Exelon Nuclear

Quad Cities Extended Power Uprate (EPU) Meeting

March 16, 2006

Exelon Nuclear

Introduction

Patrick Simpson

Licensing Manager

Agenda

Exelon Nuclear

- Introductions
- Root Cause Evaluation and Conclusions
- EPU Extent-of-Condition (EOC) Review
- Quad Cities Unit 2 (QC2) Outage Inspection Scope
- Planned Design Changes
  - Electromatic Relief Valve (ERV) Modification
  - Acoustic Side Branch (ASB) Modification
- QC2 Startup Test Plan Overview
- Planned NRC Interactions
- Summary and Conclusions

Exelon Nuclear

ERV Root Cause Evaluation

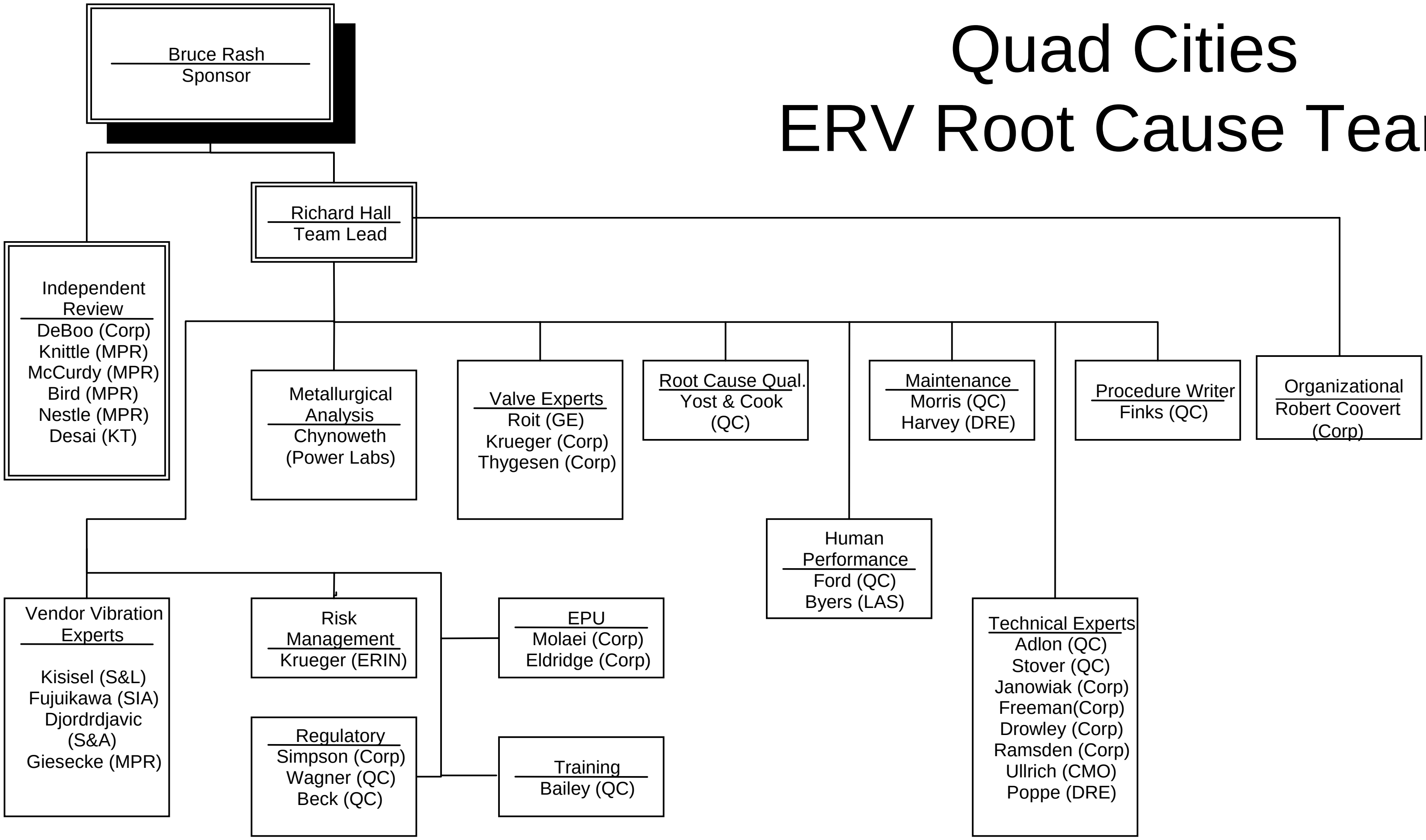
Karl Moser

Site Engineering Director

Quad Cities Nuclear Power Station

Root Cause Evaluation

Quad Cities
ERV Root Cause Team



Root Cause Evaluation

Exelon Nuclear

- Root Cause Team
  - A multi-discipline team comprised of expertise inside and outside of Exelon resulted in a thorough and comprehensive root cause product
- Investigation Scope
  - Review details surrounding failure and wear of the ERV solenoid actuators
  - Review maintenance practices and operating experience
  - Perform historical review (ERV performance issues and previous corrective actions taken)
  - Evaluate EOC
  - Review of organizational factors by Corporate Human Performance subject matter expert

Root Cause Evaluation

Exelon Nuclear

- Root Cause
  - Failure to correct the source of Main Steam Line (MSL) vibrations
    - Vibration effects were historically addressed at the component level through enhanced/increased preventive maintenance and modifications that hardened individual components
    - EPU increased MSL vibrations
      - EPU task report projected a 50% increase and made recommendations that included establishment of a start-up monitoring plan for MSL vibrations with specific acceptance criteria
        - » Monitoring plan included location of accelerometers based on analysis and testing of ERVs
        - » Analysis and testing of ERV and actuator failed to identify the impact EPU operation would have on ERV actuators

Root Cause Evaluation

Exelon Nuclear

- Contributing Factors
  - Inadequate design test control for ERV actuators
    - Unique ERV endurance testing (no Institute of Electrical and Electronics Engineers (IEEE) guidance existed)
