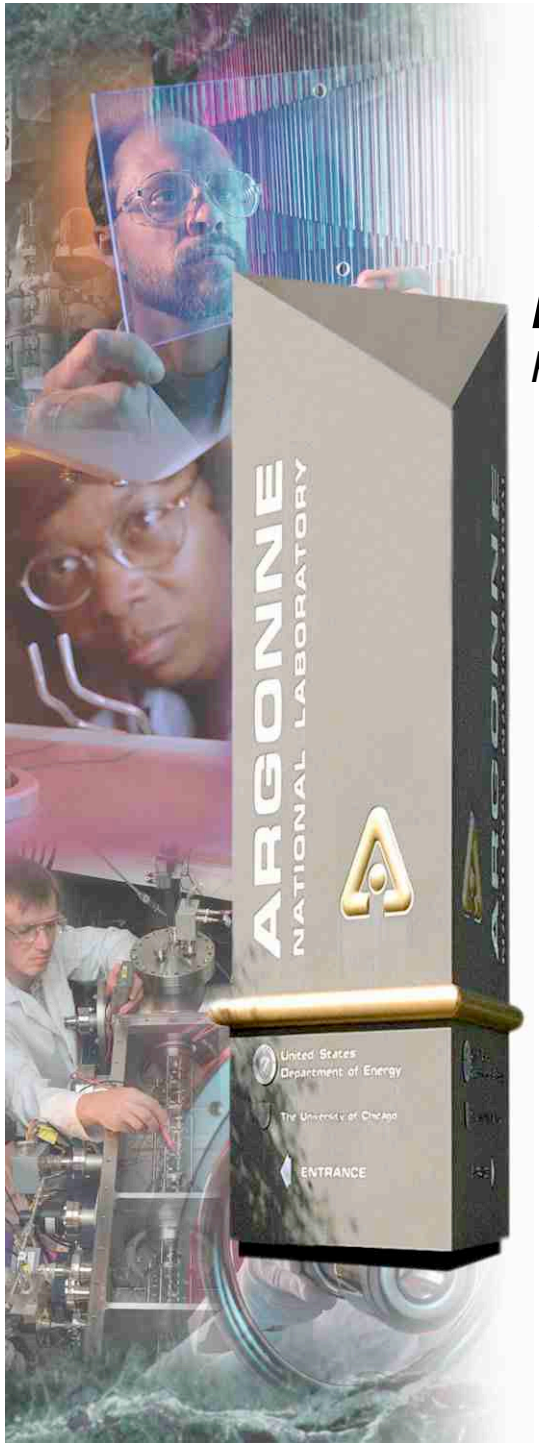

Environmentally Assisted Cracking

NRC JC W6388 *[10/01/00 – 09/30/06]*

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U.S. Department of Energy

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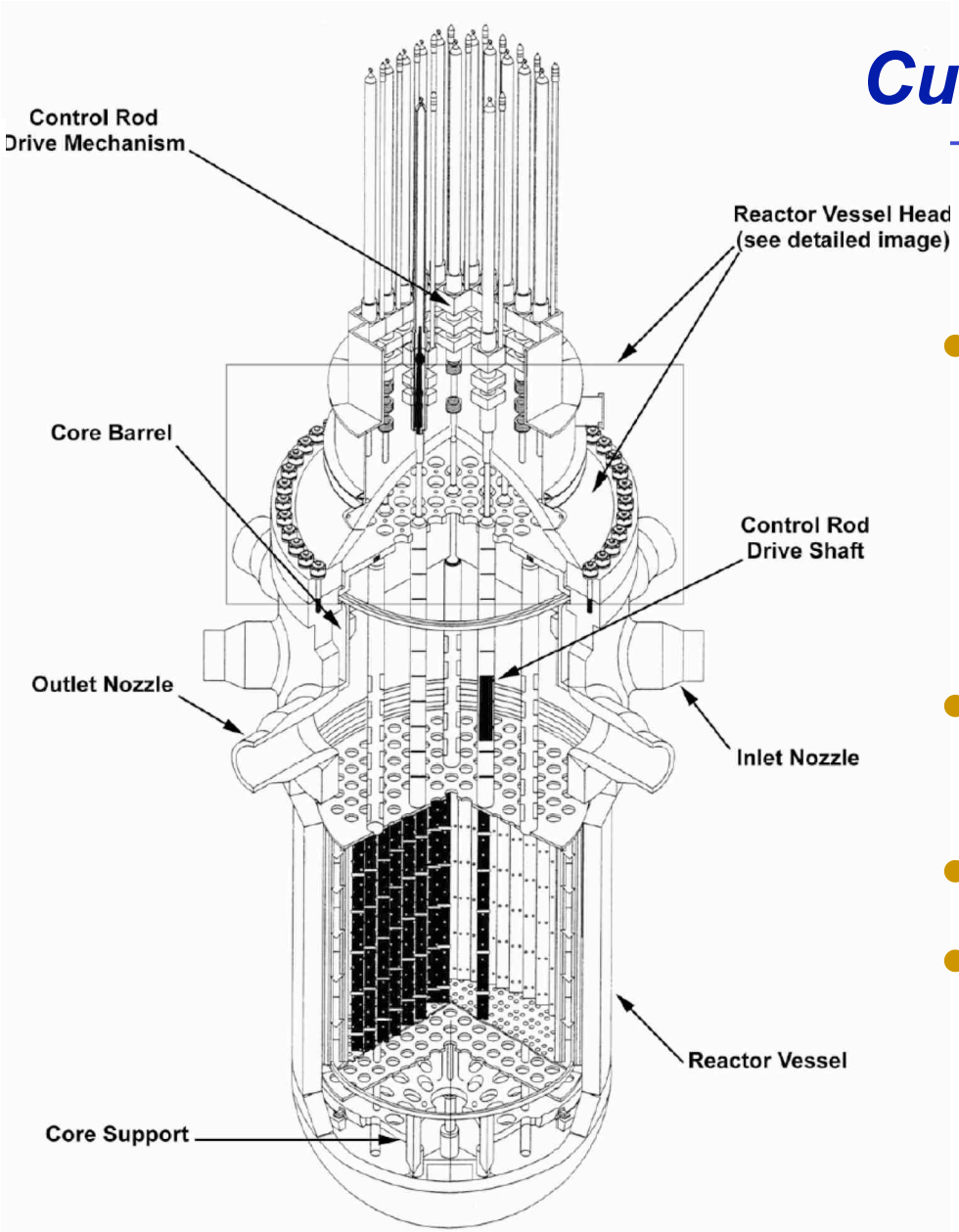
U.S. Nuclear Power Plants

