EPRI Collaboration on EAF Component Testing

Project Overview

Jean Smith, Ph.D., P.E.
Principal Technical Leader

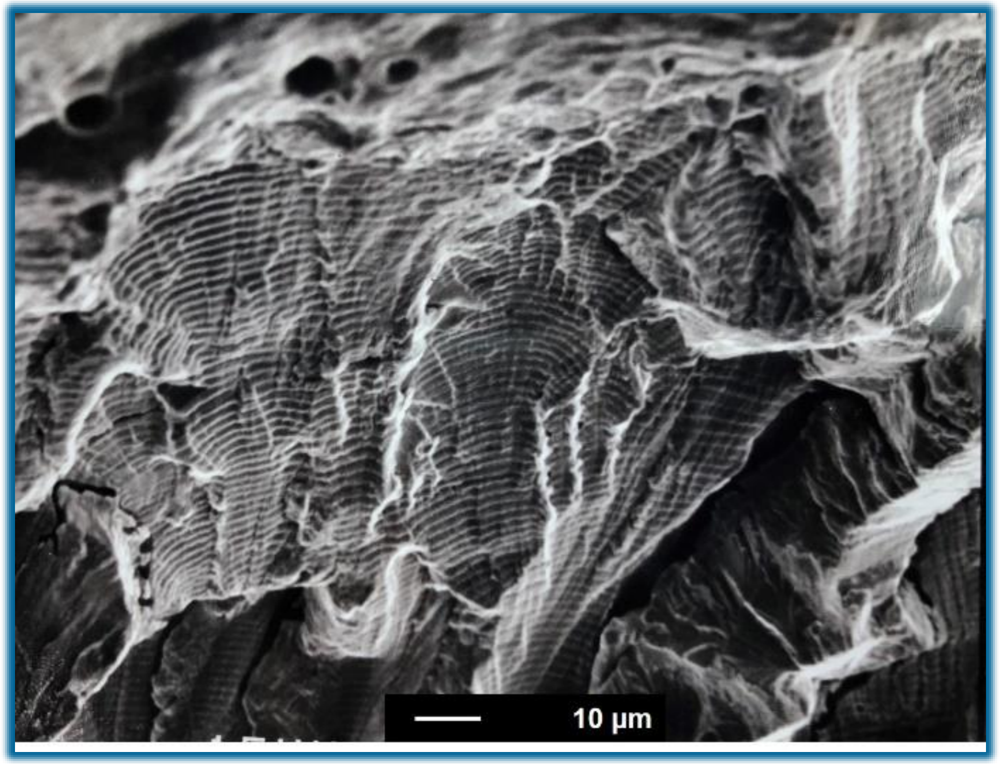
U.S. Nuclear Regulatory Commission Public Meeting on Environmentally Assisted Fatigue Research
September 25, 2018

Rockville, Maryland

EAF Component Testing

Objectives:

