

Power Plant Asset Management

Cost Analysis and Cost-Based Power Plant Asset Management –Thermal Power Plant Cycling Costs

Presented by

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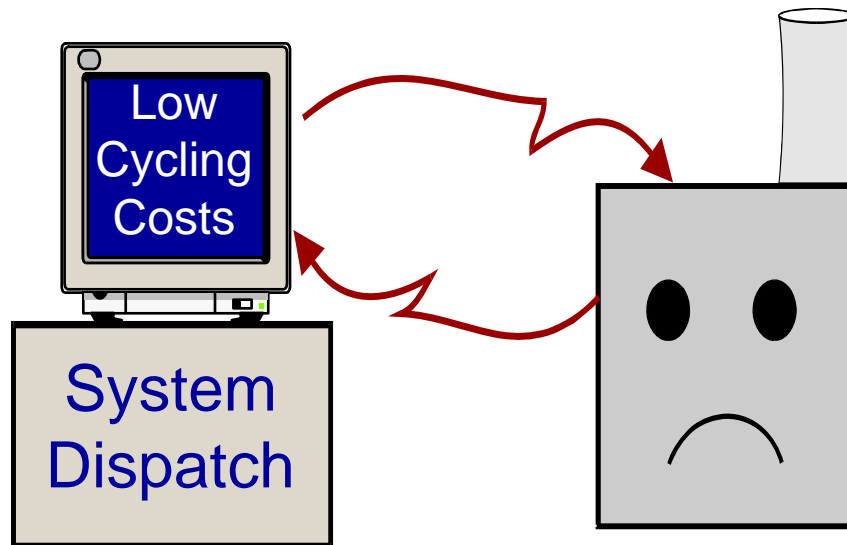
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Power Plant Asset Management

- Know Your Costs- Hot, warm, cold starts, load follow and regulation/AGC costs
- Reduce Costs of O&M
- Reduce Operational Damage
 - Results in Lower O&M
- Reduce Outages and Lost Capacity
 - Reduce Cycles and Optimize Full Load Operations 80-110% of MCR
Maximum Rated Capacity
- Know Plant Component Condition
 - Monitor Plant and Component Life
- Maximize Plant Value
 - Know Your Market/Mission
- Compete Based on Costs – Dispatch fleet on costs

Problem Definition

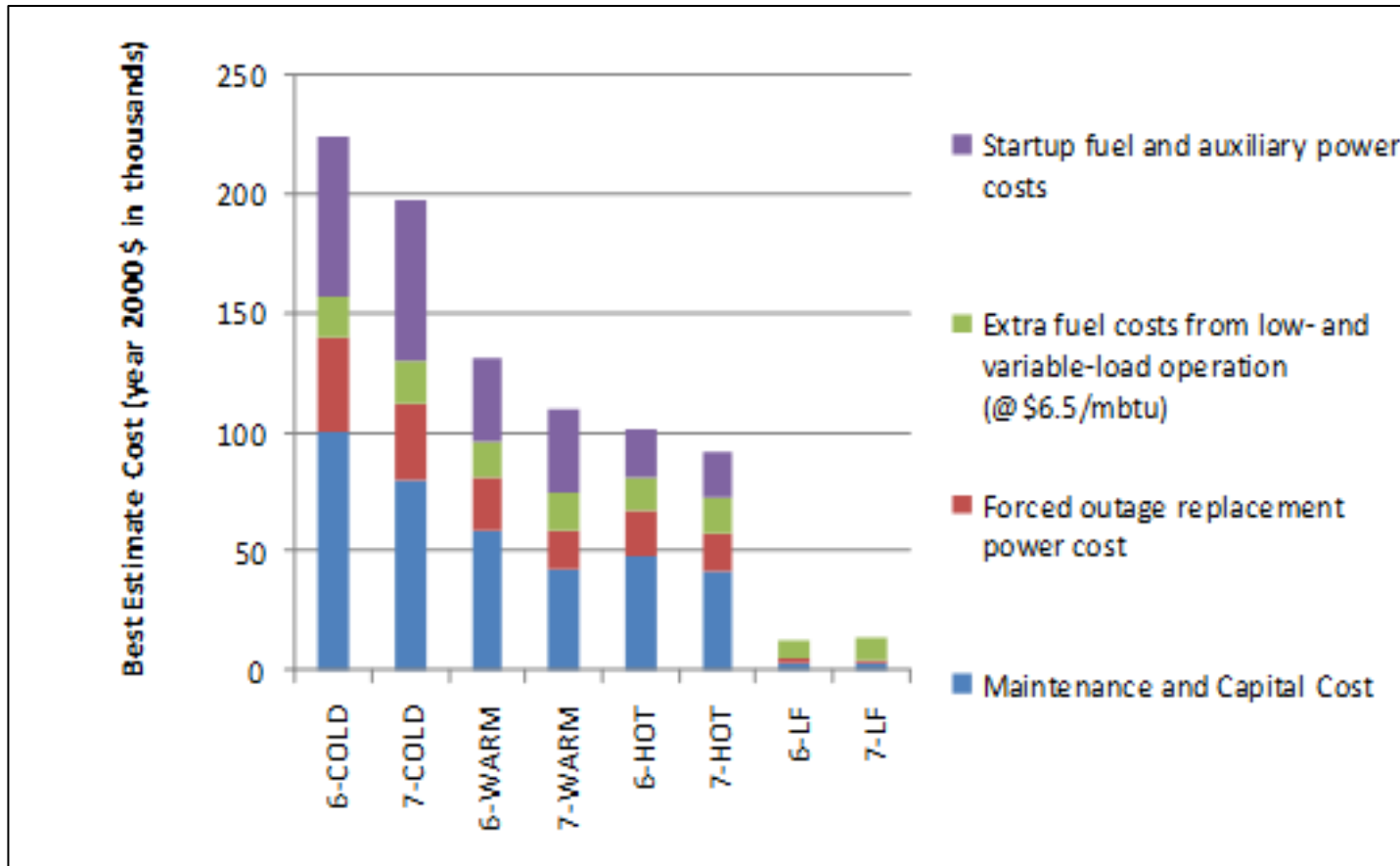


Generation Units
Originally Designed
for Baseload
Operations Running
in Cycling Modes

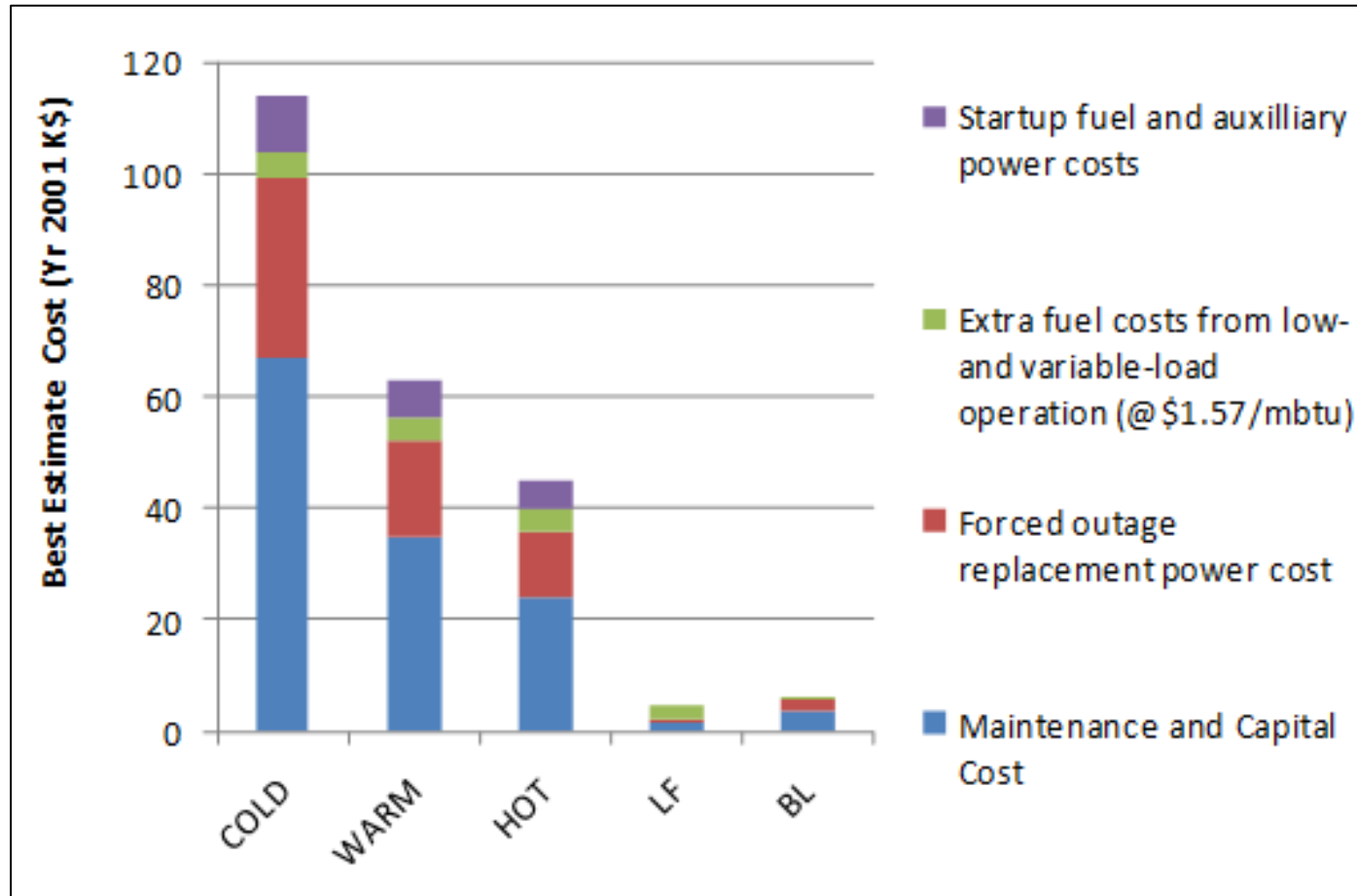
Current System Operations are Likely to be Very
NON-Optimal in Terms of Minimizing Long-Term Revenue Requirements

- Increased Maintenance costs
- Higher EFOR and Higher Probability plant will not return to service as scheduled.
- HILP High impact Low Probability events

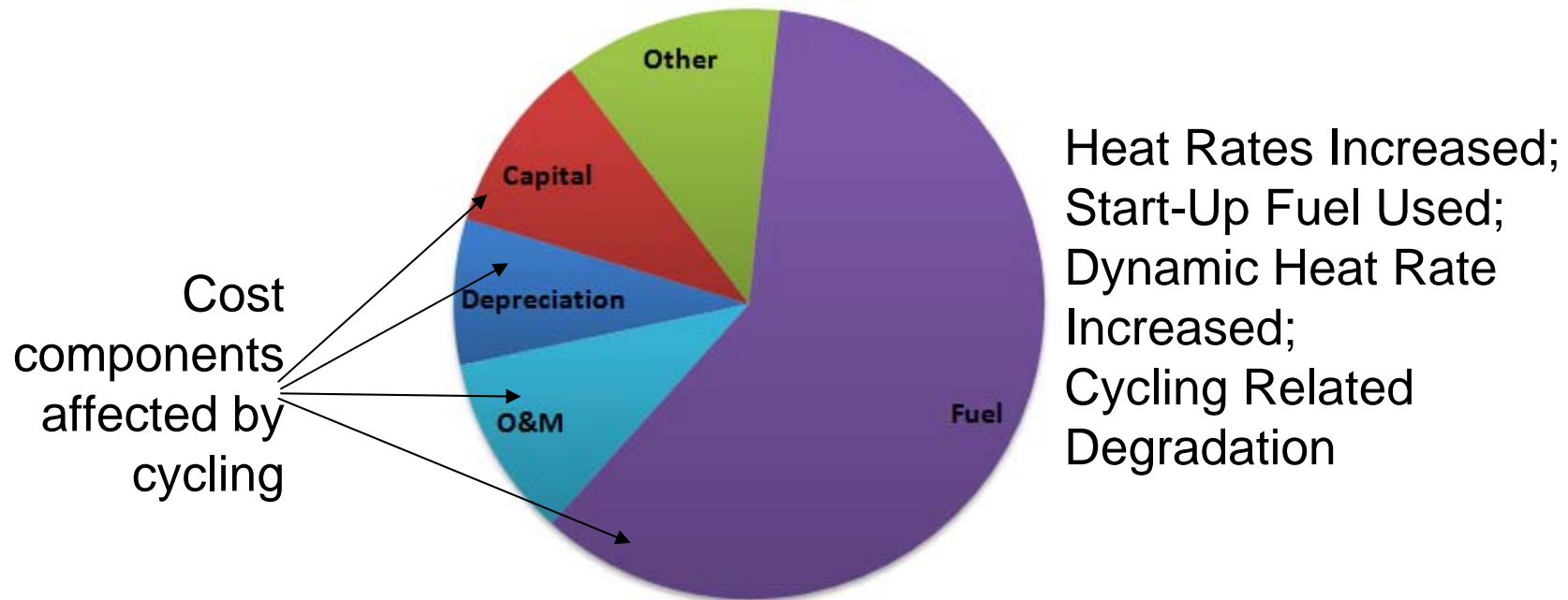
Typical Cycling Cost Breakdown for Two Large Units



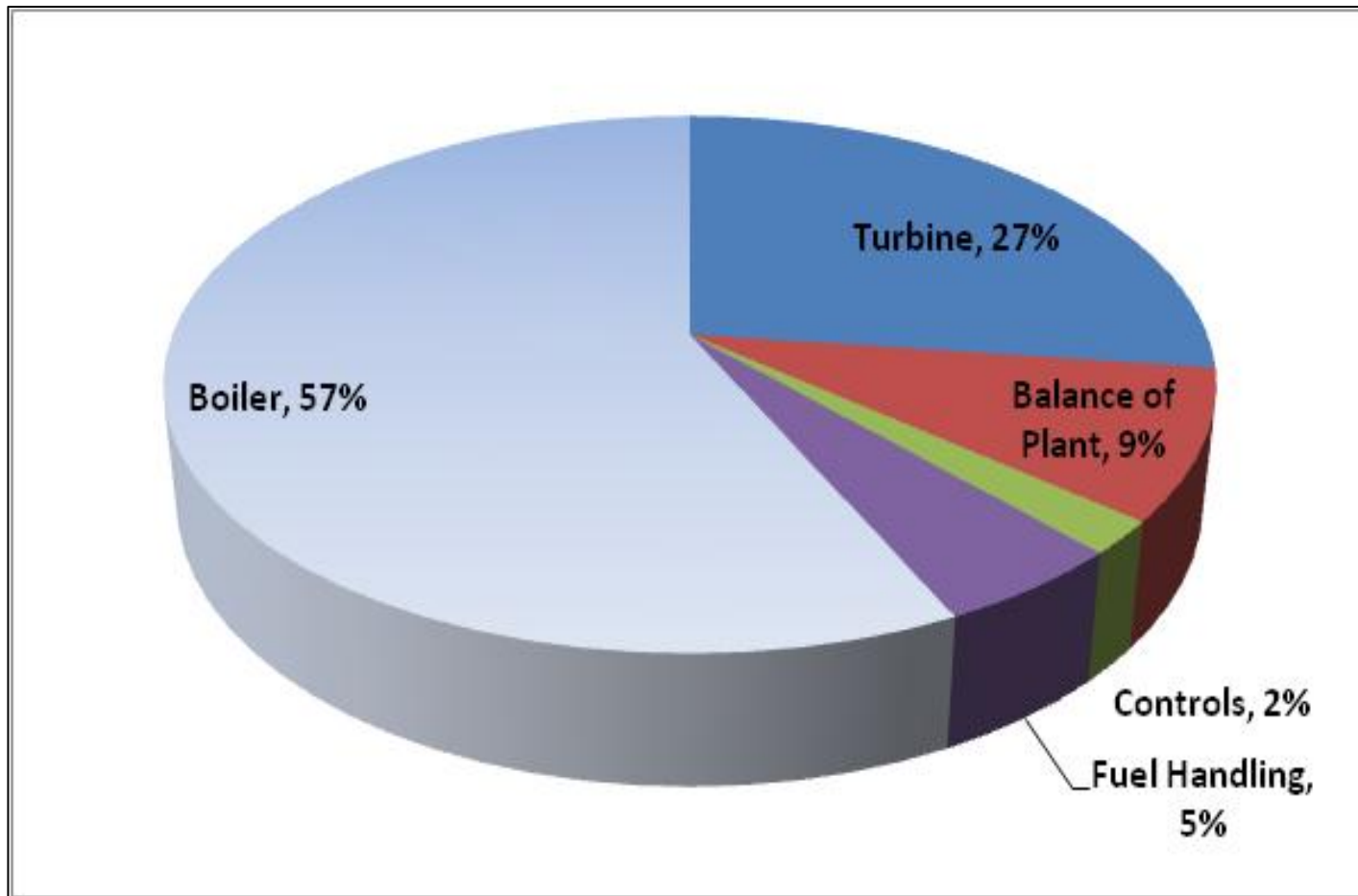
Typical Cost Breakdown – Large Coal Unit



