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Tritium Effects on Mechanical Properties of Austenitic Stainless Steels

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Department of Energy Tritium Focus Group

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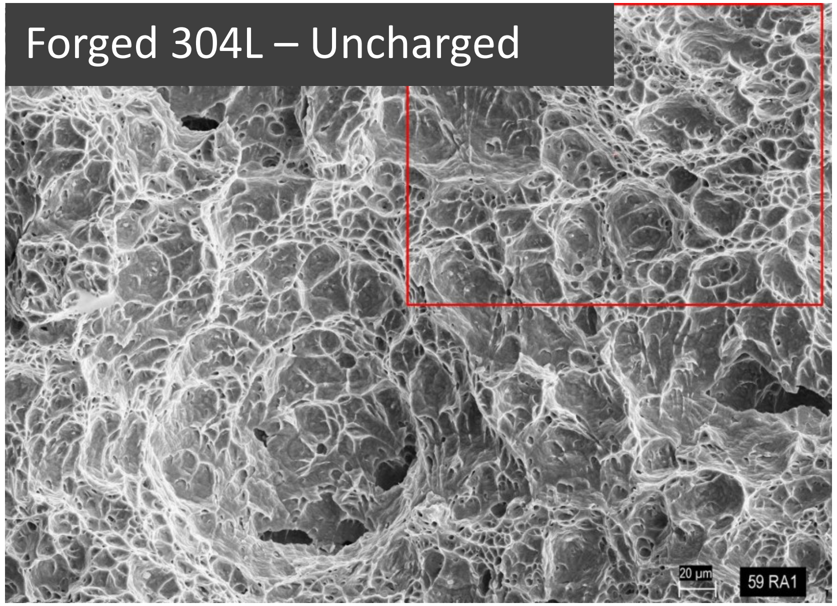
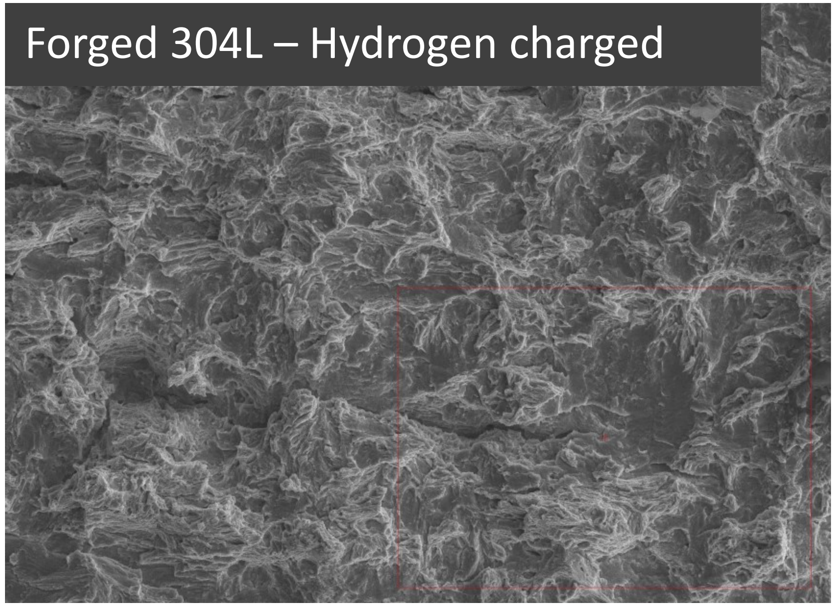
Why Austenitic Stainless Steel for Tritium Service?

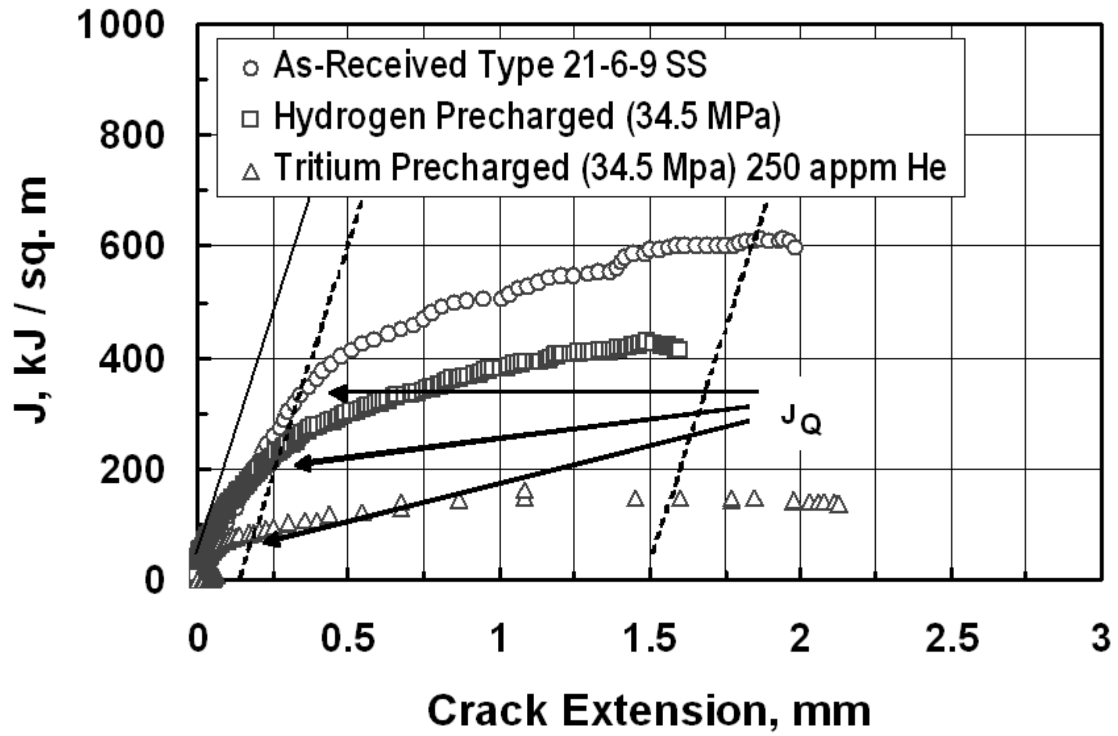
- High strength and ductility for structural components and pressure boundaries
- Austenitic SS is highly resistant to hydrogen isotope embrittlement
  - Not immune though

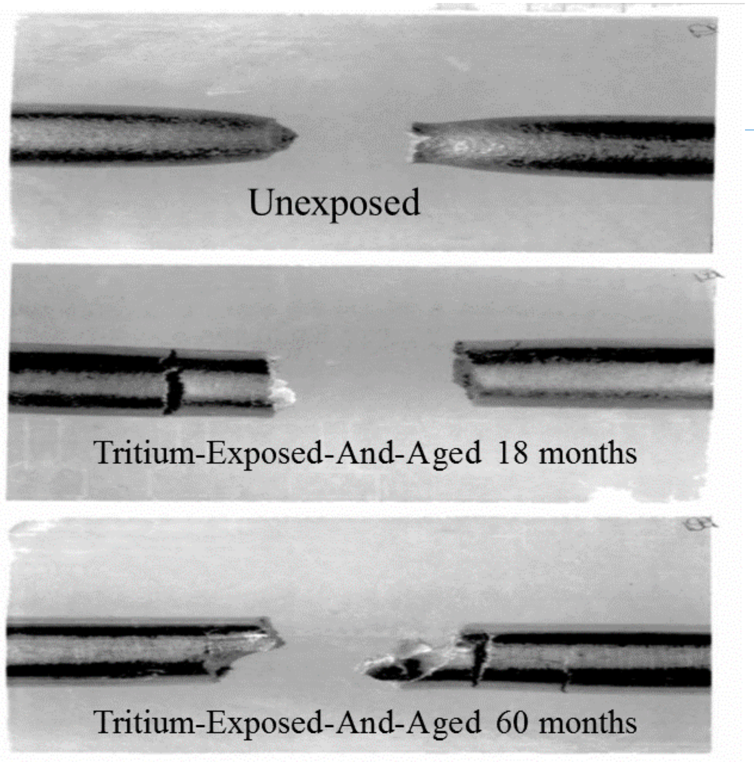




Why Mechanical Properties?