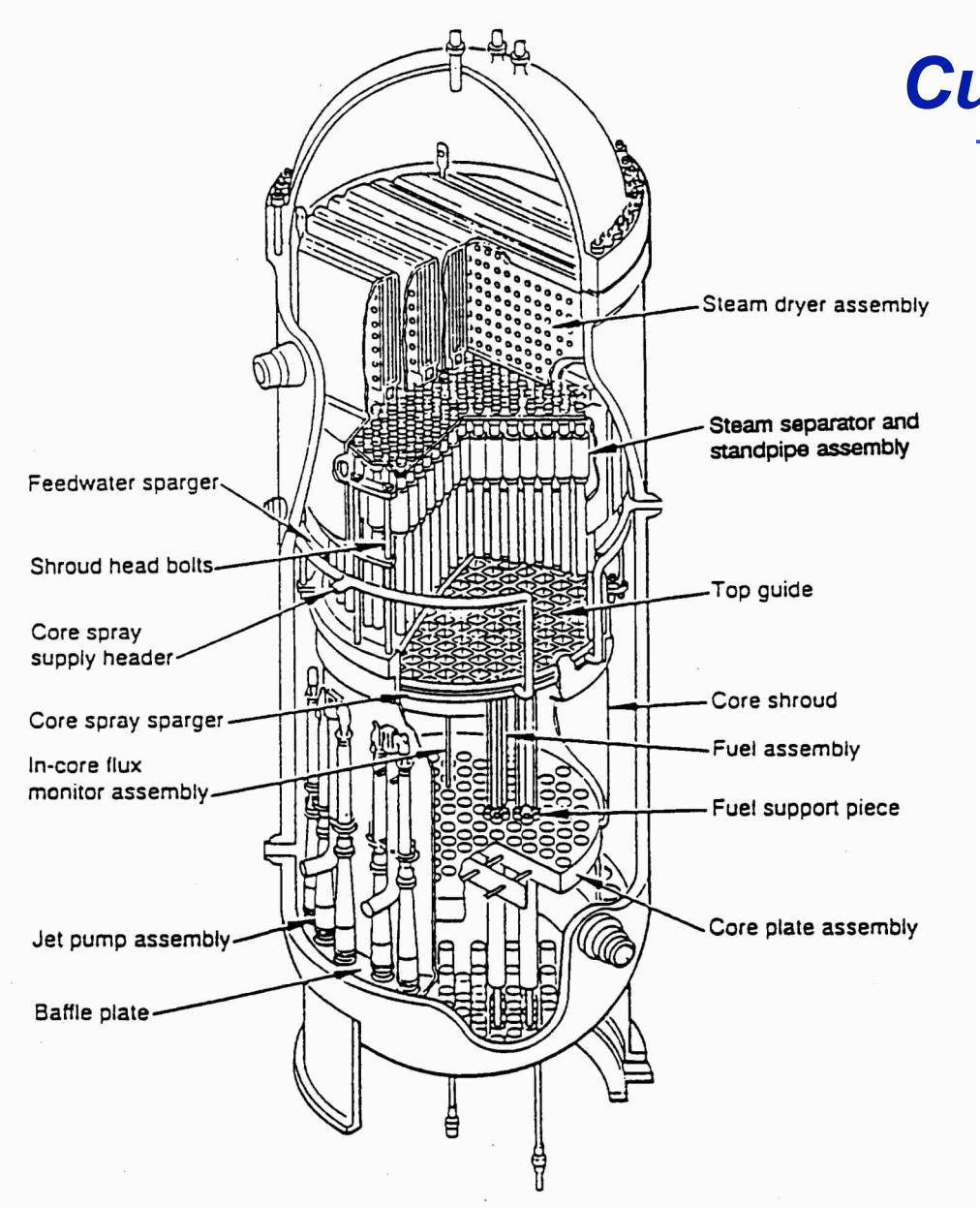
- Regulatory Issue: Integrity of reactor components is subjected to Environmentally Assisted Cracking (EAC). Need to
  - determine crack growth rates to assure that selected inspection intervals are adequate to assure structural integrity
  - identify susceptible materials and conditions, &
  - verify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

Current Issues in PWRs



- Ni–Alloy Cracking
  - CRDM nozzles
  - Outlet nozzle weld
  - BMI penetrations
- Reactor Vessel Head Wastage
- Baffle Bolt Cracking
- Aging & License Renewal Issues