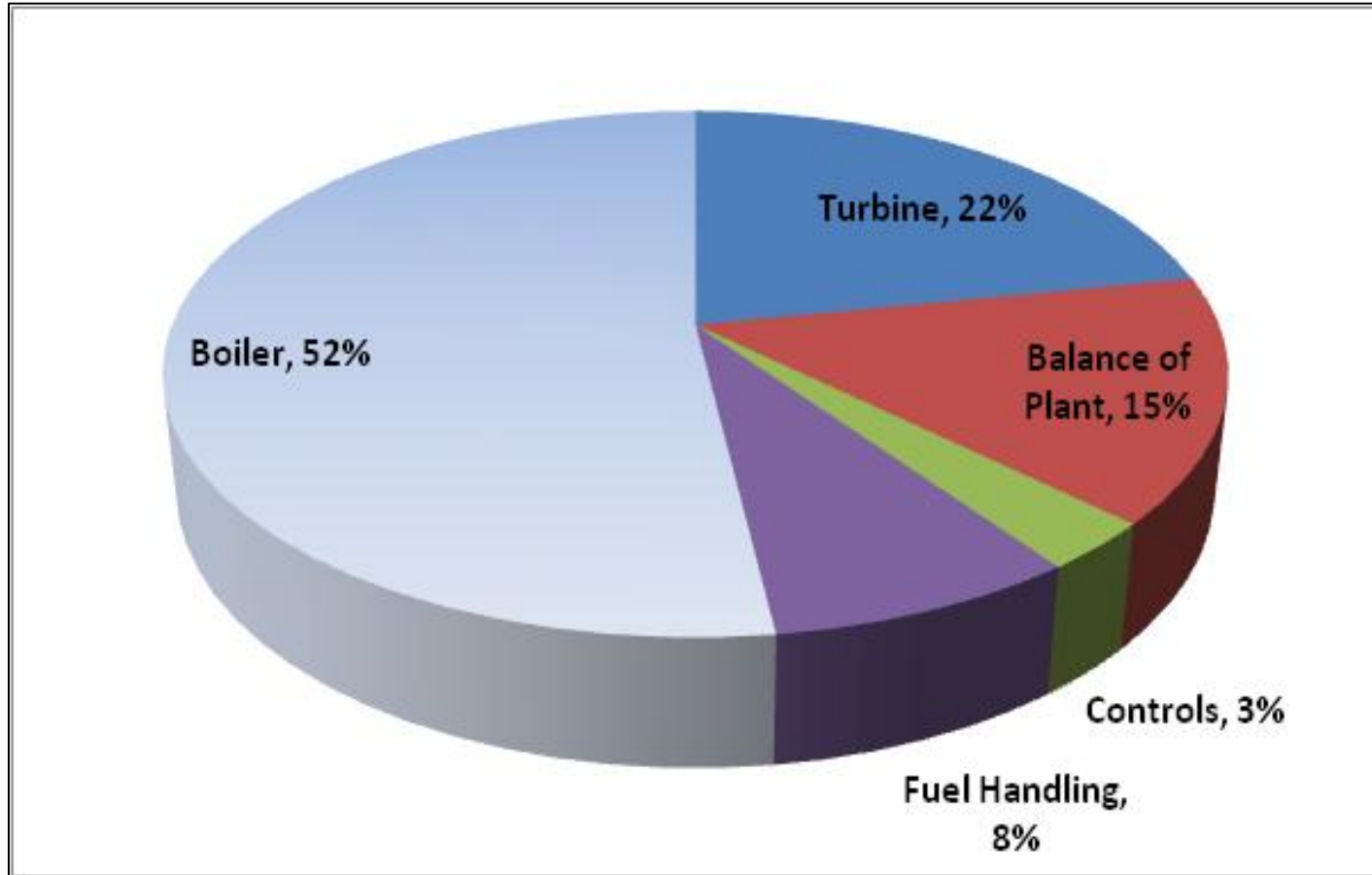
Typical Production Cost Components



Breakdown of Cycling-Related C&M Costs 1990-97



Breakdown of Cycling-Related C&M Costs 1990-97



Generation Unit Cycling Definitions

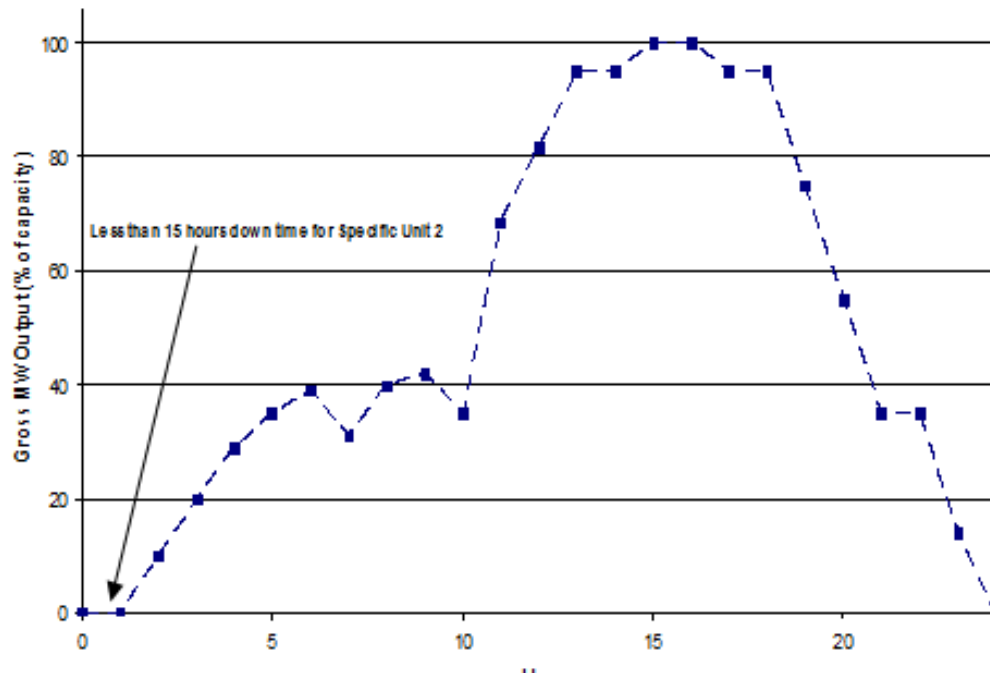


- Load Cycling

- LL1: Lowest Load at Which Design SH/RH Temperatures can be maintained
- LL2: Current “Advertised” Low Load
- LL3: Lowest Load at Which the Unit can Remain On-Line

Equivalent Hot Start (EHS) Damage measured

One-Day Transient defined as One Equivalent Hot Start (EHS)

