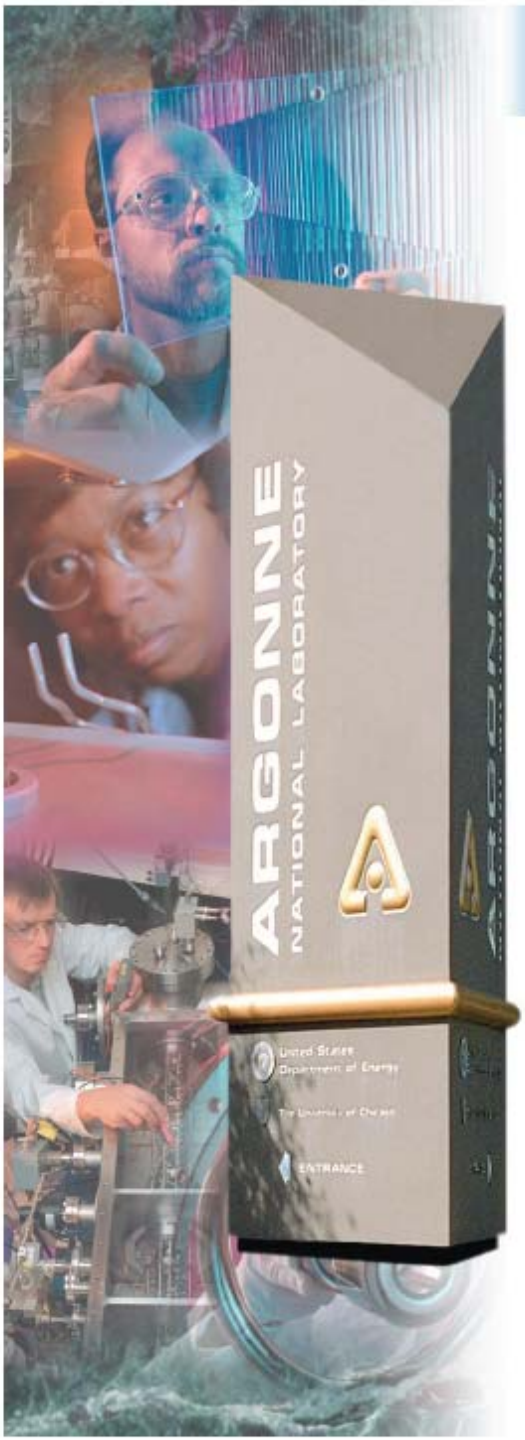


ARGONNE NATIONAL LABORATORY

# Regulatory Information Conference (RIC) 2006
# U.S. Nuclear Regulatory Commission

**March 6 – 9, 2006, Bethesda, MD**

## Session Th5-BC - Materials Degradation

*License Renewal Issues & Irradiation Assisted Stress Corrosion Cracking*

# *Studies on Irradiation Assisted Stress Corrosion Cracking of Austenitic Stainless Steels in LWR Environments*

*by* Omesh Chopra, Hee Chung, & Bill Shack

Presented by: Omesh Chopra, Senior Metallurgist
Argonne National Laboratory, Argonne, Illinois
March 9, 2006

THE UNIVERSITY OF CHICAGO

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# U.S. Nuclear Power Plants

- **Regulatory Issue: Integrity of reactor components is subjected to Environmentally Assisted Cracking (EAC). Need to**
  - develop technical information needed to assure that selected inspection intervals are adequate to assure structural integrity
  - identify susceptible materials and conditions, &
  - verify effectiveness of industry–proposed mitigating measures
- Current concerns focused on
  - cracking of core internals,
  - cracking of nickel alloys & welds,
  - aging and license renewal issue, &
  - wastage of PV head

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# Cracking of Core Internals

- **Technical Issue:** High irradiation levels in reactor core can increase susceptibility to stress corrosion cracking (i.e., IASCC) by affecting both material & environment
- **Program Activity:**
  - Understand mechanisms of various types of cracking; material selection & identify solutions
  - Develop technical information such as
    - *crack growth rates*
      *to determine inspection intervals & disposition components*
    - *fracture toughness*
      *also to disposition components*

