Tritium Effects on Materials Overview

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SAVANNAH RIVER NATIONAL LABORATORY

We Put Science To Work

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Materials Science and Technology
VLT Research Highlight July 18, 2006

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SRNL Programs on Tritium Effects

Outline

- Present an overview of tritium effects on materials programs at SRNL

  I. Aging Effects on Tritium-Exposed Materials
  II. Lifecycle Engineering for Tritium Containment Vessels
  III. Welding / Repair Technologies for Tritium-Exposed and Irradiated Steels

- Emphasis on containment alloys
- Highlight facilities available

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I. Aging Effects on Tritium-Exposed Materials

Material Class	Aging Phenomena
Metal Hydrides for Tritium Storage	▪ Storage capacity reduced ▪ Unrecoverable tritium ▪ Change in adsorption / desorption kinetics ▪ Helium release
Polymers for valves	▪ Radiation hardening ▪ Seal ability degradation ▪ Gas production and release
Containment Alloys	▪ Decay helium embrittlement ▪ Susceptibility to slow crack growth ▪ Helium-induced hot cracking during welding

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Aging Effects on Metal Hydrides

Metal Hydride Investigations

- Pd
- Pd (thick film) on supports (kieselguhr, alumina)
- La-Ni(5-x)-Al(x) alloys – various comps. 0>x>1.0
- La-Ni-Sn alloy
- Pd alloys – Pd-Cr, Pd-Co, Pd-Ni, Pd-Rh, Pd-Rh-Co, Pd-Al (int. ox.)
- Titanium
- NdCo3
- Zr-Fe-Cr alloy

Objectives

Increase understanding of tritium and decay helium effects on metal hydrides.

Develop and characterize new metal tritides of interest to the NNSA including LaNi5Al and Palladium

Tasks

Tritium Aging Studies of Metal Hydrides for NNSA Applications

Development of Predictive Models of Tritium & ^{3}He in Metals and Hydrides

Tritium Aging Studies of Storage and Separation Materials

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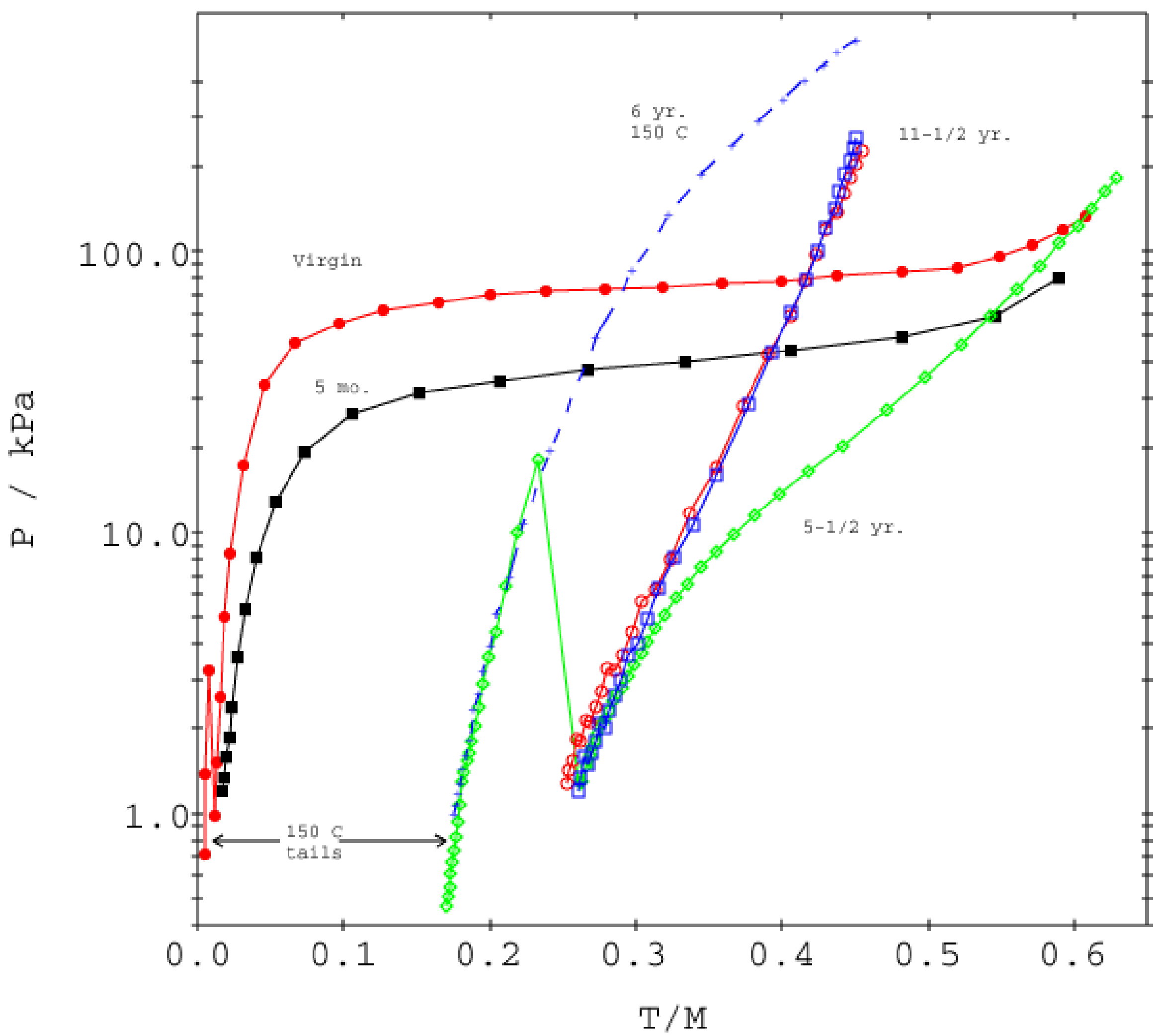
Tritium Aging Phenomena in $LaNi_5Al$



Tritium Desorption Isotherms

- (80° C) for $LaNi_{4.25}Al_{0.75}$
- Various Aging Times.

● Virgin Material;

■ Aged 5 Months in Tritium;

◇ Aged 5.5 Years in T2;

❑, ❍ Aged 11.5 Years in T2.

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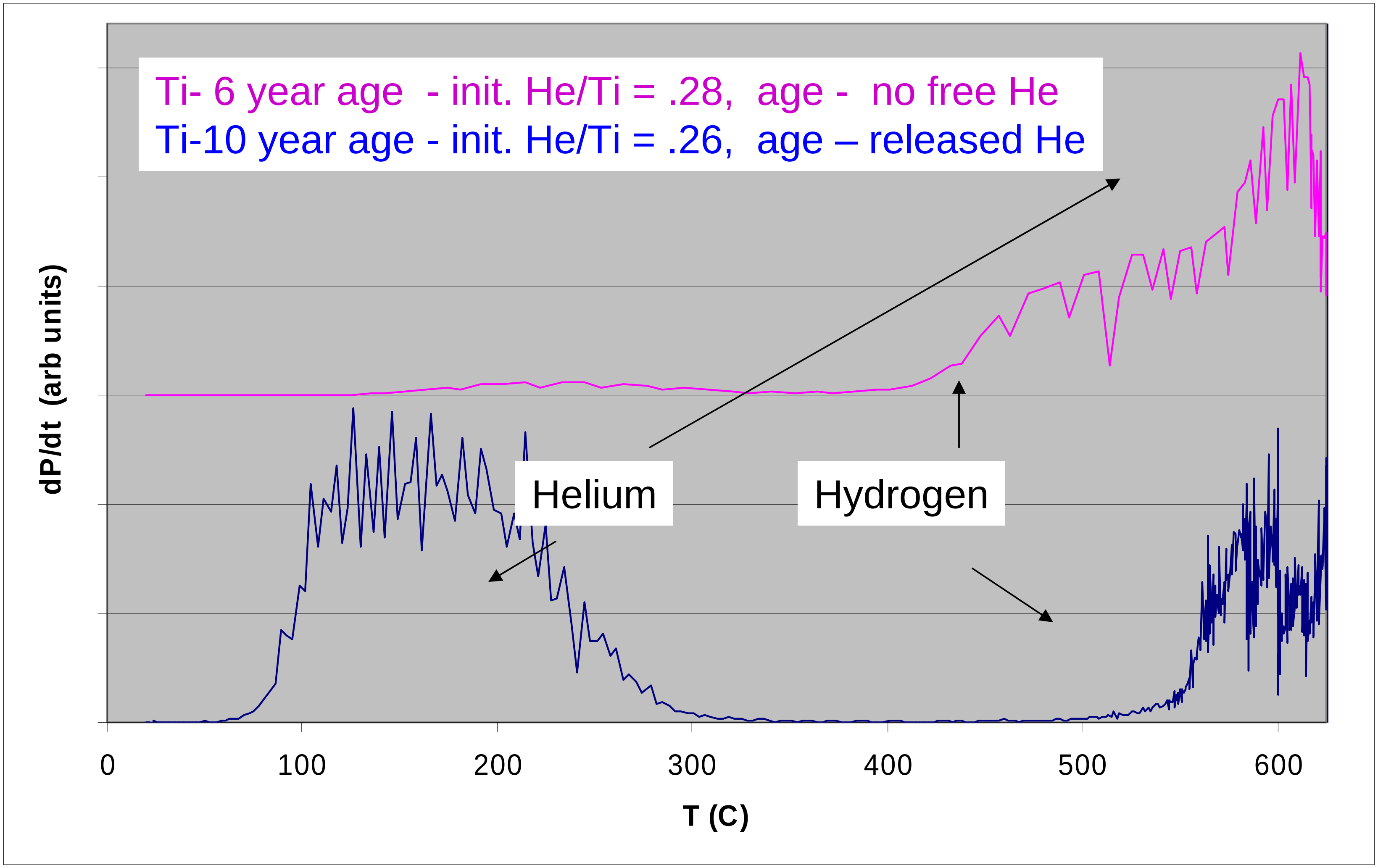
Thermal Desorption from Aged Ti Tritides