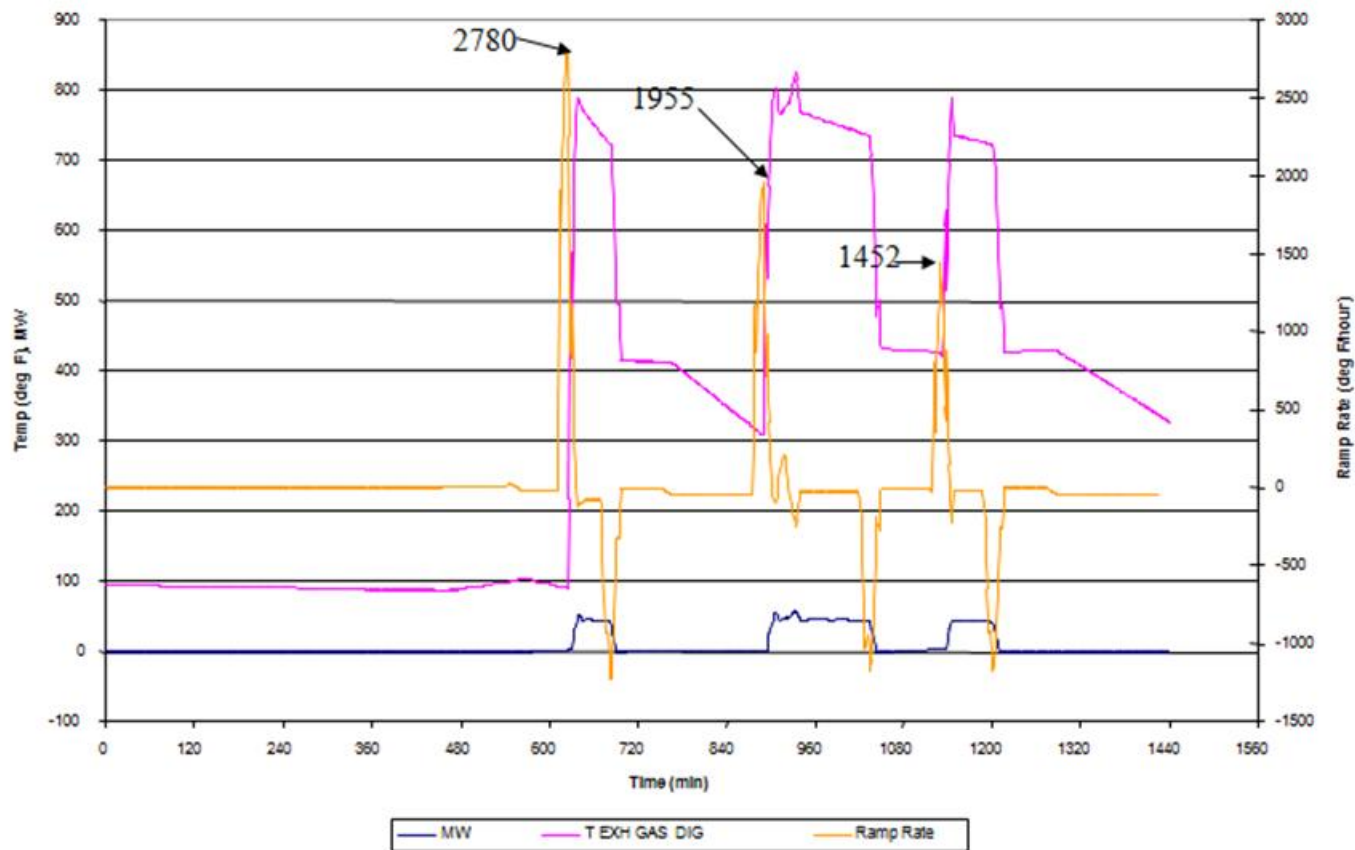


Standard EHS - Actual ramp rates and maximum load measured

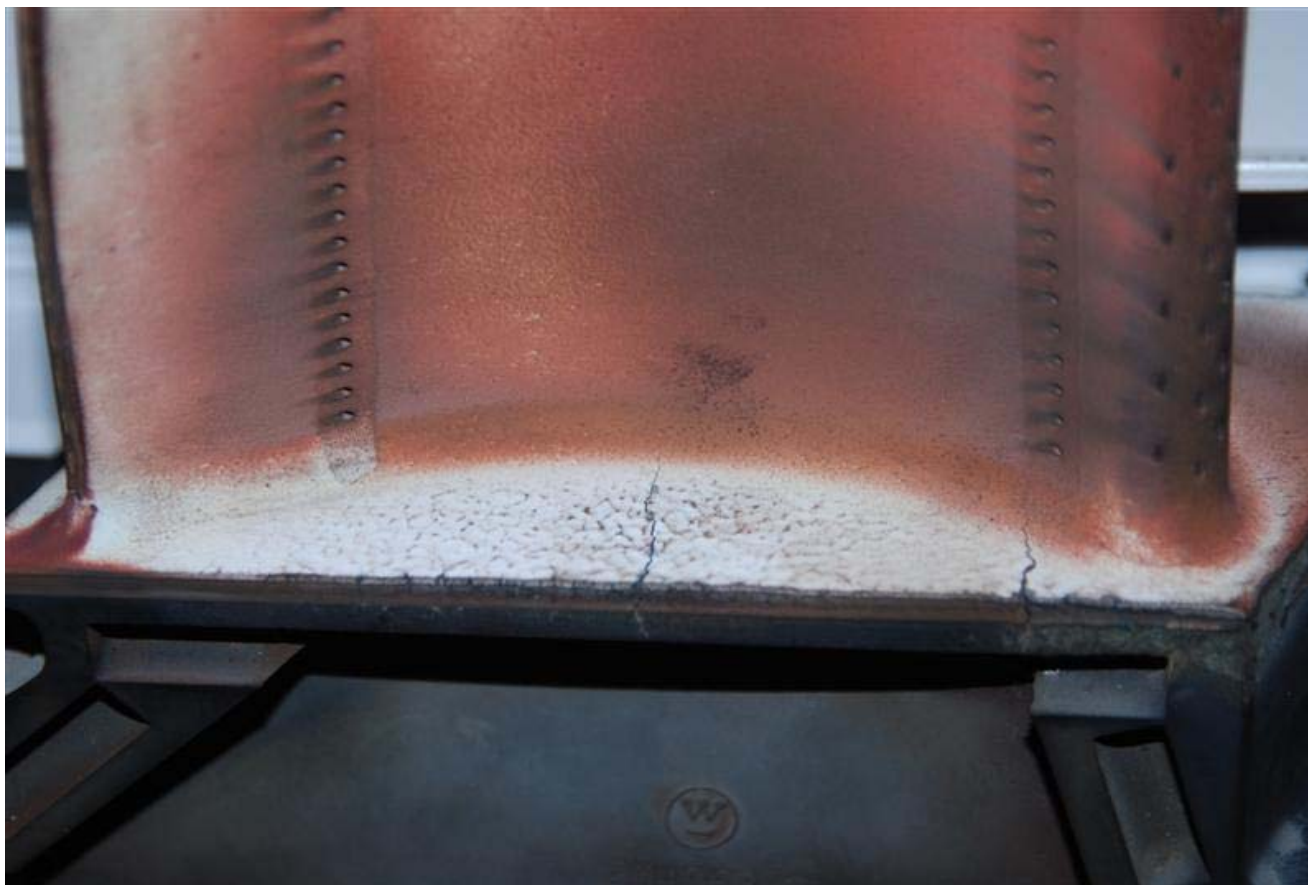
ABB 11N – 3 Starts Cold, Warm, Hot

Ramp Rate : 2870°F/hr Cold, 1955°F Warm, and 1452°F/hr Hot

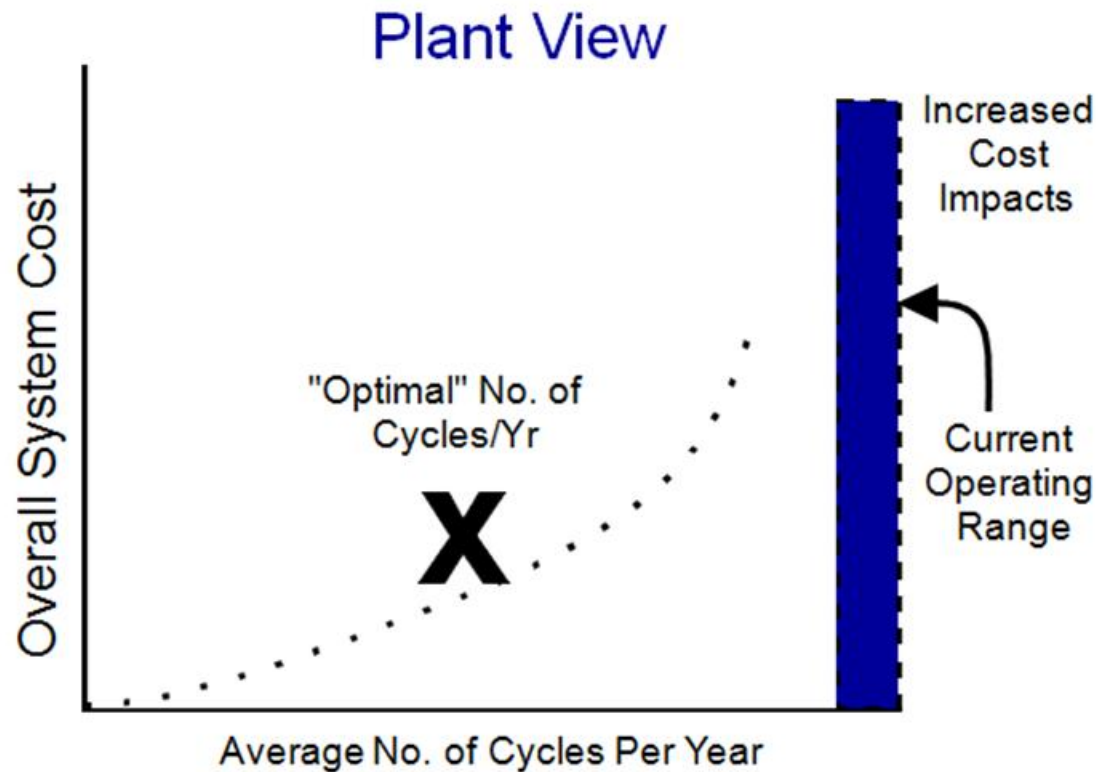
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Hot Gas Parts Fall Out

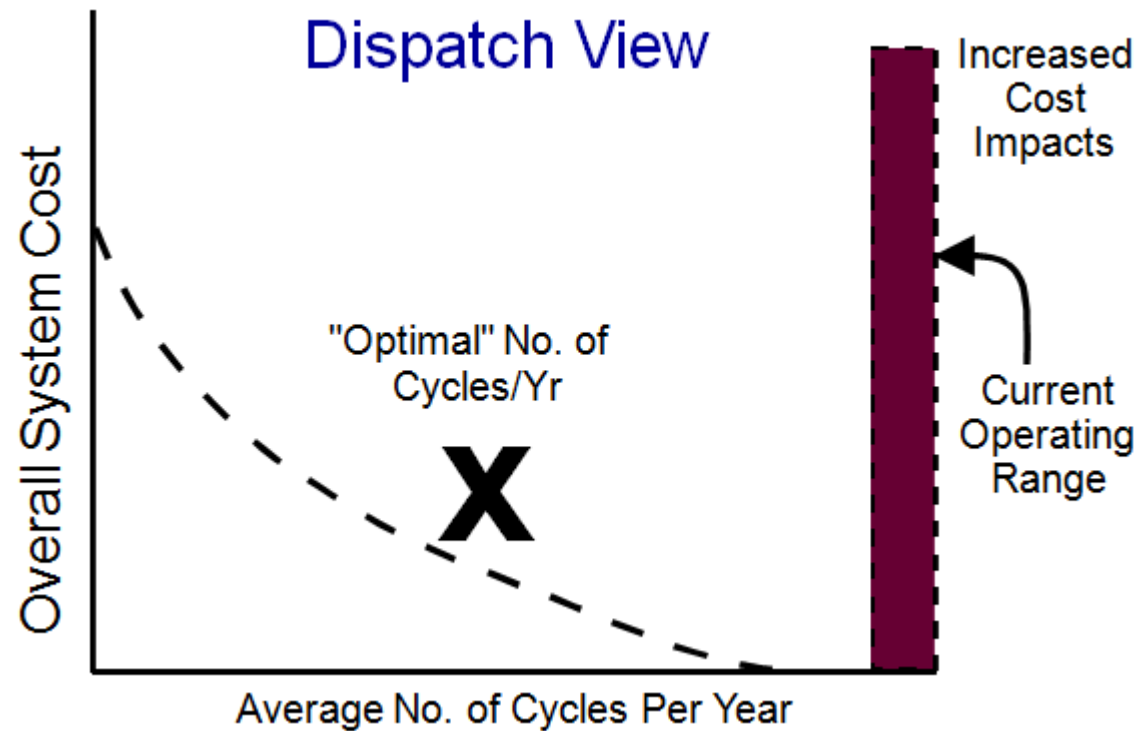


Overall System Costs vs. Average Cycles Per Year for Utility Power Plants



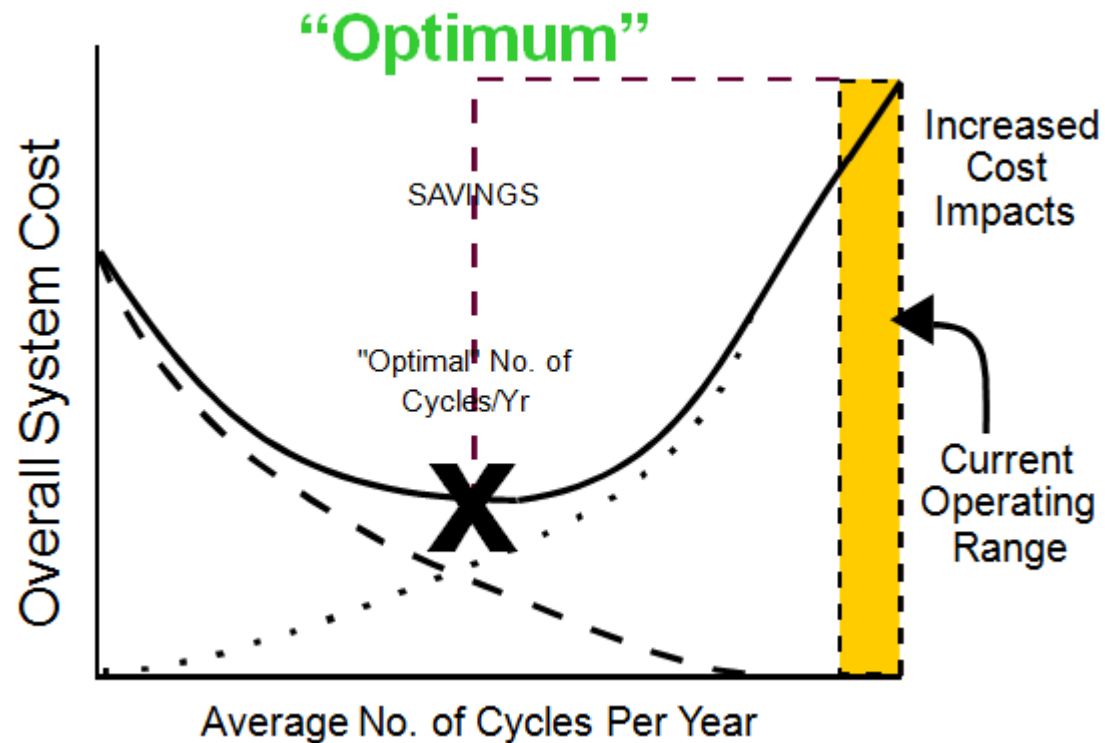
- • • • Total Capital and Maintenance Costs Resulting from Cycling Equipment (Wear and Tear Costs)

Overall System Costs vs. Average Cycles Per Year for Utility Power Plants



- - - Reduced Fuel and Production Costs Incurred by a Unit Cycling to Respond to Real-Time Load Dispatch Needs

Overall System Costs vs. Average Cycles Per Year for Utility Power Plants



- · · Capital and Maintenance Costs Resulting from Cycling Equipment (Wear and Tear)
- - - Cost Incurred by Inability to Respond to Real-Time Load Dispatch Needs

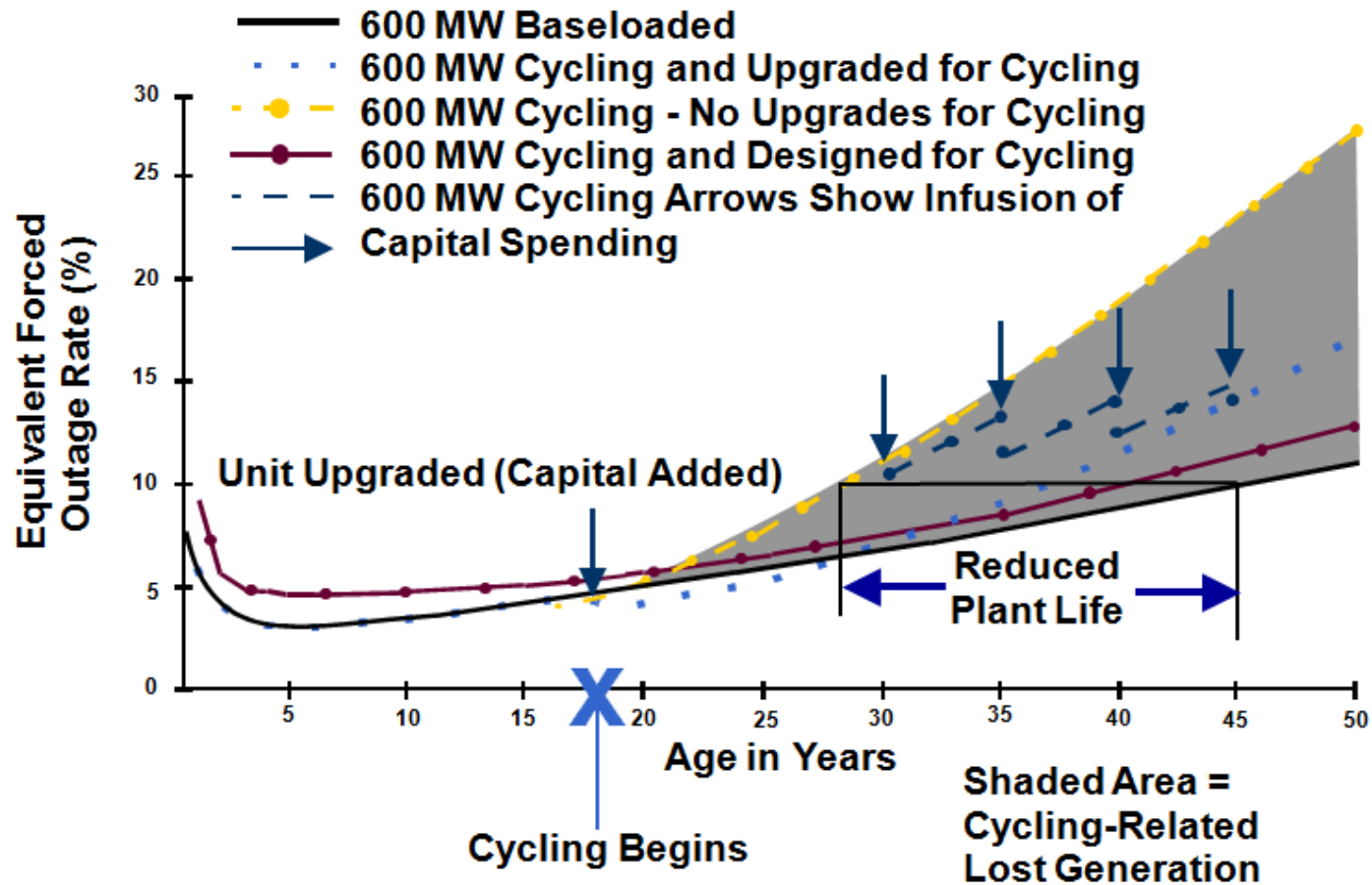
How Do We Measure the Costs of Increased Cycling?

Total Cost of Cycling

- = Δ Maintenance and Capital Spending
- + Δ Replacement Power Cost Due to Forced Outages
- + Δ Long-Term Heat Rate Impacts
- + Δ Operational Heat Rate Impacts
- + Δ Startup Auxiliary Power and Chemicals
- + Δ Startup Fuel and Manpower
- + Δ Capital Cost Impacts Due to Unit Life Shortening

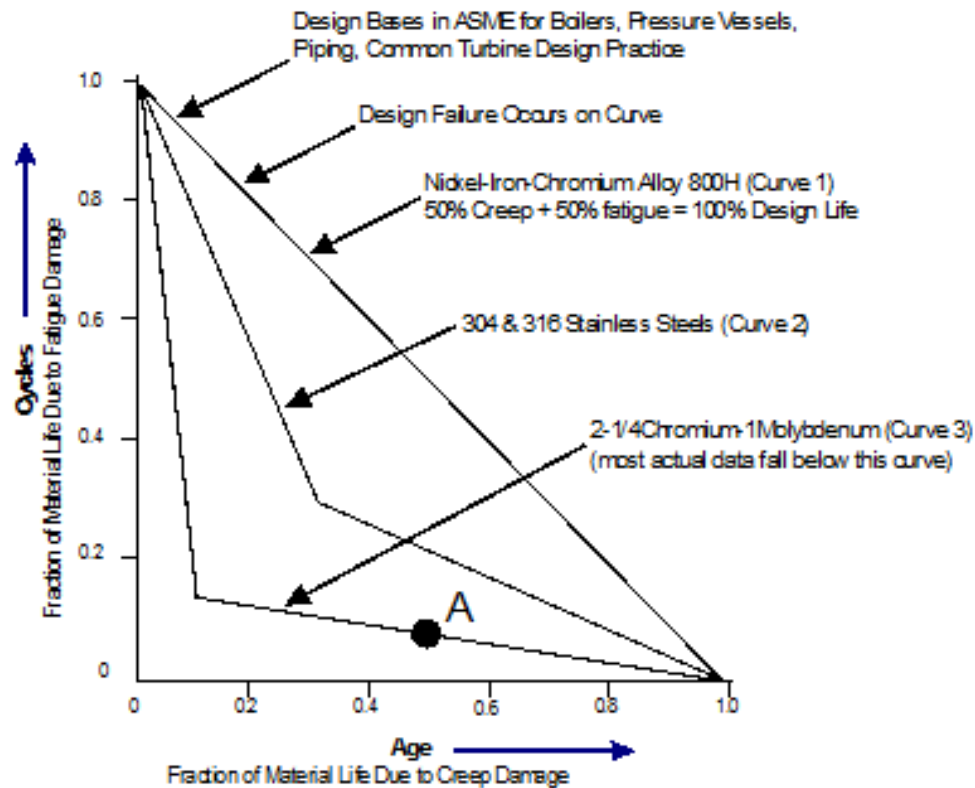
Here, Δ Refers Only to Those Costs Attributed to Cycling