Current Issues in BWRs



- Core shroud cracking
- Aging & License Renewal Issues

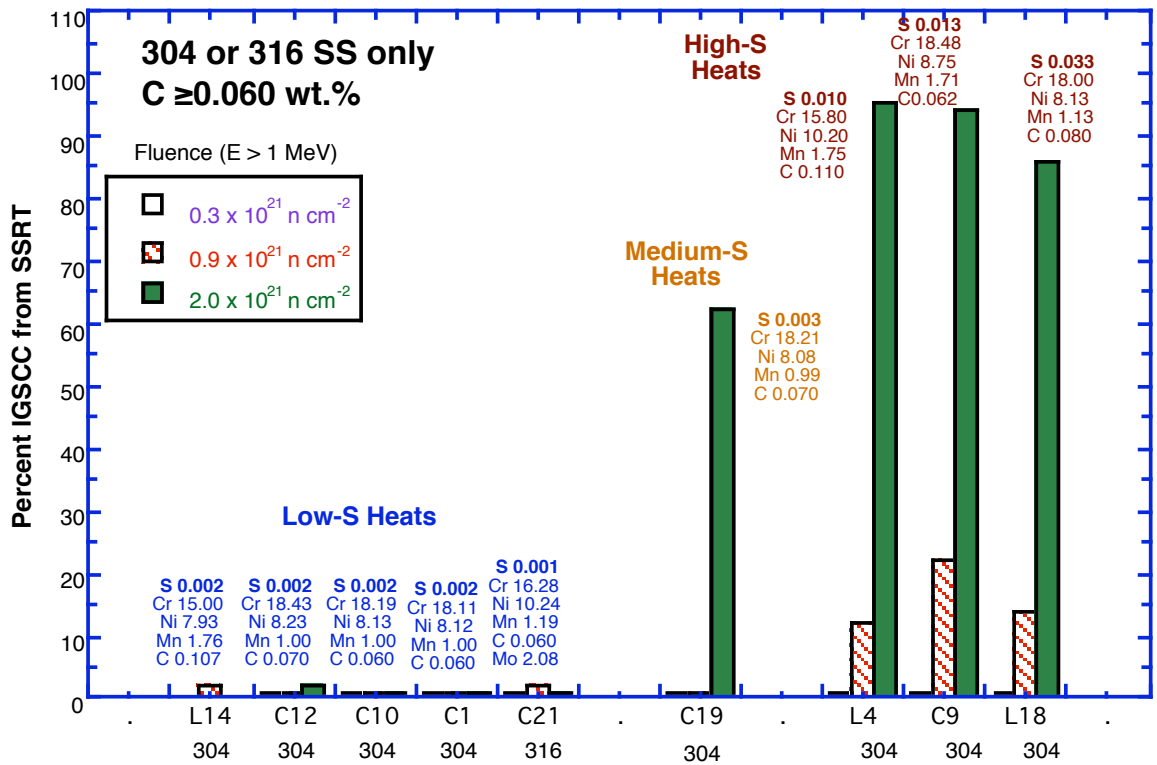
Program Scope

- Provide short–term assistance in regulatory treatment of critical age–related degradation issues in LWRs
- In longer–term develop independent technical information needed to provide stable regulatory environment for future decisions:
  - Degradation of reactor vessel internal components
  - PWSCC of Ni–alloy primary pressure boundary components
  - Environmental effects on fatigue crack initiation
  - Wastage of PV head material
- Work coordinated with industry cooperative groups to leverage results, coordinate testing, verify unexpected results & get peer review

Cracking of Core Internals

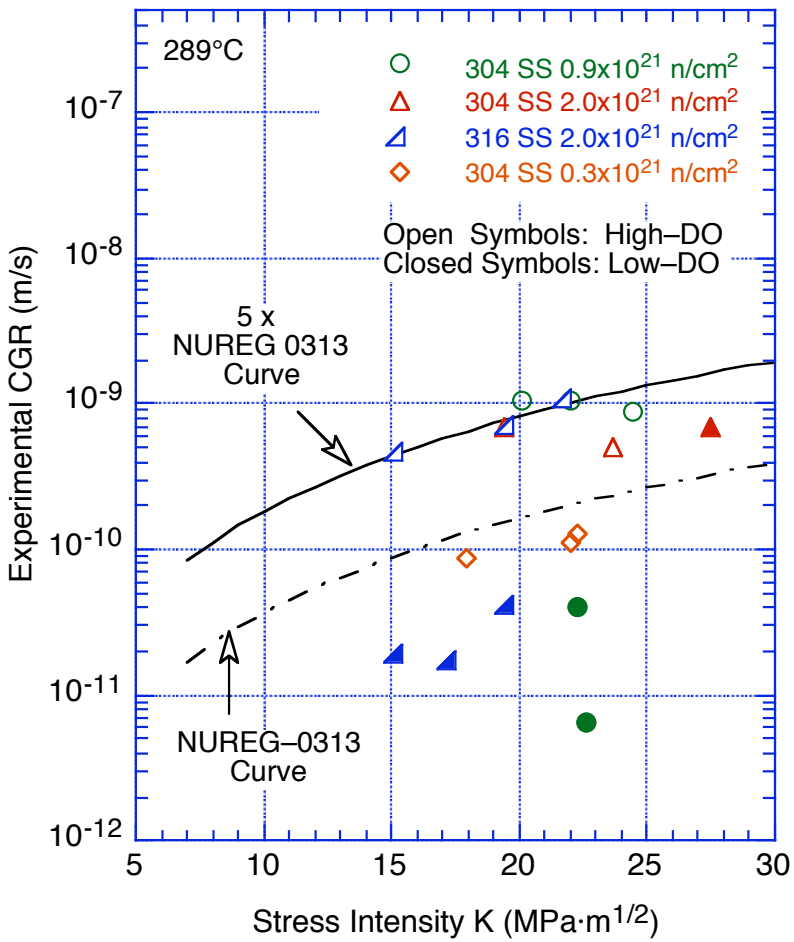
- Technical Issues: High irradiation levels in core can increase susceptibility to SCC by affecting both material & environment
- Program Activities:
  - Understand mechanisms of various types of cracking; needed to rank materials & identify solutions
  - Determine crack growth rates as a function of water chemistry, loading, & fluence; needed to disposition components & determine inspection intervals
  - Determine fracture toughness as a function of fluence; also needed to disposition components