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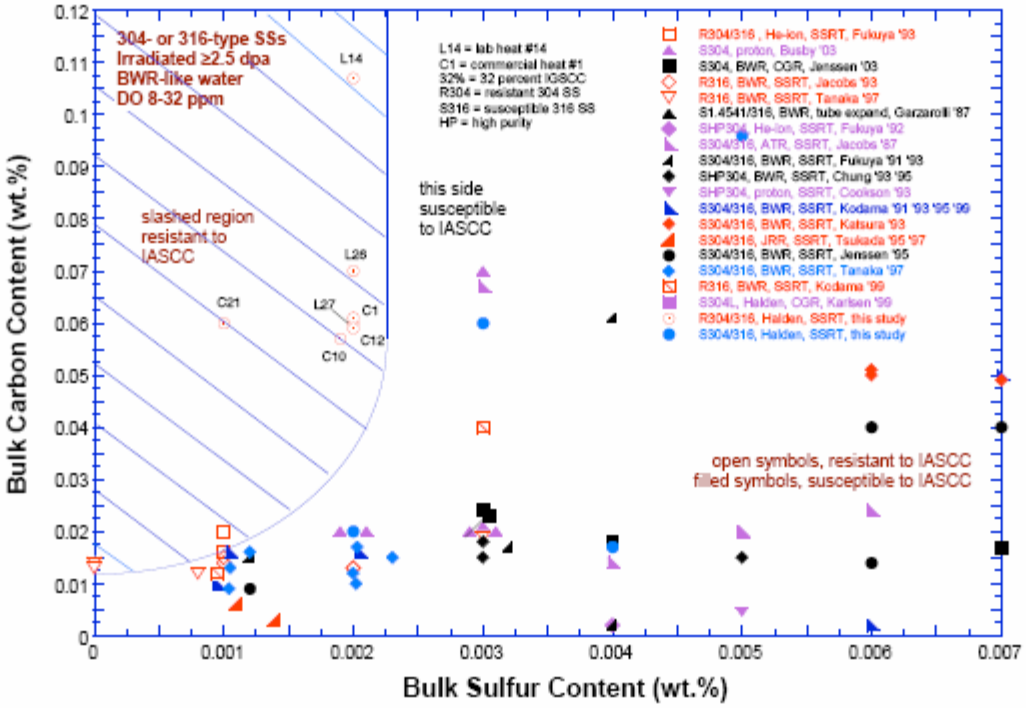
# IASCC Susceptibility - Effect of Sulfur & Carbon Content




- Stainless steels with ≤0.002 wt.% sulfur are resistant to IASCC; low carbon steels must have very low sulfur to minimize susceptibility

* 1 dpa ≈ 7 x $10^{20}$ n/$cm^2$ (E > 1 MeV), or ≈7 y service for BWR Top Guide

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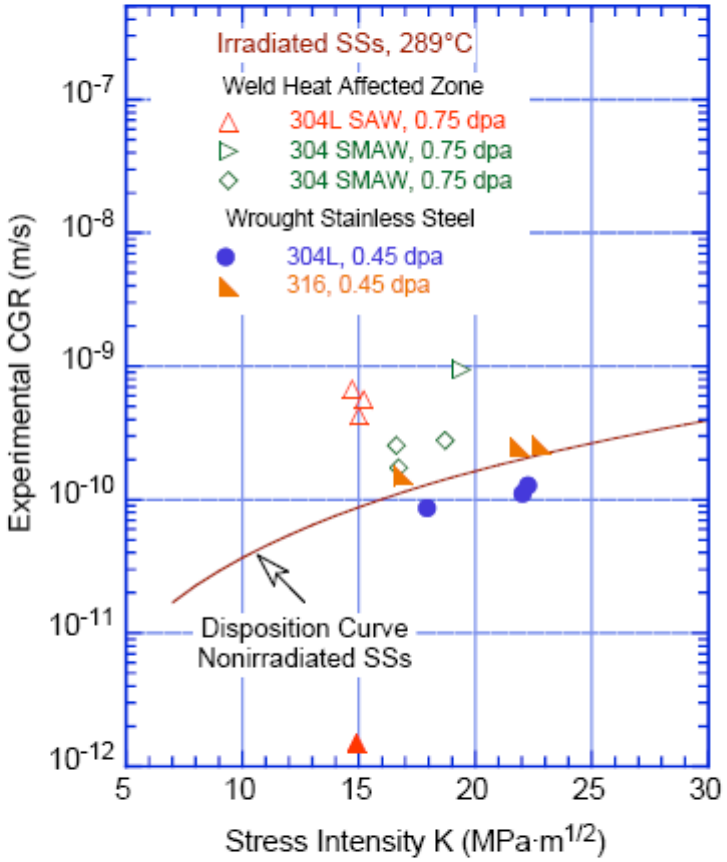
# Crack Growth Rates for SSs Irradiated to <0.75 dpa




