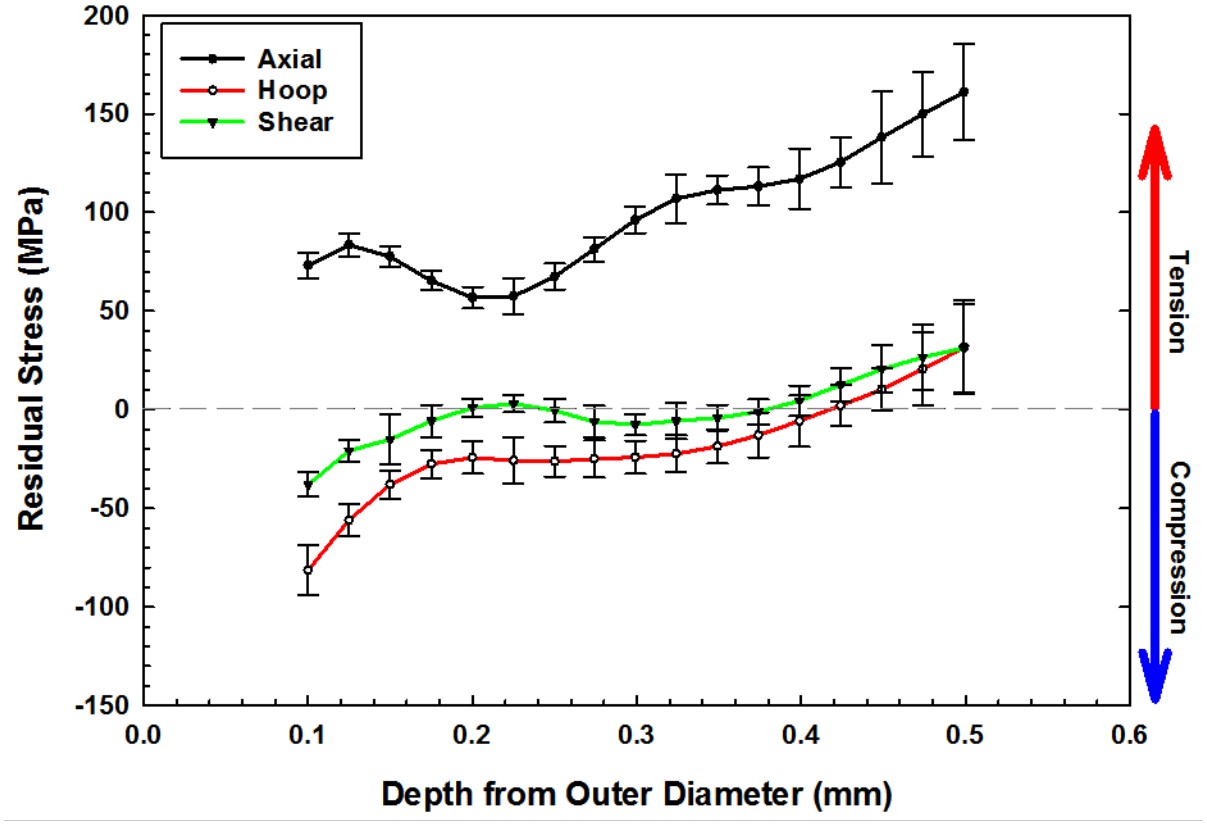
- Due to large stresses present in weld, material will yield as the core is cut for traditional DHD – as a result, incremental DHD measurements are made



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

Residual Stresses in Longitudinal Weld (Centerline)