    - Although wear was replicated, testing did not predict type of failure observed in this event
  - Inadequate ERV rebuild and inspection procedure
    - Lessons learned from 2003 event not fully incorporated
    - Preventive maintenance procedure did not identify all critical ERV parts requiring inspection
    - Preventive maintenance procedure did not provide details on identification and correction of actuator tolerances

Root Cause Evaluation

Nuclear

- Contributing Organizational Factors
  - A systematic approach was not used to evaluate decisions
    - Although equipment issues were being addressed, not all organizational contributors were addressed
  - Exelon demonstrated an over-reliance on contractor products and expertise and, in some cases, their approach and methodology was less than adequate
  - Some decisions were based on the best information available; however, the collective conditions were not clearly understood

Root Cause Evaluation

Nuclear

- Corrective Action to Prevent Recurrence
  - Plant design change
    - Provide design change to reduce overall MSL vibrations to a level that supports safe and reliable operation of the MSLs and attached components during future operating cycles at EPU power levels

Root Cause Evaluation

Exelon Nuclear

- Key Corrective Actions
  - Plant design changes
    - Design and install ASB to reduce overall MSL vibrations
    - Design and install more robust ERV actuators
  - Development of a comprehensive test control program that includes Failure Modes and Effects Analysis for critical projects
  - Revisions to ERV actuator/pilot valve rebuild and inspection procedures to address preventive maintenance weaknesses

Root Cause Evaluation

Exelon Nuclear

- Key Corrective Actions (cont.)
  - Revise and provide training to Engineering on the requirements and application of OP-AA-106-101-1006, "Operational and Technical Decision Making Process," for engineering
    - Proven systematic approach to complex decision-making
    - Provides guidance on developing plans to address complex issues
    - Includes a systematic approach to evaluating decisions
      - Revision will include lessons learned from the ERV root cause and applying investigative analysis