IGSCC of Austenitic Stainless Steels



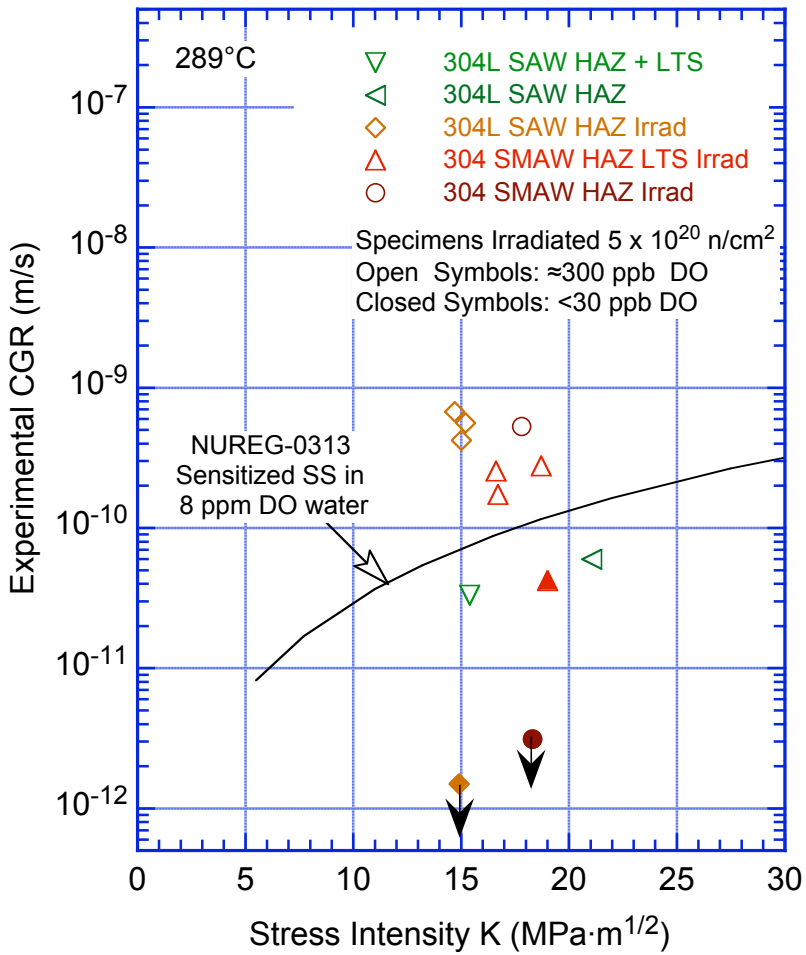
- SSs with ≤0.002 wt.% S are resistant to IGSCC, whereas susceptibility increases significantly at higher S contents

Crack Growth Rate Data for Irradiated SSs



- In BWR NWC, CGRs factor of 5 higher than NRC disposition curve for sensitized SSs
- In BWR HWC, CGRs are an order of magnitude lower than in NWC
- SSRT data and PWR experience show beneficial effect of HWC lost at high enough fluence
- Some CGR data suggest this can occur at lower than expected fluences

CGR Data for Irradiated SS Weld HAZs



- In NWC BWR environment:

  CGRs of nonirradiated HAZ are factor of 2 below the 0313 curve

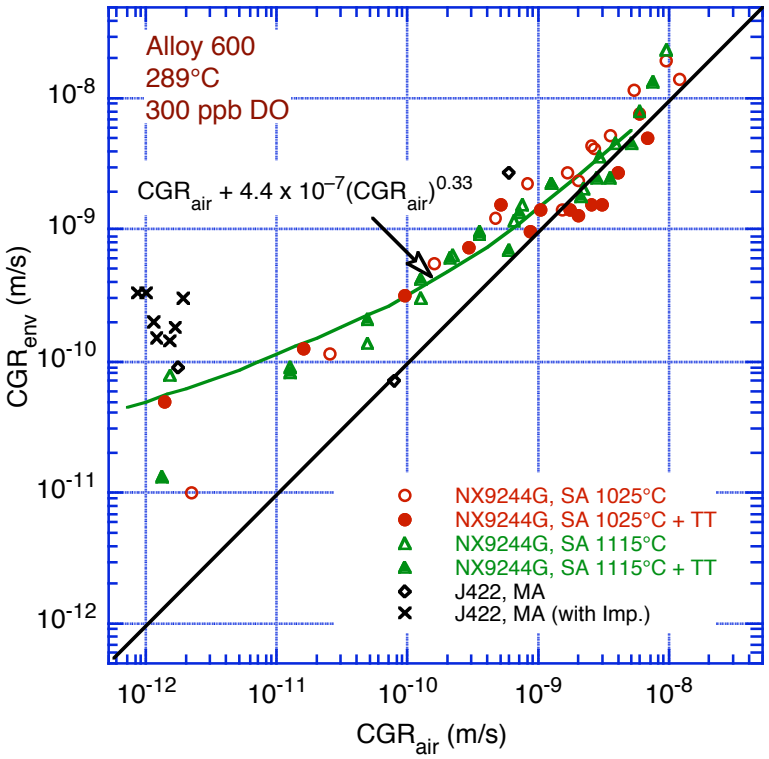
  CGRs of HAZ irradiated to 5×10^{20} n/cm^2 are a factor of ≈5 higher than 0313 curve