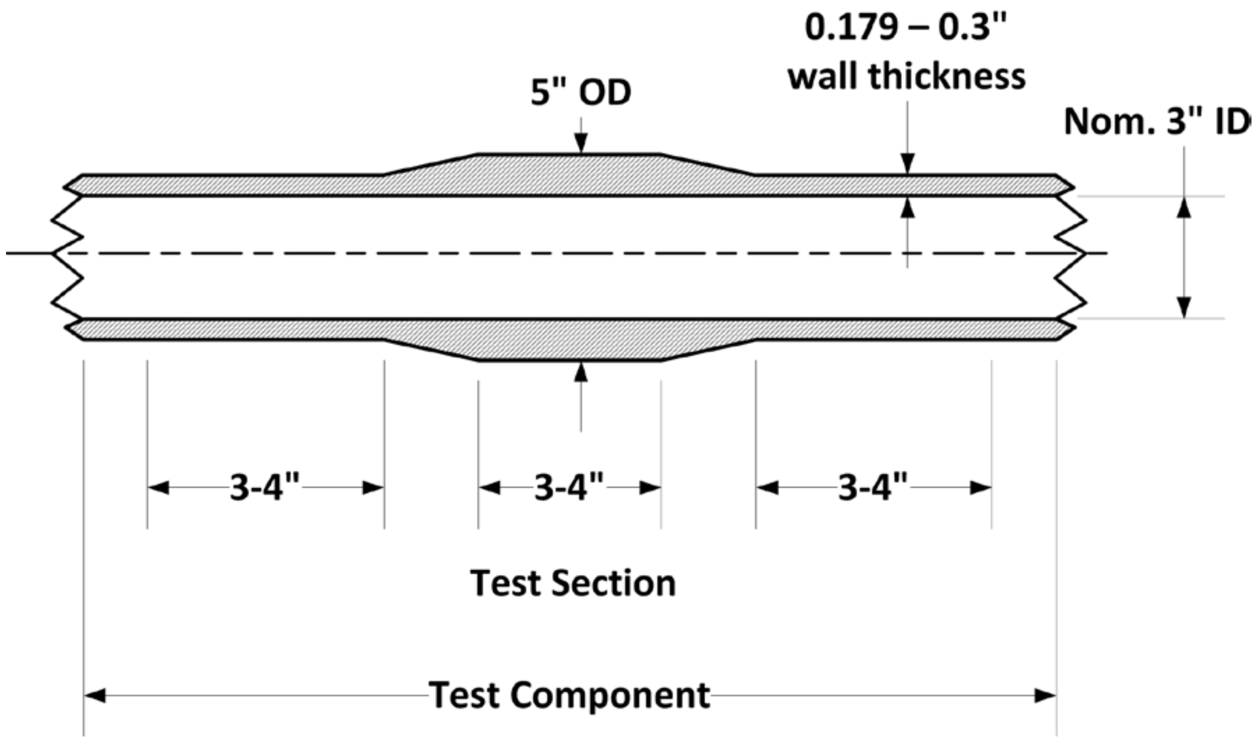
- Understand the effect of light water environments on the fatigue life and resultant CUF on component materials,
- Reconcile the differences between the current CUF methodology results and the fleet operating experience with respect to EAF failures, and
- Provide the technical basis for an improved CUF analytical methodology for EAF



Program jointly funded by EPRI, EDF, Rolls-Royce, Naval Nuclear Labs

EAF Component Testing – Test Component

- Test Material
  - Type 304L stainless steel compliant with ASME BPVC IIA and RCC-M SA-312 specifications
  - As-received surface condition
  - Thorough characterization of test material
    - Chemical composition
    - Metallurgical evaluation
    - Mechanical testing (including fatigue)
- Test Environment
  - PWR primary water
  - 325 °C to 38 °C to allow for thermal transients



