Life Modelling of Critical Steam Cycle Components

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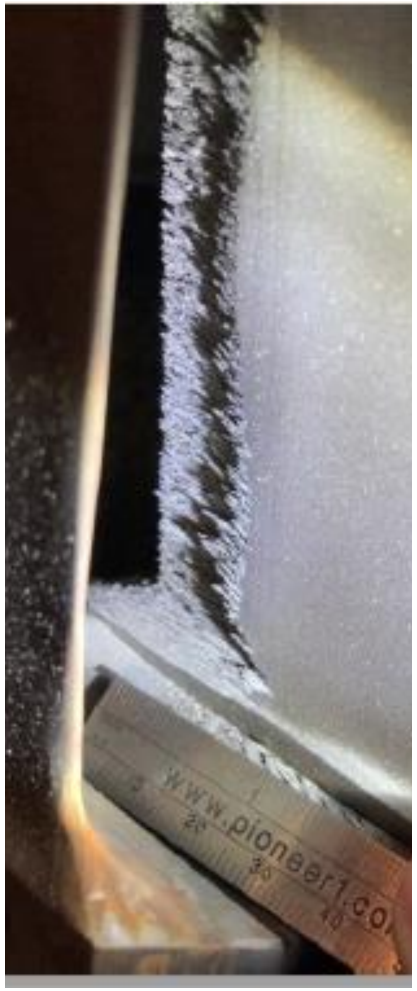
Project Description and Objectives

L-0 Last Stage Bucket (Turbine Blade) Water Droplet Erosion

- Calibrate life prediction models (Kitagawa Diagram) for L-0 Jethete buckets experiencing water droplet erosion
  - Industrial relevance for coal fleet (per industrial partner)
    - Low load operation and frequent cycling- outside of scope of original design
    - L-0 failure could result in plant retirement- must reduce risk of failure
    - Unnecessary (preemptive) replacement is budgetary nightmare- optimize L-0 maintenance scheduling and preventative maintenance forecasting



Project Description and Objectives

L-0 Last Stage Bucket (Turbine Blade) Water Droplet Erosion

- Modeling Existing Coal Plant Challenges- "…to enhance the performance and cost-effectiveness of coal-based power generation…required to maintain grid stability."
- Driving Question(s) (from industry partner Southern Company):
  - Can we predict failures based upon operational and inspection data?
  - Can the results be applied to various sizes of L-0 buckets made of same material?

Project Description and Objectives

L-0 Last Stage Bucket (Turbine Blade) Water Droplet Erosion

Technology Benchmarking

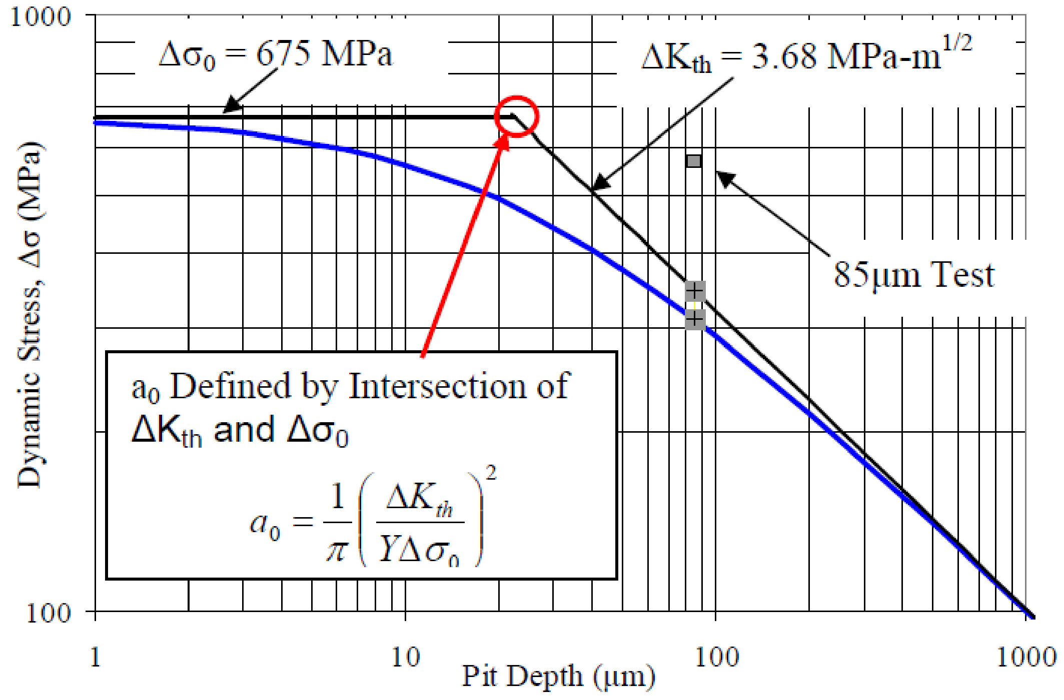
- Current state-of-the-art (SOA) technology includes
  - Collection of erosion inspection data
  - Comparison to prior inspection data and failure cases
  - General guidance taken from existing fitness-for-service guidelines for L-0 blade of different material class
  - No clear guidance on fitness for service for L-0 buckets of Jethete material
- Proposed research will provide fitness-for-service guidelines specific to water droplet erosion of L-0 buckets made of Jethete material
  - as a function of operational hours, starts, etc.
  - as a function of operating conditions
  - as a function of inspection data