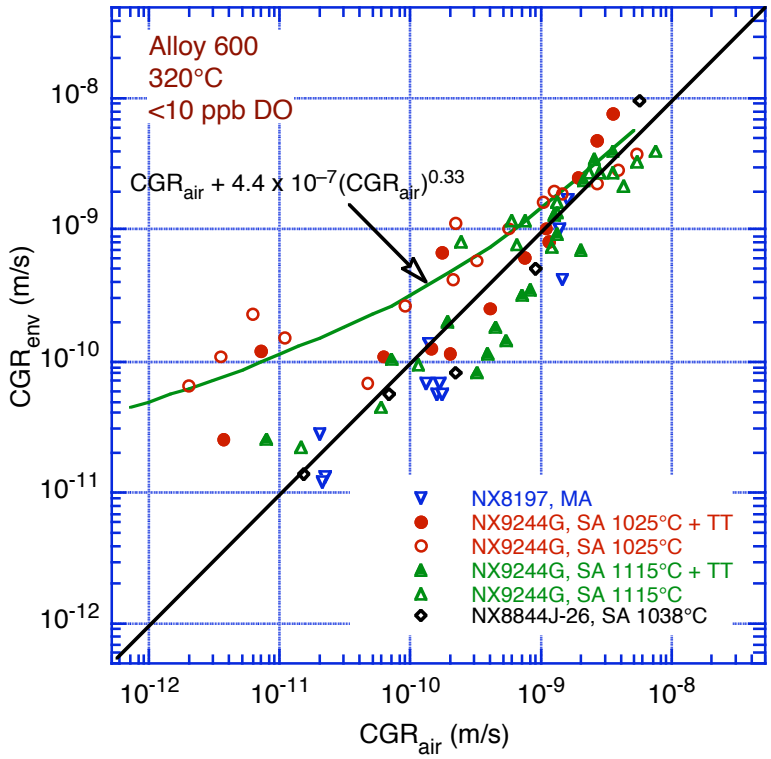
- CGRs decrease significantly in low–DO water

Nickel–Alloy Cracking

- Technical Issues: Determination of CGR curves for safety assessment of cracking of Ni–alloy LWR components
  - Industry CGR models proposed in BWRVIP and MRP reports are used to disposition service cracks & assess effectiveness of mitigating measures
- Program Activities:
  - Determine CGRs in Ni–alloys & welds in LWR environments using laboratory heats & material from reactor components
  - User need request issues; review of industry CGR data & models in BWRVIP/MRP, participate in CRDM expert panel review, perform CRDM probabilistic analyses