- For BWR normal water chemistry, crack growth rates of steels irradiated to 0.45 dpa are consistent with the disposition curve for nonirradiated steels
- Disposition curve for nonirradiated steel may not be adequate for weld heat affected zones, e.g., crack growth rates of HAZ material irradiated to ≈0.75 dpa are factor of ≈5 higher

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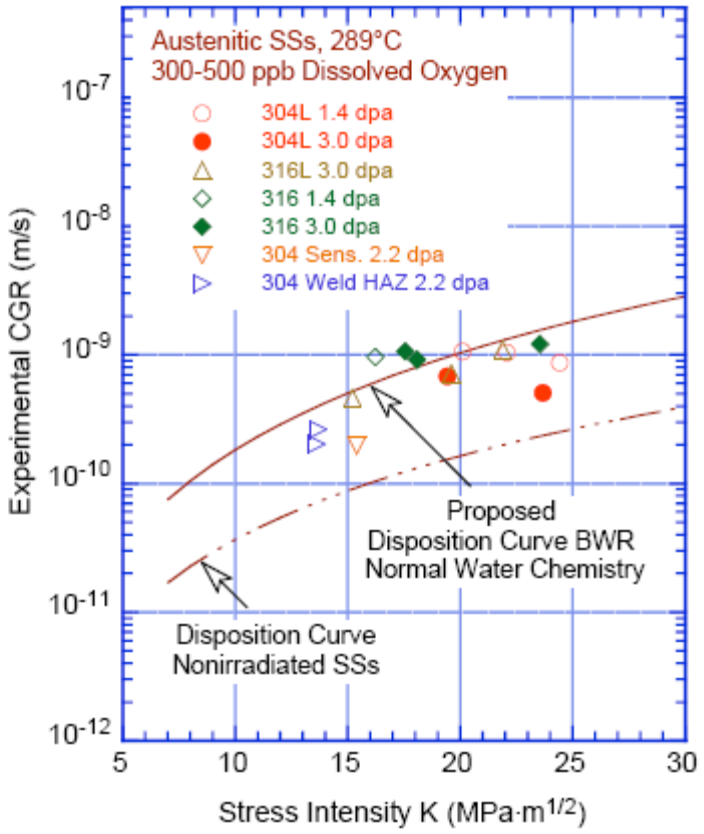
# Crack Growth Rates for SSs Irradiated to >0.75 dpa




- For BWR normal water chemistry, crack growth rates of steels irradiated between 0.75 and 3.0 dpa are a factor of ≈5 higher than the current disposition curve for nonirradiated stainless steels
- For BWR hydrogen water chemistry, growth rates decrease more than an order of magnitude