- Austenitic SS is not immune to embrittlement
- Mechanical testing data aids material development and models for system design

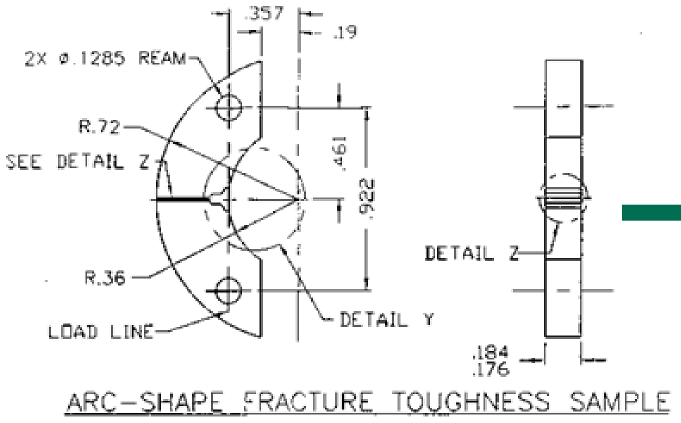


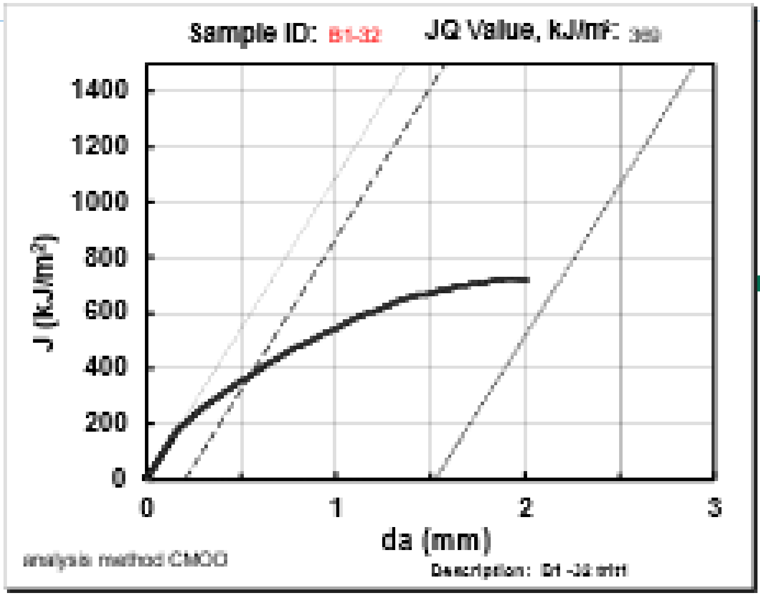


Rawl, D. (1979). Savannah River Laboratory notebook.

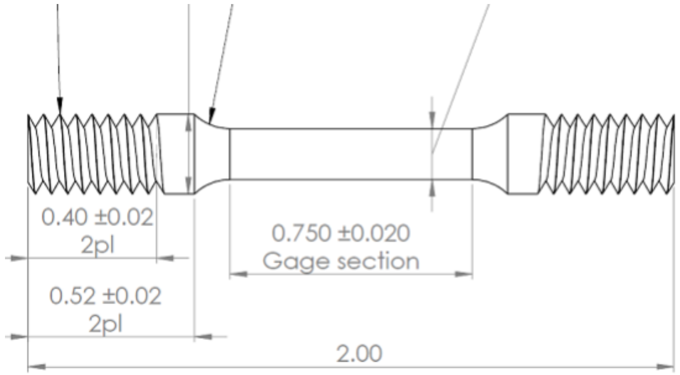
Morgan, M. J., et al. (2007). Tritium Aging Effects on Fracture Toughness of Type 21-6-9 Stainless Steel WSRC-TR-2007-00479. Savannah River Site, Aiken, SC, USA, Savannah River National Laboratory, Washington Savannah River Company.

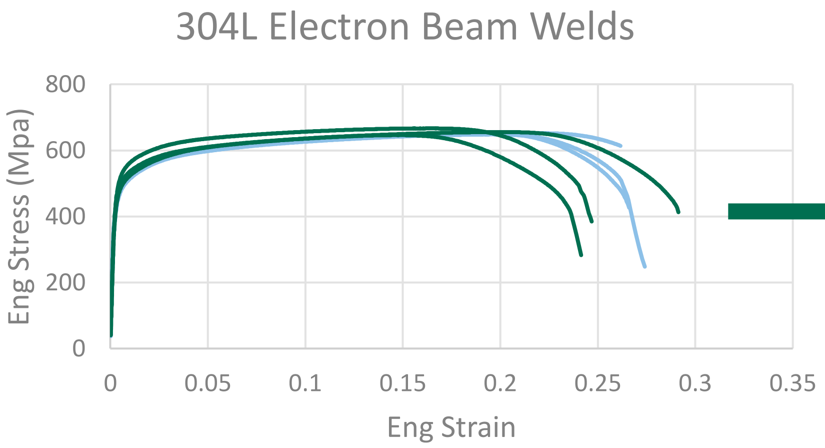
Fracture mechanics and tensile testing





Fracture Resistance (J_Q)

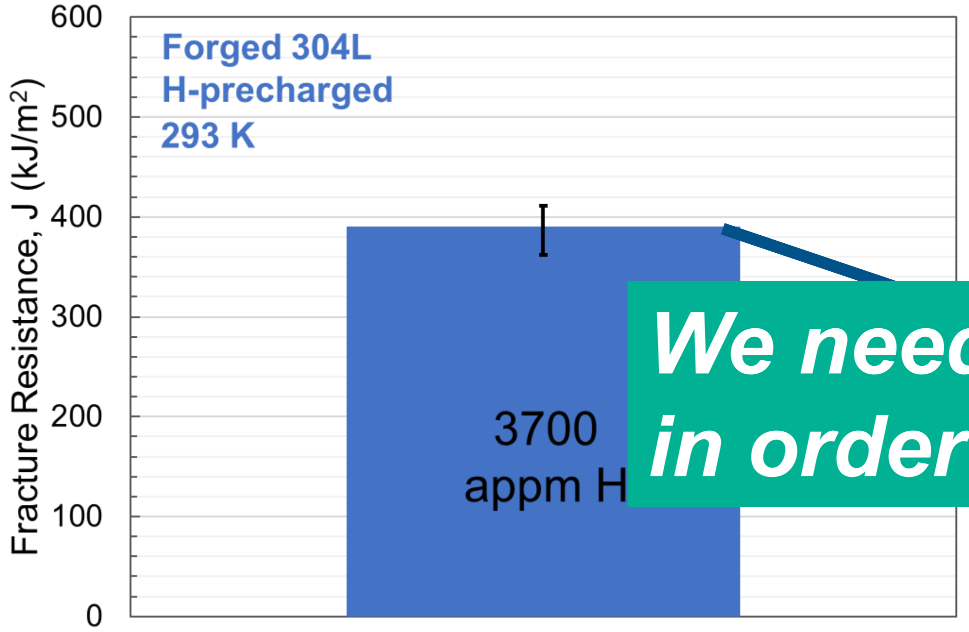




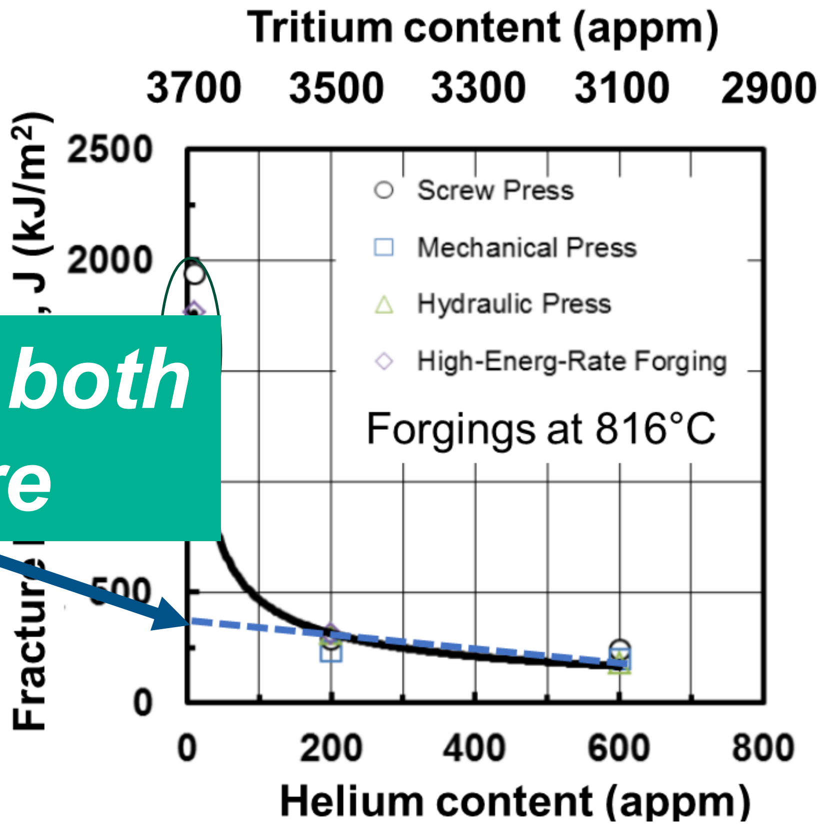
Yield Strength
Ultimate Tensile Strength
Elastic Modulus
Reduction of Area