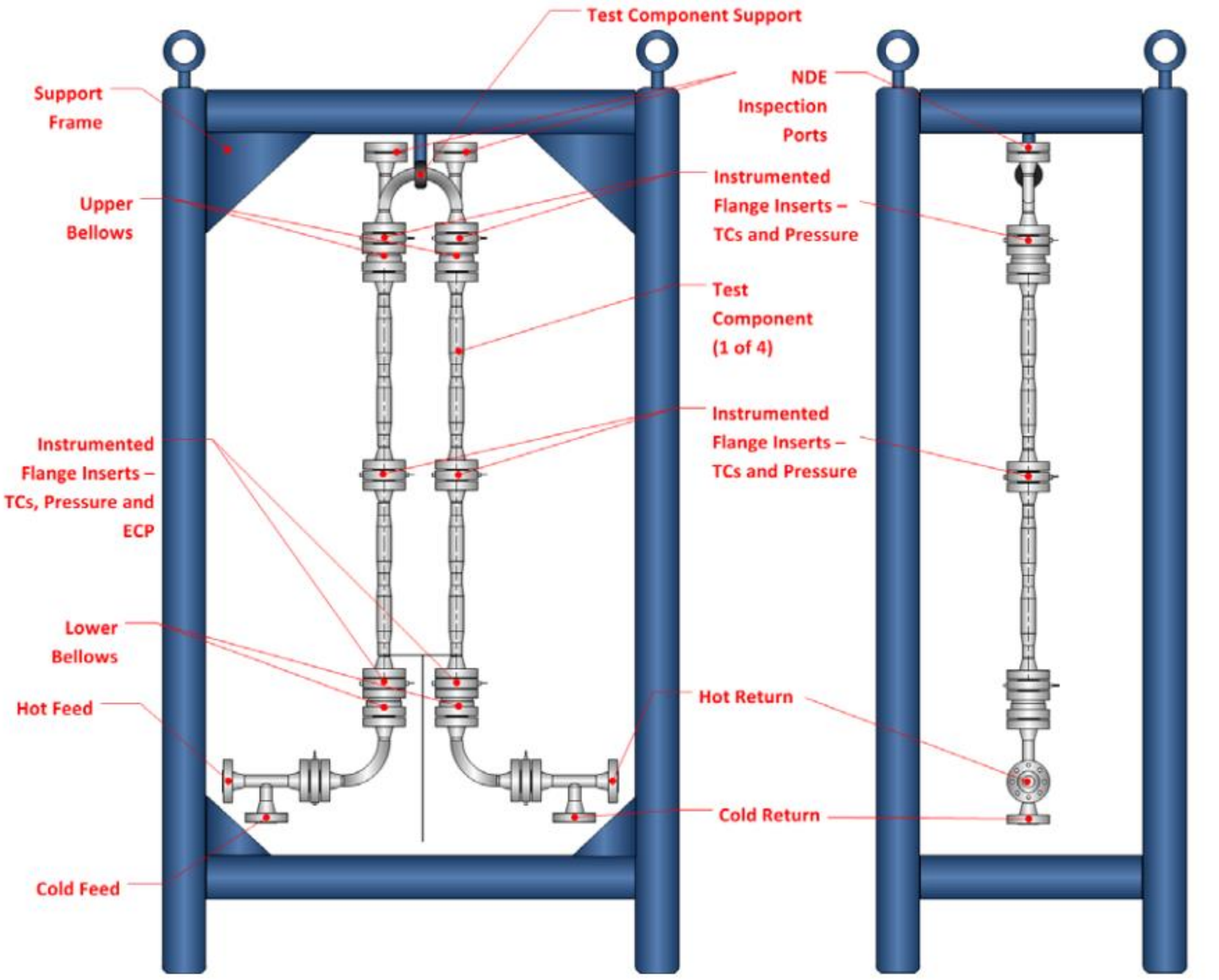
EPRI ELECTRIC POWER RESEARCH INSTITUTE

EAF Component Testing – Test Fixture

Preliminary Fixture Design

- Test fixture designed to accommodate different test component geometries and loading methods to facilitate extension to other PWR, BWR, and new plant components
- Straight pipe, multiple-stepped pipe, component with wetted-surface notches

- ***Thermal strains applied without mechanical loading***



EPRI ELECTRIC POWER RESEARCH INSTITUTE

EAF Component Testing – *Proposed* Transients

Transient #1 – Thermal Shock

- Simulates sudden injection of cold water into a hot PWR nozzle pipe during a turbine roll
- High surface strain is expected to readily initiate cracks
- Environmental effects may not be observed do to the high strain rate
- Thermal shock equivalent to ~ 333,000-344,000 °C/h produced by rapid injection of a slug of cold water (38°C) into hot pipe (325°C) over 1 to 3 seconds and reverse transient

Transient #2 – Moderate Ramp

- Crack initiation and growth under this moderate strain, strain rate, and gradient to provide intermediate data required to validate the best fit model
- Moderate ramp of ~39,000-41,000 °C/h shall be produced by ramping from hot (325°C) to cold (38°C) over ~25s and reverse transient

Transient #3 – Slow Ramp

- Slow-rising strain simulates normal plant cooldown of a PWR nozzle pipe and is expected to allow assessment of environmental enhancement effects
- Slow ramp of ~10,000 °C/h produced as a slow decrease from hot (325°C) to cold (38°C) over ~100s and reverse transient

EAF Component Testing – Overall Process

- Five-year test program consists of four phases
- Program begins 2018 and finishes in 2022

FEA Modelling and Design
- Define component parameters
- Define transient parameters
- Component FEA model outputs
- Predict fatigue behavior

→

Commissioning
- Thermal and strain FEM benchmarking
- NDE calibration
- FEA alignment
- NDE crack siding calibration
- Revise fatigue predictions