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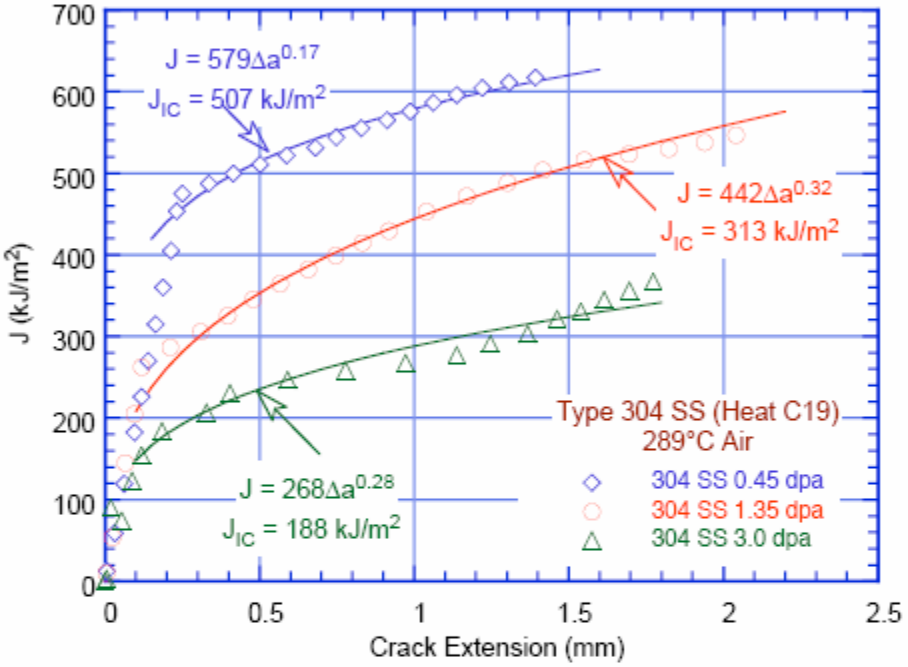
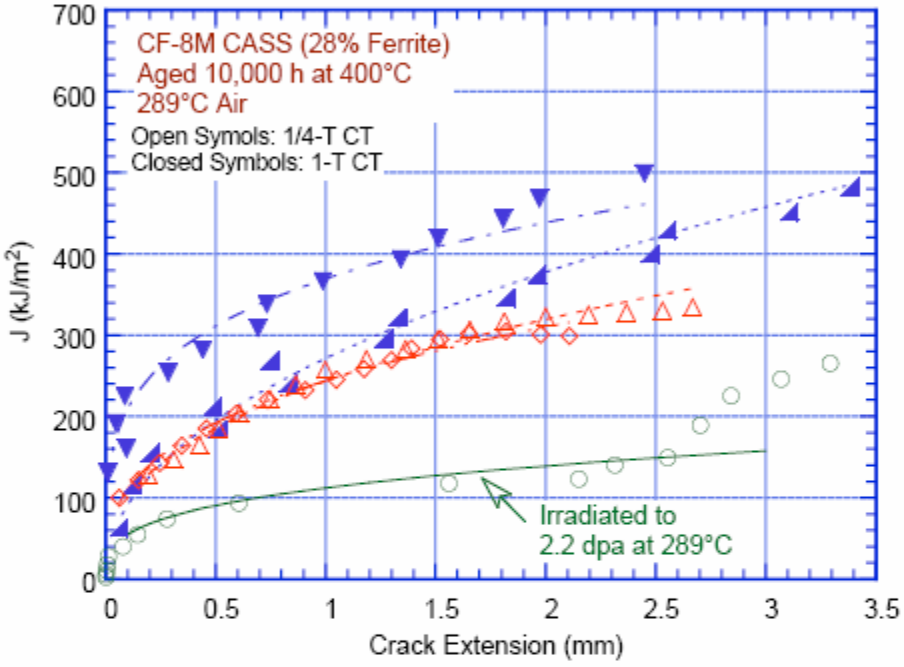
# Fracture Toughness of Irradiated Stainless Steels




- Neutron irradiation decreases the fracture toughness of wrought & cast austenitic stainless steels
- For cast stainless steels, thermal aging embrittles the ferrite phase, neutron irradiation embrittles also the austenite phase