Fracture resistance of hydrogen charged vs tritium charged

Aging is due to **hydrogen-isotope embrittlement** *AND* **helium bubble** hardened microstructure



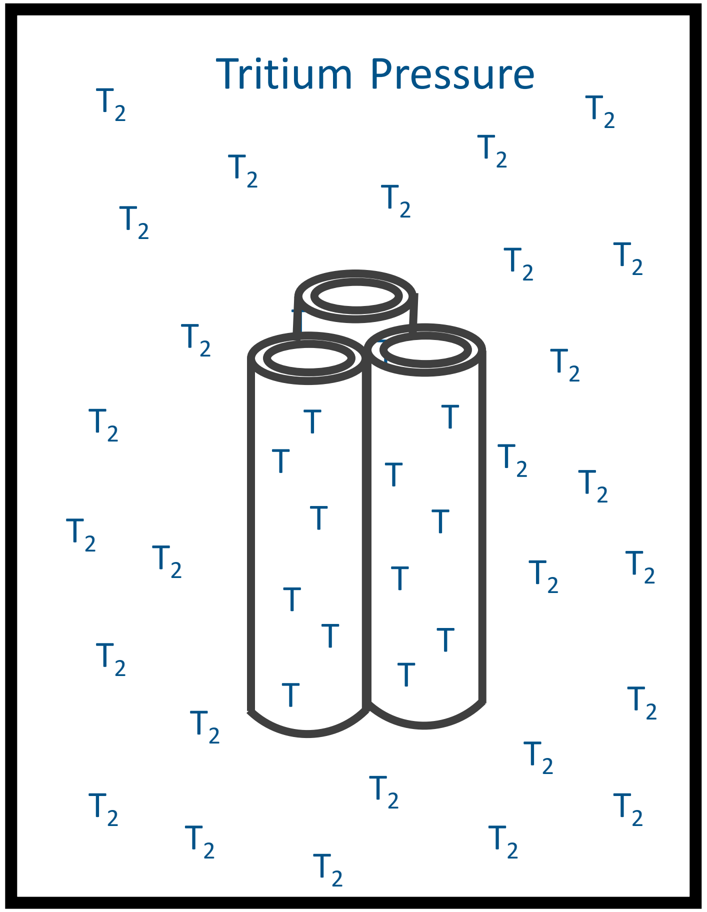
We need to understand both in order to predict failure



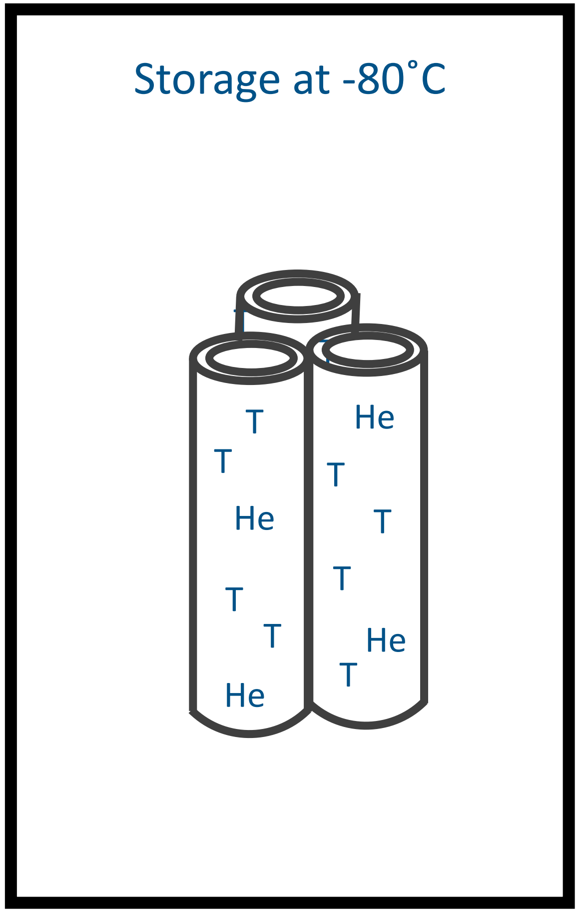
Morgan. (2016). International Hydrogen Conference. Jackson, WY.

- **Initial loss of fracture resistance** is largely due to H-isotope
- Further degradation due to born-in helium

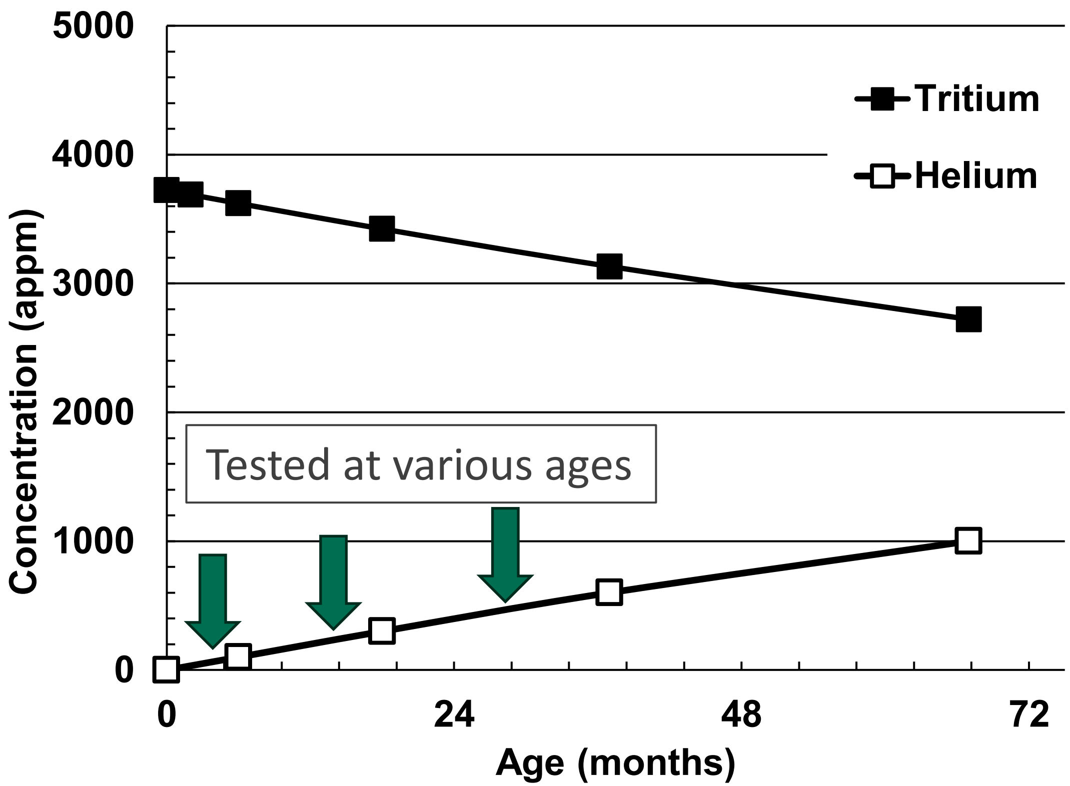
Tritium charging and aging enables control of helium content