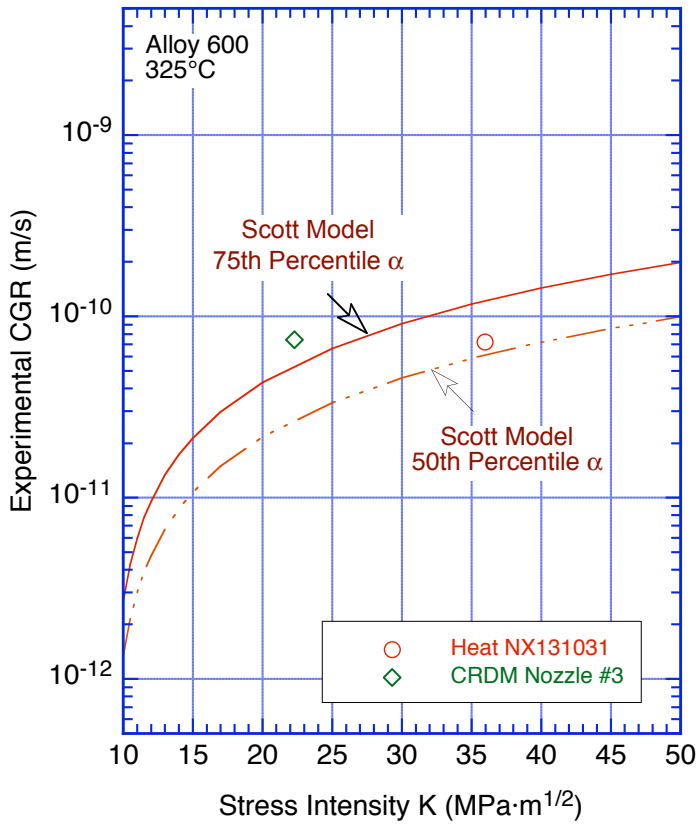
Crack Growth Rates in LWR Environments

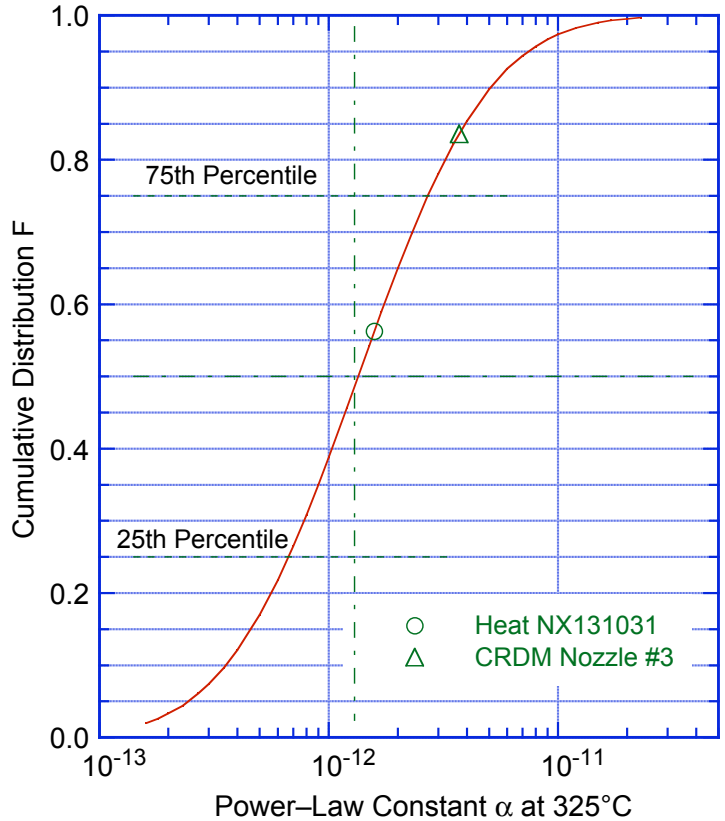




- CGRs enhanced in high–DO water; material condition has little effect
- Environmental enhancement in low–DO depends on material condition

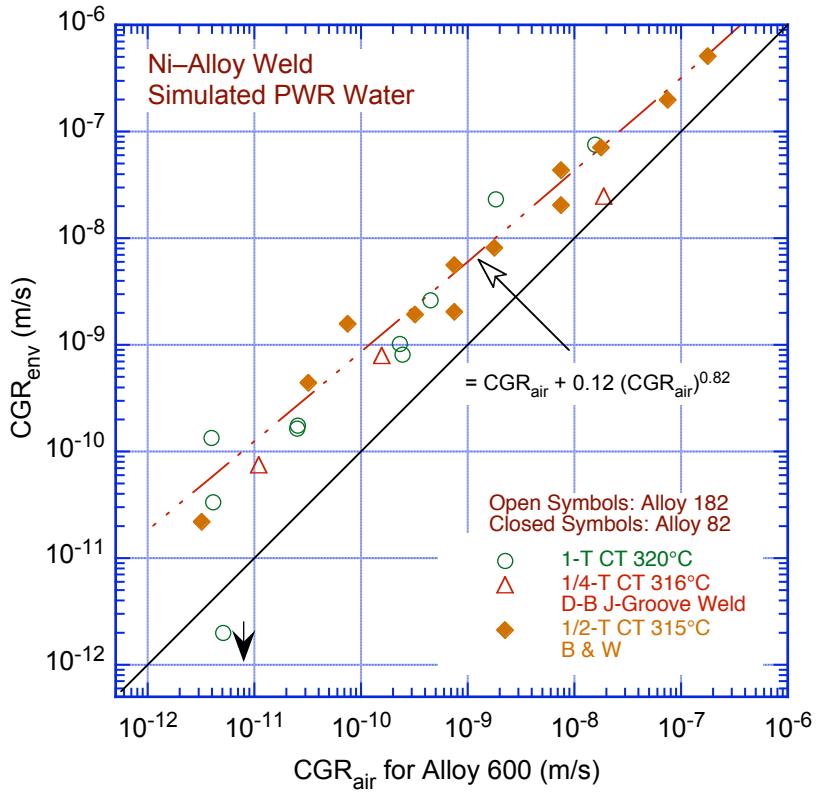
SCC CGRs of A600 in PWR Environment

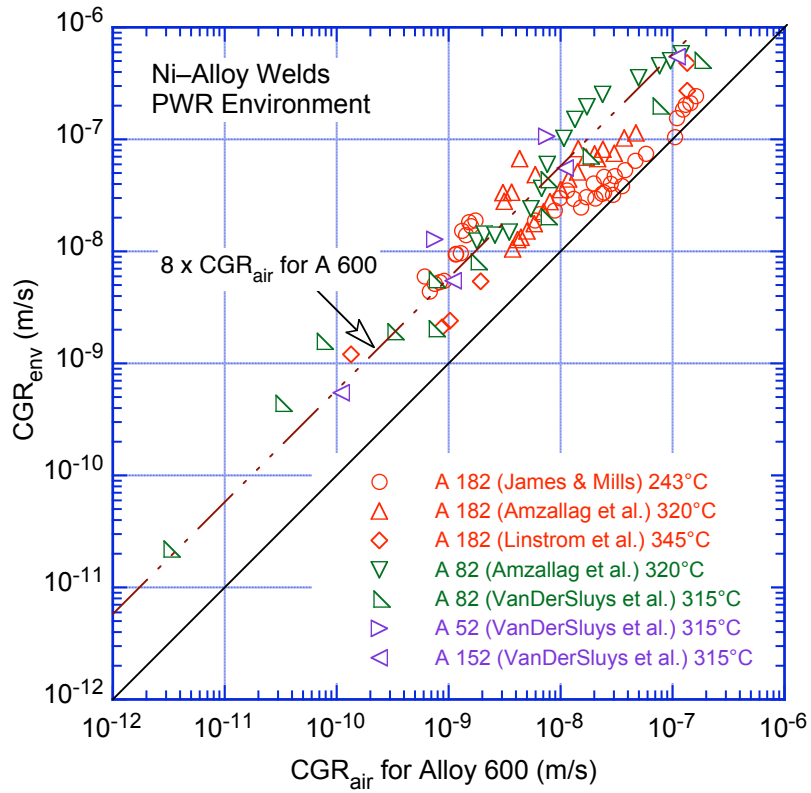




- Experimental CGRs correspond to 83rd percentile for D-B nozzle alloy & 56th percentile for Heat NX131031