Root Cause Evaluation

Exelon Nuclear

- Key Corrective Actions (cont.)
  - Revise HU-AA-1212, "Technical Task Risk/Rigor Assessment, Pre-Job Brief, Independent Third Party Review, and Post-Job Brief," and provide training to Engineering on the requirements and application for vendors providing high-risk or critical analyses for station use
    - Changes to this procedure will include a link to OP-AA-101-1006 for complex Engineering decisions and products which involve historical data, repeat equipment failure, risk, and complex analysis

Exelon Nuclear

EPU EOC Review

Bruce Rash

Corporate Design

Engineering Director

EOC Review (What and Why)

Exelon Nuclear

- Purpose is to evaluate fatigue and wear susceptibility
- Scope includes components on the MSLs from vessel to turbine control valves, including High Pressure Coolant Injection (HPCI) and Reactor Core Isolation Cooling (RCIC) piping
- Relative importance of evaluations
  - Potential event initiators
    - Piping failure that causes scram or requires shutdown
    - Inadvertent relief valve opening
    - Main Steam Isolation Valve (MSIV) closure
    - Turbine main stop or control valve closure/failure
    - MSIV limit switch failure potential scram
  - Potential mitigating system impacts
    - Main Steam relief valve capacity
    - HPCI and RCIC

EOC Review (When)

Exelon Nuclear

- Project divided into multiple phases to evaluate conditions prior to and following modifications to reduce vibration
  - Phase I: Past measured plant EPU vibration data used as input - complete
  - Phase II: Projected post modification data used as input - complete
  - Phase III: Actual measured post modification data will be used as input – scheduled to complete shortly after achieving full EPU power

EOC Review (How)

Exelon Nuclear

- Methodical approach for each component
  - Identify the applicable spectra of vibrations
  - Obtain and review existing documentation including drawings, qualification reports, vendor manuals, and other documents
  - Review documentation to determine potential vulnerabilities to vibration for frequencies and amplitudes considered
  - Identify natural frequencies and assess potential amplification due to frequency content considered
  - Determined wear susceptibility and fatigue sensitivity

EOC Review

Exelon Nuclear

- Determined wear susceptibility and fatigue sensitivity
  - Analytical models developed for components and subsystems
  - Vibration data input and susceptibility determined
  - Wear reviewed by evaluation where possible with confirmation by walkdowns of selected samples
  - As-built configurations will be verified
  - Results will be integrated and assessed collectively

EOC Review
Results To Date

Exelon Nuclear

- Phase I potential vulnerabilities identified
  - Target Rock vacuum breaker
  - Local leak rate test (LLRT) taps
  - Small bore piping
  - Limitorque SMB000 actuators
  - Turbine control valve accumulators
  - MSIV limit switch
- Phase II results
  - No significant new insights
- Phase III activities
  - Walkdowns
  - Reanalysis with plant data

EOC Review

Exelon Nuclear

- Going forward acceptance criteria
  - Installed instrumentation will monitor component vibrations and collect data for analysis
  - Installed more instrumentation on key components
  - Data will be evaluated against established acceptance criteria determined by analytical evaluation

QC2 Outage Inspection Scope

Steve Boline

Deputy Engineering Director

Quad Cities Nuclear Power Station

QC2 Outage Inspection Scope

- ERV inspections
- EOC inspections
  - EOC team identified components potentially susceptible to vibration-related wear at EPU conditions
  - Evaluations considered external wear (interference with nearby components) and internal wear
  - Components with low margin selected for additional inspections/evaluations
  - Selected components will be visually inspected during MSL walkdowns; certain components to be removed for additional inspections to confirm acceptability for operation at EPU
- EPU vulnerability inspections
- Inspection results will be documented and evaluated within the Corrective Action Program