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Aging Effects on Polymers

Degraded Valve Stem Tip

Dynamic Mechanical Analysis

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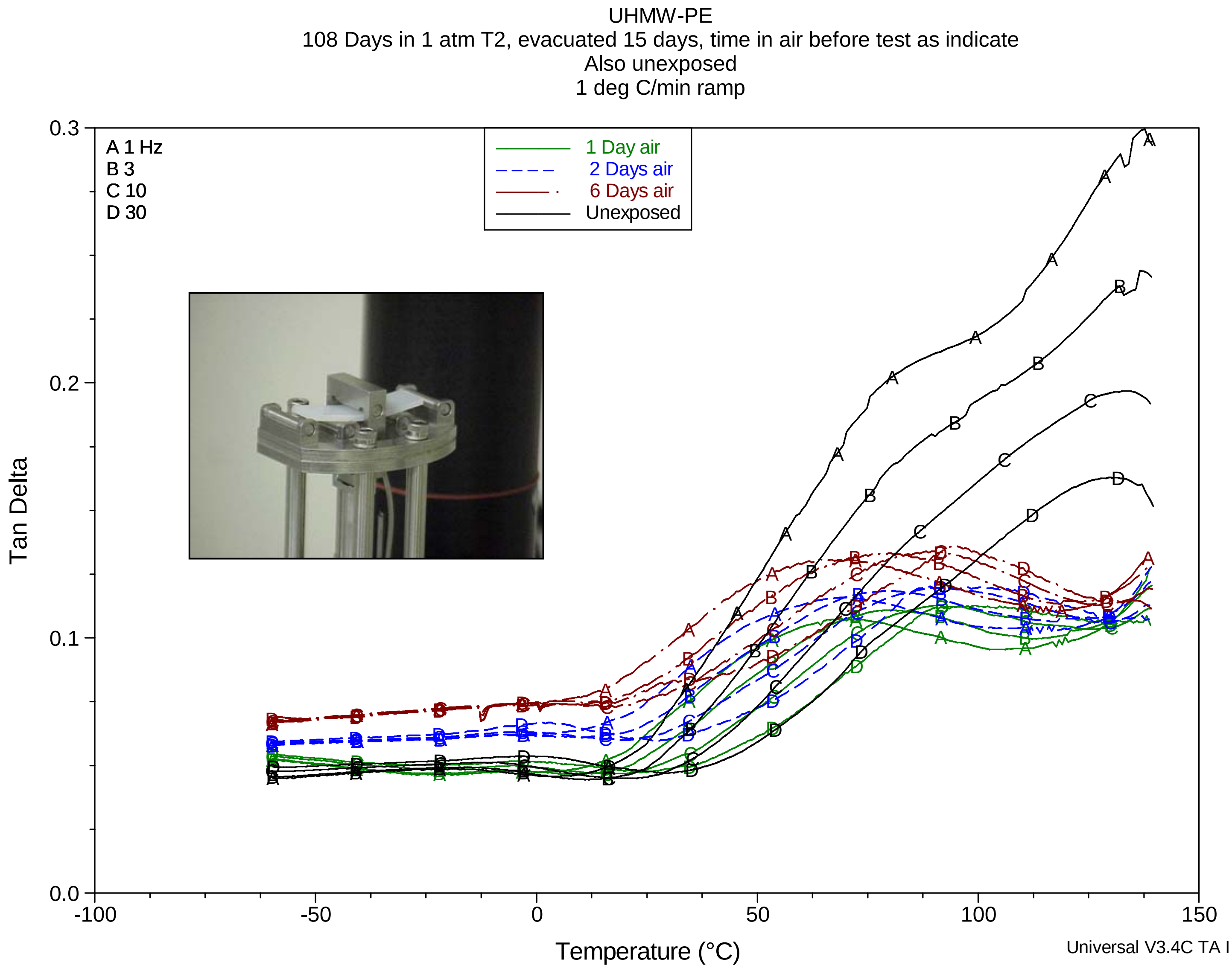
<u>Objectives</u>

- Characterize radiation damage and gas generation from polymers used in tritium processing
- EPDM, Teflon, Vespel® and UHMW-PE
- Synthesize tritium compatible polymers
- Develop radiation damage models

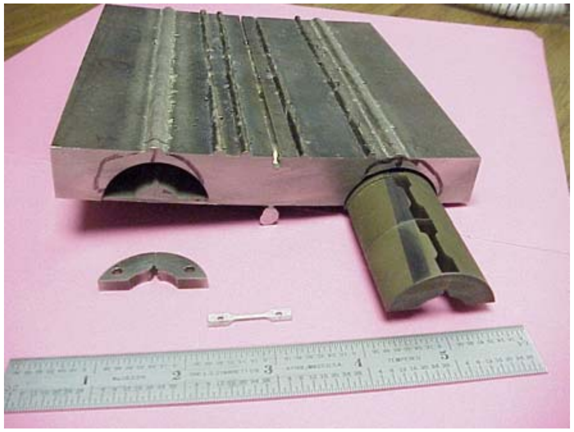
"Effects of Tritium on UHMW-PE, PTFE, and Vespel® Polyimide", Elliot Clark

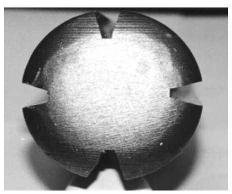
Submitted for presentation and publication at the 17th Topical Meeting of Fusion Energy

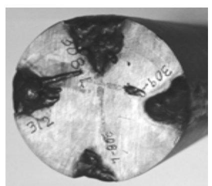
Viscoelastic Property Degradation From Tritium Exposure

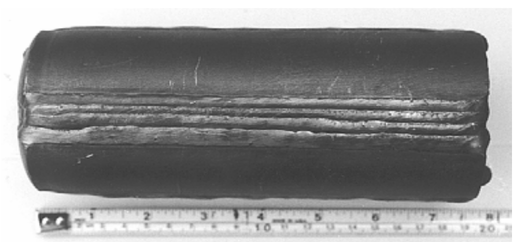


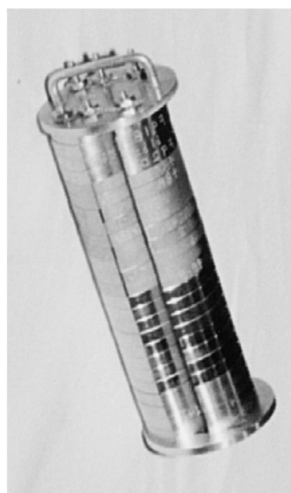
Aging Effects on Tritium-Exposed Containment Alloys











Objectives

- Increase understanding of tritium & decay helium effects on structural alloys.
- Define conditions that lead to tritium-induced crack growth in fielded components

Tasks

- Measure mechanical & fracture toughness properties and crack growth rates of alloys as a function of hydrogen isotope and helium content
- Investigate role of microstructures including weldments and heat-affected zones on tritium compatibility
- Develop techniques for acquiring relevant data from retired components.