Cycling Effects



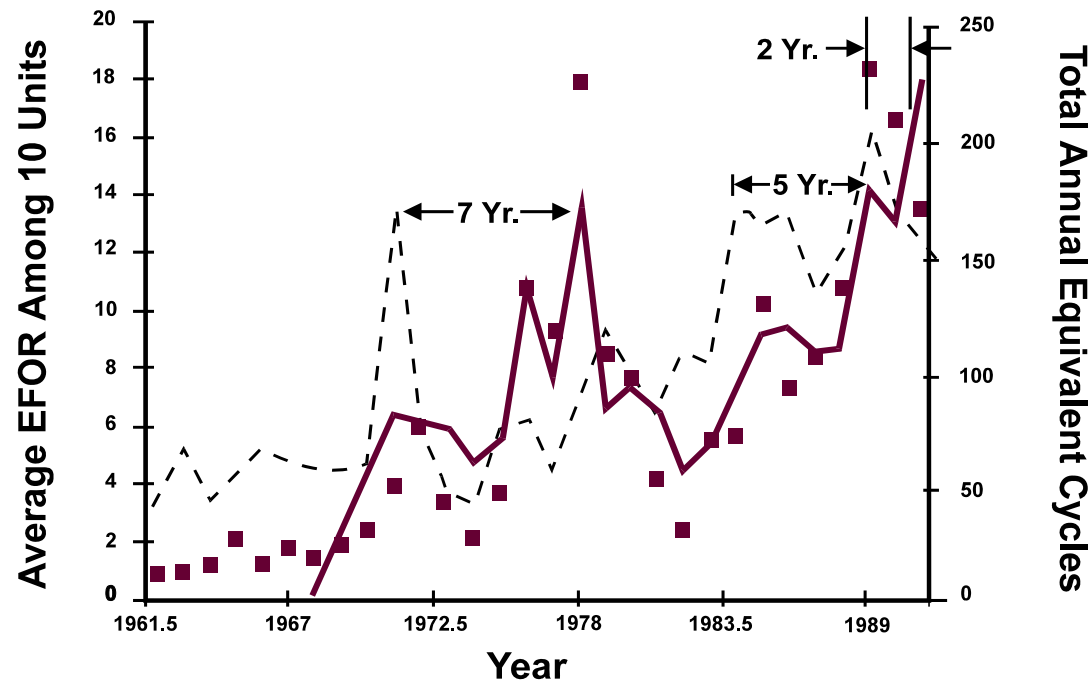
Creep Fatigue Interaction (CFI) Design

Curves for Several Materials



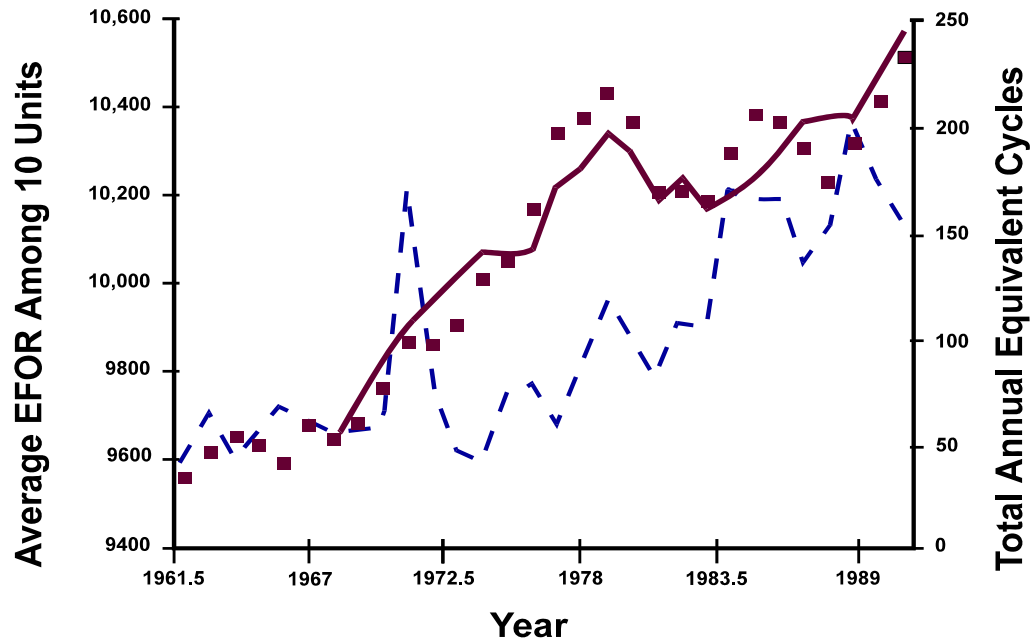
CFI adds significant damage! And shortens life!

Cycling Effect on Plant Reliability



Actual Plant Data Reflects Creep Fatigue Interaction Design Curve

Cycling Effects on Heat Rate



10% Increase Partially Due to Cycling
 1-5% Reasonably Attributable to Cycling

Cycling Effects

Accelerated Boiler Failures Due to Cycling

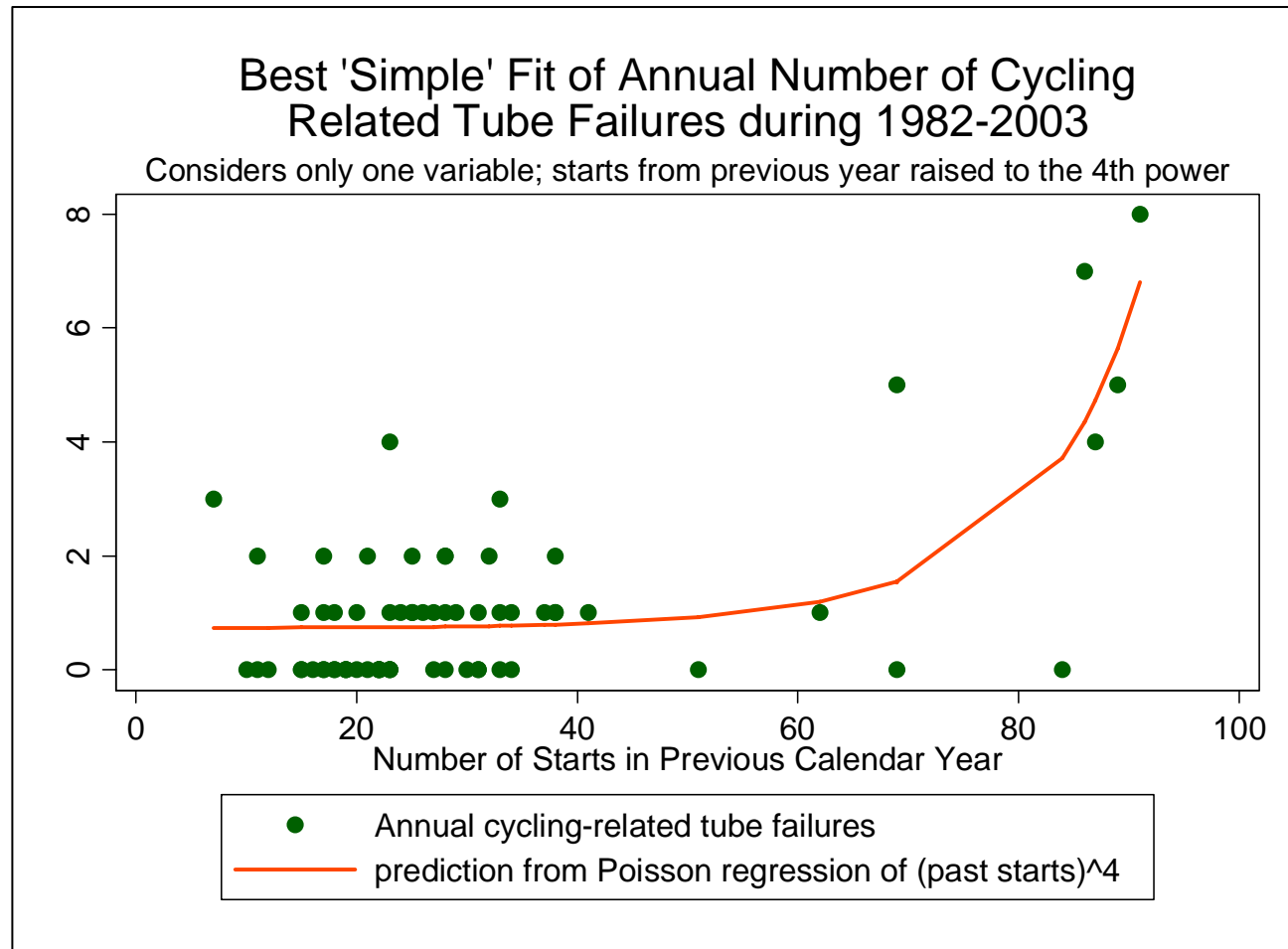
- Boiler Seals Degradation
- Tube Rubbing
- Boiler Hot Spots
- Drum Humping/Bowing
- Downcomer to Furnace Sub cooling
- Expansion Joint Failures

Cycling Effects

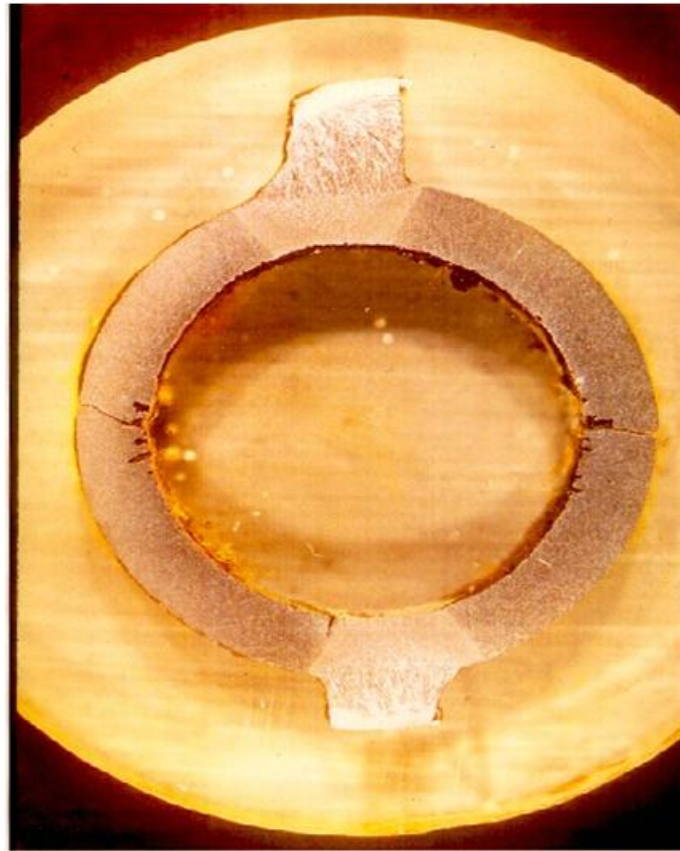
Accelerated Boiler Failures Due to Cycling (cont'd.)

- Superheater/Reheater Tube Leg Flexibility Failures
- Superheater/Reheater Dissimilar Metal Weld Failures
- Startup-Related Tube Failures in Waterwall, Superheater, and Reheater Tubing
- Burner Refractory Failure Leading to Flame Impingement and Short-Term Tube Overheating

Best "Simple" Fit of Annual Number of Cycling-Related Tube Failures (During 1982 through 2003)