QC2 Outage Inspection Scope
ERV Actuators

Exelon Nuclear

- ERV Actuator Inspections
  - As-found testing will be performed
  - Shop inspections will be performed to identify potential vibration-related degradation
    - Inspection guidance detailed in approved work package
  - Results will be evaluated to determine appropriate actions for QC1 and Dresden Nuclear Power Station
- 3E ERV turnbuckle will receive non-destructive examination (NDE)

QC2 Outage Inspection Scope

EOC Inspections

Exelon Nuclear

- Outage inspection team
  - Team lead involved with EOC reviews
  - Inspectors will include system manager, check-valve and MOV engineers, VT-3 qualified personnel
- Detailed inspection guidance developed
  - Component-level inspection criteria
- Component evaluations
  - Power Labs
  - Corporate Engineering
  - Plant Engineering

QC2 Outage Inspection Scope

EOC Inspections

Exelon Nuclear

- MSL piping from vessel to turbine control valves
  - Penetrations, supports, LLRT taps, snubbers, drain piping, insulation
- HPCI and RCIC steam piping to outboard isolation valve
  - Penetrations, supports, LLRT taps, snubbers, drain piping, isolation valves
- Steam system valves
  - MSIVs including limit switches, actuators, accumulators, air lines, solenoids, flex hose, temperature elements
  - ERVs, Main Steam Safety Valves (MSSVs), Safety/Relief Valve (S/RV) including small bore lines, actuators, temperature and acoustic monitors, electrical junctions, pressure switches
  - Turbine control and stop valves including accumulators, pressure switches, supports

QC2 Outage Inspection Scope

EOC Inspections

Exelon Nuclear

- Components selected for internal inspections
  - Target Rock S/RV
    - Pressure switch (bellows switch interface)
    - Solenoid internals
    - Bellows cap and spring
  - Main turbine control valve – Electrohydraulic Control System (EHC) pressure switch
  - Inboard MSIV limit switch
  - MSIV solenoid actuator and valve
  - Main turbine steam seal supply manual isolation valve
  - Limitorque operators
    - Inboard RCIC/HPCI steam supply
    - Inboard MSL drain line

QC2 Outage Inspection Scope

EPU Vulnerability Inspections

Exelon Nuclear

- EPU vulnerability assessments completed in June 2004
  - Identified potential EPU-related vulnerabilities and actions to prevent failures
  - Actions included component inspections and piping system walkdowns

QC2 Outage Inspection Scope
EPU Vulnerability Inspections

Exelon Nuclear

- Component inspections
  - Shroud head
    - Locking pin window
    - Head bolt ring gussets
    - Standpipe welds (sample)
  - Feedwater spargers
    - Including end-bracket pin hardware
  - Jet pump assembly restrainer gate wedges
  - Selected system valves
    - Feedwater pump minimum flow valve and actuator
    - Heater level control valve actuator and positioner
    - Turbine control valve mechanical and electrical connections
  - Low pressure turbine inner casing and extraction boxes inspections

QC2 Outage Inspection Scope

EPU Vulnerability Inspections

Nuclear

- Piping system walkdowns
  - Feedwater and Condensate
    - Heater drains and vents
  - EHC
  - Extraction steam