T-charging

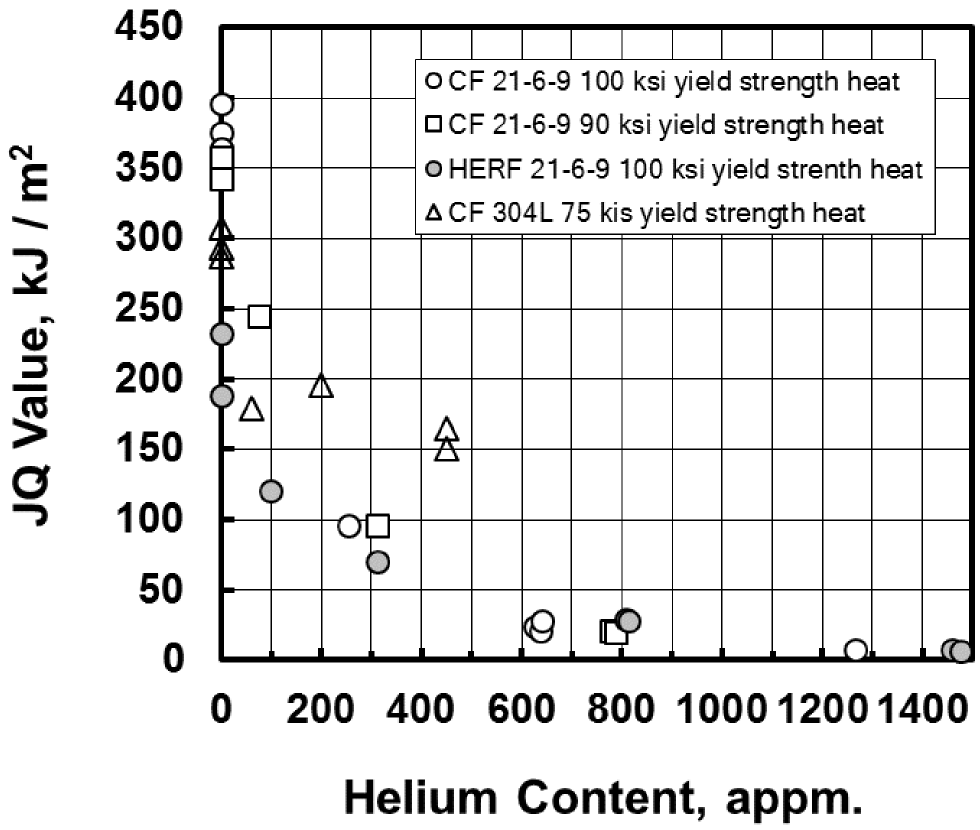


Low-temperature aging

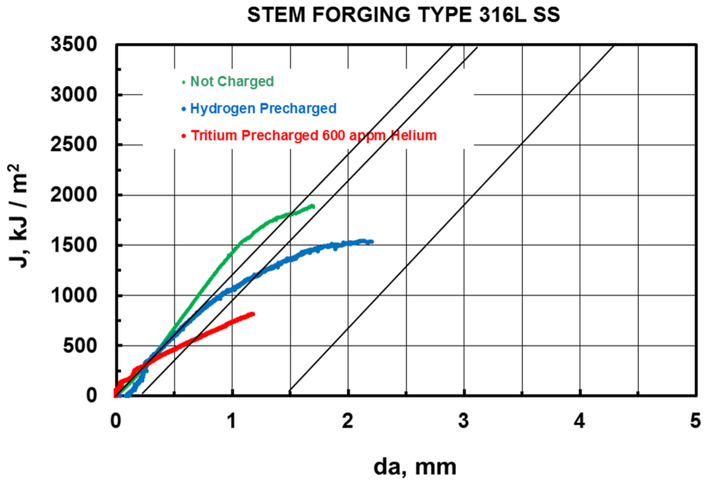


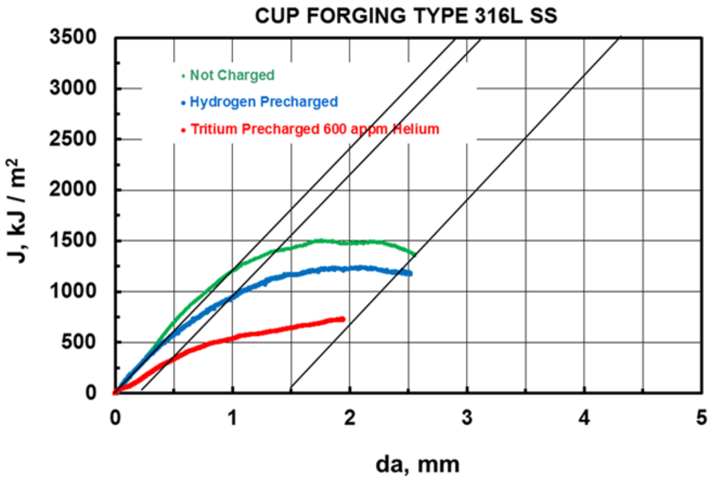
Helium increases as T decays

SRNL has been studying tritium effects on structural materials for more than 30 years



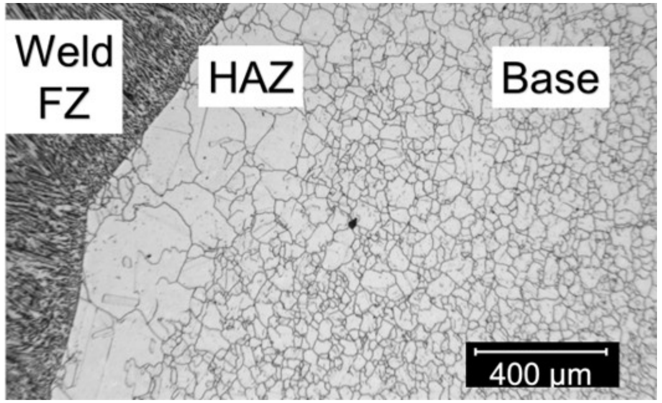
- Fabrication processes (forging, welds, etc.)
- Alloys (21-6-9, 316L, 304L, Inconel, Hastelloy)
- Helium bubble imaging



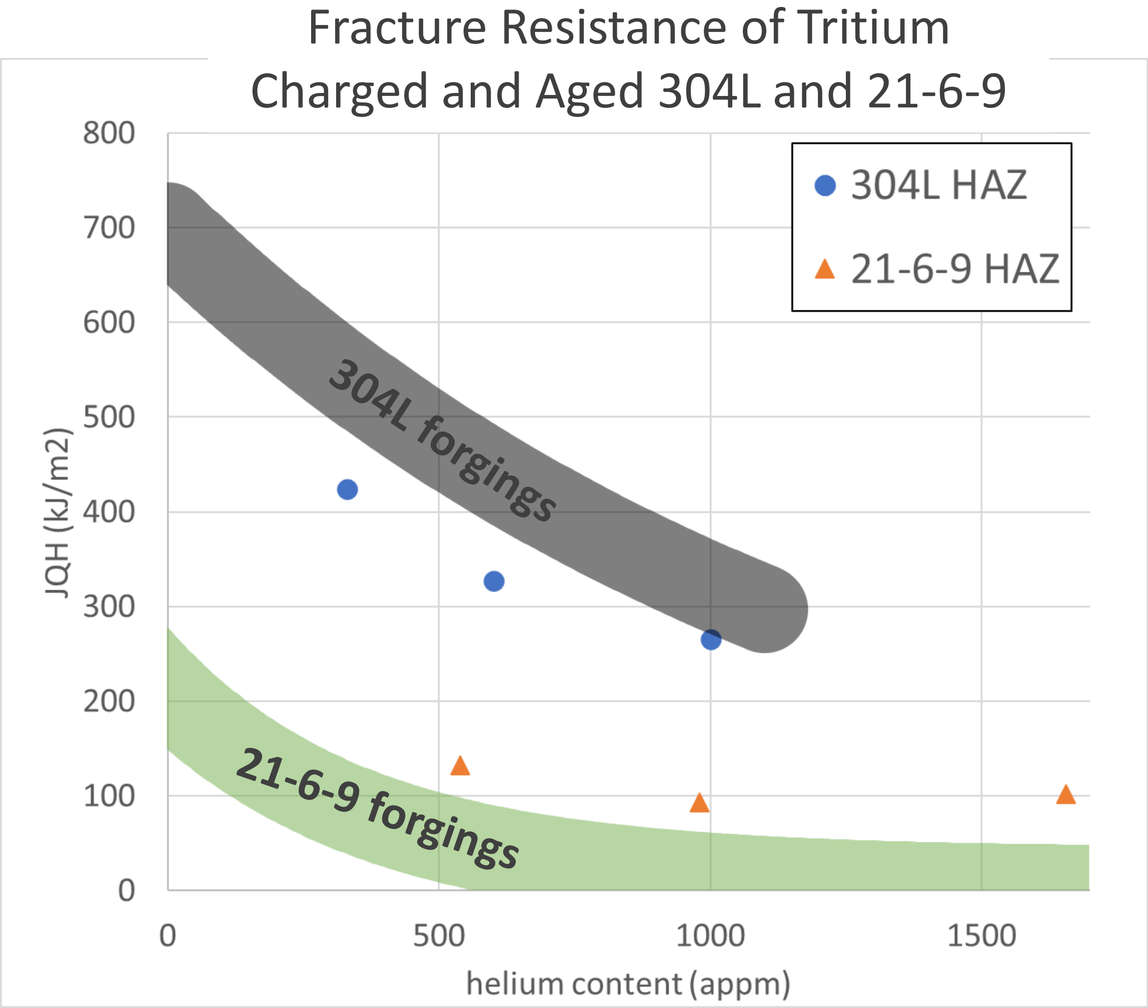


Heat affected zones of GTA welds in 304L and 21-6-9 behave more like forged material