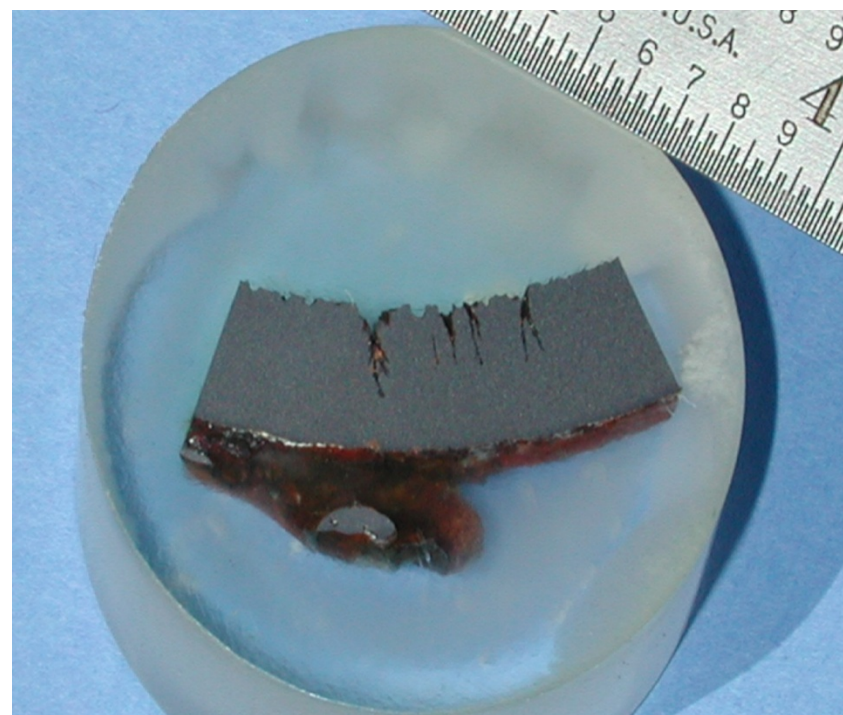


Corrosion Fatigue Damage of Subcritical Boiler Waterwall Tubing

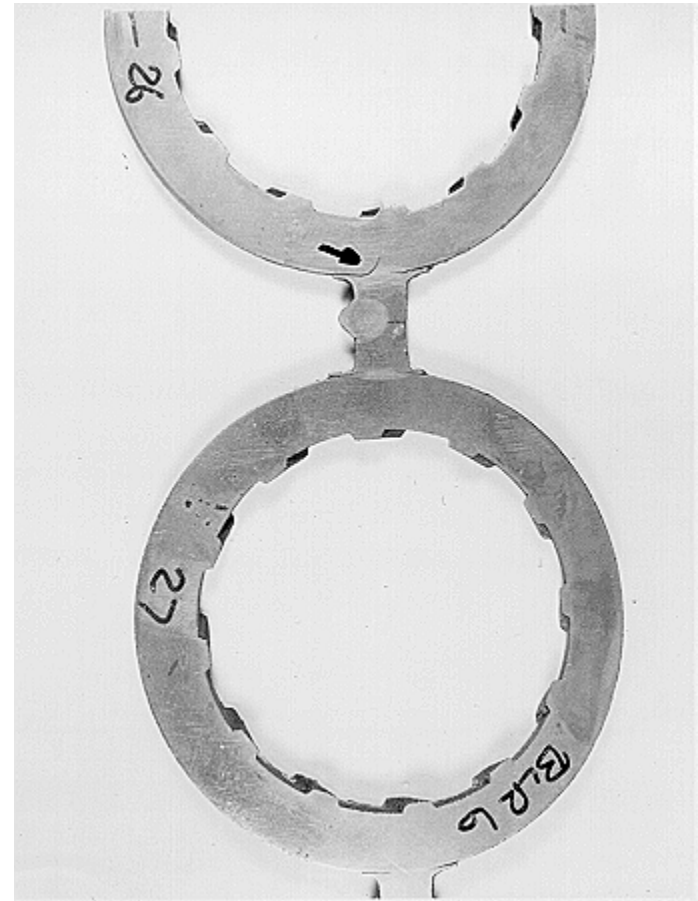
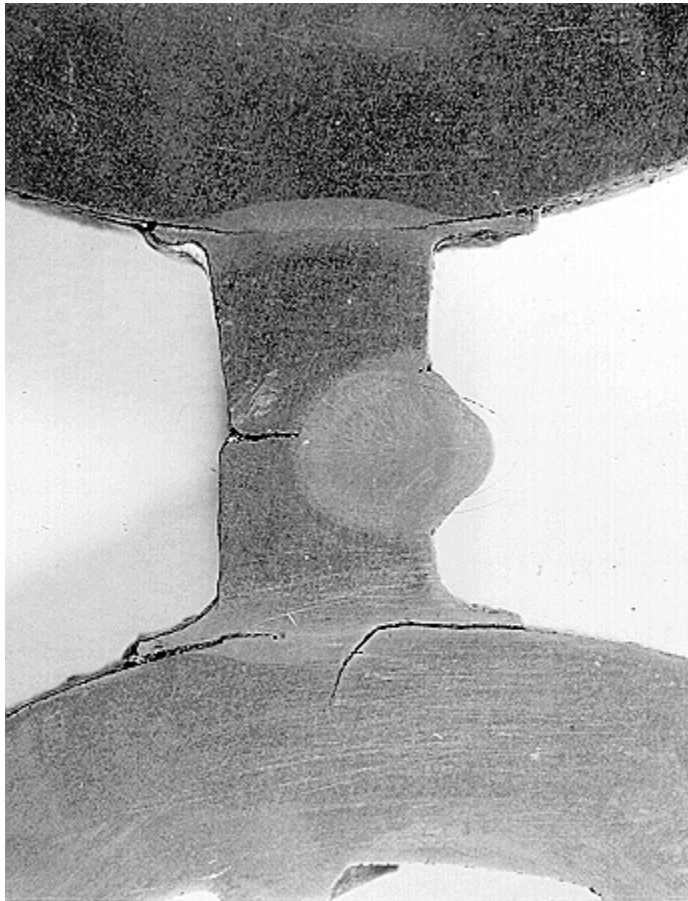


Note oval
tube
resulting
from
restrained
expansion

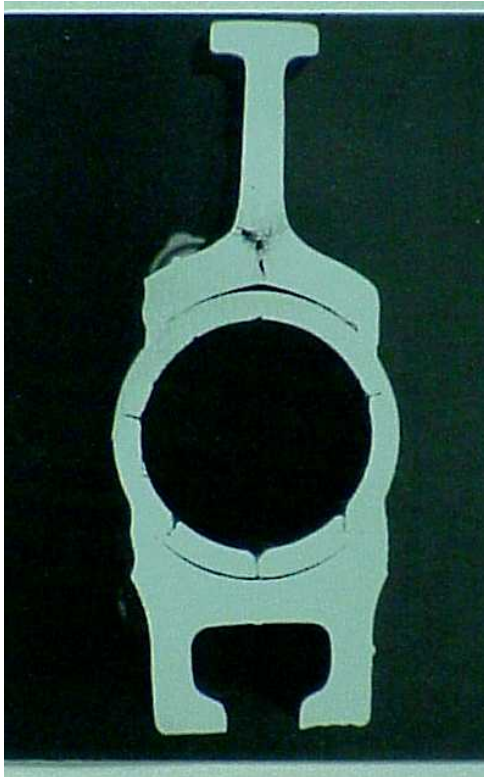
Boiler corrosion fatigue



Waterwall Cracking at Membrane



Superheat/Reheat Attachment Fatigue

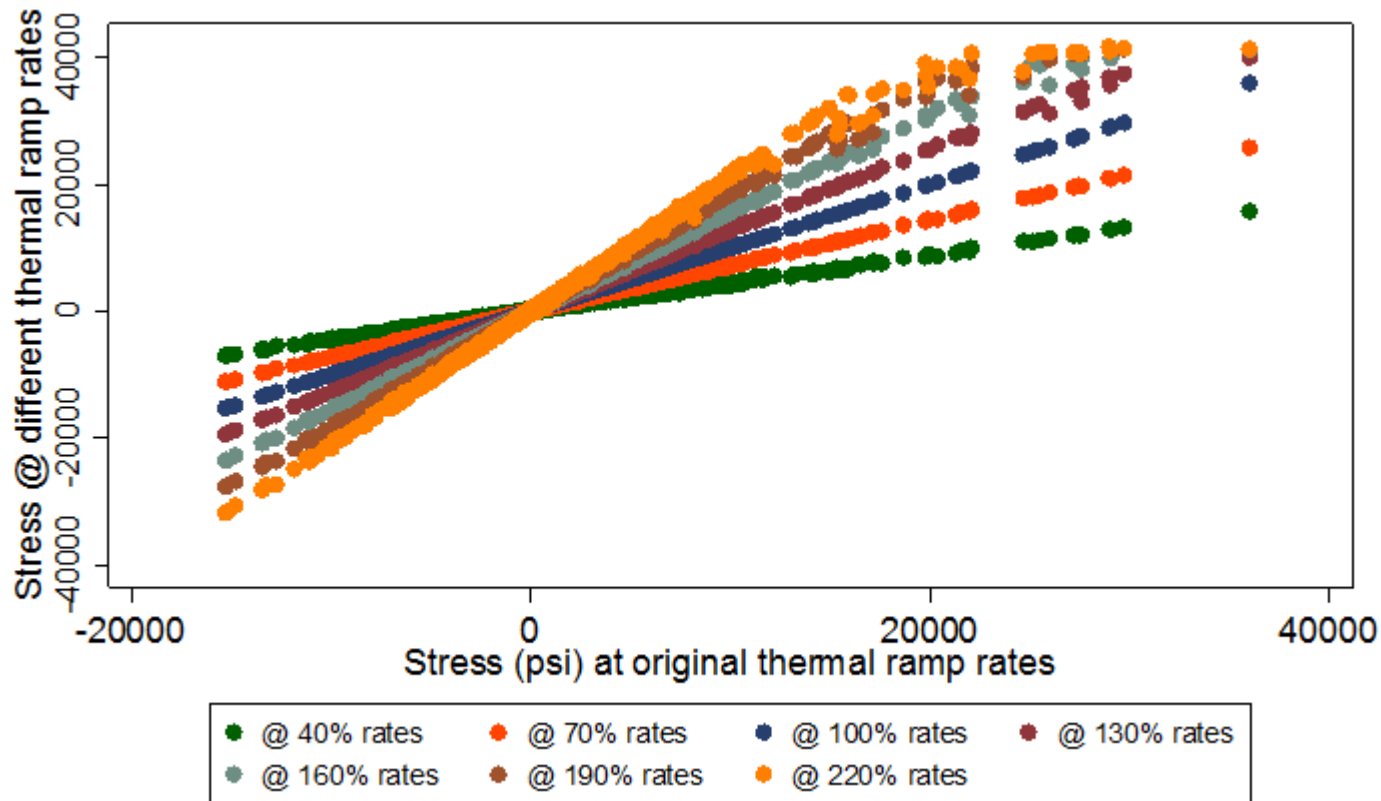


Cycling Effects

Turbine Effects Due to Cycling

- Water Induction to Turbine
- Increased Thermal Fatigue Due to Steam Temperature Mismatch
- Steam Chest Fatigue Cracking
- Steam Chest Distortion
- Bolting Fatigue Distortion/Cracking
- Blade, Nozzle Block, Solid Particle Erosion
- Rotor Stress Increase
- Rotor Defects (Flaws) Growth

HP rotor bore surface stresses as computed from 1st stage temperatures

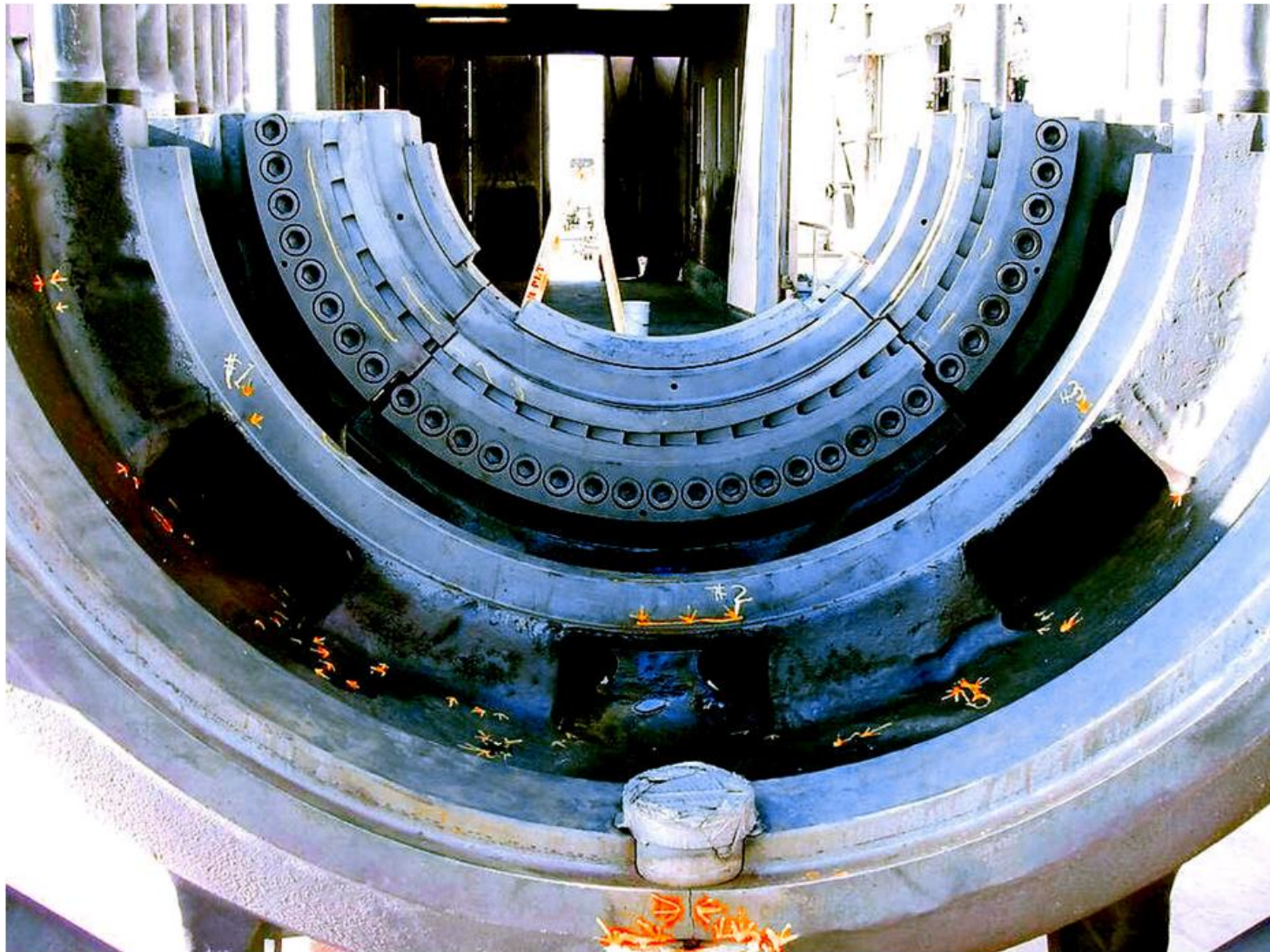


Stresses at highest rate multiples are limited only because no ramp rate is allowed to exceed the original maximums.

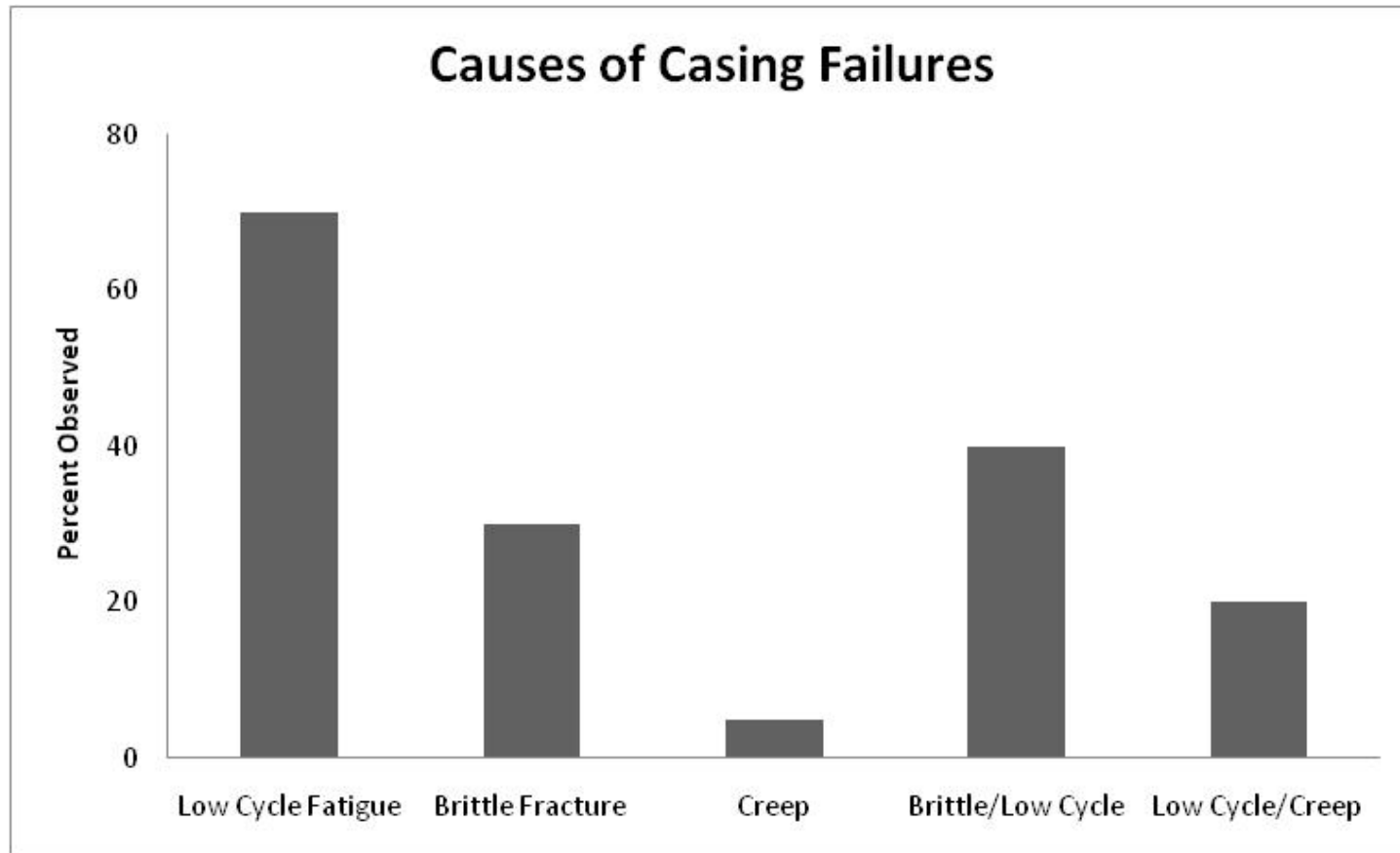
To reduce file size, a random 5% of all 50000+points are plotted

Cycling effects on Turbine due to cycling

- Seals/Packing Wear/Destruction
- Blade Attachment Fatigue
- Disk Bore and Blade Fatigue/Cracking
- Silica and Copper Deposits
- Lube Oil/Control Oil Contamination
- Shell/Case Cracking
- Wilson Line Movement
- Bearing Damage
- Reduced Life



Turbine fatigue failures Dominate Data Base



Cycling effects on Chemistry due to Cycling

- Corrosion Fatigue
- Oxygen Pitting
- Corrosion Transport to Boiler and Condenser
- Air, Carbon Dioxide, Oxygen Inleakage (Require NH₃ Countermeasures)
- NH₃ - Oxygen Attack on Admiralty Brass

Cycling effects on Chemistry due to Cycling (contd.)