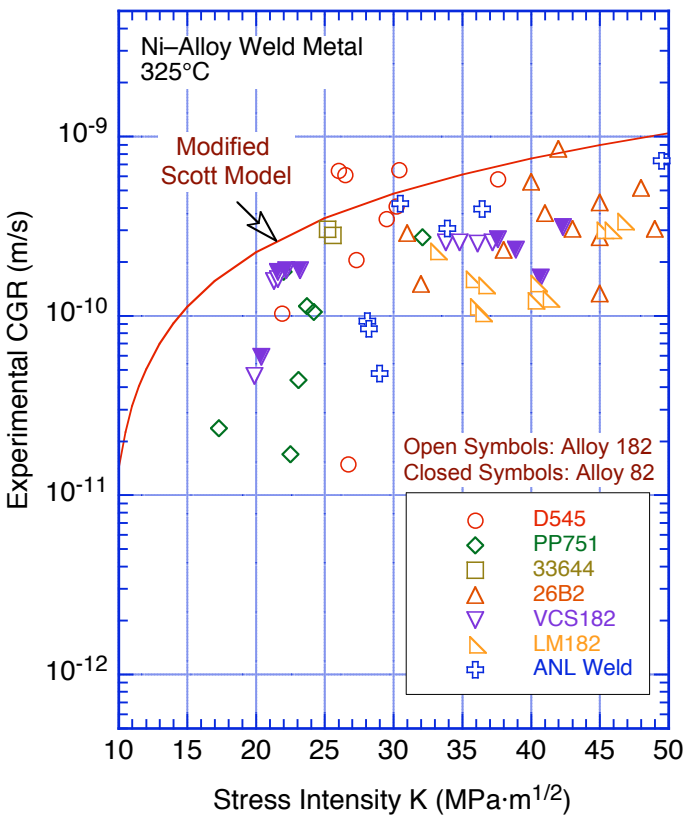
Fatigue CGRs of Ni–Welds in PWR Water

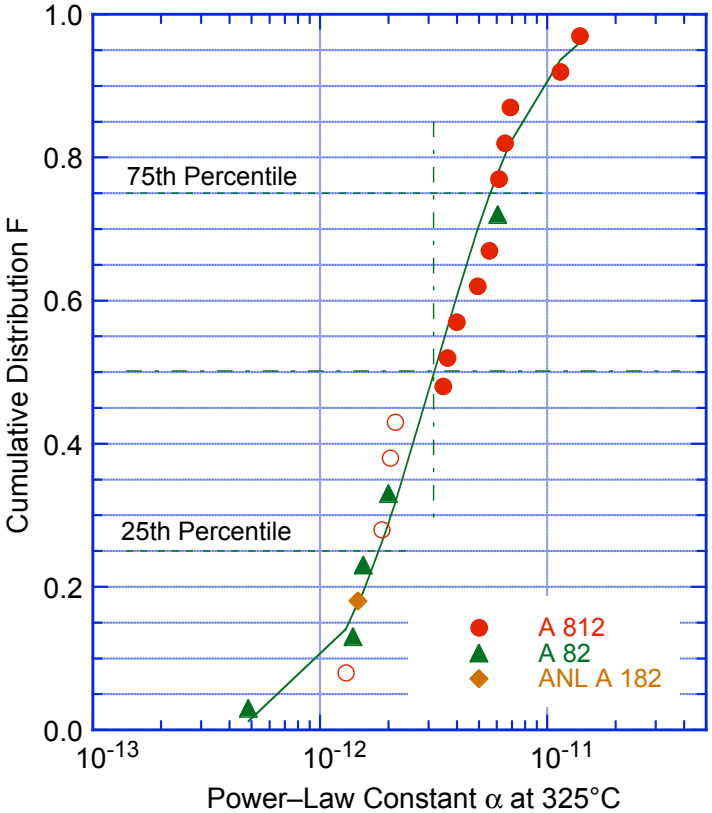




- Little or no enhancement of CGRs in PWR environments in limited data available for $CGR_{air} < 5x10^{-10}$ m/s
- CGRs of Ni–alloy welds are factor of ≈2 higher than for Alloy 600