QC2 Outage Inspection Scope

Additional Inspection Activities

Exelon Nuclear

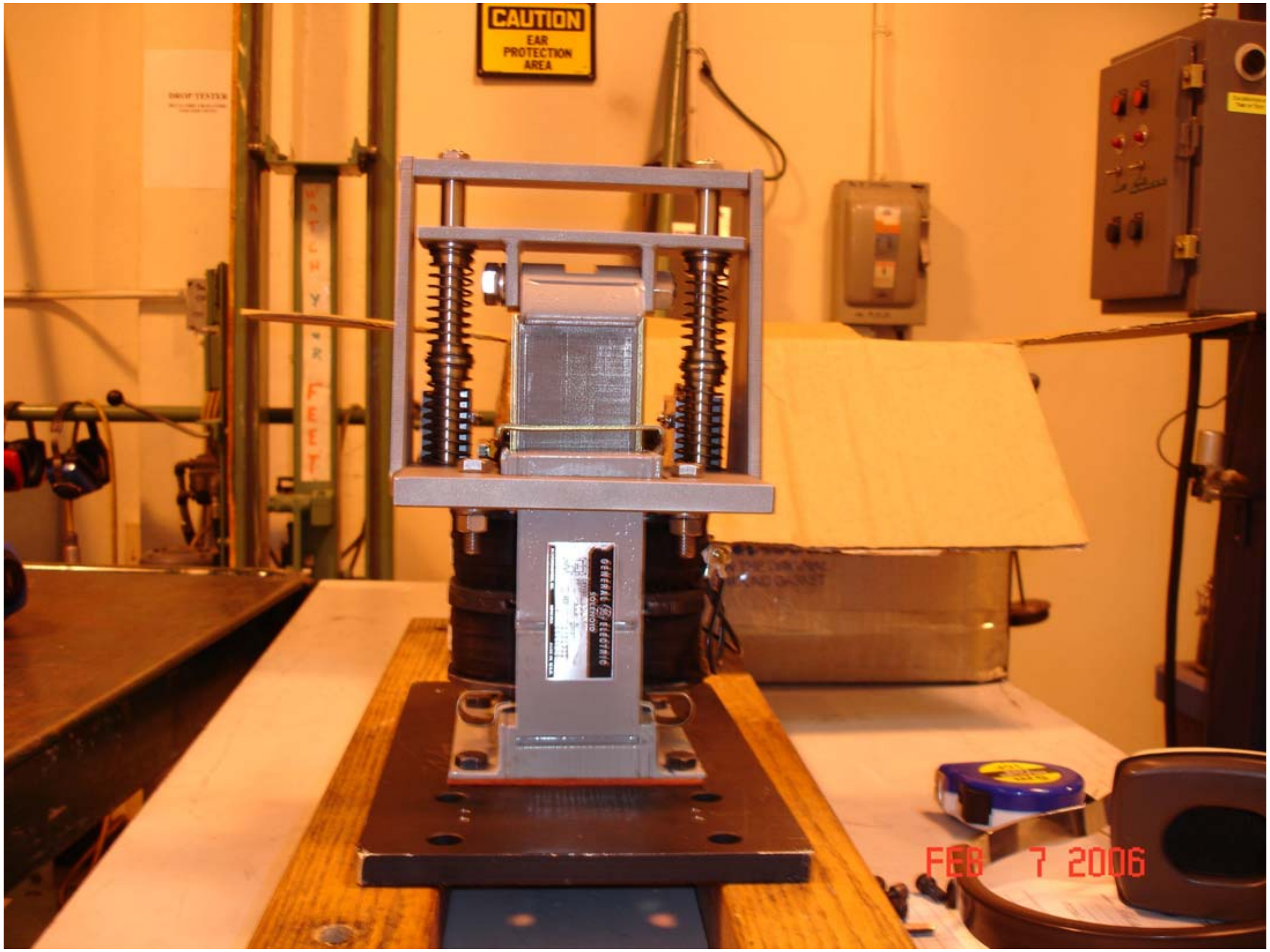
- Shroud tie rod assemblies (Plant Hatch operating experience)
- Steam dryer (BWRVIP-139)