- Grooving of Condenser/Feedwater Heater Tubes at Support Plates
- Increased Need for Chemical Cleaning
- Phosphate Hideout Leading to Acid and Caustic Attack
- Silica, Iron, and Copper Deposits
- Out of Service Corrosion

Cycling Effects on Electrical and Control System due to Cycling

- Increased Controls Wear and Tear
- Increased Hysteresis Effects that Lead to Excessive Pressure, Temperature, and Flow
- Controls Not Repeatable
- Motor Control Fatigue
- Motor Insulation Fatigue
- Motor Insulation Failure Due to Moisture Accumulation

Cycling Effects on Electrical and Control System due to Cycling (contd.)

- Motor Mechanical Fatigue Due to Increased Starts/Stops
- Wiring Fatigue
- Insulation Fatigue Degradation
- Increased Hydrogen Leakage in Generator
- Fatigue of Generator Leads

Cycling Effects on Electrical and Control System due to Cycling (contd.)

- Generator Retaining Ring Failures
- Generator End Turn Fatigue and Arching
- Bus Corrosion When Cool (i.e., low amps)
- Breaker Fatigue
- Transformer Fatigue Degradation

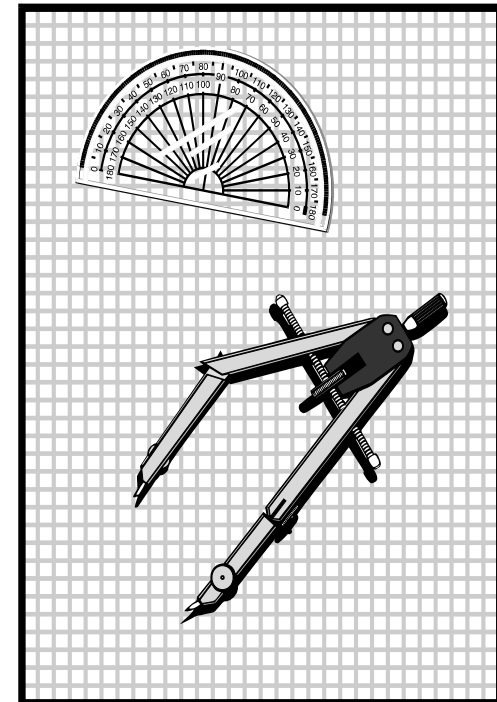
Cycling Effects

- Increased Risk of Personnel Errors Due to Cycling
 - Implosion
 - Explosion
 - Low Water in the Boiler
 - Water Induction into the Turbine
 - Low Load Instability
 - Improper Valve Alignment
 - Other Man/Machine Interface Problems during starts and load follows

How Do We Measure the Possible Long-Term Costs of Excessive Cycling?

Total Cost of Cycling

- ↑ Maintenance/Overhaul Costs
- ↑ Maintenance/Overhaul Time
- ↑ Forced Outage Rates
- ↓ Plant Performance (efficiency)
- System Production Cost
 - ↓ In Short Term
 - ↑ Over Long Term
- ↑ Emissions Per kWh Generated
- ↓ Unit Life Expectancies
- ↑ Long-Term Capacity Costs



Factors Affecting Cycling Cost

- Unit Design
- Operator Care
- Already Performed Upgrades for Cycling
- O&M, and Capital Expenditures vs. EFOR
- System Marginal Energy and Capacity Costs
- Cost of New Capacity
- Past Annual Maintenance and Capital Costs
- Past Cycles

Cost of Cycling Analysis Methods

Top-Down Method

Annual Cycling
damage regression of
EHS vs. Costs



Bottom-Up Method

Detailed analysis of 7-
10 years of Work orders



Top Down Method

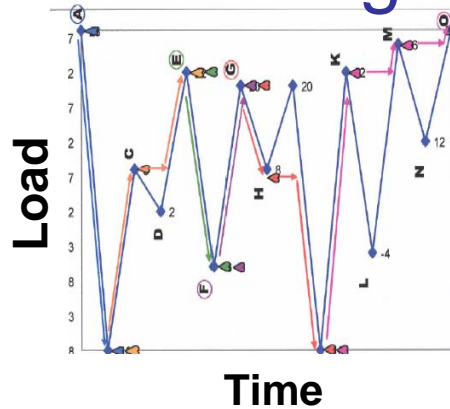
- Industry Parameters
 - EFOR
 - Maintenance Costs
 - Capital Costs
 - Capacity Replacement Costs
 - Design, Size, etc.
 - Pressure / Temperature
 - Costs vs. Equivalent Hot Starts
 - Statistical Analysis
- Expert Opinions
 - Plant Operator Surveys
 - Expert Analysis



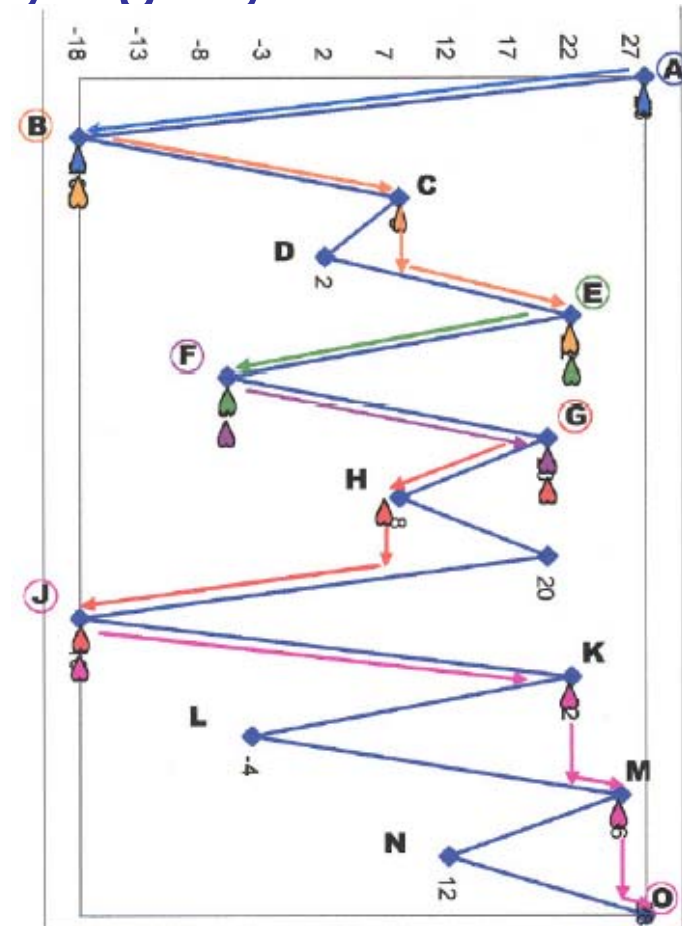
Annual Damage Accumulation- EHS

- Count and Classify Load Changes Based on Duration, Previous Offline Period, and MW Output
- Each Classification of Cycling Type has Different Level of Damage
- Accumulate the Amounts of Damage that Grow Over Time
- Count all cycles using Rainflow techniques

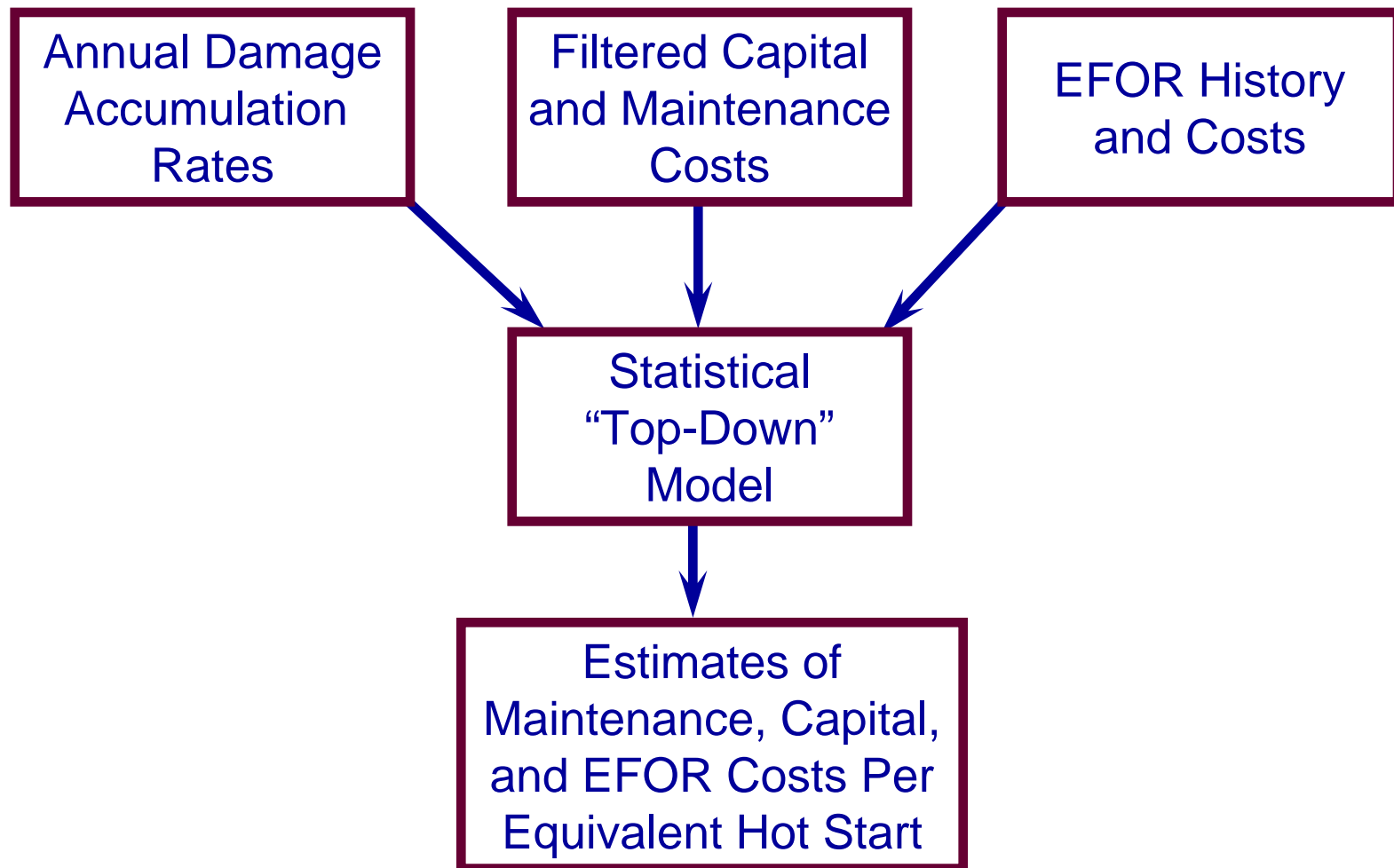
Rainflow Method: Counting and Classifying Cycles



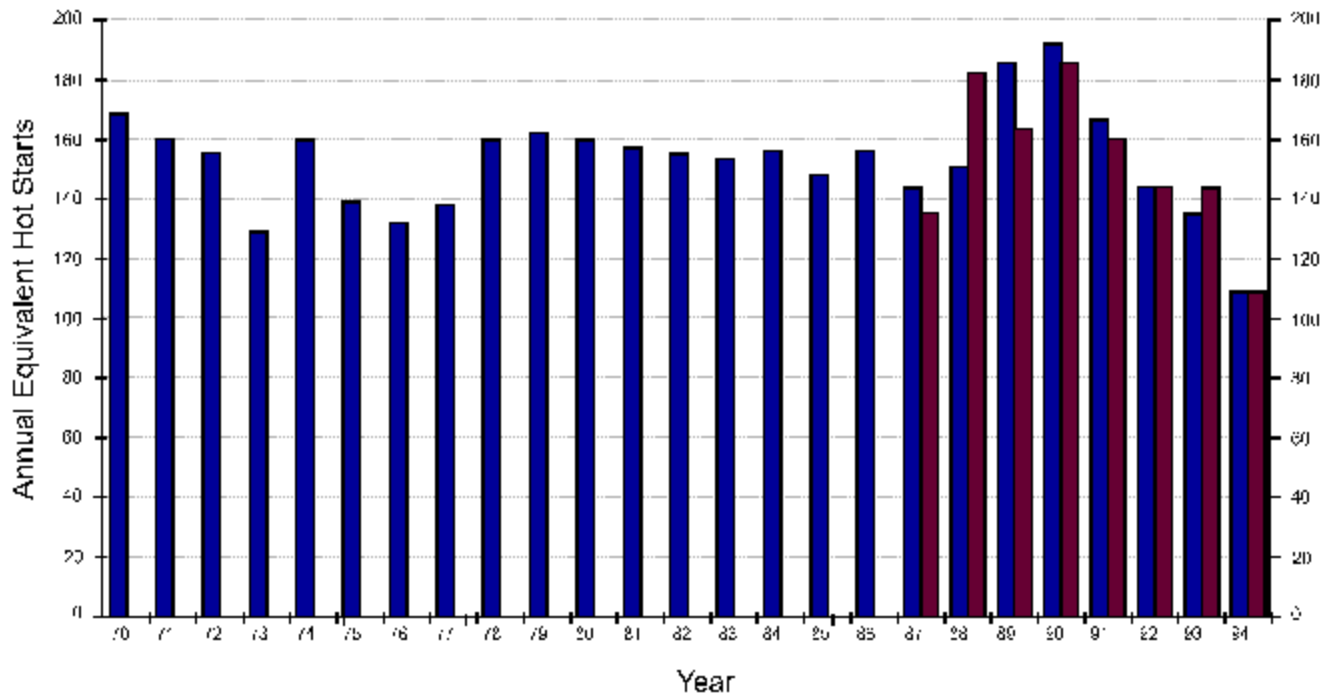
- Rotate Load Curve 90 Degrees
- Imagine Raindrops Rolling down a Roof
- Circle the Start of the drop
- Circle the Node when a drop falls past a rooftop
- Delete all un-circled nodes and label them cycles
- Define these cycles based on criteria
- Repeat and count all smaller cycles