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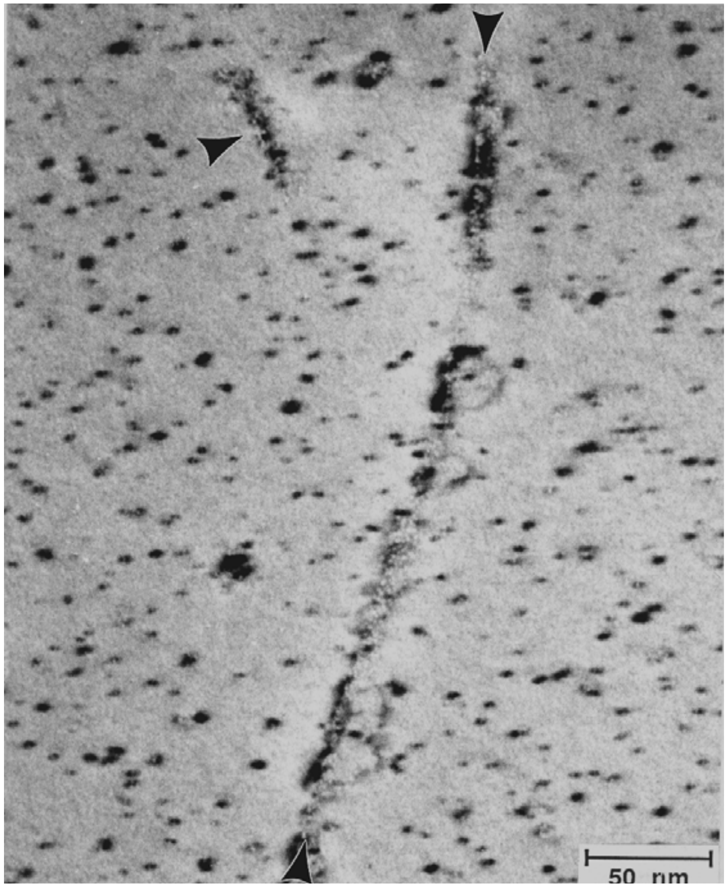
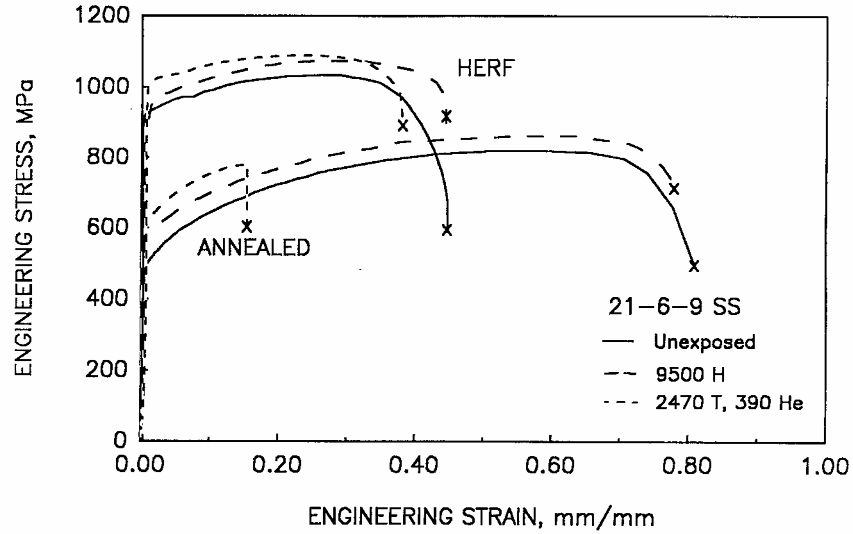
Helium Hardened Microstructure



Tritium-exposed Microstructure

- Tritium-exposure causes defect structure of nanometer-sized helium bubbles
- Bubbles associated with “punched-out” dislocation loops and clustered along dislocation lines
- Strong obstacles to dislocation motion.
- Response to tritium can’t be simulated with hydrogen and depends on material microstructure



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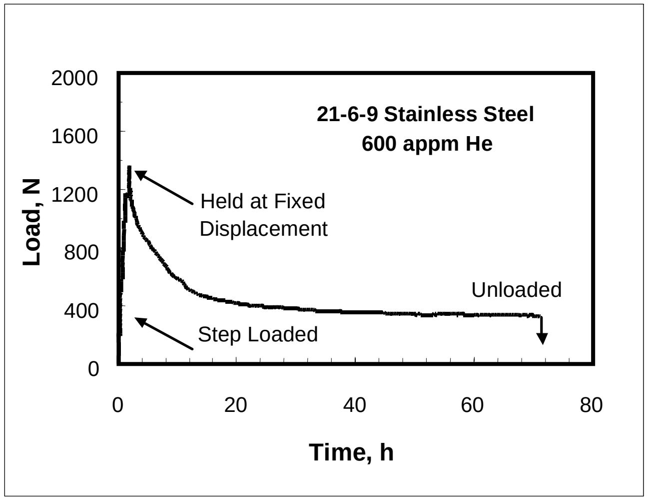
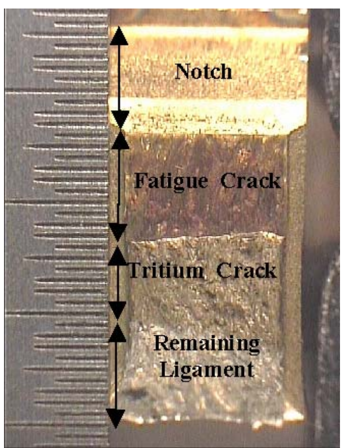
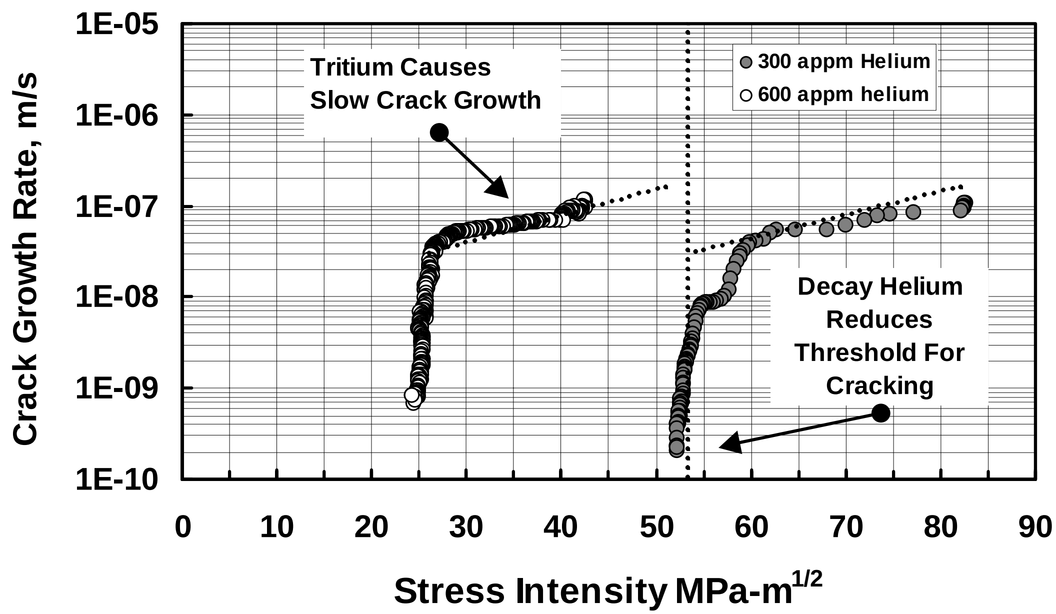
Cracking Thresholds and Crack Growth Rates