ERV Actuator Modification

Bruce Rash
Corporate Design
Engineering Director

ERV Actuator Modification

Exelon Nuclear



ERV Actuator Modification

Exelon Nuclear

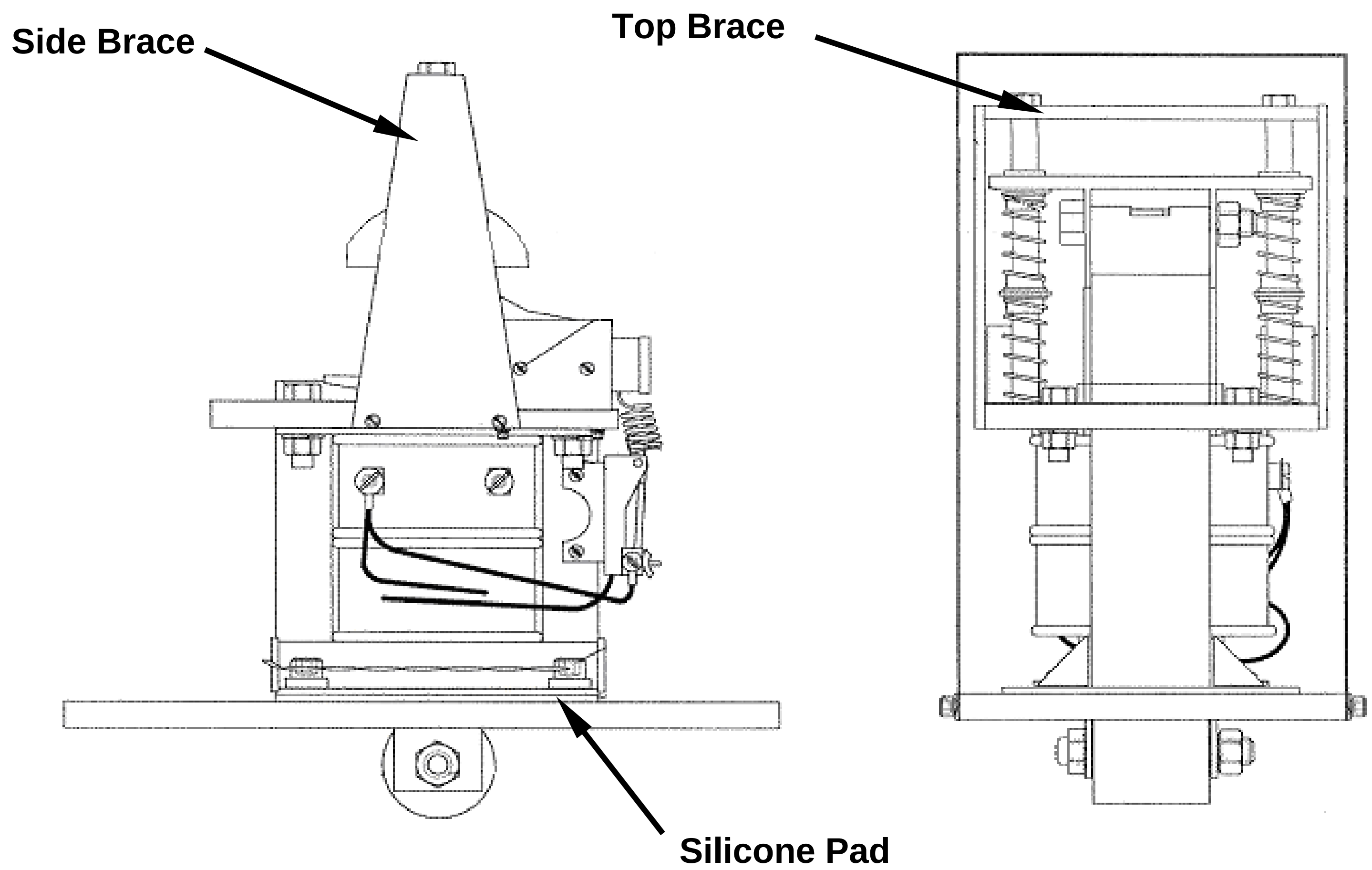
- Several ERV actuator replacement options evaluated
- General Electric design selected – significantly improves vibration resistance
- Material improvements
  - Stellite 6B guides and guideposts
  - Stainless steel pivot pins
  - Larger diameter springs, non-buckling arrangement
  - Improved vibration isolation achieved using silicone gasket between solenoid and baseplate
  - Tighter tolerances