Top-Down Analysis Procedure



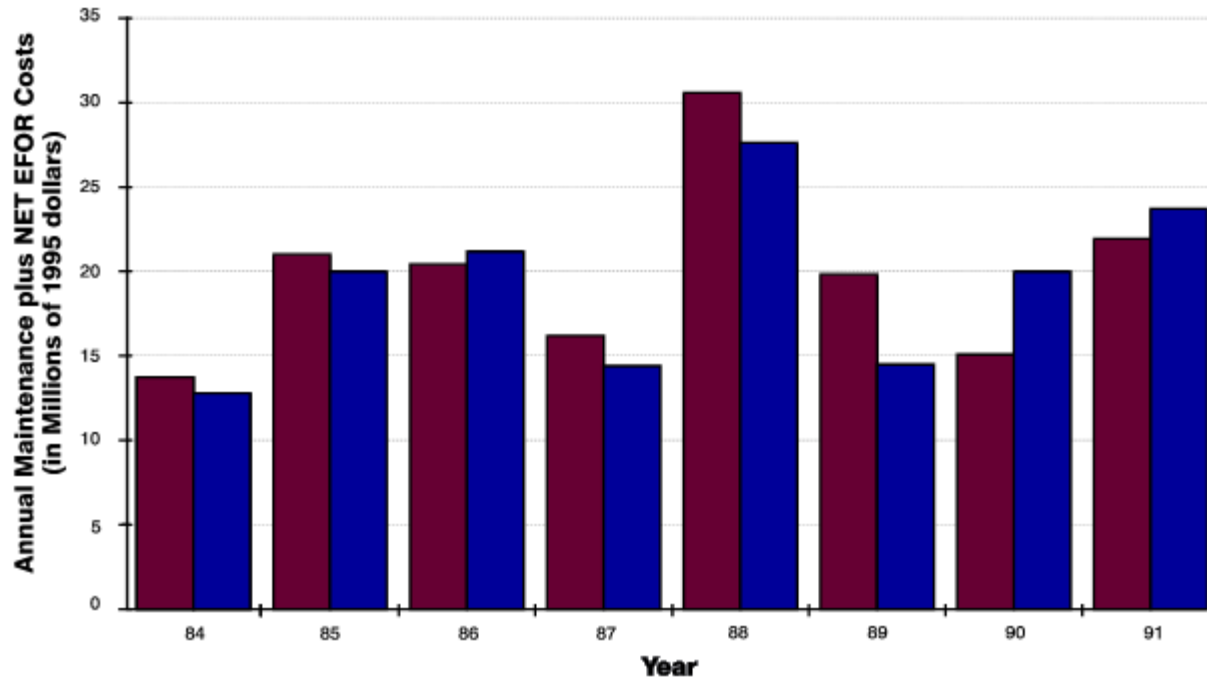
Effective Damage and Load History Estimates



Regression Analysis of Relevant Maintenance, Capital, and EFOR Costs for Oil Units 1, 2, and 3



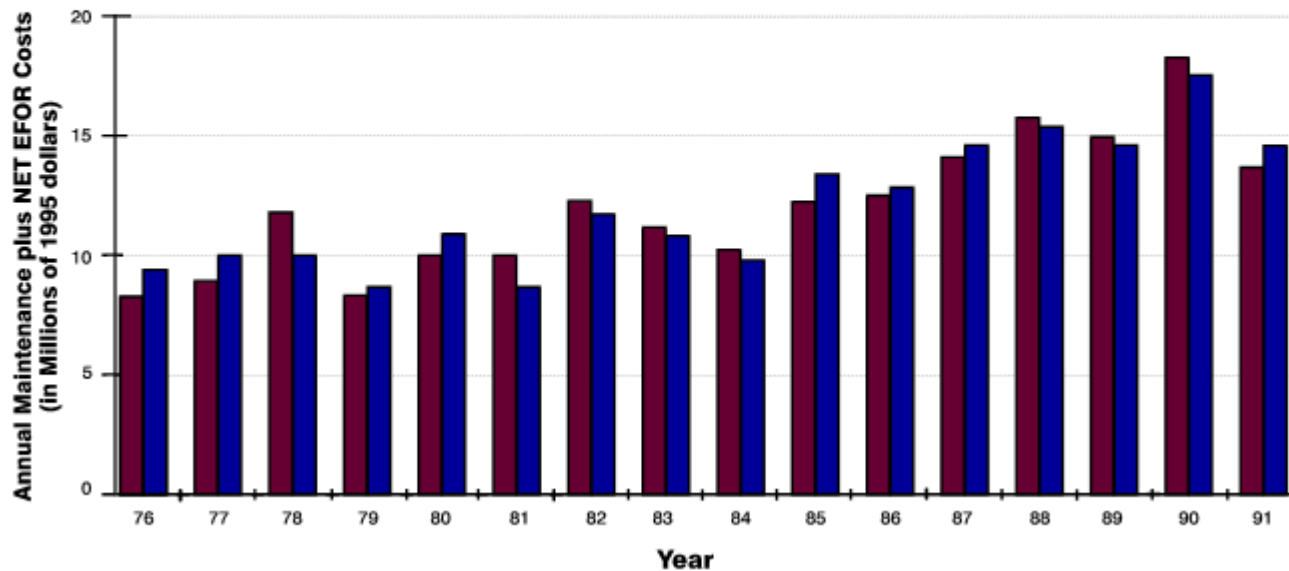
Regression-Based Total Cost per Equivalent Hot Start = \$34,000 (1995)



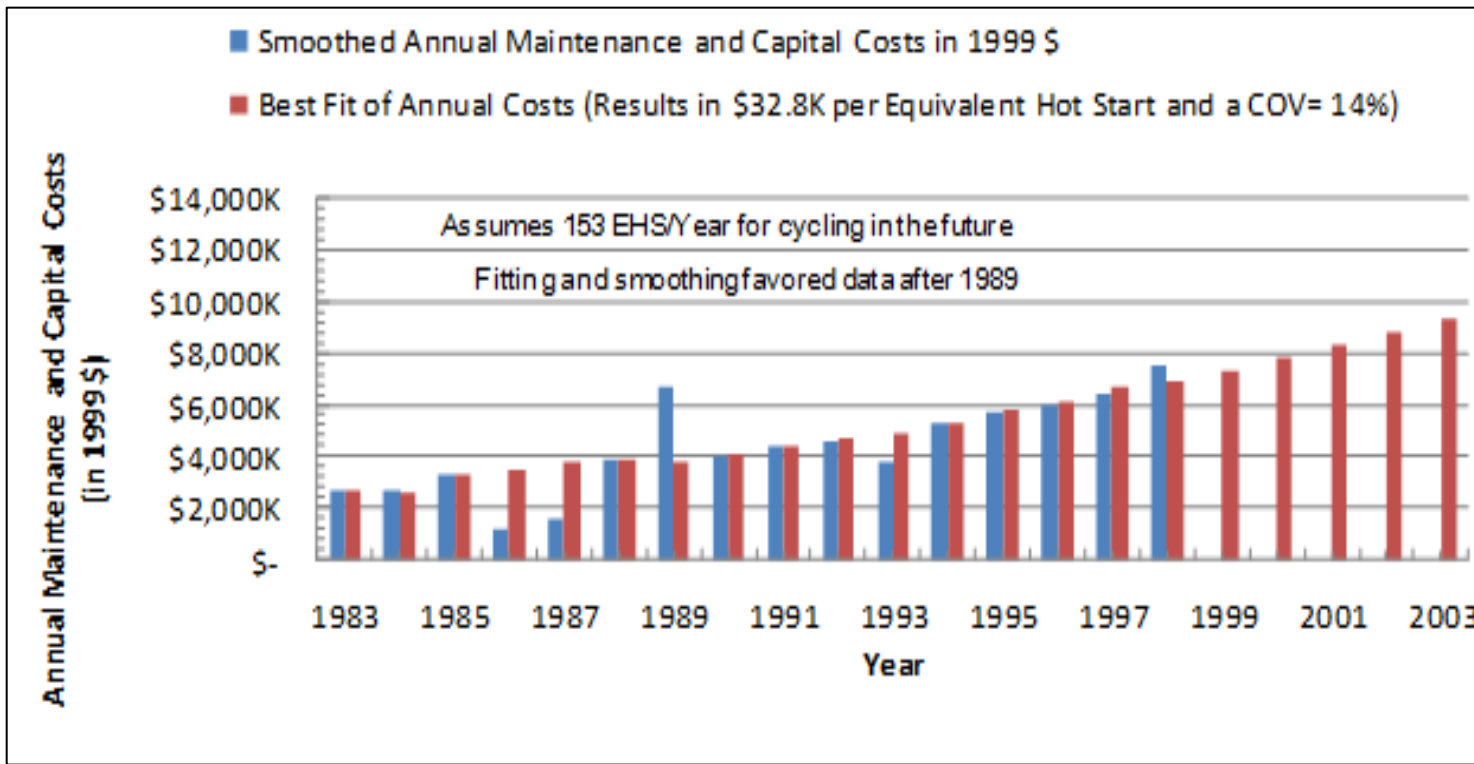
Regression Analysis of Relevant Maintenance, Capital, and EFOR Costs for Oil and Gas Units 1, 2, and 3



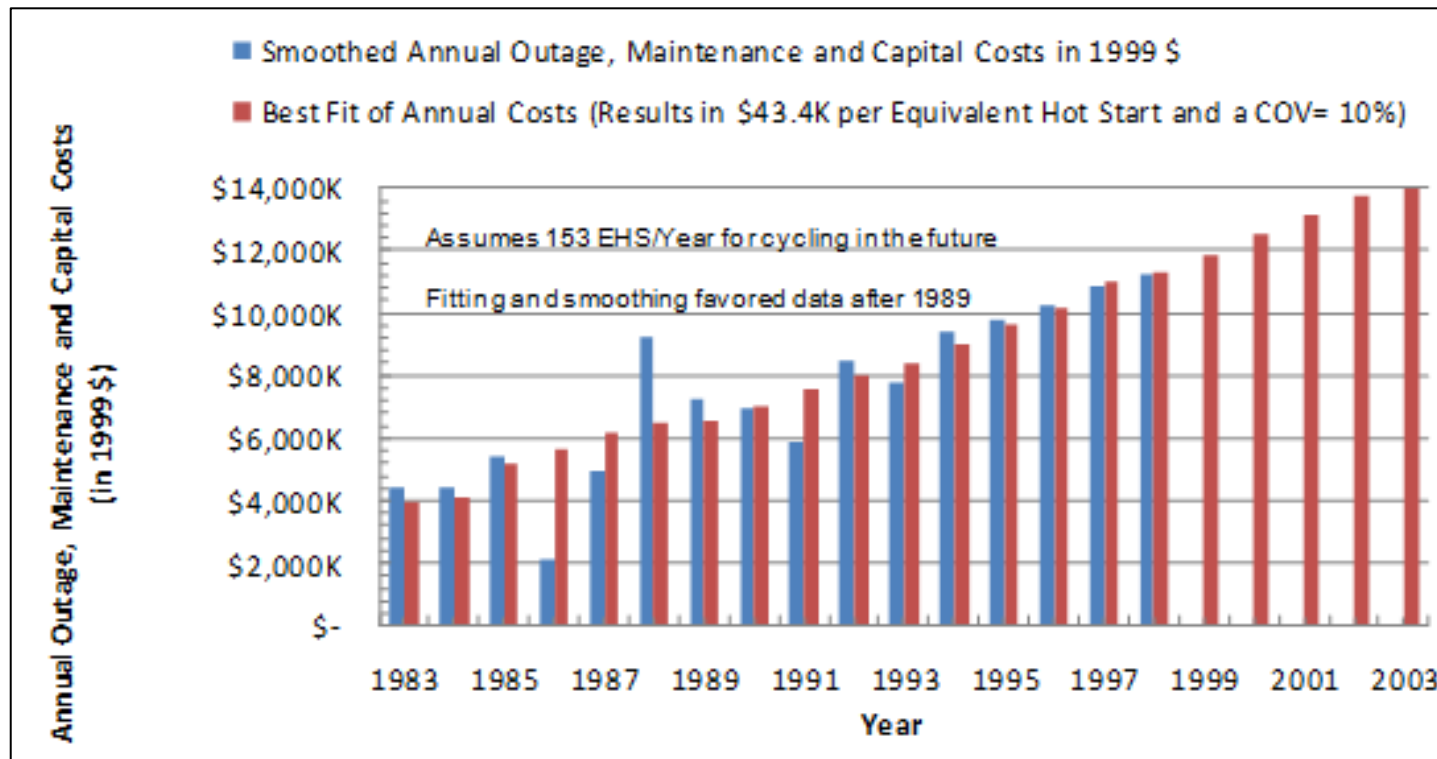
Regression-Based Total Cost per Equivalent Hot Start = \$6,000 (1995)



Best Estimate of Smoothed Colorado River Unit 5 Maintenance and Capital Costs



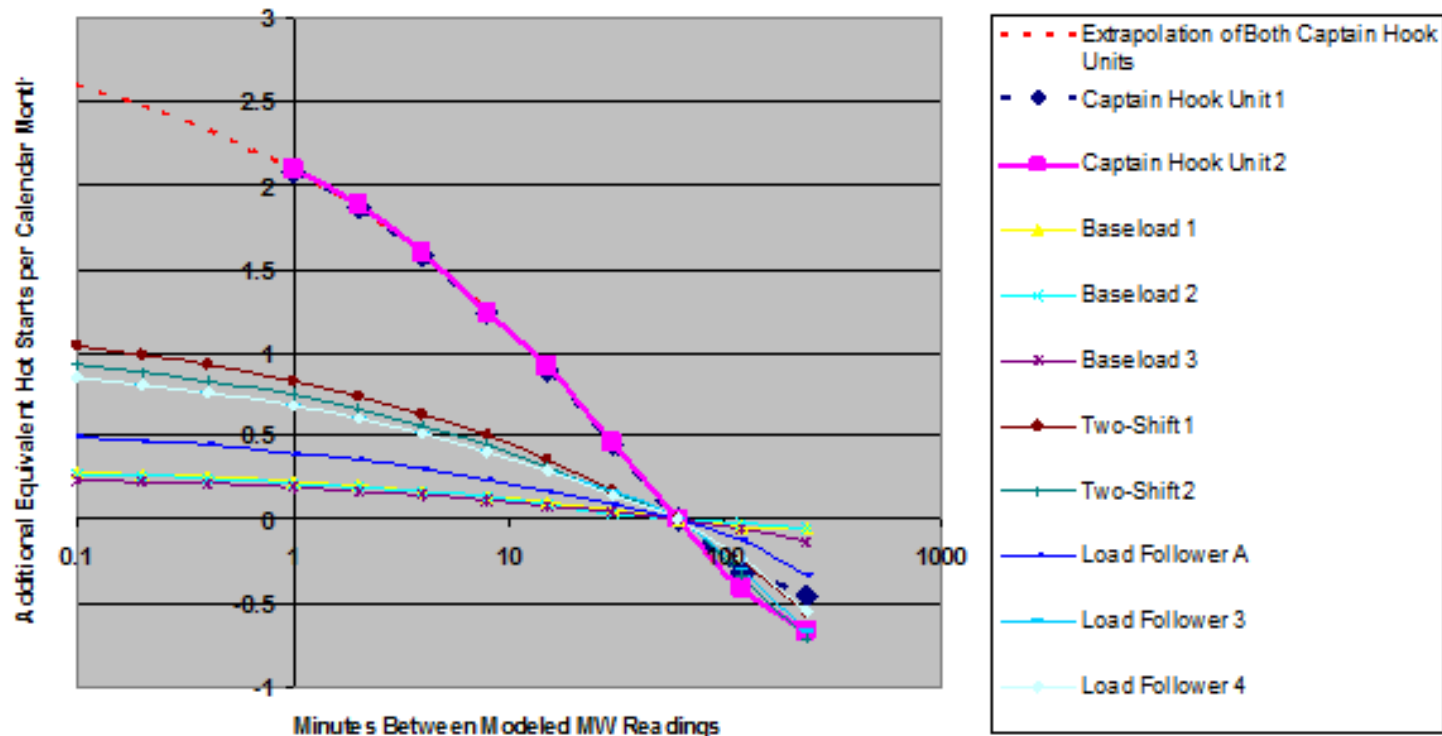
Best Estimate of Smoothed Colorado River Unit 5 Forced Outage, Maintenance and Capital Costs