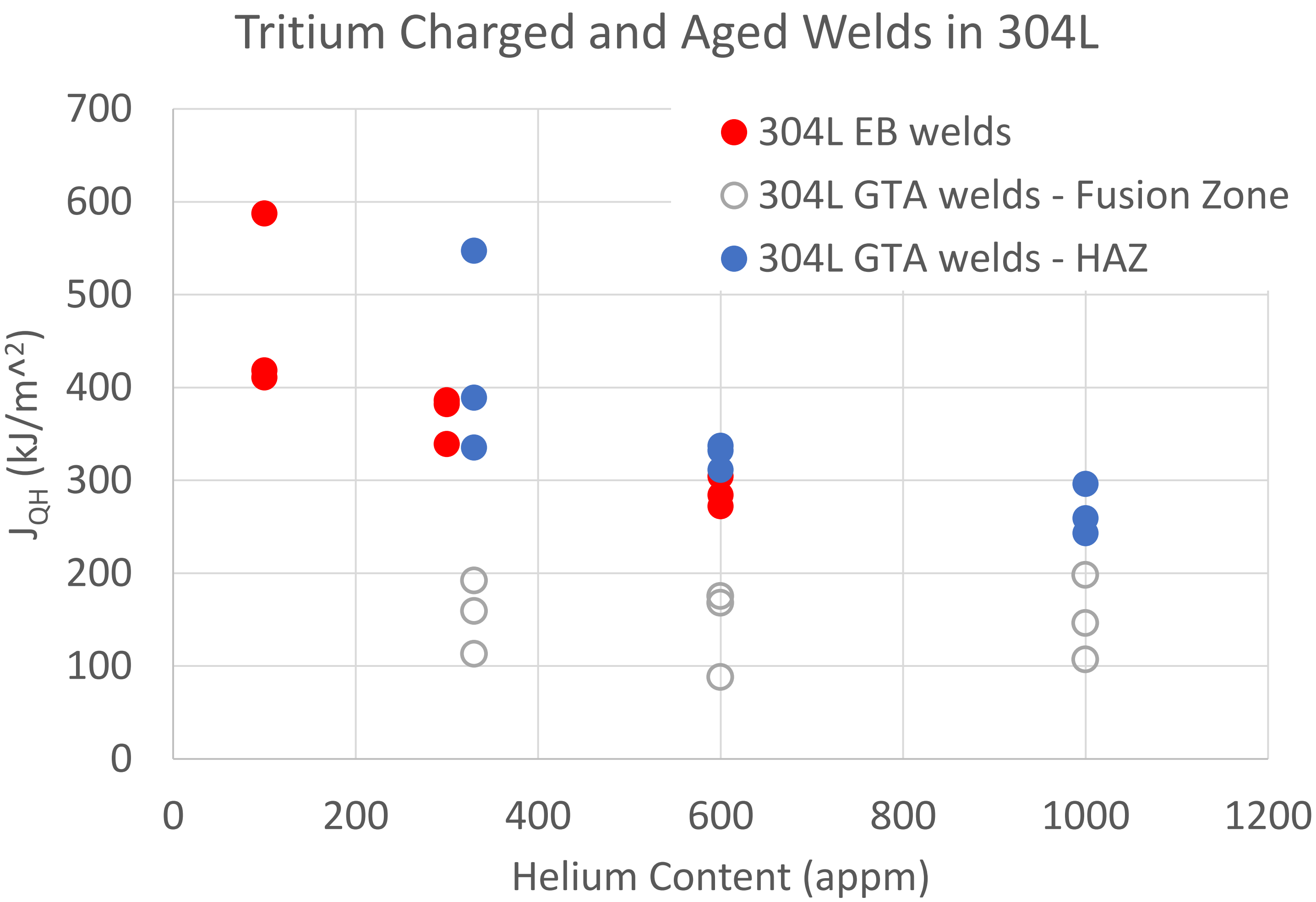
- Welds may be more susceptible to cracking upon tritium exposure
- Fracture resistance follows trend of forged material, despite microstructural similarities with annealed material



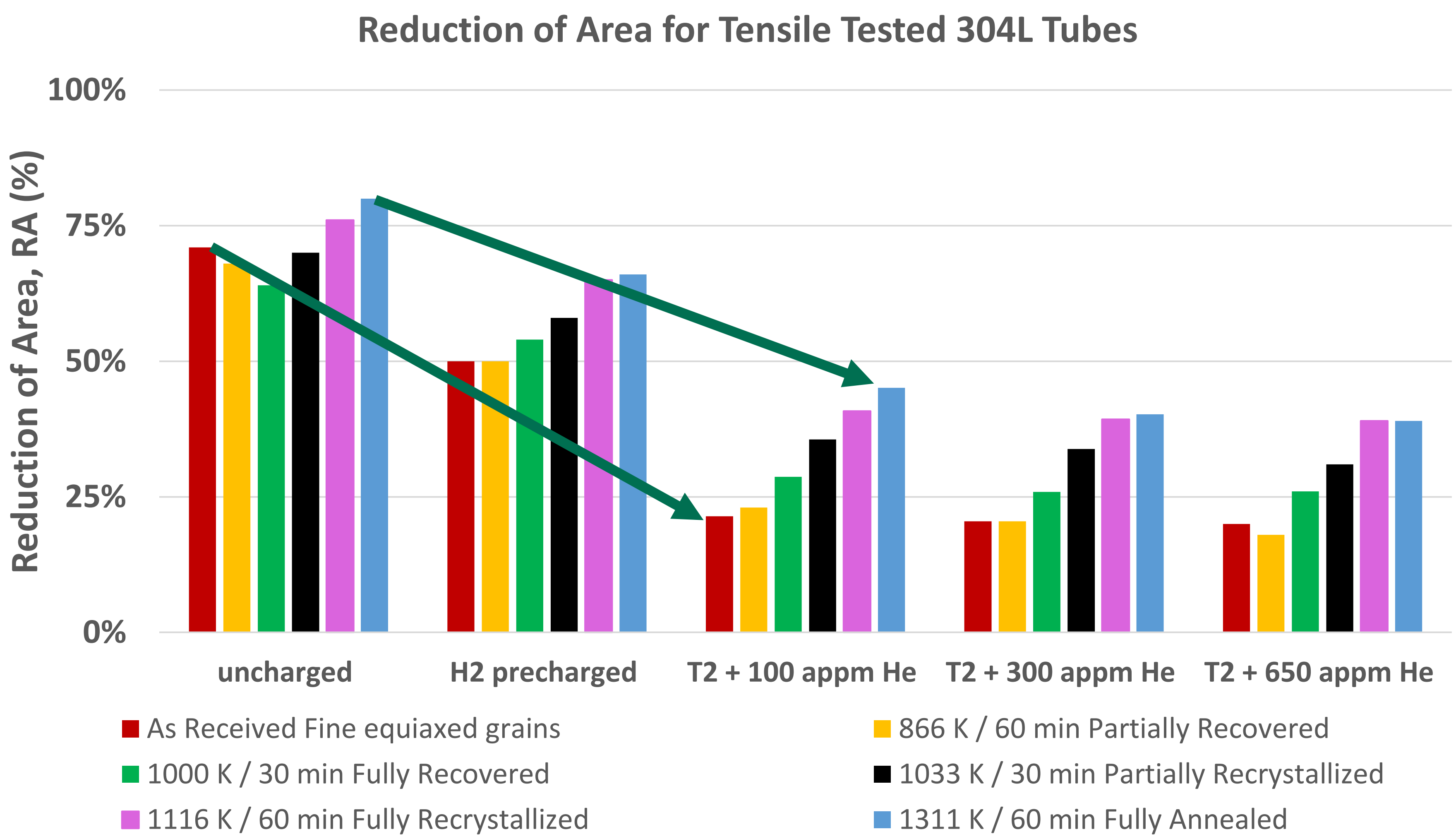
- Welds and HAZ should be tested along with base material