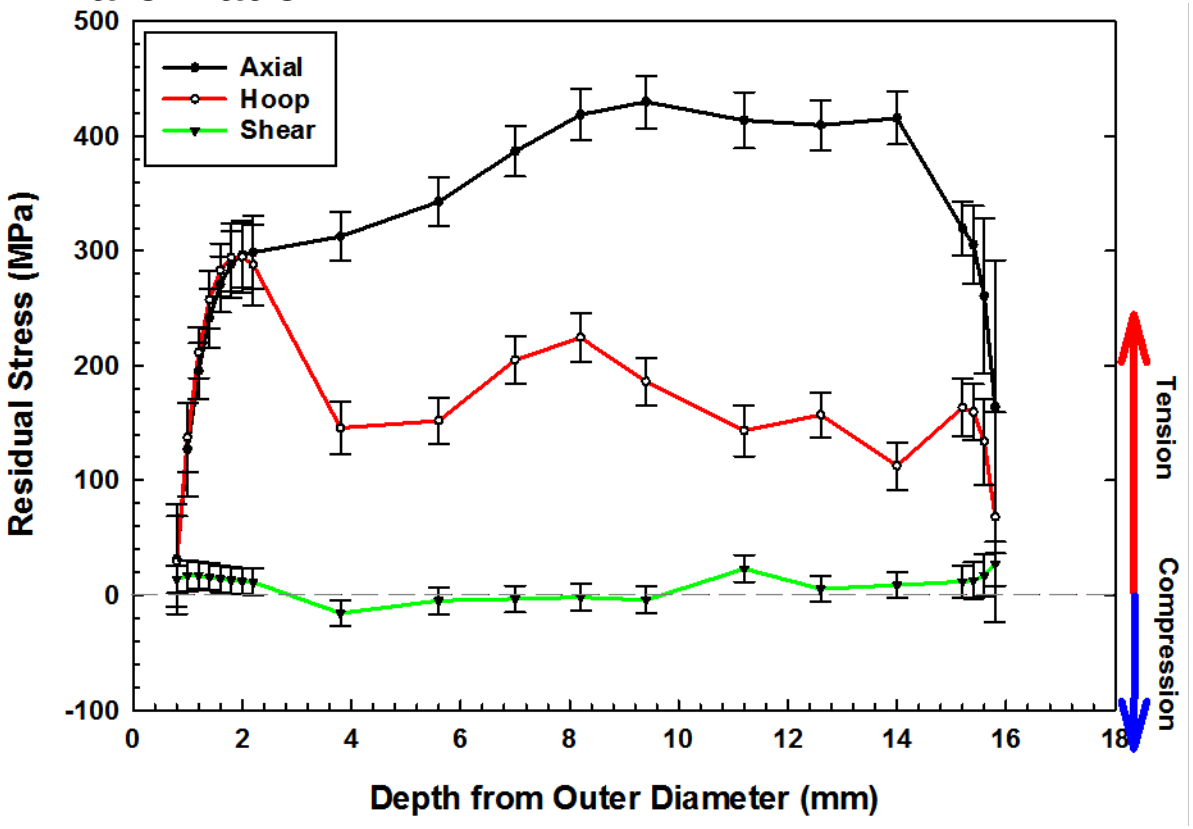
- iCHD used to assess stress state in region very close to the surface of the container (on the OD)



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

Residual Stresses in Longitudinal Weld (Centerline)