SCC CGRs of Ni–Welds in PWR Water

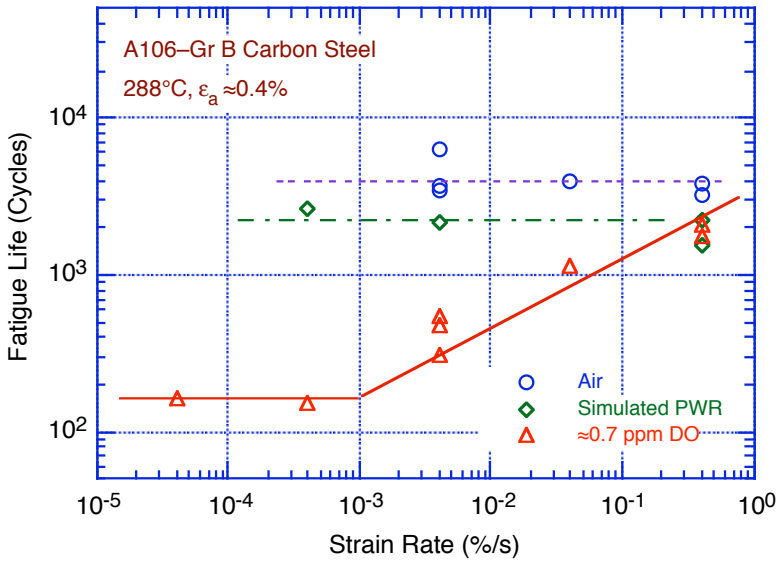


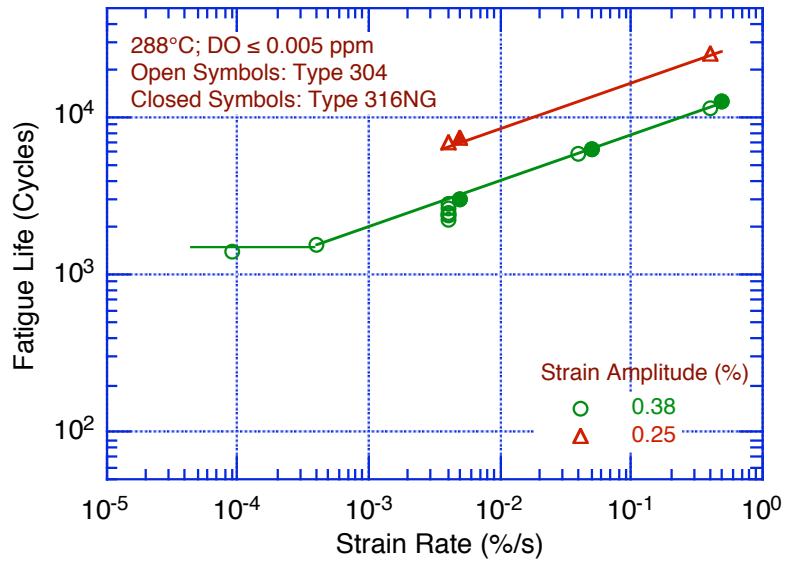


- ANL data on 2 lab–prepared welds, Davis Besse CRDM nozzle #11 J-groove weld, & V. C. Summer nozzle-to-pipe weld

Environmental Effects on Fatigue

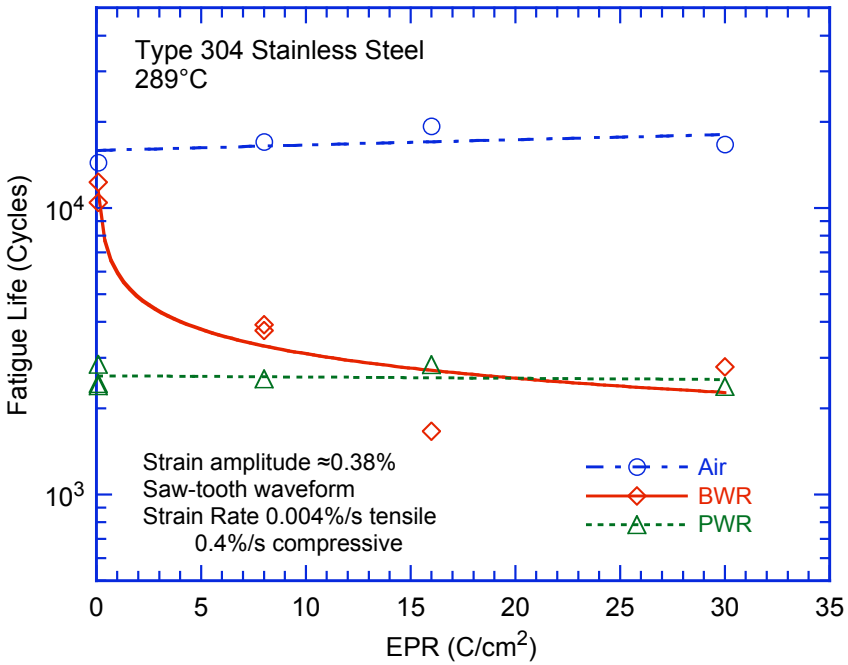
- Technical Issue: ASME design curves based on fatigue life in air
  Life in LWR environments can be much shorter

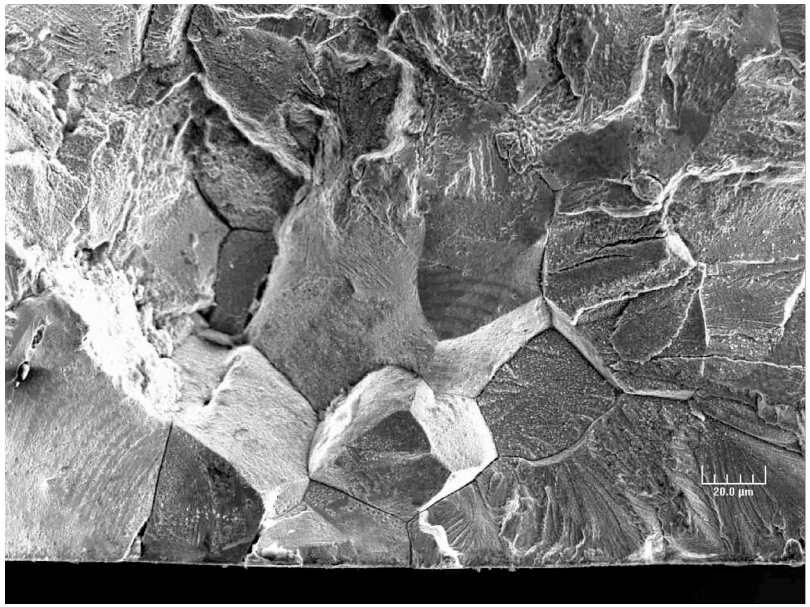




- Program Activities: Determine fatigue lives of materials in LWR environments; identify critical regimes where lives are shortened
- Work with ASME, EPRI to develop code procedures

Effect of Heat Treatment on Fatigue Life





- Heat treatment has no effect on fatigue life in air & PWR water
- In BWR environments life decreases with degree of sensitization