Erosion Depth (M or N)	Countermeasure
(M or N) < 0.5 mm	Inspect at next outage
0.5 mm ≤ (M or N) < 0.9 mm	Refurbish at next outage
(M or N) > 0.9 mm	Refurbish during current outage

Project Update

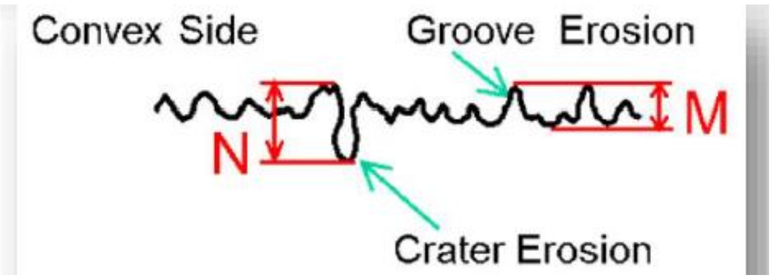
L-0 Last Stage Bucket (Turbine Blade) Water Droplet Erosion

- Fitness-for-service model selected: Kitagawa Diagram for Jethete water droplet erosion lifing



$$a_0 = \frac{1}{\pi}\left(\frac{\Delta K_{th}}{Y\Delta\sigma_0}\right)^2$$

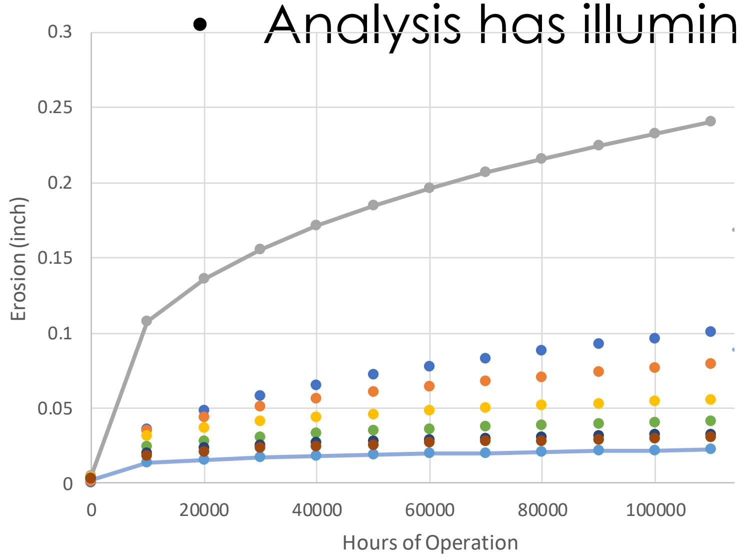
- Must know state of stress at locations of interest- finite element model created
- Must know erosion depth as it relates to "grooves" and "craters"- modification of inspection techniques