→

Testing
- Initiate fatigue cracks
- ET for crack detection
- Propagate fatigue cracks
- UT for crack growth monitoring
- Post-test examinations

→

Integration into FEA Models
- Calculate CUF (crack initiation
- Calculate through-wall crack growth

EAF Component Testing – FEA Modelling and Design

Define Component Parameters

- Component Geometry
- Notch Geometry
- Material Parameters

Define Transient Parameters

- Water transient parameters
- Fluid parameters

Component FEA Model Outputs

For each of the four components and three water transients

- Water transient temperature as a function of time and distance from inlet
- Metal wetted surface and thru-wall temperature and stress/strain state in test components f(time, thru-wall position, axial distance)

Predict Fatigue Behavior

- Predict fatigue crack initiation and crack growth rate
- Apply NUREG/CR-6909 Rev. 1 to predict life

Commissioning

- Repeat process to ensure fatigue crack initiation/growth
  - Changing fluid transient parameters
  - Modifying component Geometry
  - Adding stress raisers (ID notches)
  - Applying mechanical loads
- Commissioning

EAF Component Testing – Commissioning

Fabricate Test Components
Construct Test Fixture
Upgrade Flow Loop

Thermal & Strain FEM Benchmarking

- Install 4 instrumented components
- Perform water transients
- Acquire detailed thermal and strain data for input into FEA model

NDE Calibration

- Baseline NDE data
- Initiate crack via Transient #1
- Inspect with ET
- Grow crack with Transient #3
- Monitor with UT

NDE Crack Sizing Calibration

- Post-test examination to align NDE methods with actual crack depths

FEA Alignment

- Adjust FEA model inputs (material and fluid properties) and FEA model parameters
- Re-calculate predicted wetted surface and thru-wall thermal and strain history
- Iterate until the FEM matches experimental values

Revise Fatigue Predictions

EAF Component Testing – Test Process

Test Set-Up

4 test components

Baseline NDE

→

Initiate Fatigue Cracks

Test 1: Thermal Transient #1 (thermal shock)

Test 2: Thermal Transient #2 (moderate ramp)

→

NDE Inspections for Crack Initiation

Periodic ET from ID

↓

Grow Fatigue Cracks

Test #1: Thermal Transient #1 (thermal shock)

Test #2: Thermal Transient #3 (slow ramp)