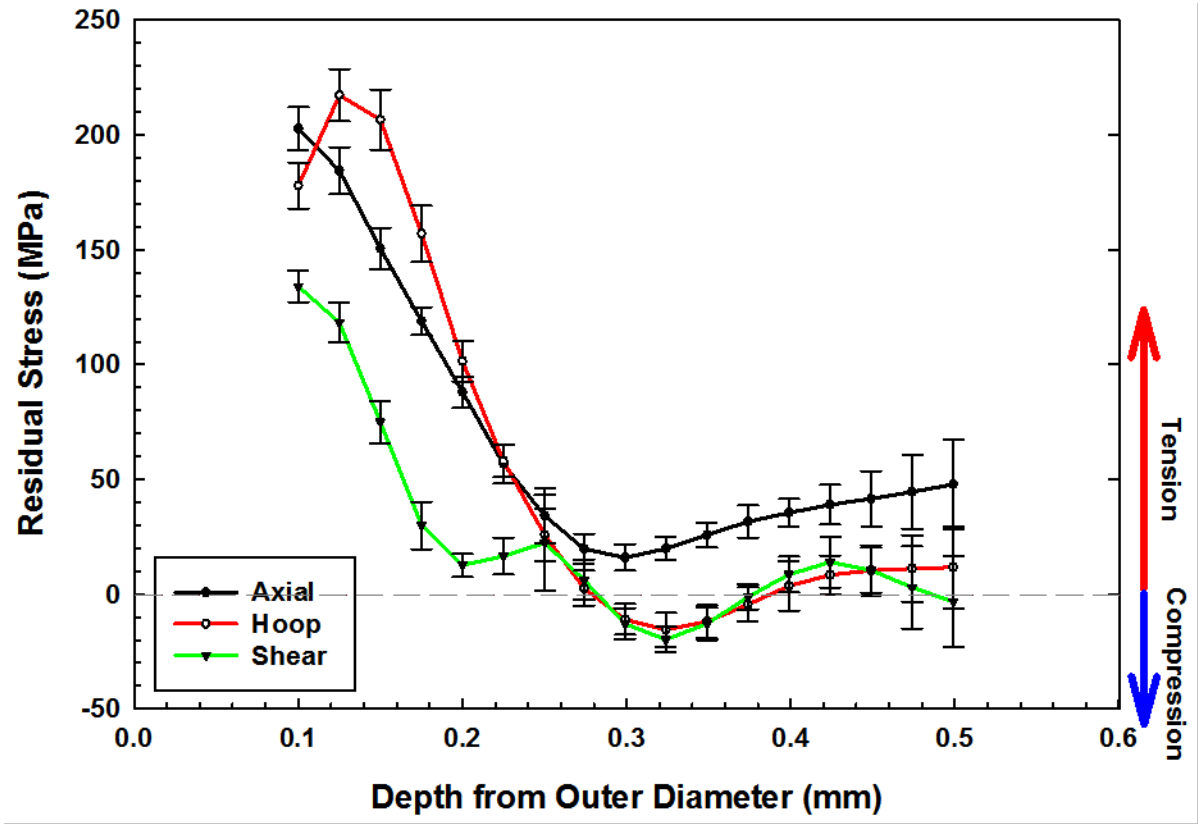
- Due to large stresses present in weld, material will yield as the core is cut for traditional DHD – as a result, incremental DHD measurements are made



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

Residual Stresses in Longitudinal Weld (HAZ)

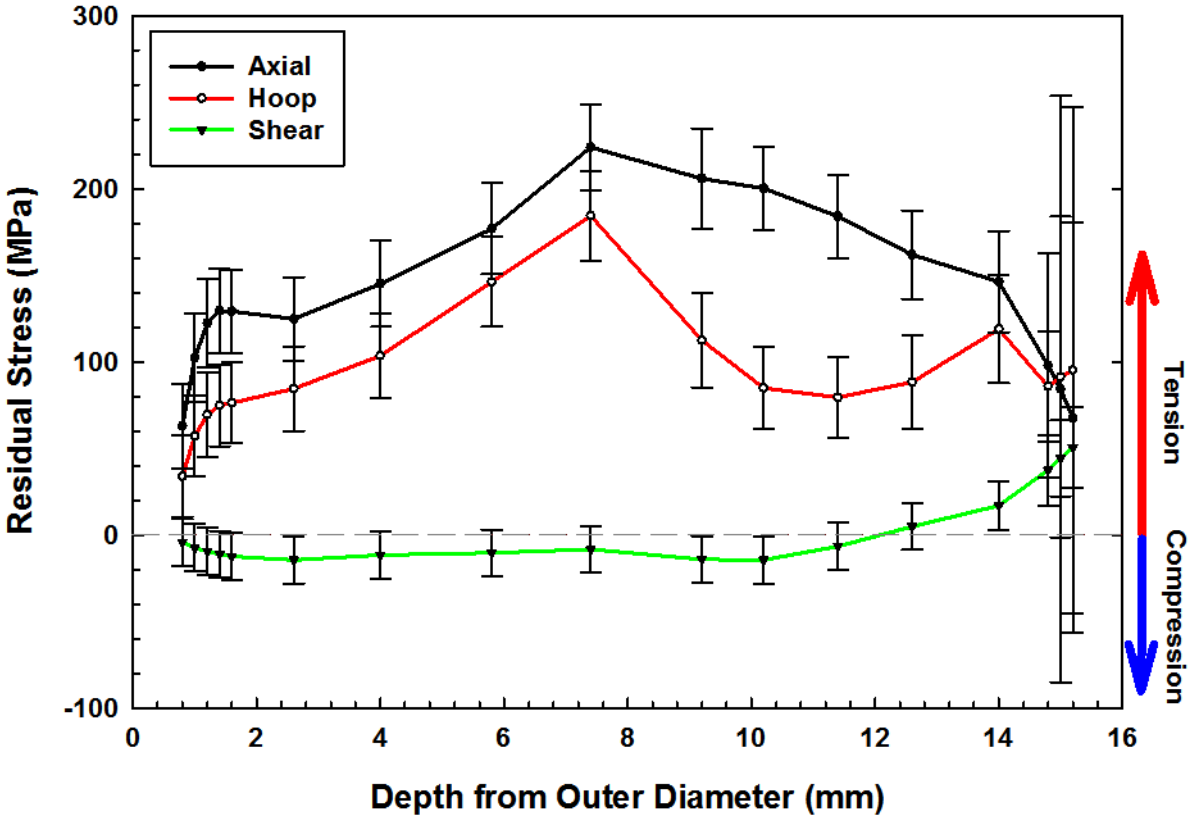
- Looking at 4mm from weld toe
- iCHD used to assess stress state in region very close to the surface of the container (on the OD)