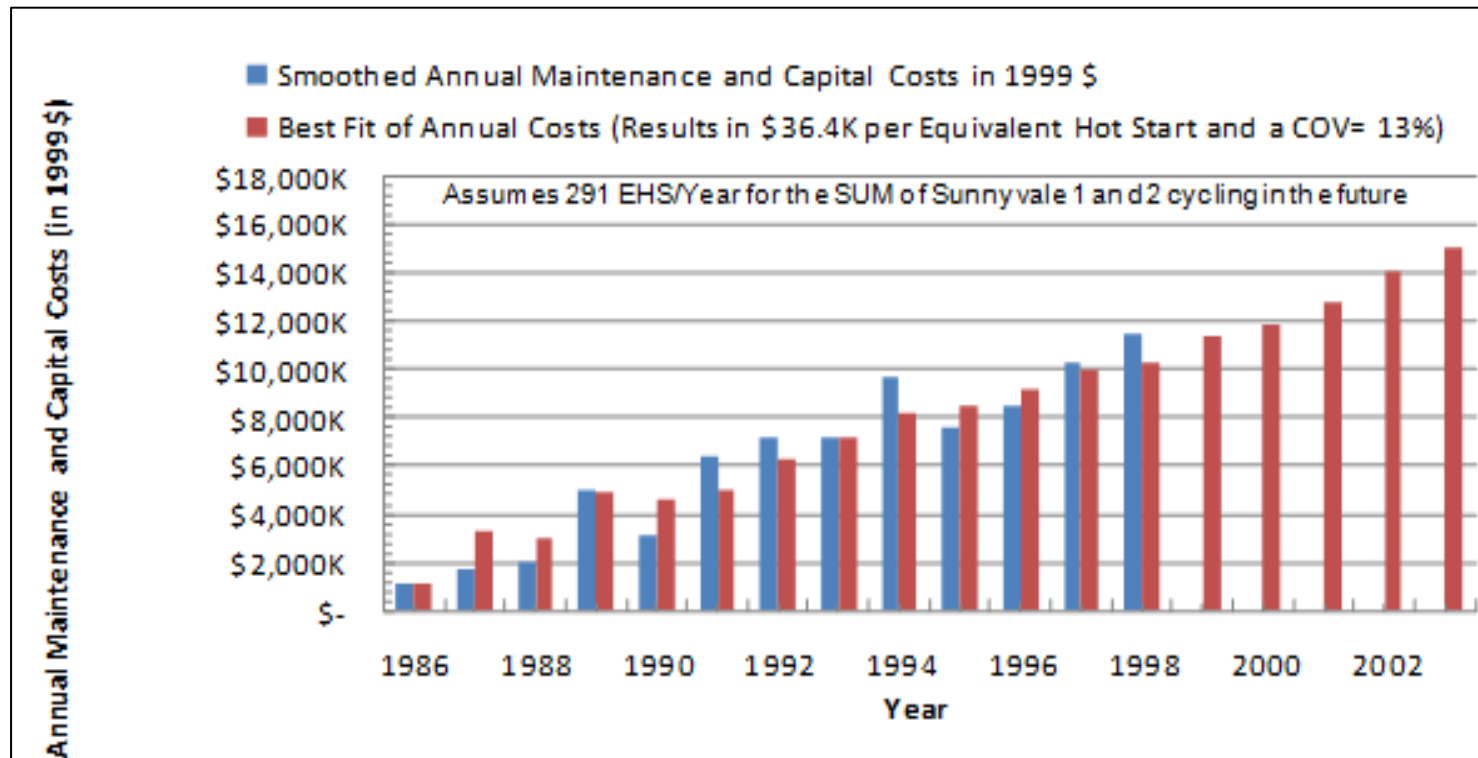
Captain Hook Regulation Damage/costs

Shows the Much Greater AGC Regulation and Other High-Frequency Cycling Damage at Captain Hook Units 1 and 2 (Summer 1998) than at Eight Other-Utility Units (27 months starting in January 1994) Modeled by Aptech

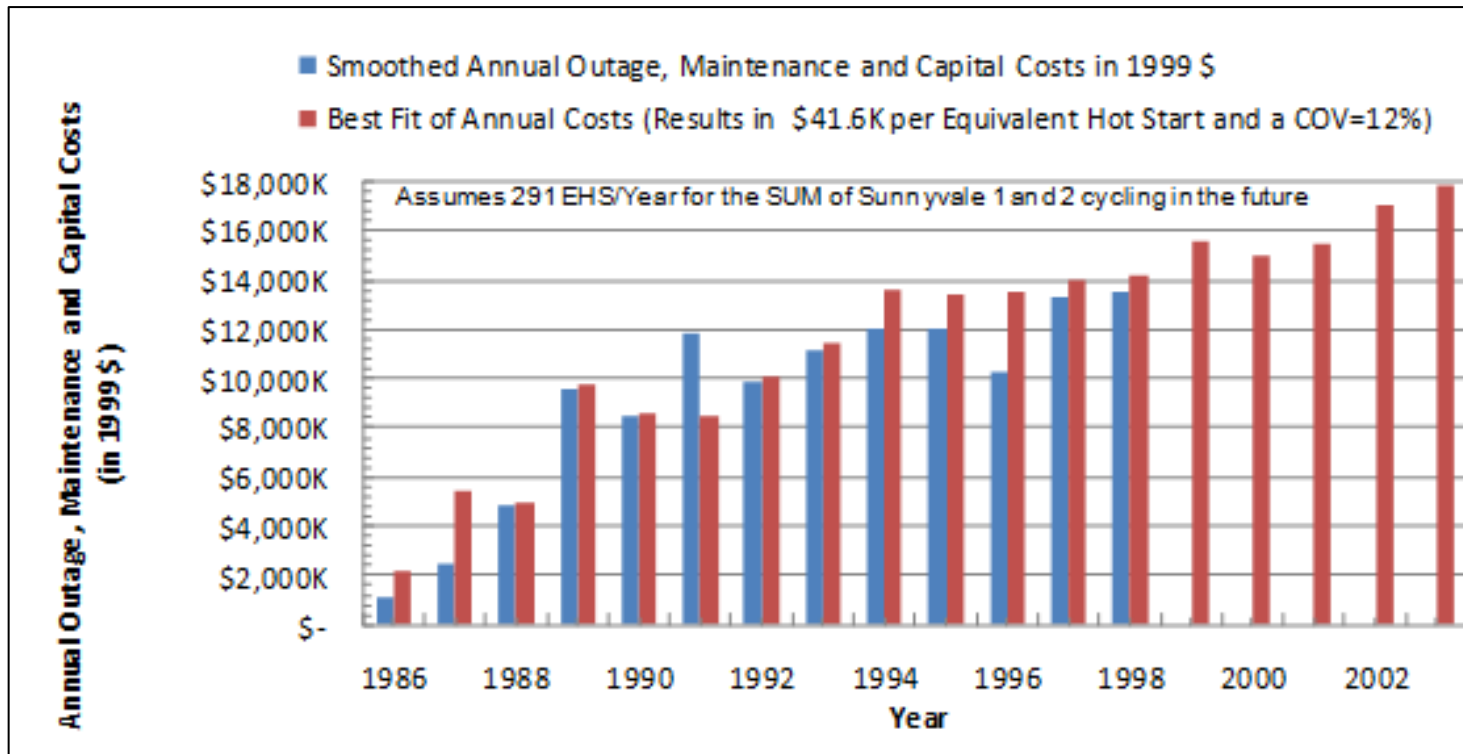
All Units are extrapolated to a six-second interval using similar regression models



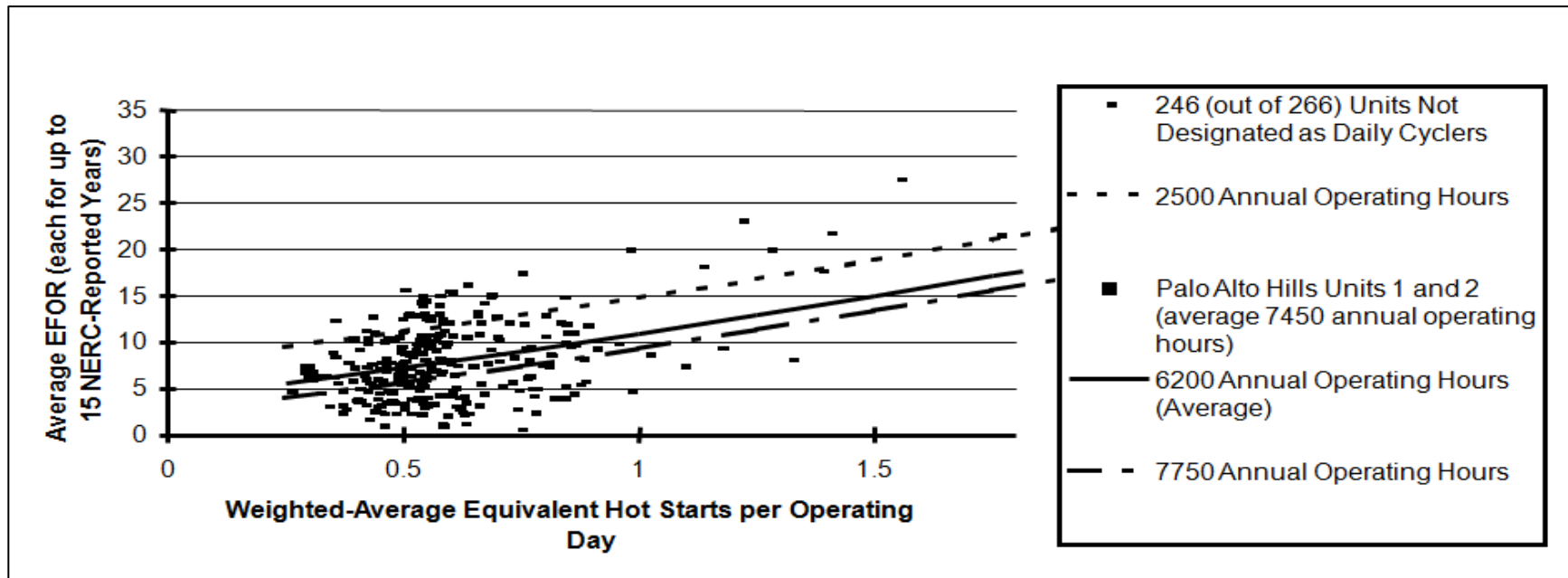
Best Estimate of Smoothed Sunnyvale Units 1 and 2 Maintenance and Capital Costs



Best Estimate of Sunnyvale Units 1 and 2 Forced Outage, Maintenance and Capital Costs



Increased EFOR with Increased Cycling

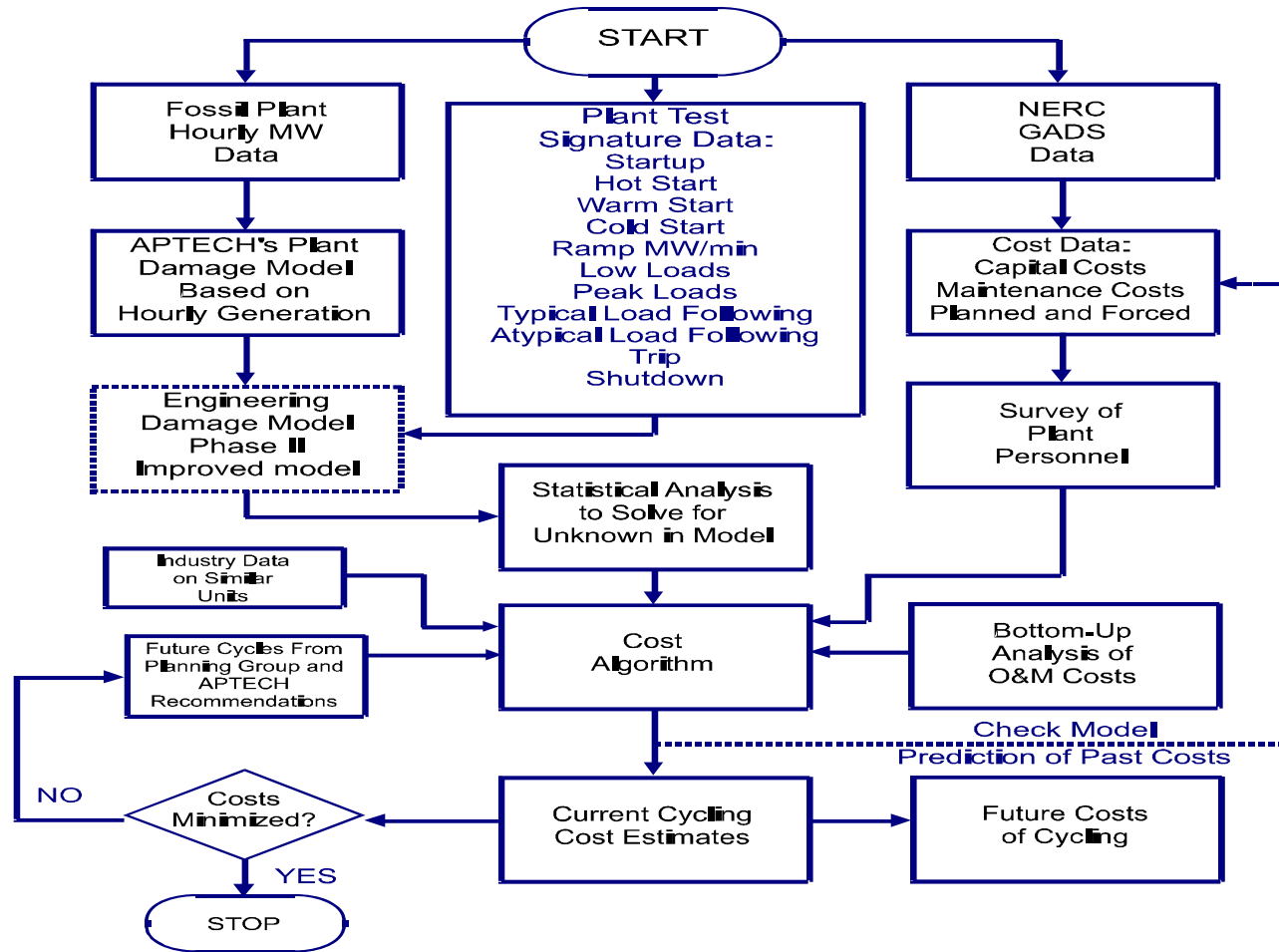


- Benchmarking
 - EFOR vs. Equivalent Hot Starts for Palo Alto Hills Units 1 and 2. Compares Palo Alto Hills Plant with 266 Other (237<MW<1000) Coal Primary Subcritical Units Not Designated by NERC as Daily Cyclers (excludes 20 "Outliers")

Bottom-Up Methodology

1. Detailed Audit of Maintenance and Capital Costs (90-95% of plant work orders W/O)
2. In-Plant Investigations (Q&A regarding W/O)
3. Detailed Review of boiler/HRSG Tube Failures/all major maintenance reviewed
4. Analysis of Cycling-Related Costs for all key plant components:
 - Boiler, Turbine, generator, GT, condensers, feedwater heaters, BOP

Intertek APTECH Flowchart to Estimate Future Cycling Cost



How Total Cycling Cost Information Can be Used