ERV Actuator Modification

Exelon Nuclear

- Actuator rigidity improved
  - Upper angle bracket added to fix guide post alignment
- Guide posts attached to stainless steel brace assembly
- Actuator performance demonstrated through qualification testing
  - Timing tests
  - Vibration endurance (shaker table tests)

ERV Actuator Modification



Design Issues and Resolutions

Exelon Nuclear

Issue	Impact	Resolution
Guidepost and Spring Interaction	Component Failure Origin	Redesigned Frame, Post, Springs
Pivot Bolt Wear	Impacts Cutout Switch Operation	New Material, Bushing in Angle
Electrical Connection	Potential to Lose Coil Connection	3 Wire Changed to 1 Wire w/Strain Relief
Base Angle Iron Crack	Actuator Could Fail Mechanically	Gussets Added for Strength

Initial Test Results

Exelon Nuclear

Actuator	Initial Measurement	Final Measurement	Wear
Dresser #1 Prior to Jan	Guidepost 501	Guidepost 420	Guidepost 81 Mils
Dresser #2 Current Model	Guidepost 501	Guidepost 433	Guidepost 68 Mils
Dresser#3 New Actuator	Guidepost 505	Guidepost 502	Guidepost 3 Mils

Exelon Nuclear

ASB Modification

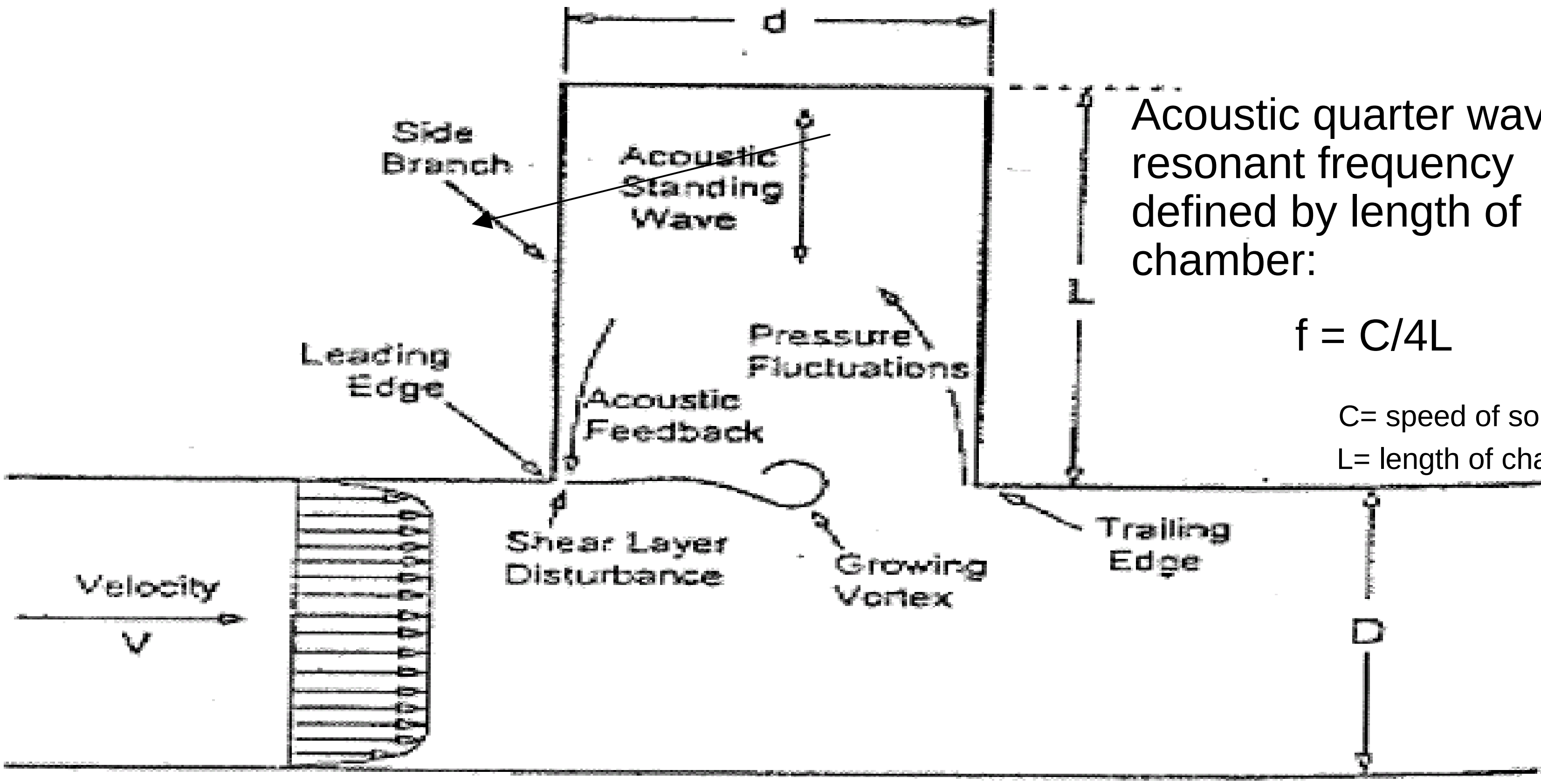
Roman Gesior
Director – Engineering Programs