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

Residual Stresses in Longitudinal Weld (HAZ)

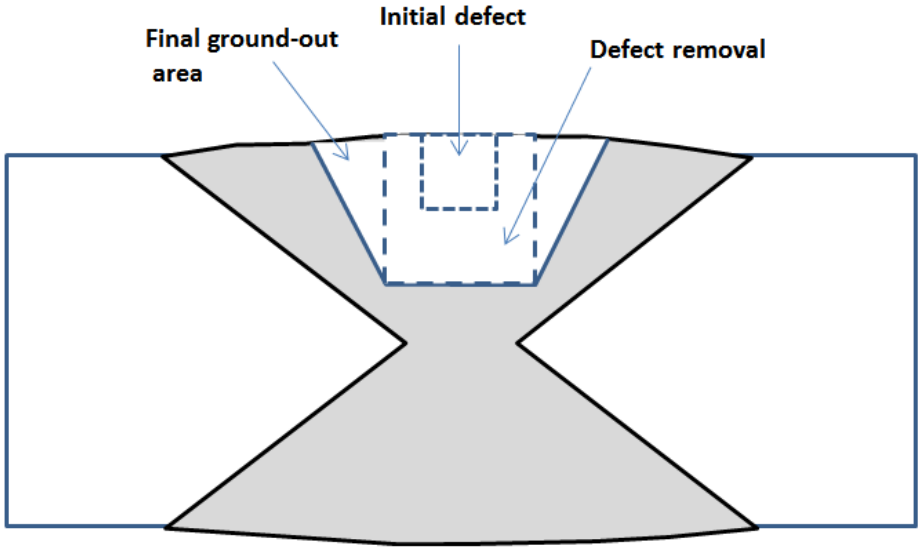
- Due to large stresses present in weld, material will yield as the core is cut for traditional DHD – as a result, incremental DHD measurements are made