Threshold Cracking Test



Fracture Surface



Threshold Cracking Results

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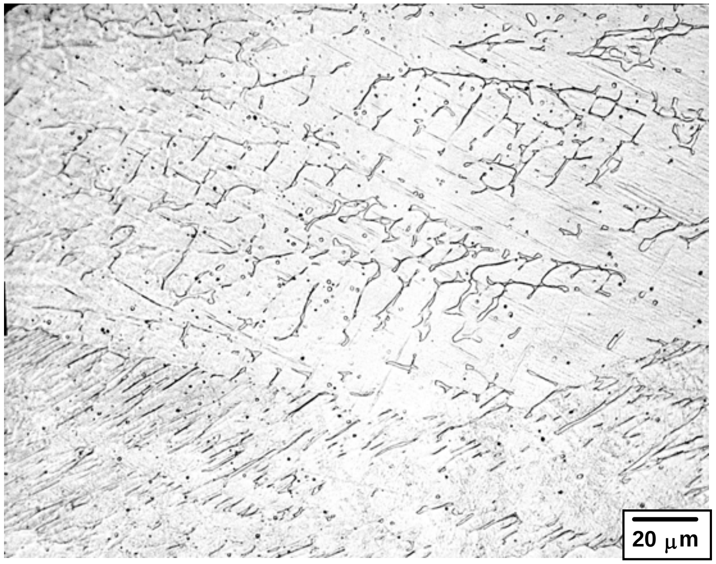
304L Stainless Steel Typical Weld Microstructure



308L Filler Wire

Typical Weld Ferrite Content 8-10% by Volume

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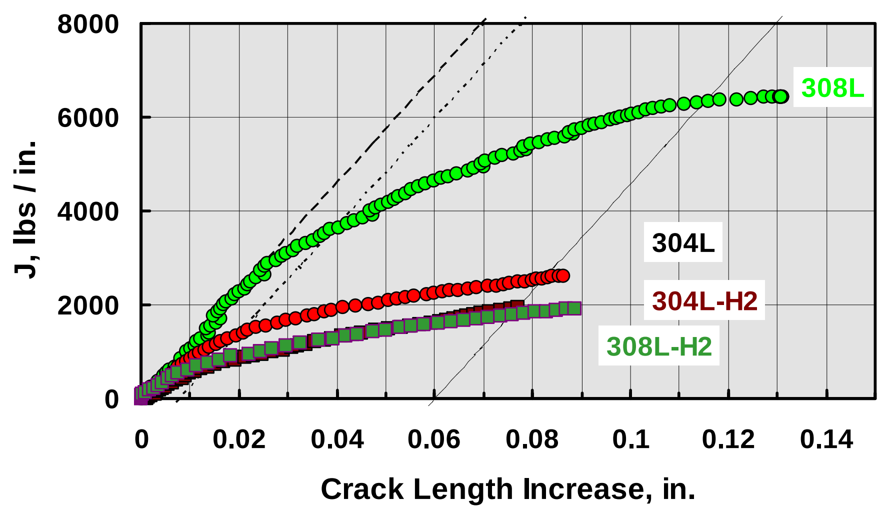
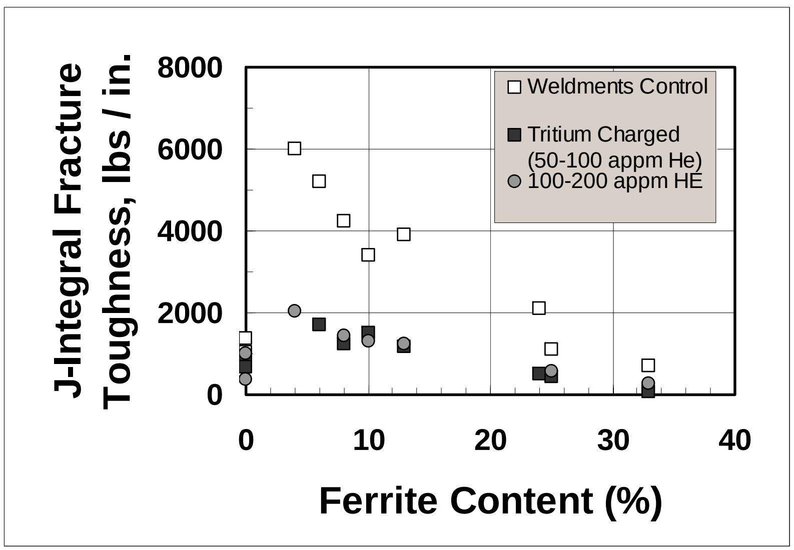
J-Integral Fracture Toughness Properties of Weldments





- Weld ferrite prevents shrinkage cracking during weld solidification.
- Ferrite beneficial for unexposed material toughness;
- More susceptible to hydrogen / tritium embrittlement
- Aging behavior reduced in weldments in part because of greater off-gassing losses
- *"The Effect of Tritium on the J-Integral Fracture Toughness Properties of Type 304L Stainless Steel Weldments" by Michael Morgan Submitted for 17th TOFE, November 2006*

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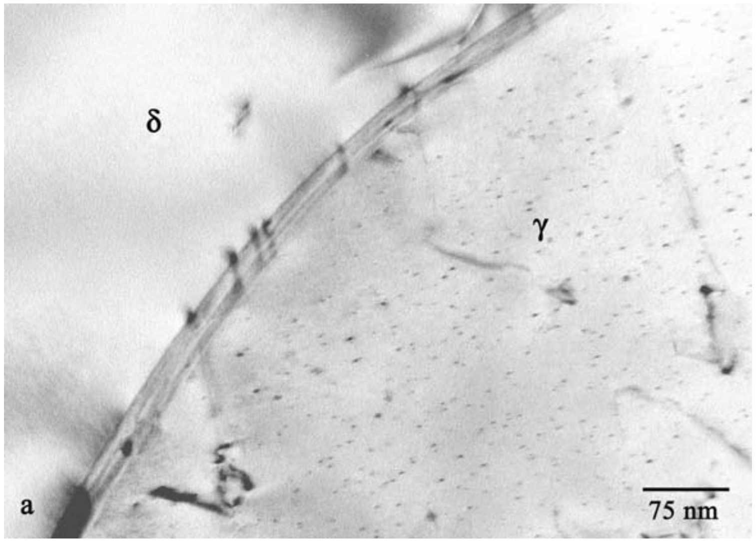
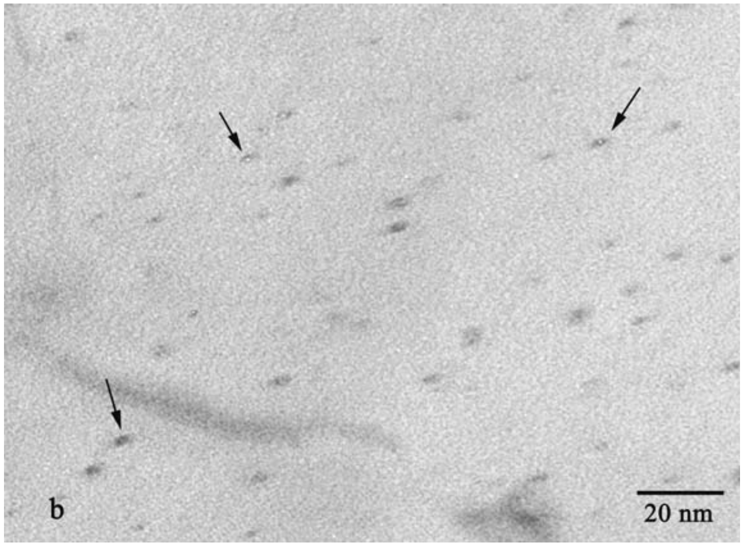
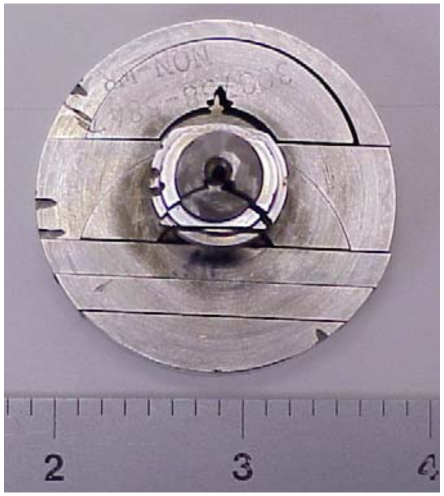
Defect Structure in Tritium-Aged Weldment