Electron-beam welds in 304L fare better than GTA welds

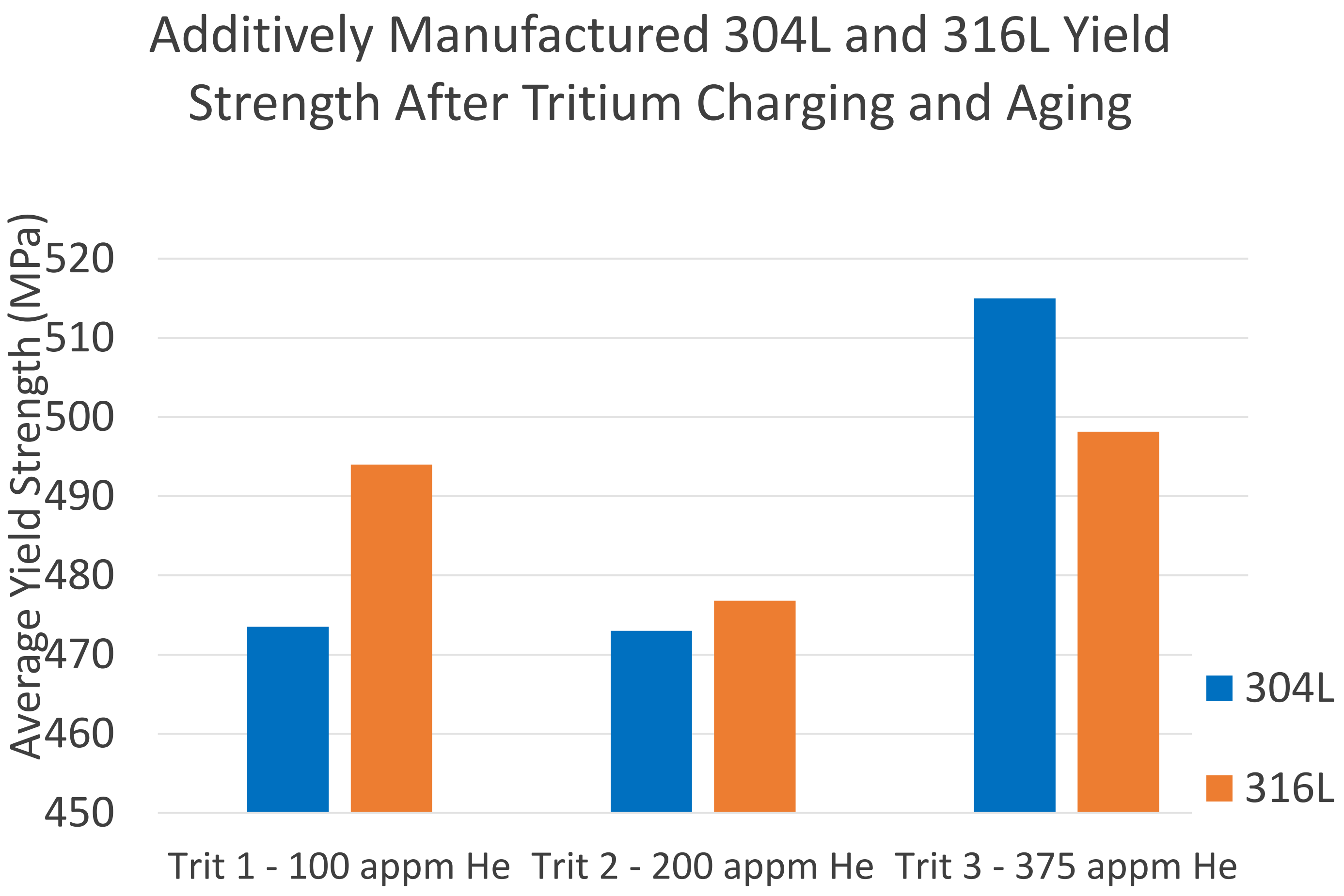


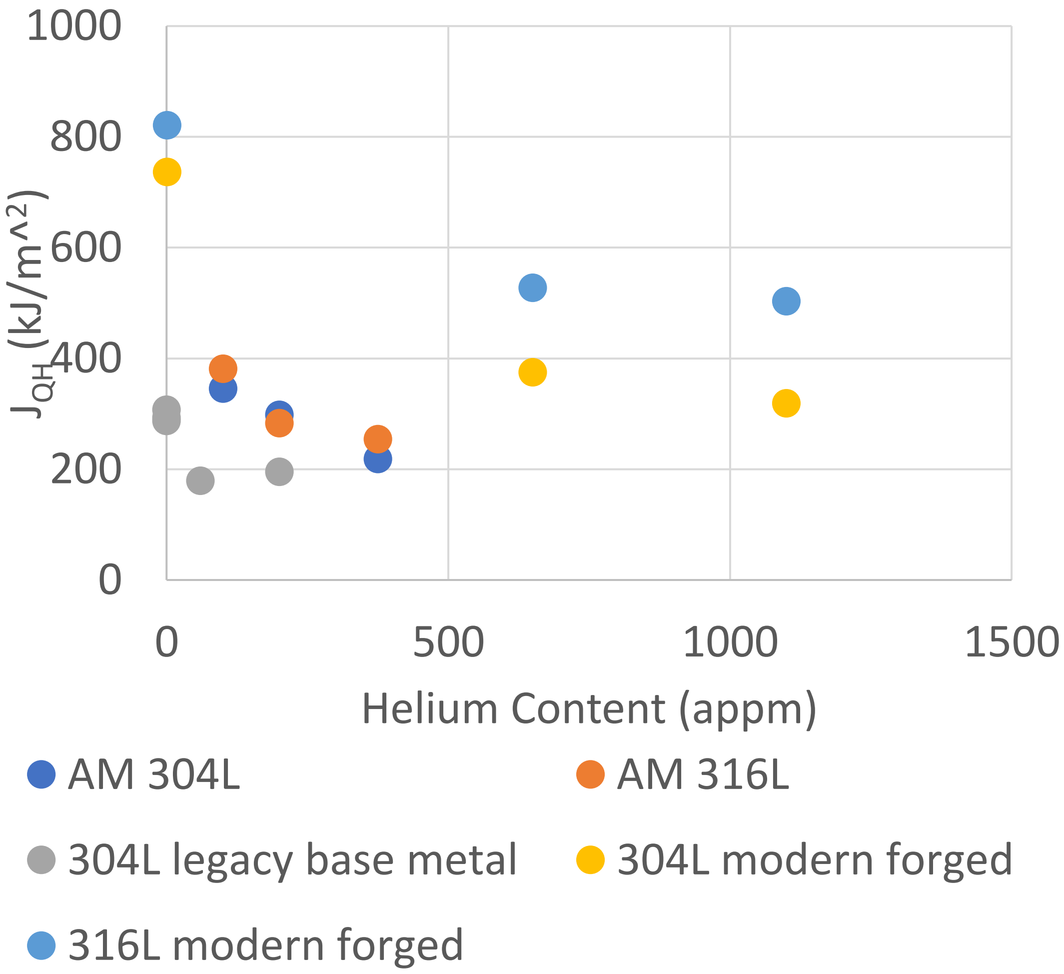
304L tube ductility loss after tritium aging depends on initial strength



- Tubes decrease in strength from as-received to annealed
- Higher strength microstructures see greatest loss in ductility from noncharged to tritium charged/aged

AM 304L and 316L both experience hardening and decreasing fracture resistance with increasing He contents