- 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

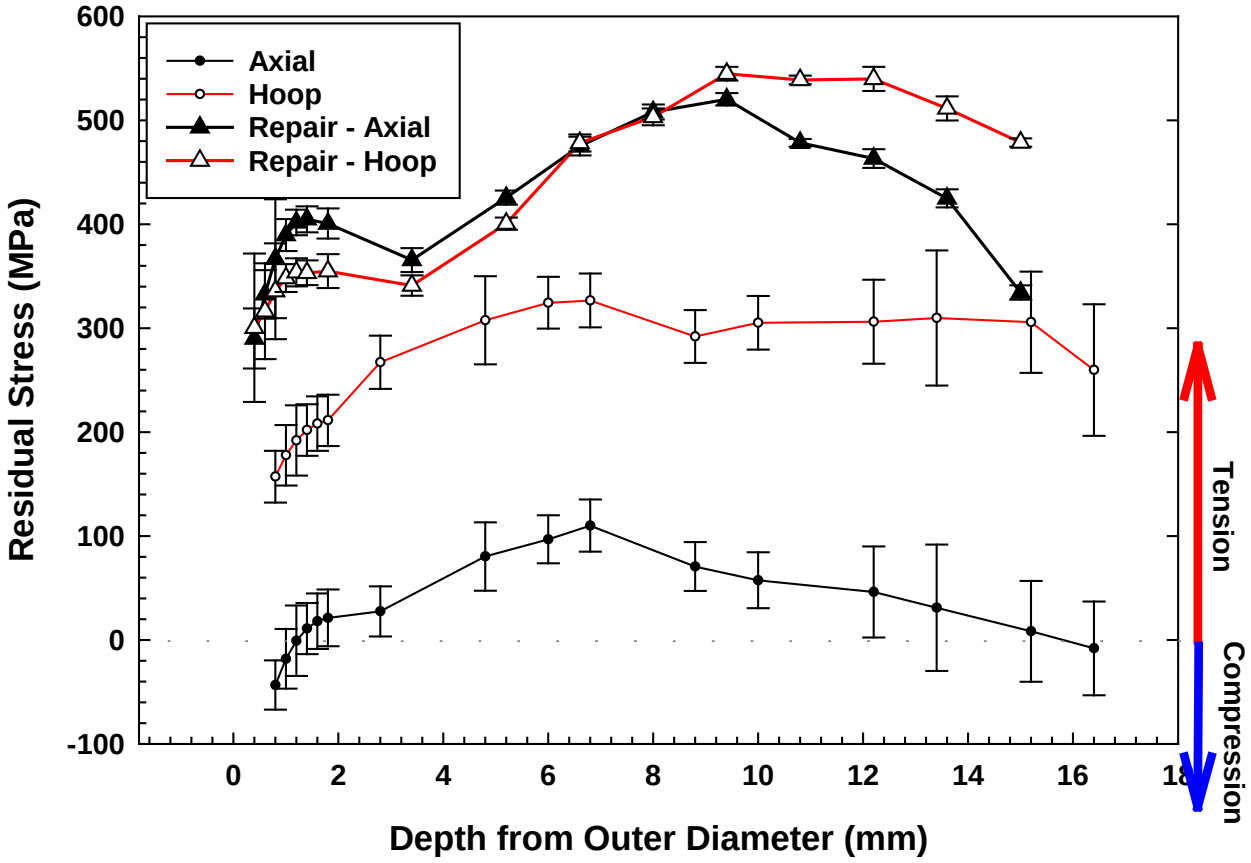
- Welds were fabricated via submerged arc welding using a well defined protocol/schedule – very low defect density
- Manufacturer (Ranor) created a repair typical for this type of weld (simulating a local defect due to entrained slag at a weld stop/start point, etc.)
- mock defect into the container 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 ¼” 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.



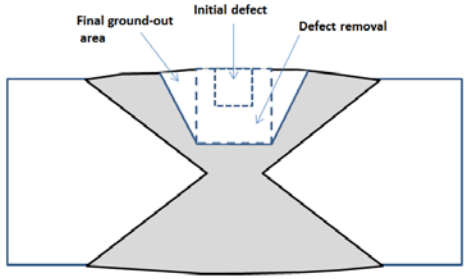
Used Fuel Disposition

Residual Stresses in Repair: Circumferential Weld (Centerline)