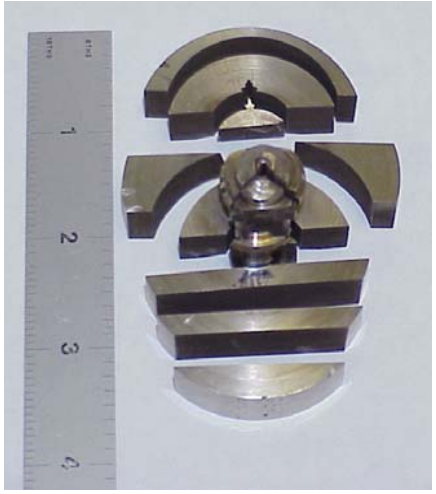


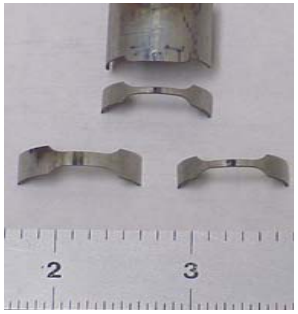


- Low diffraction contrast image showing helium bubbles (arrows)
- Ferrite phase free of helium bubbles
- Helium bubble from tritium decay seen in austenite only
- Results show that embrittlement from aging is lower in weldments than base metals

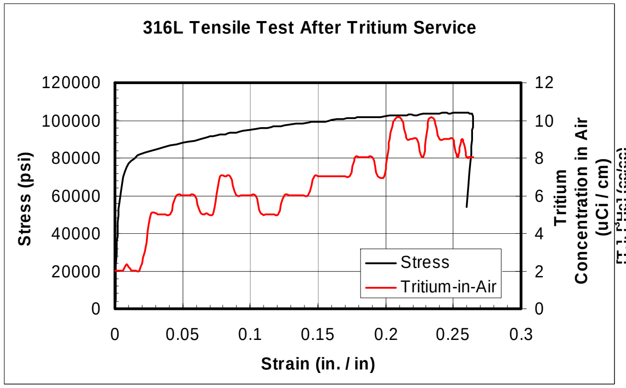
Precision Electric Discharge Machining for Harvesting Data from Exposed Components

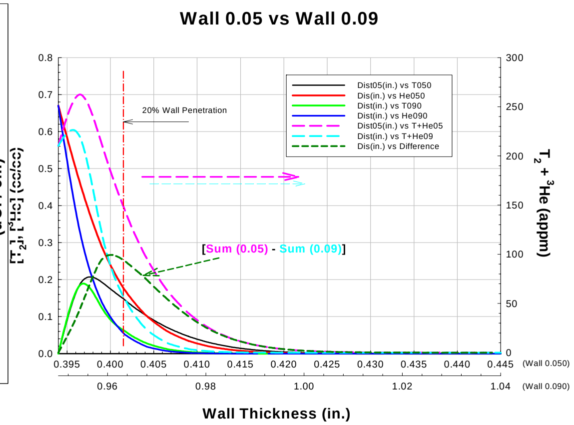






Longitudinal and transverse tensile specimens cut from outer wall of reservoir mock-up (1/2" sch 10 pipe, 0.083 inch wall)





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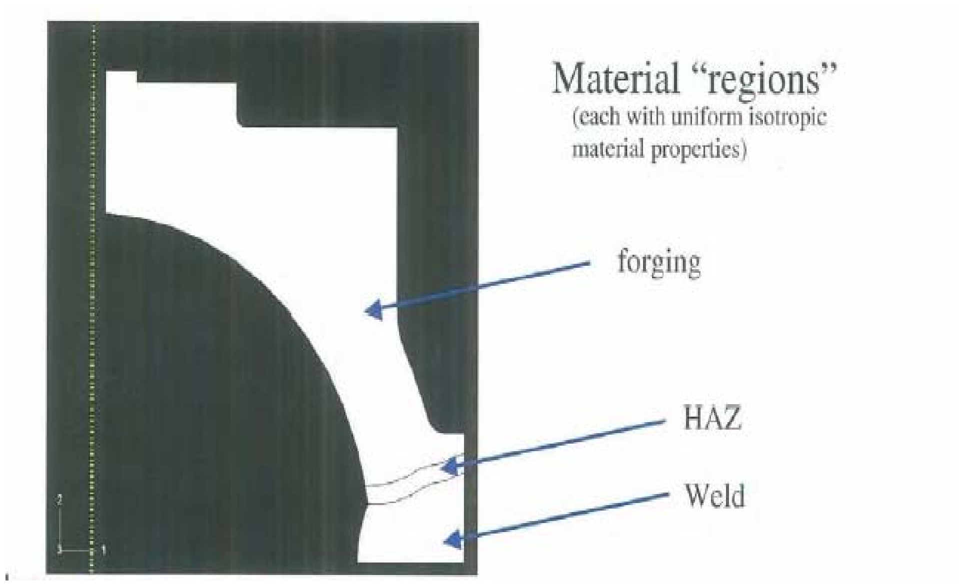
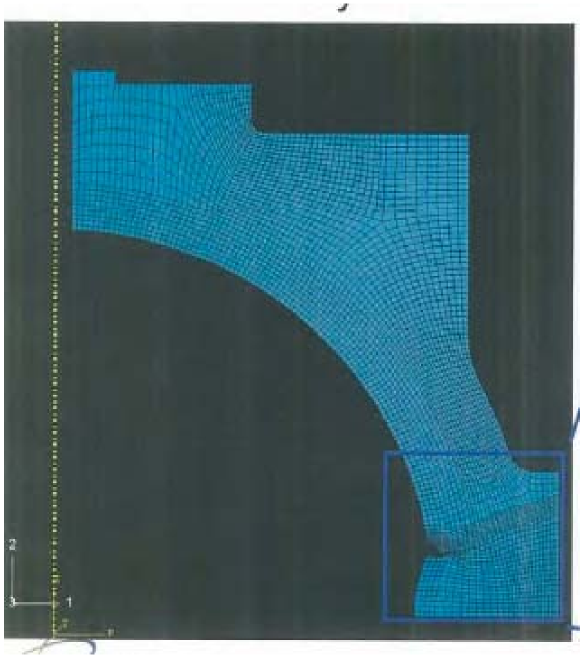
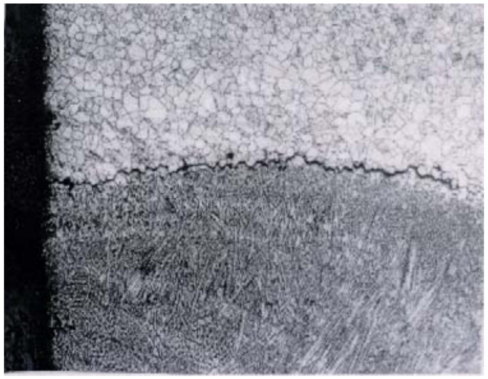
II. Lifecycle Engineering for Tritium Containment Vessels





- Develop continuum models for crack propagation
- Develop microstructural models for bulk regions, weld regions and heat-affected zones
- Include region's unique properties: fracture, tritium solubility & diffusivity, & aging
- Use FEM analysis for performance prediction