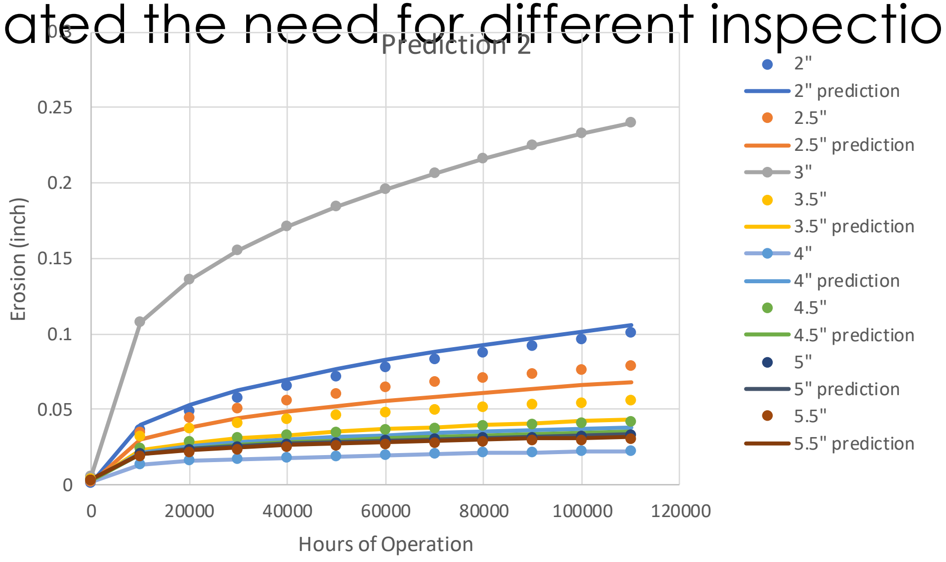


Project Update

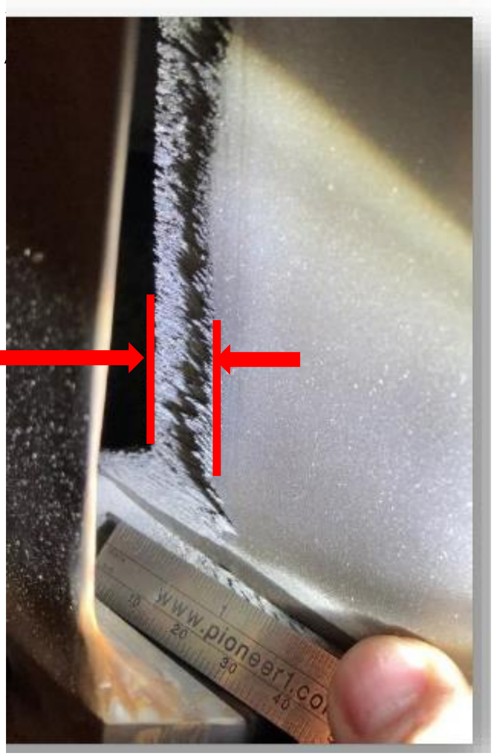
L-0 Last Stage Bucket (Turbine Blade) Water Droplet Erosion

- Operations and inspection data for 4 plants received from Southern Company
  - Preliminary modelling indicates a single location of primary interest for future inspections
  - Preliminary modelling indicates that operational hours (and not starts) with erosion kinetics
  - Analysis has illuminated the need for different inspection techniques





Measured Erosion Depth



Project Update

L-0 Last Stage Bucket (Turbine Blade) Water Droplet Erosion

- Single L-0 bucket received from Southern Company
  - Intending to get 20+. COVID pandemic pushed back schedule for plant shut down
- Virgin Jethete material received
  - Virgin Jethete test matrices created
- Testing supplies received from supplier
  - COVID pandemic delayed supplies by 3 months

Test Matrices

- K_{th} or crack initiation tests on virgin material (at temp)
- da/dN on virgin material (at temp)
- K_{IC} on virgin material (at temp)
- da/dN and K_{IC} on "used" blade material (at temp)

Turbine Blade Solid Model from 3D Point Cloud

Turbine Blade (damaged) Removed From Service

Project Update

L-0 Last Stage Bucket (Turbine Blade) Water Droplet Erosion

Next Steps

- Create test specimens
- Perform FCG, fracture, and threshold testing on virgin material
- Perform FCG and fracture testing on service material
- Calibrate Kitagowa diagram/model to test results
- Create user-friendly program to couple inspection results with future maintenance and inspection needs

Project Description and Objectives

Main Steam Piping Wye-Block Life Modelling

- Calibrate life prediction models (fatigue-creep initiation) for P22/G22 main steam wye block
  - Industrial relevance for coal fleet (per industrial partner)
    - Pipe-to-Wye block welds are the most common repairs made by Southern Company in the steam piping system
    - Weld repairs require full system shut down
      - Expensive
      - Time consuming