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

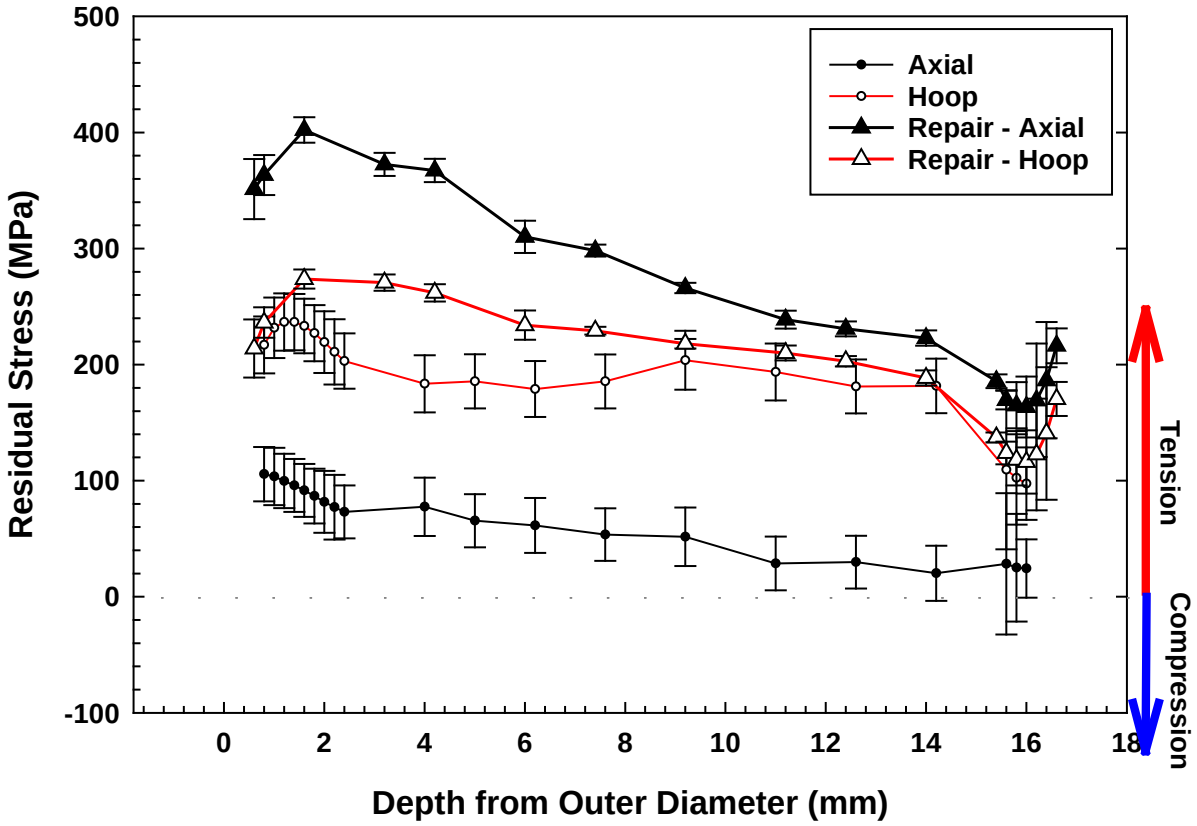


- ***DHD near surface, iDHD in bulk***
- ***Both axial and hoop stresses dramatically increased in weld repair***

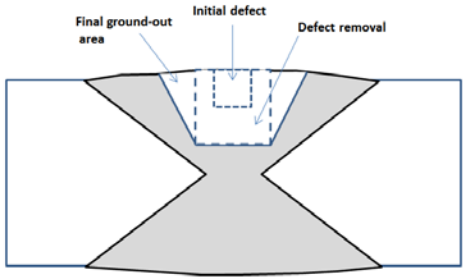


Residual Stresses in Repair: Circumferential Weld (HAZ)