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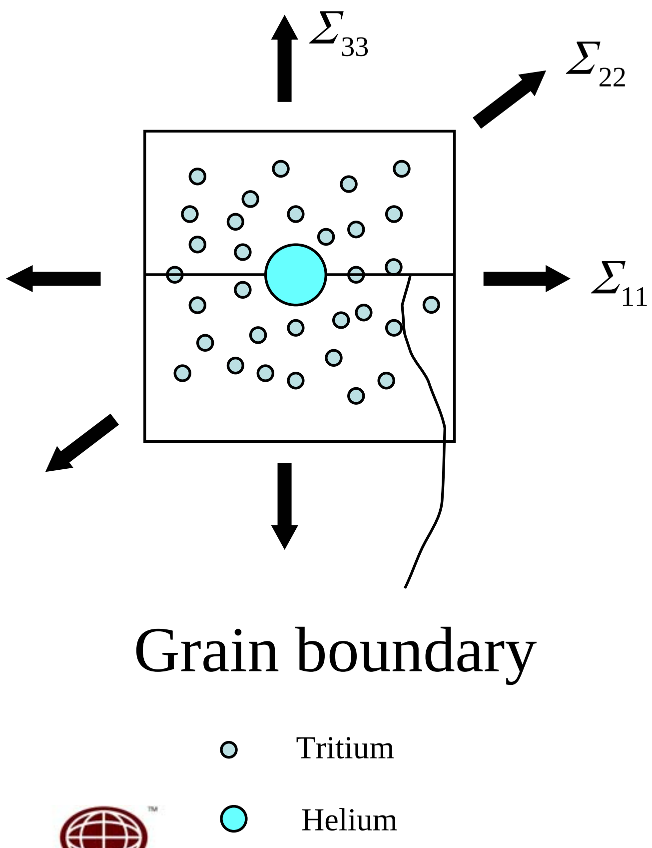
Microstructural Model Development
Helium Bubble-Tritium-Stress Interactions

- An interesting question to be addressed is whether the grain boundary can decohere by the presence of a helium bubble and its associated tritium atmosphere



Micromechanical approach here requires description of the grain boundary cohesive properties via a modified Rice-Hirth thermodynamics of decohesion to account for non-equilibrium aspects of decohesion along the grain boundary

Such a thermodynamic theory of decohesion has been developed by Liang and Sofronis (J. Mech. Phys. Solids, 51, 1509-1531, 2003) in the case of Nickel-base alloys

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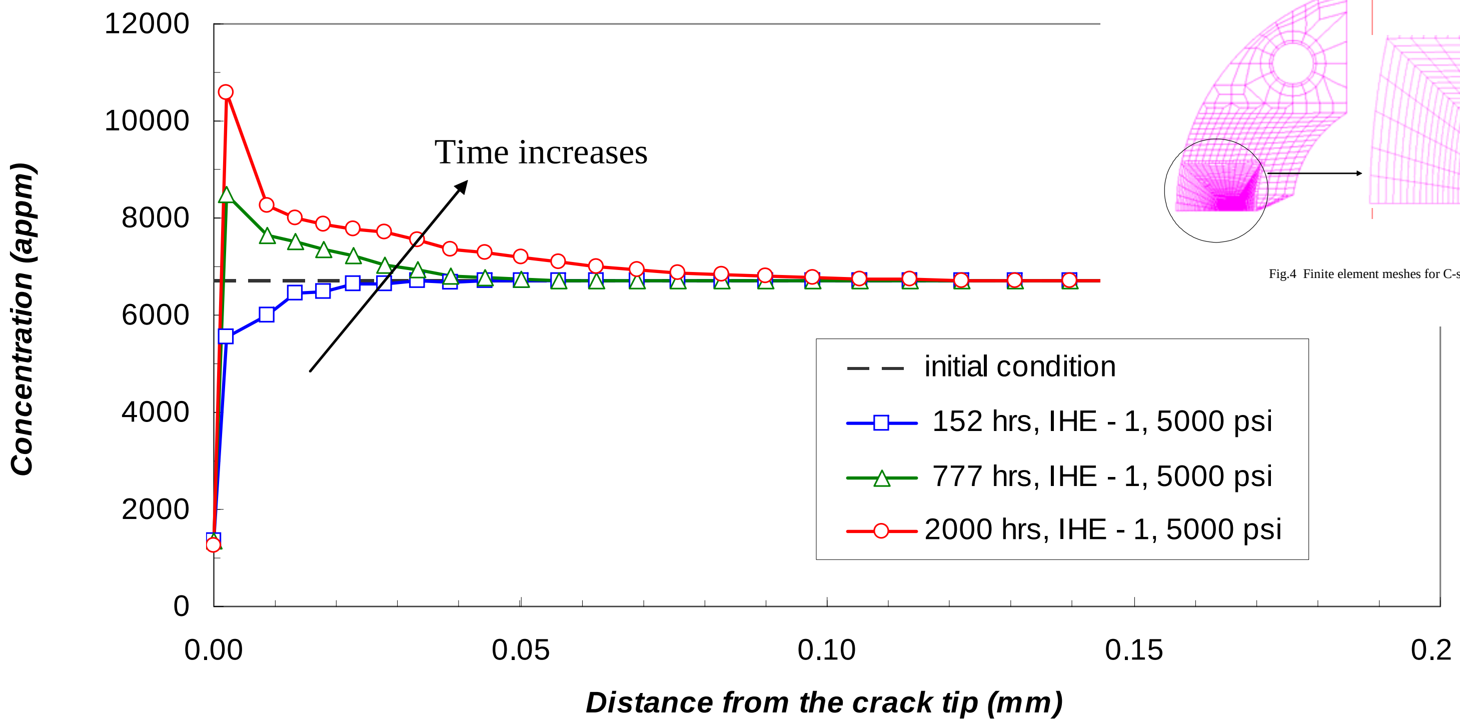
Diffusion Models: Fracture Mechanics C-Specimen



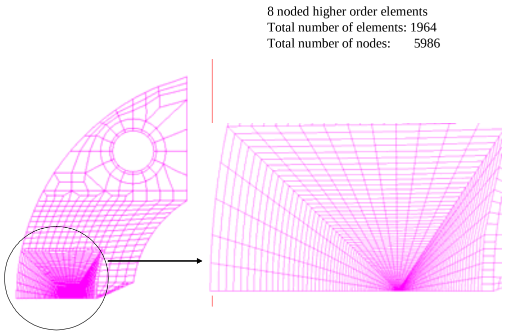


Fig.4 Finite element meshes for C-specimen

Crack Tip Enhancement in Stainless Steel

Charged and Tested in Hydrogen Gas(5000 psi)

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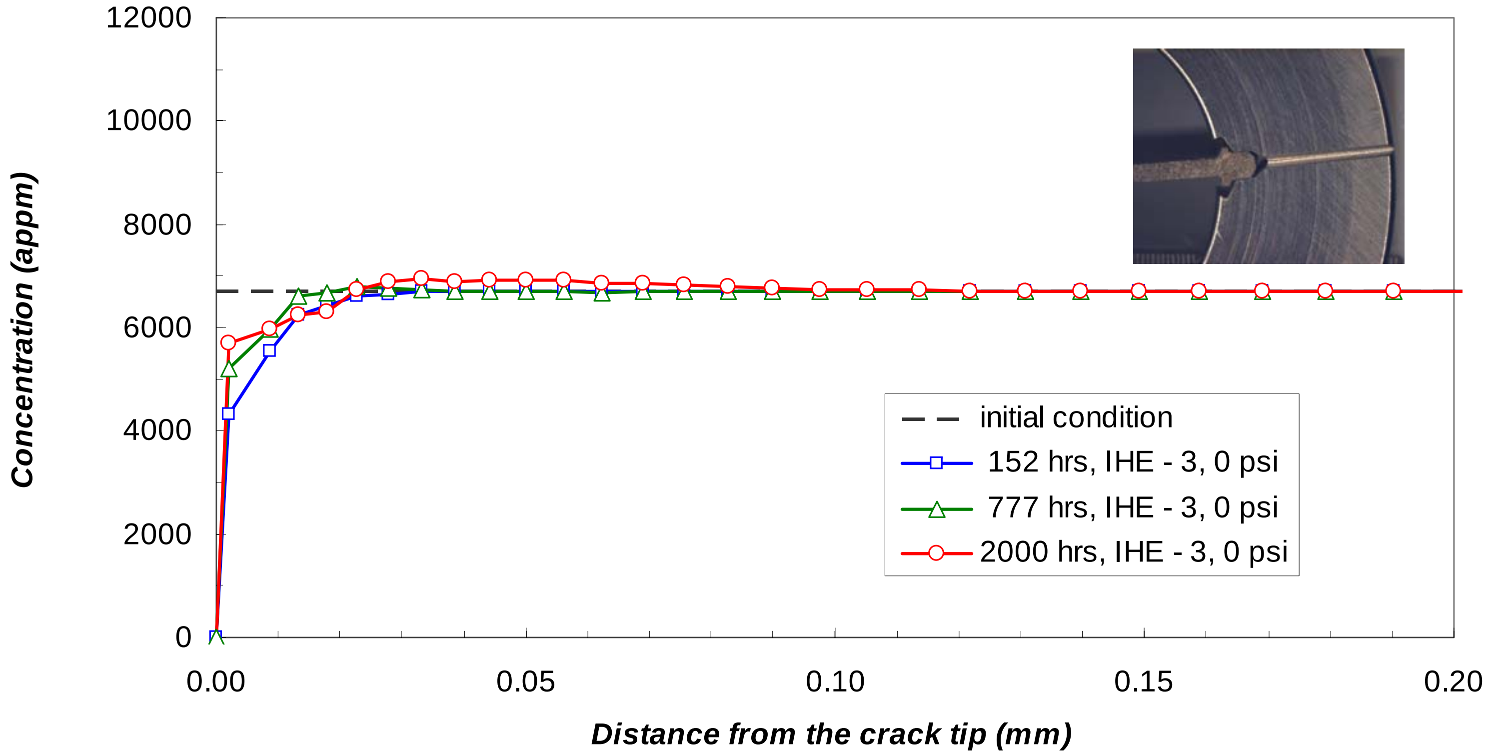
Crack Tip Depletion From Off-Gassing Losses