Project Description and Objectives

Main Steam Piping Wye-Block Life Modelling

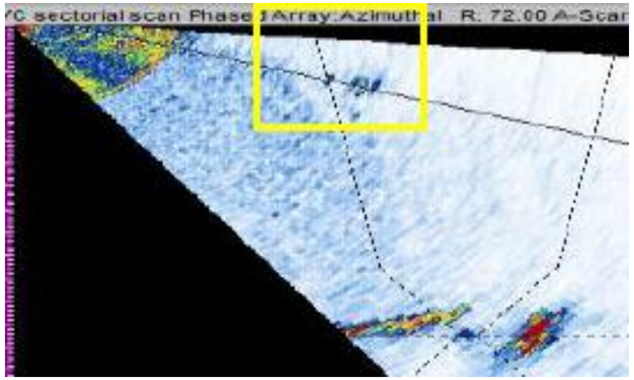
- Modeling Existing Coal Plant Challenges- "…to enhance the performance and cost-effectiveness of coal-based power generation…required to maintain grid stability."
- Driving Question(s) (from industry partner Southern Company):
  - Can we predict thermal fatigue crack initiation as a function of operating conditions and plant-specific boundary conditions?
  - Can we use these predictions to more optimally schedule inspections and maintenance?

Project Description and Objectives

Main Steam Piping Wye-Block Life Modelling

Technology Benchmarking

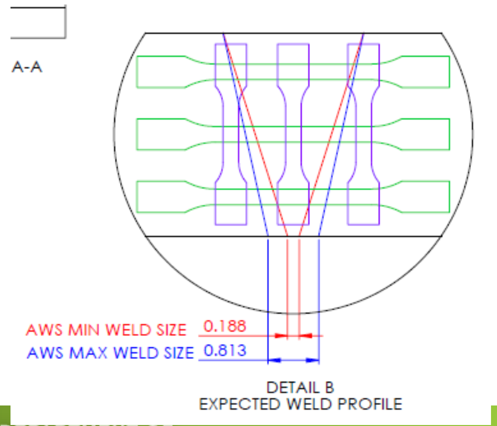
- Current state-of-the-art (SOA) technology includes
  - Shutting down main steam piping loop
  - Preparation of each weld (extensive grinding)
  - Manual NDE
  - Typical result is a go-no-go gate decision matrix
    - a < NDE detection- Inspect at next scheduled shutdown
    - NDE detection< a <a_{crit}- repair at next scheduled shutdown
    - a_{crit}< a- repair immediately
- Research will calibrate thermal-fatigue crack initiation model for P22 and its welds as a function of loading (past, present, and future) and component-specific boundary conditions
  - Optimize inspection and repair scheduling