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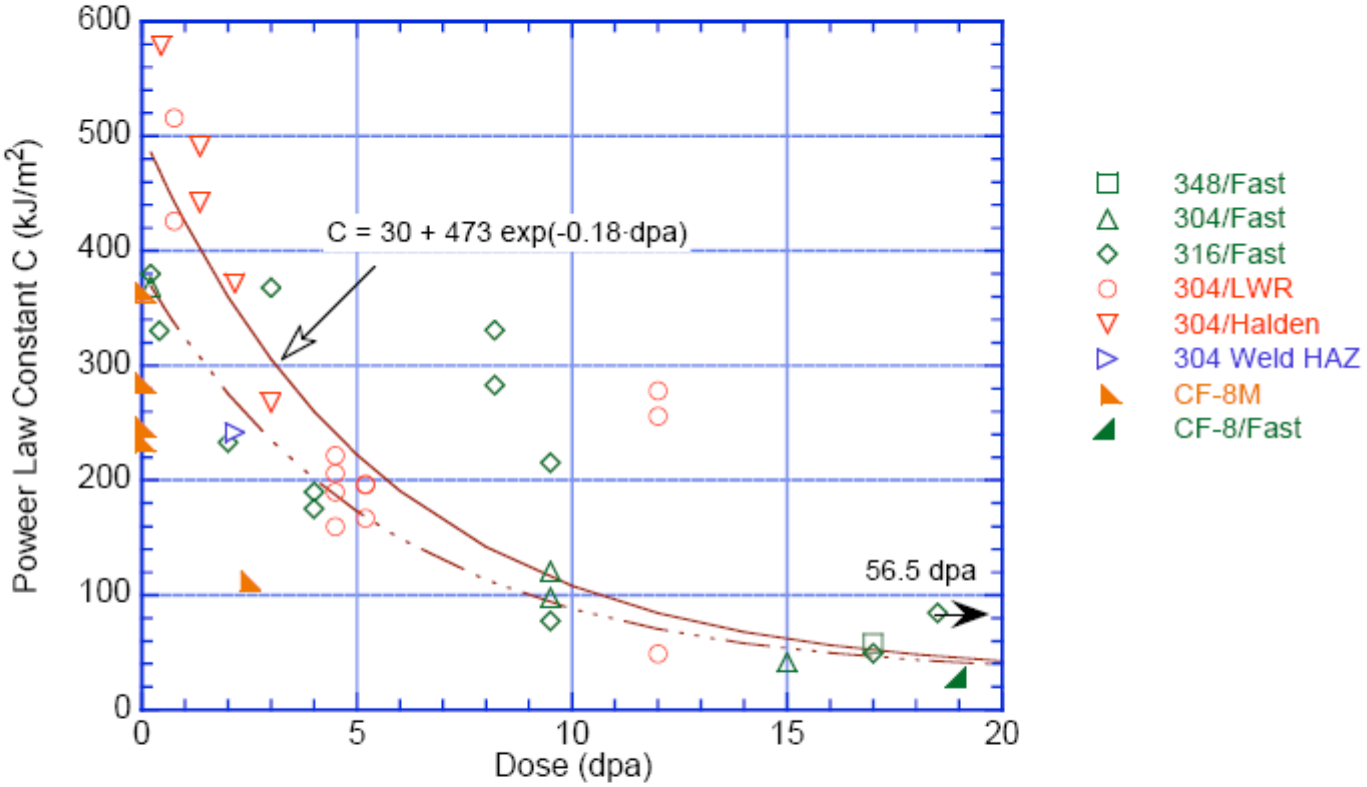
# Estimating Change in Toughness with Neutron Irradiation




- For irradiated wrought & cast austenitic SSs
  the change in toughness may be represented by a correlation between coefficient C of the power-law J-R curve & neutron dose

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# Summary

- IASCC susceptibility of irradiated SSs is being investigated as a function of material chemistry & irradiation level (NUREG/CR-5608, -6687, -6892)
  - Sulfur & carbon content in steel effect susceptibility
- Crack growth rates are being determined as a function of fluence, water chemistry, & material composition (NUREG/CR-6826, -6891)
  - In BWR normal water chemistry,
    crack growth rates of SSs irradiated to 0.75–3.0 dpa are factor of 5 higher than the disposition curve for nonirradiated SSs
  - In BWR hydrogen water chemistry,
    growth rates are order of magnitude lower than in normal water chemistry
- Fracture toughness of wrought & cast SSs is decreased by neutron irradiation
  - Effect of irradiation on cast SS is greater than on wrought SS
  - Correlation are being developed to estimate fracture toughness as a function of fluence and material type,
    including synergistic effect of thermal & neutron irradiation for cast SSs

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