No Crack Tip Enhancement in Stainless Steel

Charged in Hydrogen (5000 psi) and Tested in Air

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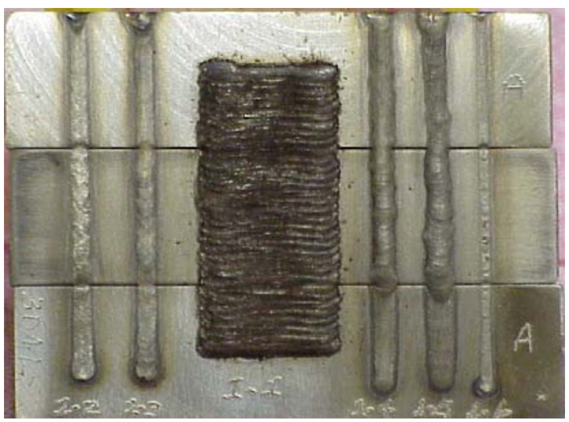
III. Welding / Repair Technologies for Fusion Materials

Welding System



Stringer beads and overlay Welds on T2-Exposed Plate

Objectives

- Study the effects of helium embrittlement cracking on Types 316LN and 304 SS plates using low heat input overlay welds and GTA stringer beads
- Characterize the He bubble microstructures in weld heat-affected zones (HAZ).

Findings

- Low-heat, Low-penetration welds reduce HAZ cracking
- Cracking in HAZ much more severe in 304 for both weld types.
- Much more porosity in 304 stringer beads; greater depth of penetration in 316 welds.
- He bubbles on grain boundaries in both steels, more Cr-rich carbides in 304

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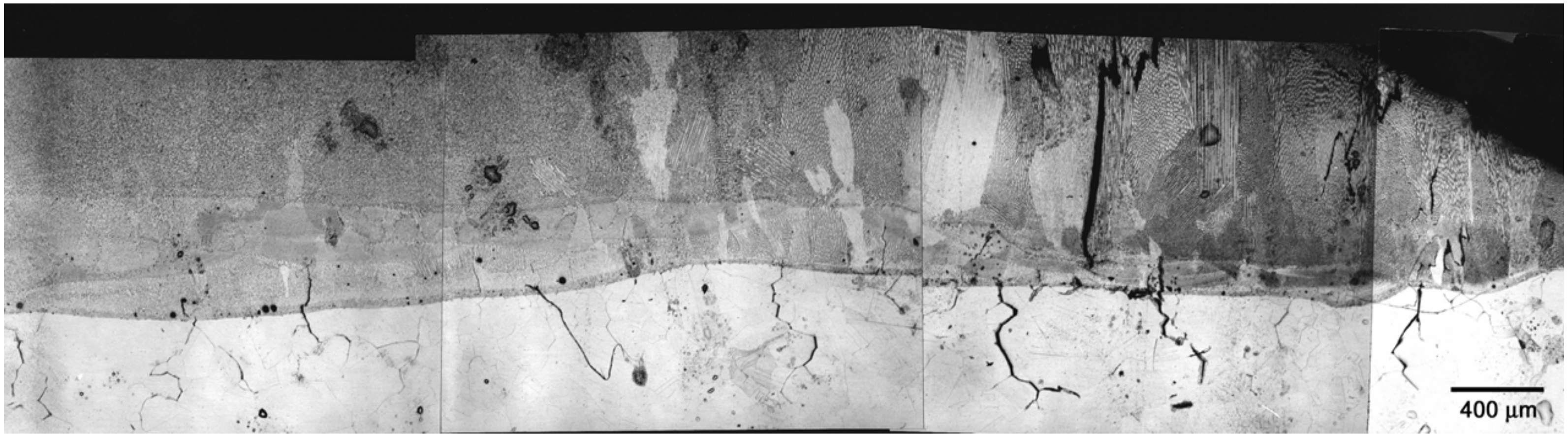
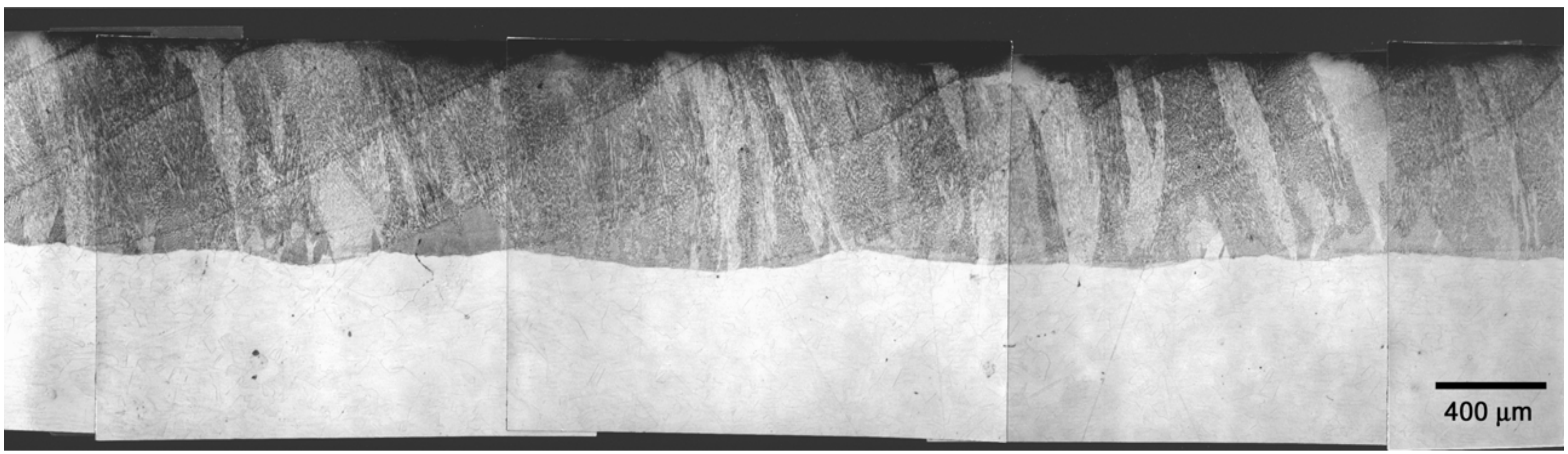
Overlay Welds On Plates With 90 appm Helium

304



316LN



Significantly more HAZ Cracking in 304 – 35.5 J/mm^2 (22.9 kJ/in^2)