Acknowledgements

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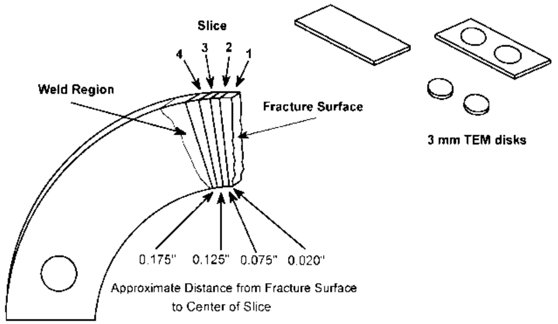
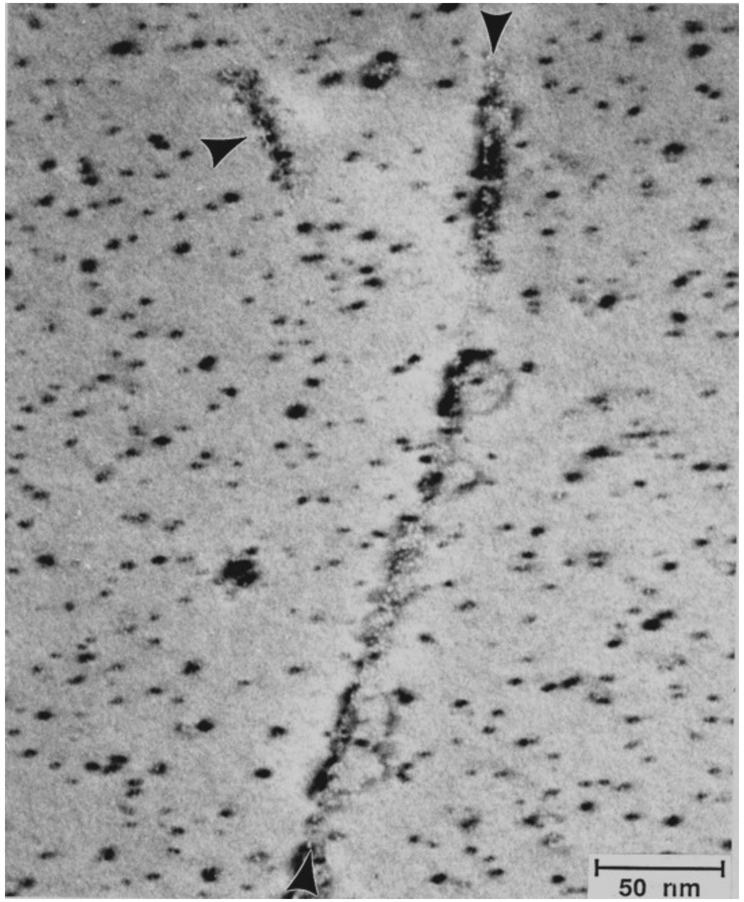
Emanuel Perez
Henry Ajo

TEM of Helium Bubbles



TEM Discs Cut, Punched, and Thinned From Near Fracture Region

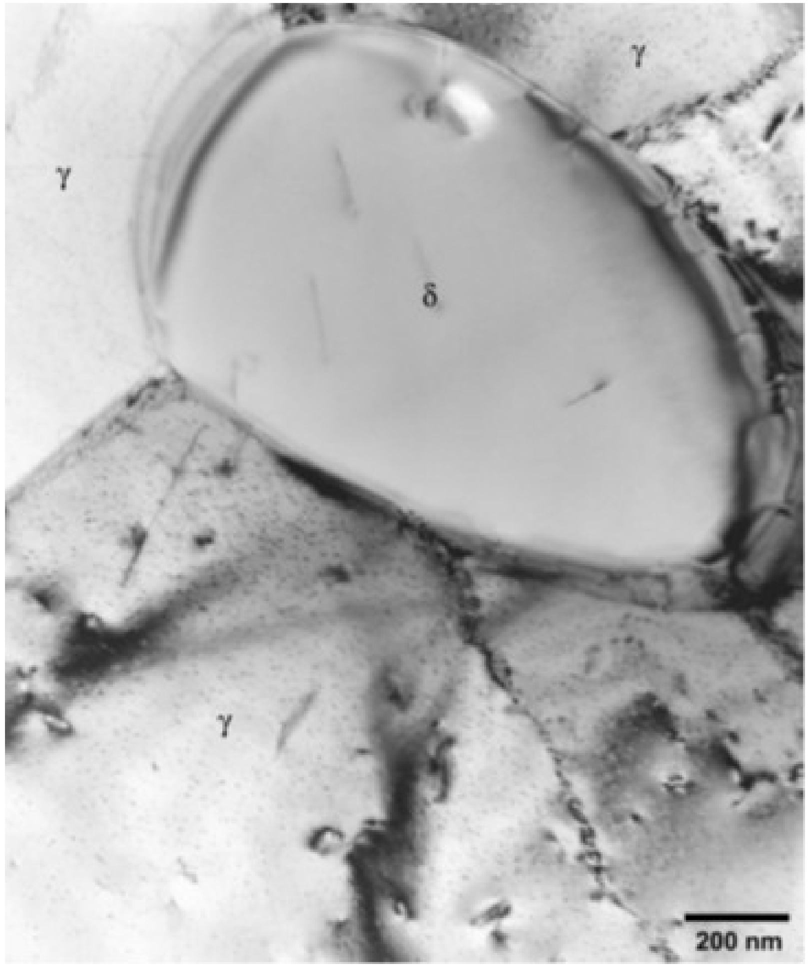
Nanometer sized bubbles randomly distributed and clustered on defects



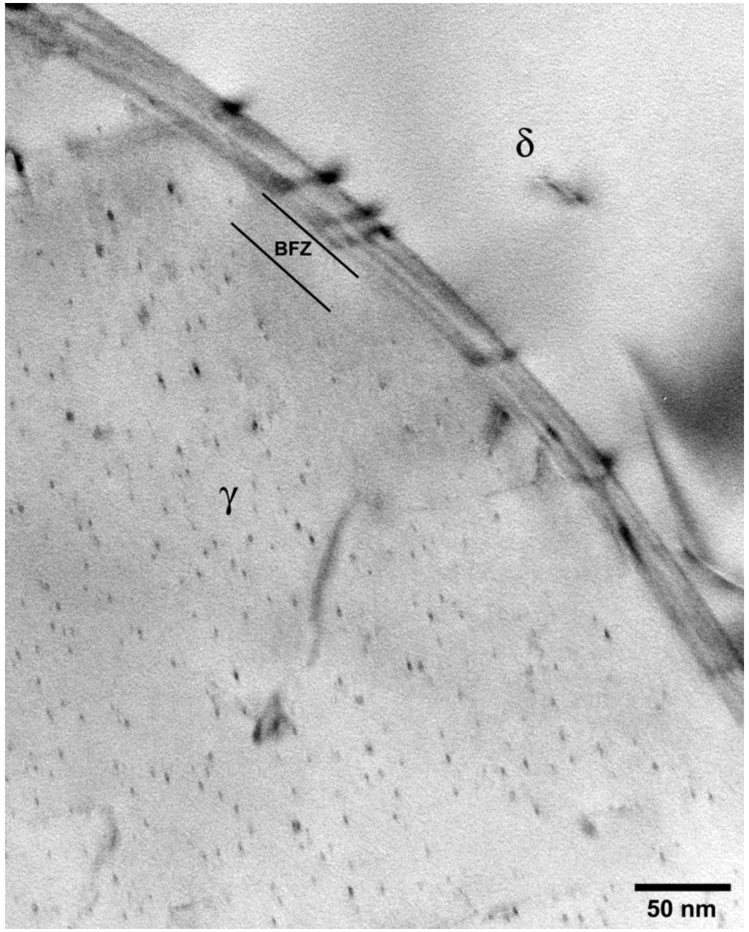
Decay Helium Bubbles Observed on Grain Boundary after Plastic Deformation

Tosten, M. H. and M. J. Morgan (2009). *Transmission Electron Microscopy Study of Helium Bearing Fusion Welds.* 2008 Int. Hydrogen Conf. - Effect of Hydrogen on Materials, Materials Park, OH, ASM International.

Decay Helium Bubbles Difficult to Resolve in Forged Steels



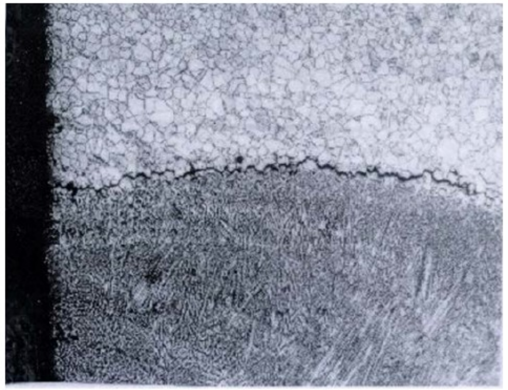
Helium Bubbles Resolved in Austenite of Weldment But Not in Ferrite



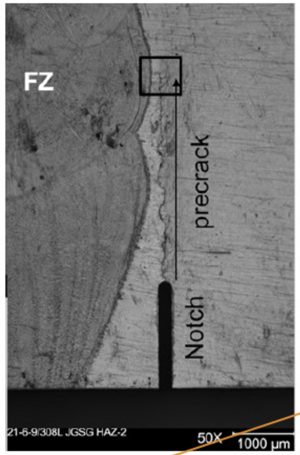
Grain boundary between austenite and ferrite. Bubbles were not observed on these type boundaries. A bubble-free zone exists in the near the boundary region in this image.