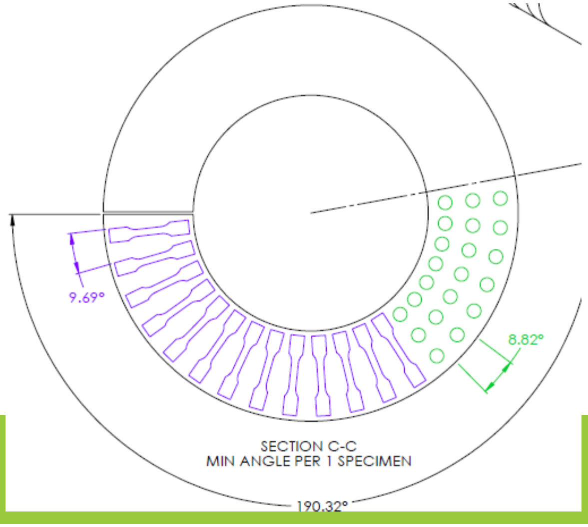


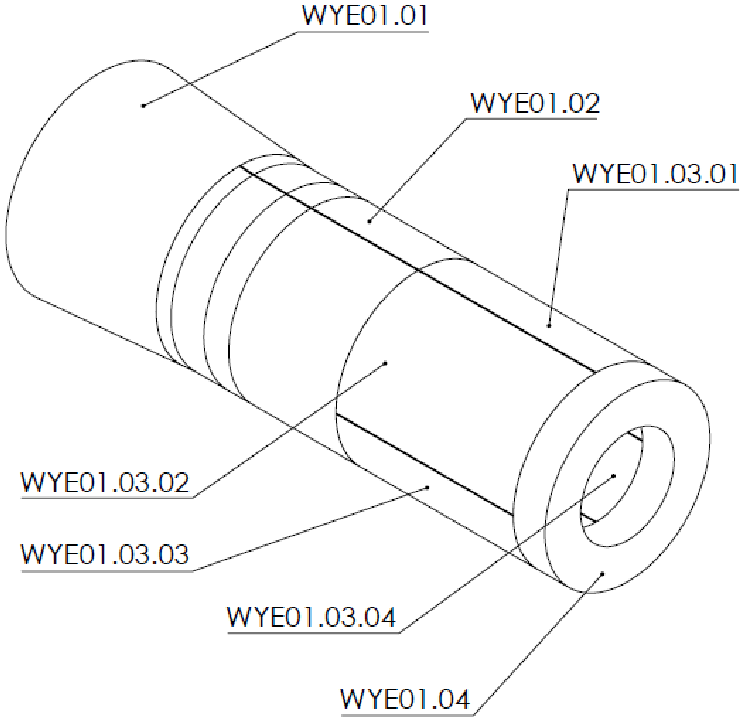
Project Update

Main Steam Piping Wye-Block Life Modelling

- Received section of wye block-pipe weld removed from shuttered coal-fueled power plant. Covid pandemic delayed delivery by 4 months.
  - G22 wye, P22 pipe, and weld are representative of main steam piping components of interest
  - Weld includes a field repair
  - Southern Company performed NDE of weld at our facility
- Pipe sent to 3rd party for (gross) sectioning
- Working with Southern Company on specimen sectio





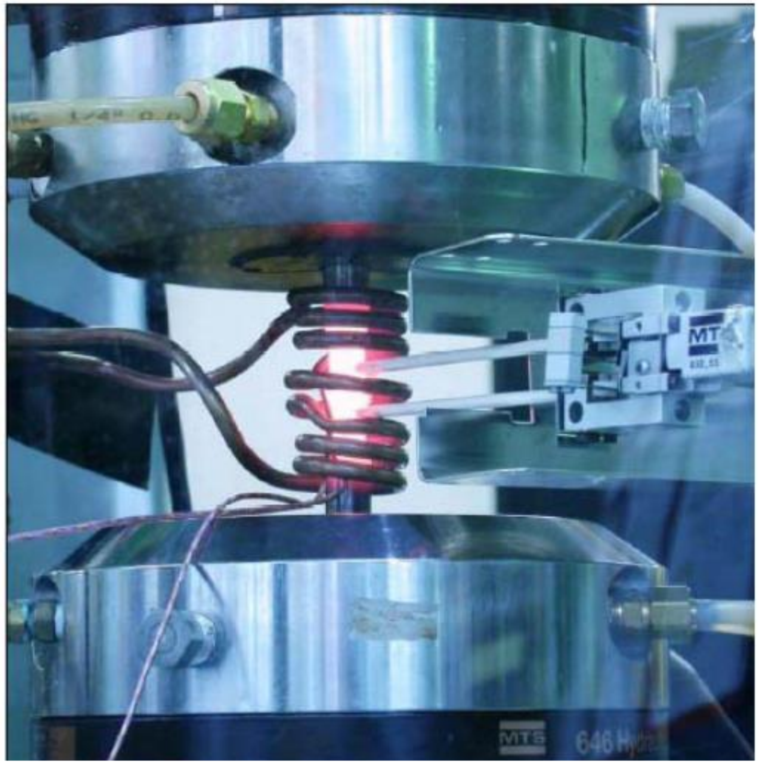


Project Update

NATIONAL ENERGY TECHNOLOGY LABORATORY

Main Steam Piping Wye-Block Life Modelling

- Materials characterization
  - Equipment assembly and tuning. Covid Pandemic delayed elevated temperature testing supplies by 3 months
  - Test matrices finalized