→

NDE Inspections for Crack Growth

Encoded UT from OD

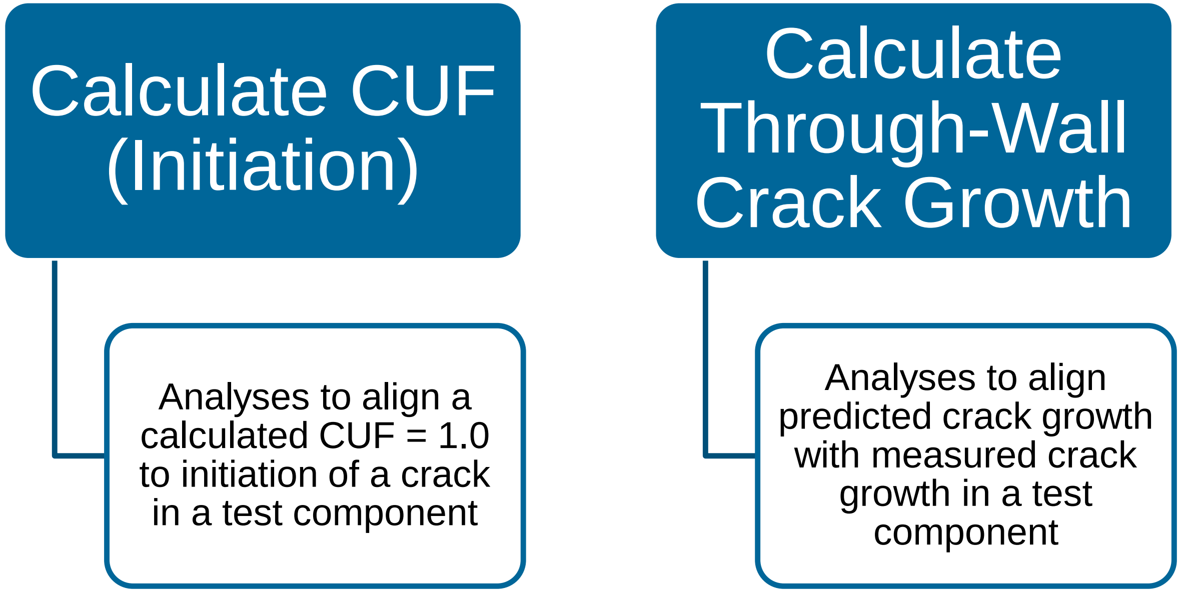
→

Test Termination Criterion Reached

Post-test NDE, destructive exams, and calculations

EAF Component Testing – Integration into EAF Models

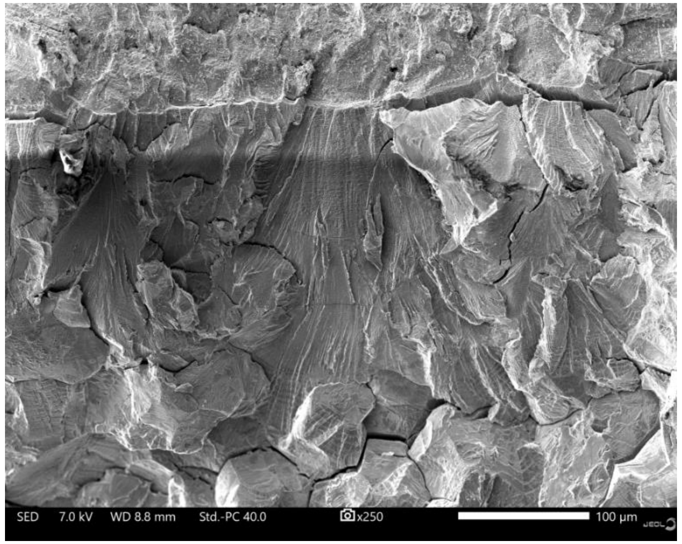
- The difference between the calculated number of cycles that result in CUF = 1.0 and the measured test cycles to produce a fatigue crack will be used to calculate a factor to represent the difference between predicted fatigue life using a laboratory specimen fatigue curve and the fatigue life of actual components
- The difference between the number of cycles that cause fatigue crack growth to depths observed in the testing and the test cycles as a function of crack depth will be used to calculate a factor to represent the difference between the calculated fatigue crack growth and the fatigue crack growth of actual components

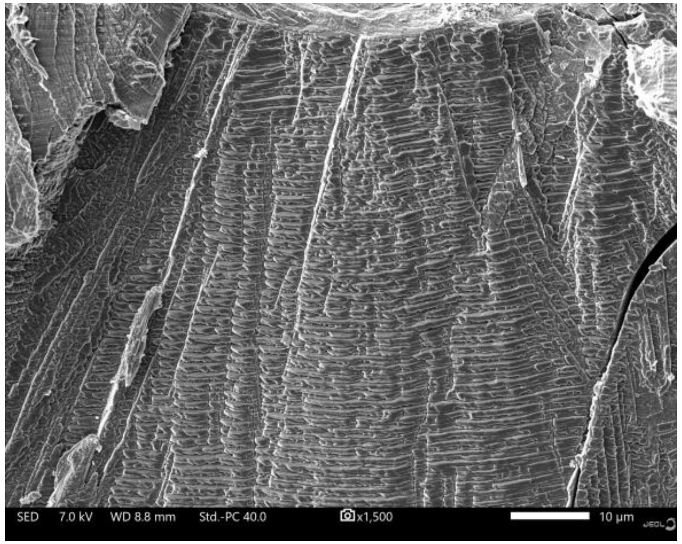


EPRI ELECTRIC POWER RESEARCH INSTITUTE

EAF Component Testing – Summary

- Comprehensive program including FEA modeling and design, commissioning (NDE calibration and FEA alignment), testing (two sets of test conditions on four specimens), and EAF modeling
- Bridge the gap between small specimen, separate-effects testing and operating plant components
- Define factors for fatigue life and fatigue crack growth to allow transference of small specimen data to plant components





Together…Shaping the Future of Electricity