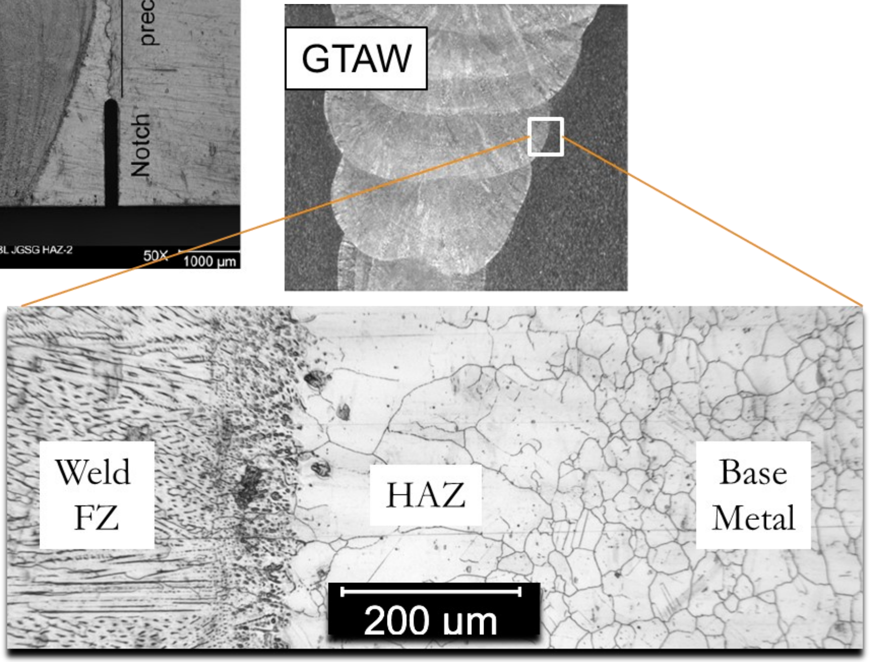
Weld Fusion and Heat Affected Zones

- Welds have inhomogeneous microstructures unlike the base metal



HAZ Cracking After Long-Term Exposure of Test Reservoir





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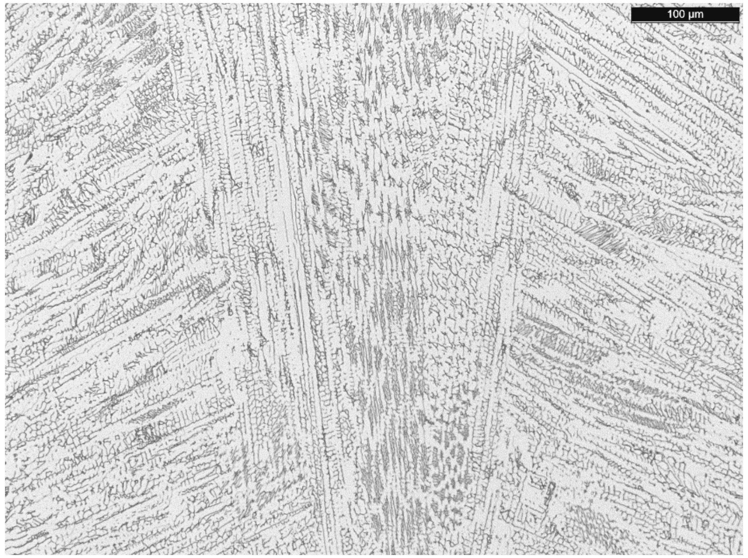
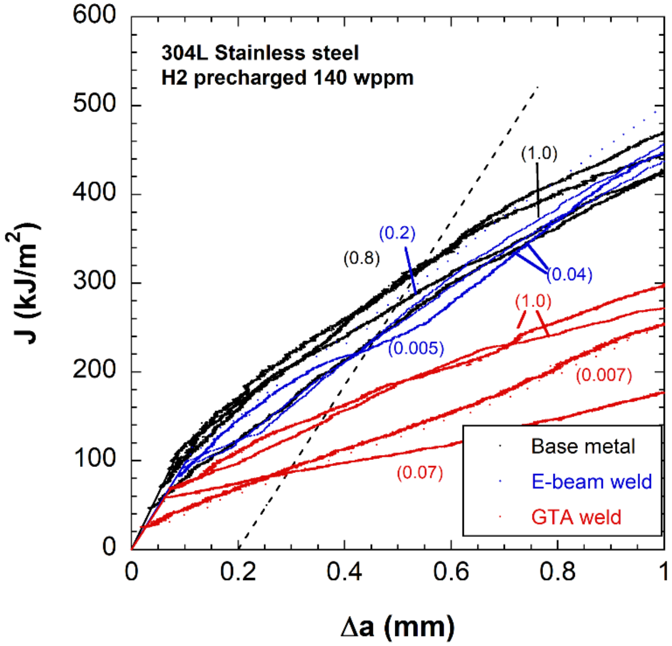
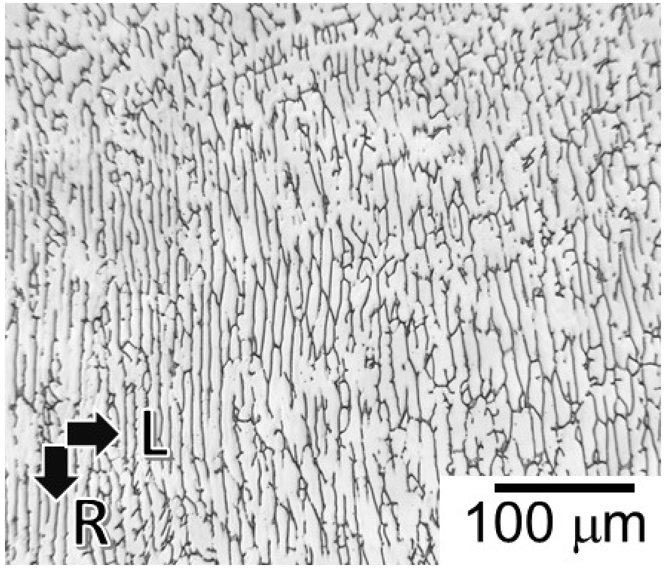
Electron-beam welds

- perform better than conventional gas tungsten arc (GTA) welds

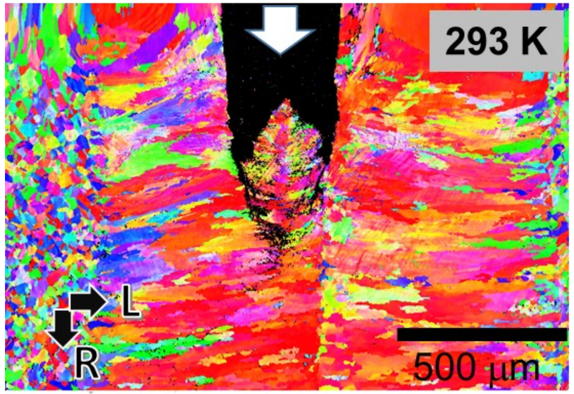
EB weld



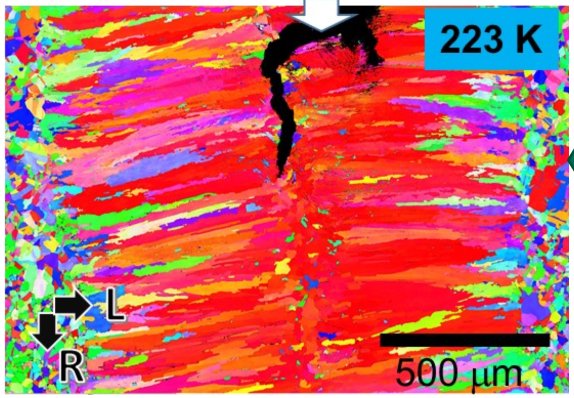




Crack growth direction

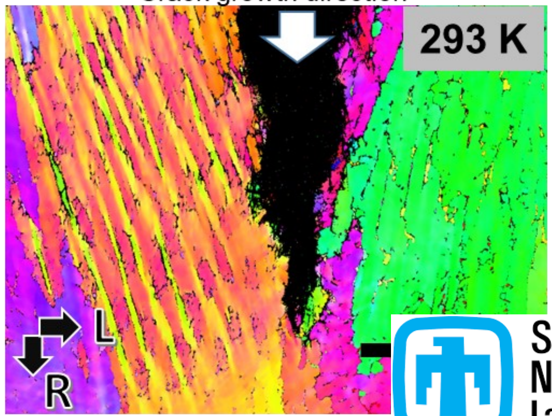


Crack growth direction



Observe tortuous crack path (branching) → improves fracture resistance

Crack growth direction



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