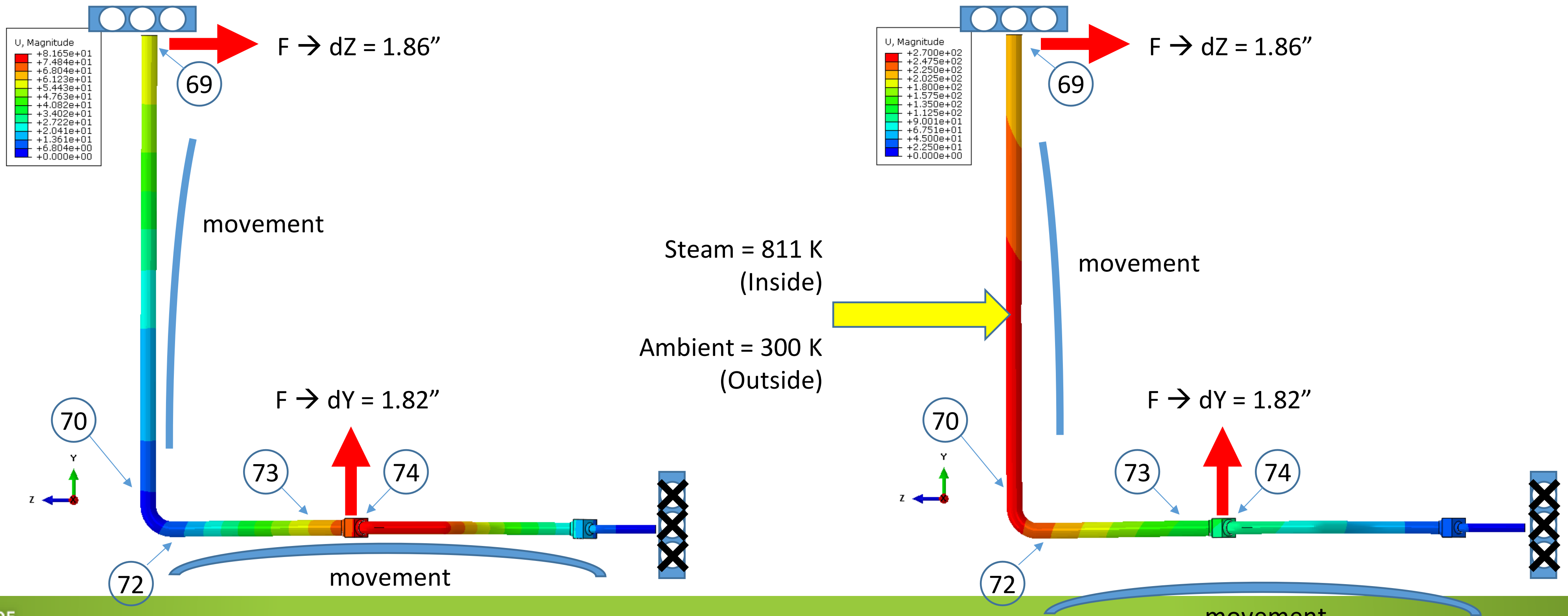
Specimen Count		Location		
		Cross-Weld	Fusion Zone	Base Material
Direction	Longitudinal	18 HT +3 extra	0	3 +3 extra
	Circumferential	0	0	12*+3extra
	Radial	0	36* +3extra	2 HT +3 extra

Number of tests performed in each location and orientation subject to change based upon initial test results

Project Update

Main Steam Piping Wye-Block Life Modelling

- Section of main steam piping of Southern Company's coal-fueled power plant (including wye-block) modeled in ABAQUS
  - Displacements resulting from operation has been calibrated and verified with plant data