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

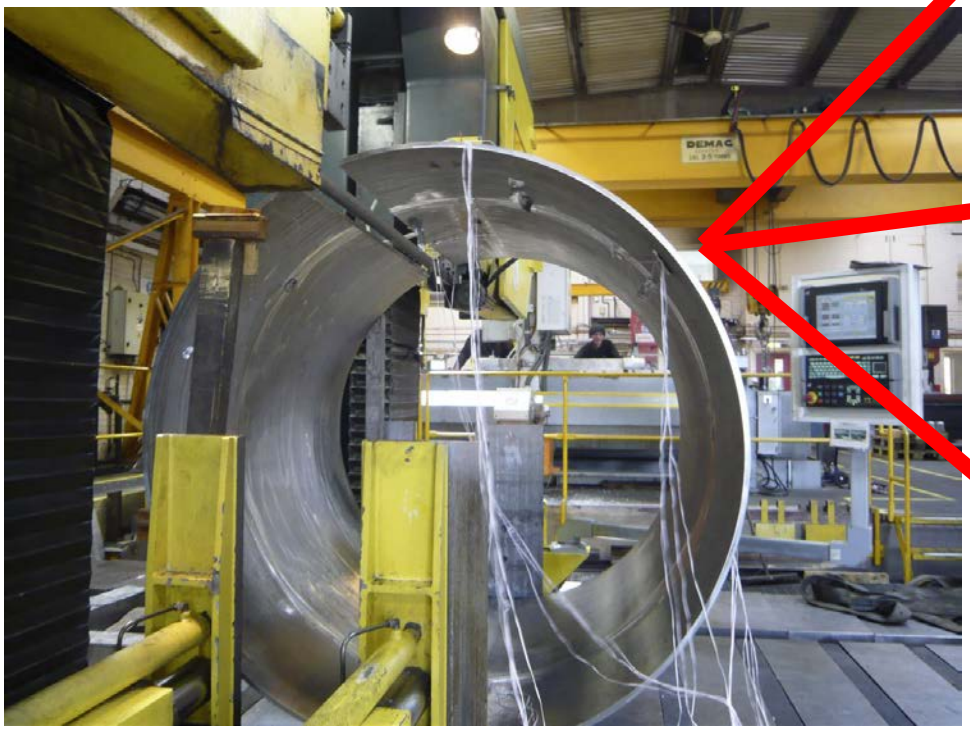


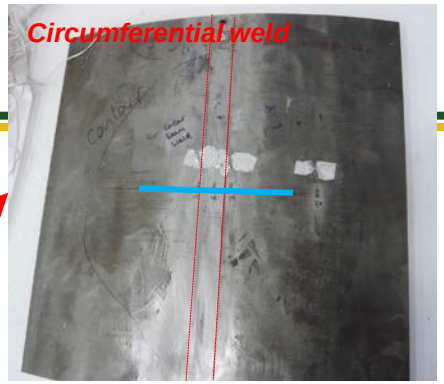
- ***4mm from weld toe***
- ***DHD near surface, iDHD in bulk***
- ***Hoop stress increased in region of weld repair***
- ***Axial stress dramatically increased in weld repair***
- ***Less significant increase in hoop stress at ID, but axial stress is elevated***

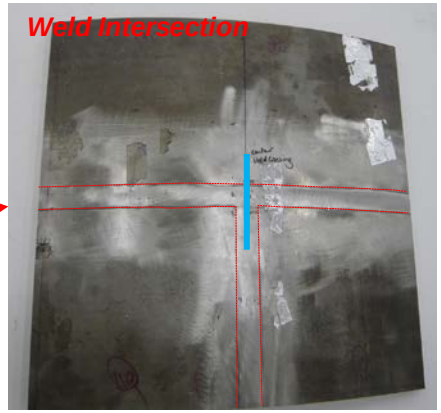


Sectioning of the Mock-Up

- **Mockup sectioned for contour measurements.**
  - Provide map of residual stresses
  - EDM cutting complete, Measurement in progress