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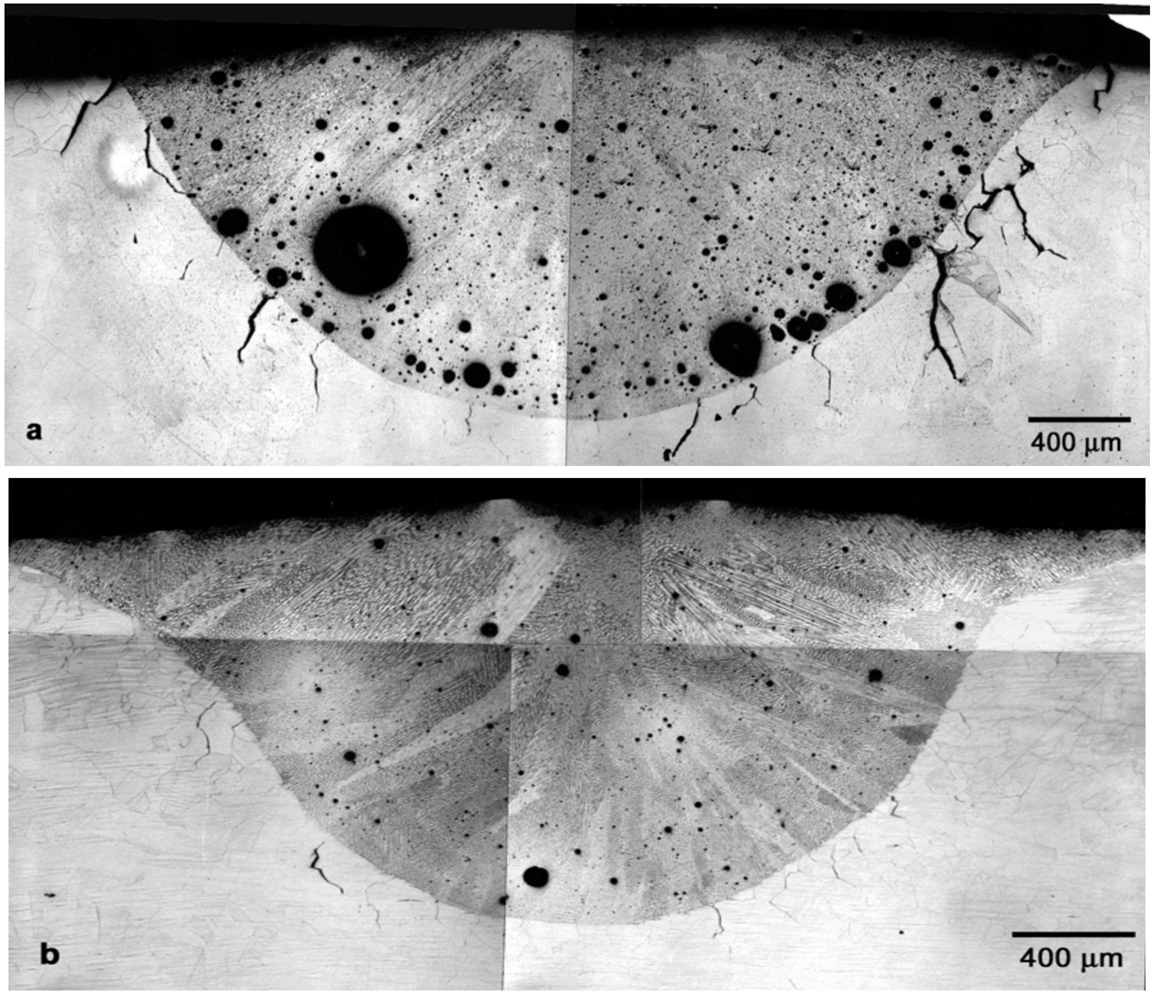
Stringer Beads 90 appm Helium

304

316LN



44.6 J/mm^2
(28.8 kJ/in^2)

More Cracking & Porosity (304), Greater Depth of Penetration (316LN)

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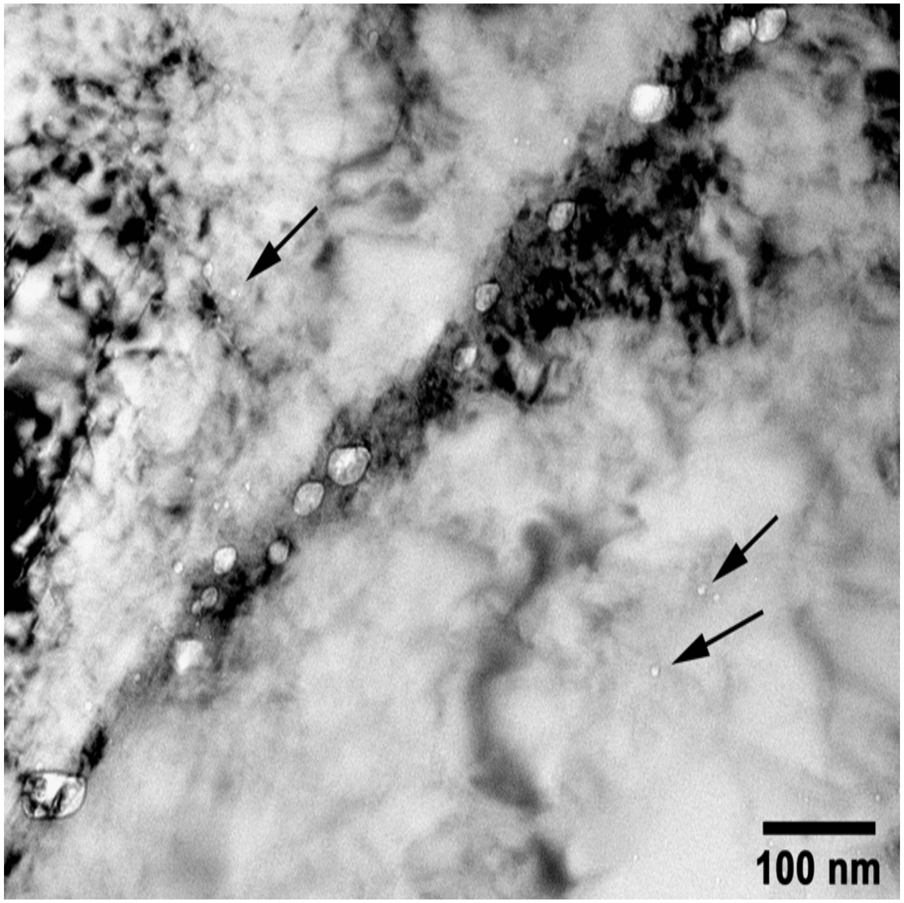
Grain Boundary in HAZ of Overlay Weld 316LN



Helium Bubble on HAZ Grain Boundary

Summary

- Tritium causes unique effects on the properties of a variety materials needed for processing tritium
- In hydride materials, tritium aging changes the thermodynamic behavior including a loss of storage capacity, unrecoverable tritium and contamination by helium release
- In polymers, beta-radiation from tritium decay causes hardening, embrittlement, seal degradation, and gas production
- In structural alloys, tritium aging results in embrittlement and slow crack growth; severity depends on original microstructure
- Weld repair technologies developed for minimizing hot cracking resulting from helium from irradiation or tritium decay
- Modeling now being utilized for improving predictive capabilities

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Summary

Tritium Facilities and Capabilities:

- Sample charging up to 5000 psi and 350 C
- Mechanical and fracture mechanics testing
- Isotherm measurements for hydrides
- Polymer dynamic mechanical analysis
- Scanning and transmission electron microscopy
- Hydrogen permeation
- Electric-Discharge machining and welding laboratory
- Modeling of tritium partitioning and effects in microstructures
- Modeling of structural / fracture performance of tritium-exposed materials

Tritium Effects Principal Investigators

- Structural alloys: *Dr. Michael J. Morgan*
- Polymers: *Dr. Elliot Clark*
- Metal Hydrides: *Dr. D. Thomas Walters*
- Microscopy / Welding Technologies: *Dr. Michael Tosten*

- Contact Dr. Robert Sindelar for additional information

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