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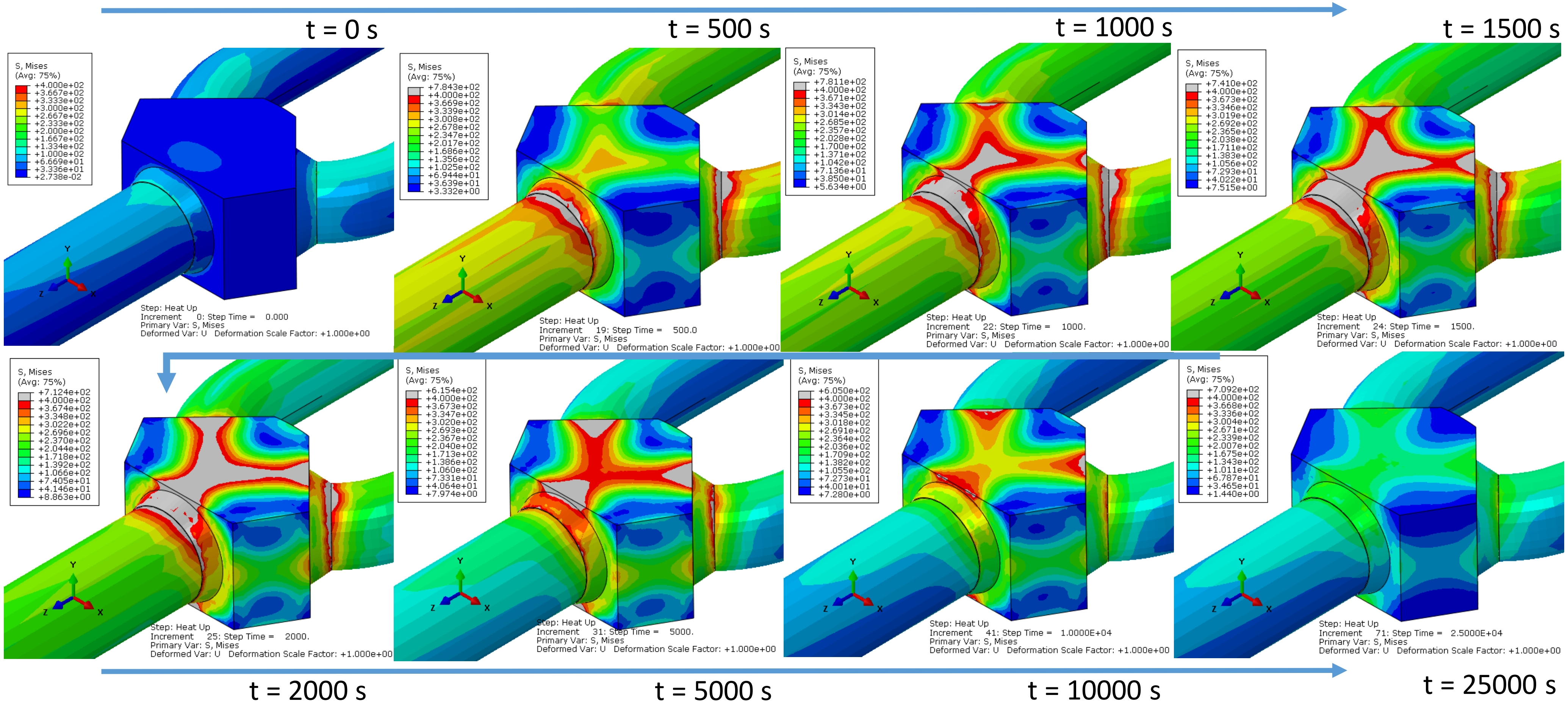
Main Steam Piping Wye-Block Life Modelling

Stress vs time



Project Update

Main Steam Piping Wye-Block Life Modelling

Next Steps

- Create test specimens
- Perform strain-controlled RT and HT fatigue and fatigue-creep tests
- Calibrate material constitutive model to test results
- Calibrate crack initiation model based upon test results
- Couple finite element “plant” model with constitutive and crack initiation models to predict crack initiation as a function of any loading conditions and boundary conditions conceivable (within reason)

Project Update

Life Modeling of Critical Steam Cycle Components

Industry Input and Validation

- Southern Company driving research question(s)
- Southern Company providing materials removed from service
- Southern Company providing operational conditions for model "loading conditions" and "boundary condition"
- Southern Company validating preliminary modelling results to operational conditions and failure data

Preparing Project for Next Steps

Life Modeling of Critical Steam Cycle Components

Market Benefits/Assessment

- Fitness-for-service models not currently available for Jethete in erosion conditions
- Existing crack initiation models calibrated to P22/G22, but not to the critical weld region
- Implementation of these evidence-based fitness-for-service models will prevent considerable unnecessary inspection and preemptive maintenance costs

Technology-to-Market Path

- Calibrated models will be disseminated via journals and conference proceedings (ASME BPV Conference). As such, any user of these materials may couple their stress analysis with the failure models for implementation in their facilities.
- Primary technological challenge remains COVID 19.
  - Power plant operations severely cut back limiting Industrial Partner support of project
  - Supply chain severely hindered

Concluding Remarks

Life Modeling of Critical Steam Cycle Components

- Completion of the project will provide two key tools which will enhance existing coal-fueled power plant operations by:
  - Enabling predictive scheduling of maintenance based upon evidence-based fitness-for-service models
  - Minimizing plant shutdowns and preemptive maintenance costs
  - Providing broader industry with calibrated fitness-for-service tools of two key maintenance challenges