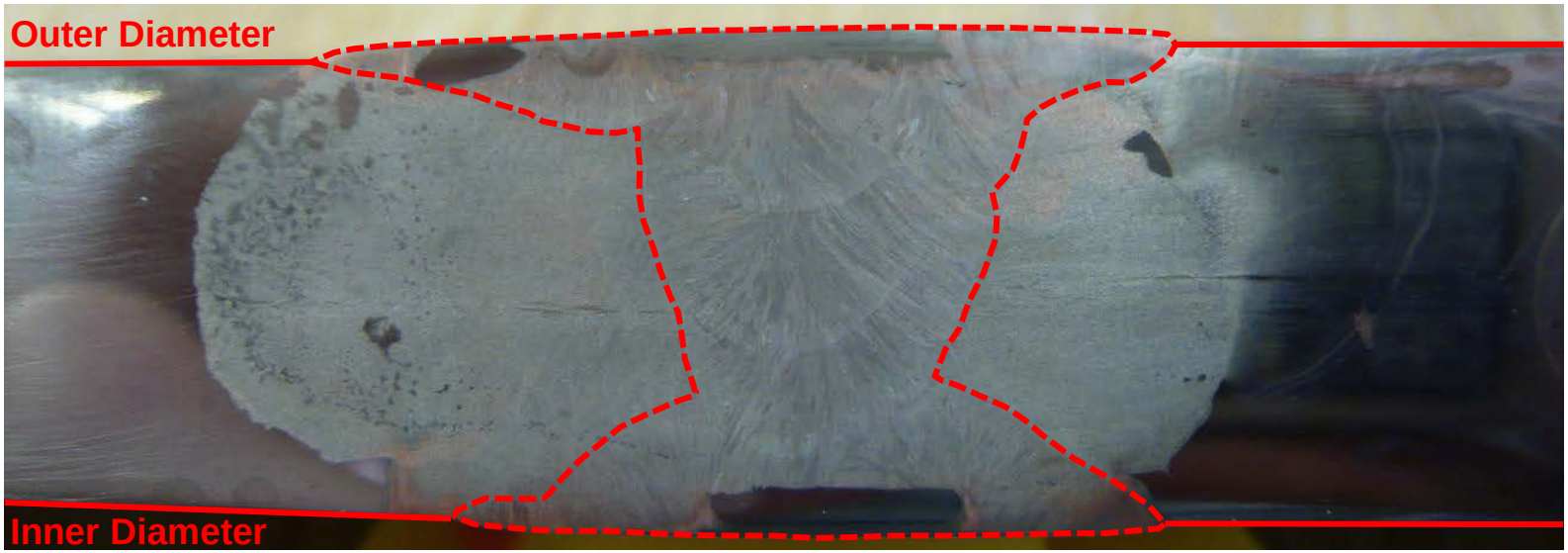




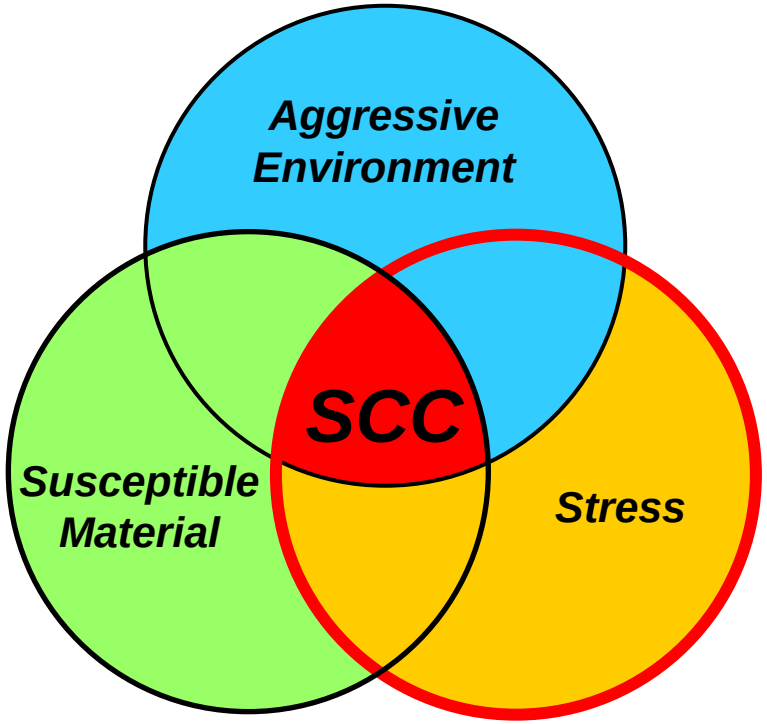


Circumferential Weld Cross Section

- 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