ASB Modification

Exelon Nuclear

- Operation at EPU has increased acoustic loads due to increased steam velocity
- Testing confirms the source of the vibrations to be from ERV and MSSV standpipes
  - Vortex shedding frequency excites acoustic standing wave in the valve standpipe
- ASB modification reduces overall MSL vibrations by reducing the acoustic pressure oscillation
  - Reduces MSL component vibration degradation
  - Reduces the steam dryer pressure oscillation load

ASB Modification
Theory



Acoustic quarter wave resonant frequency defined by length of chamber:

$$f = C/4L$$

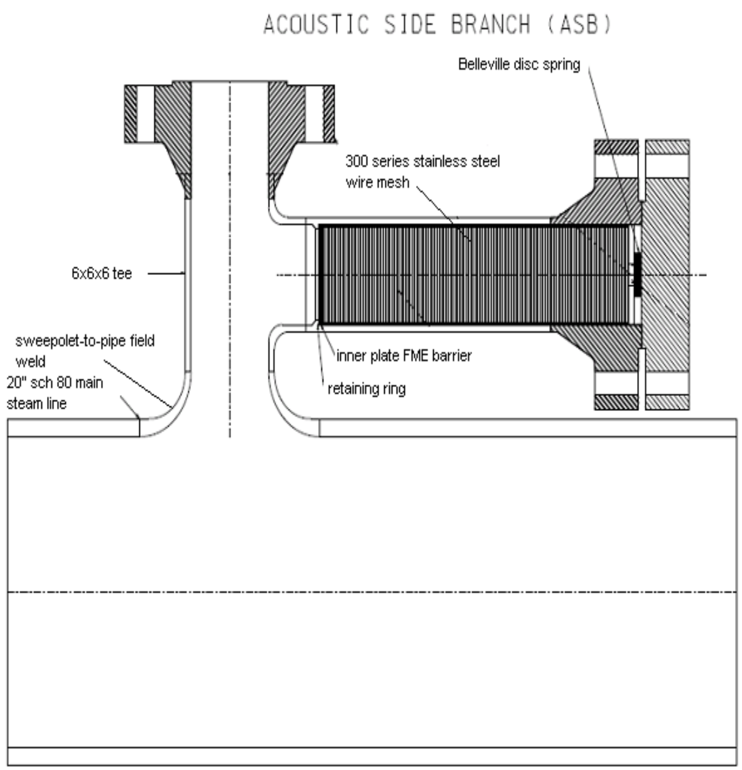
C= speed of sound
L= length of chamber

Vortex shedding frequency defined by diameter of chamber: $f = (S \times V)/d$

S=Strouhal number
d = diameter
V=velocity

ASB Modification

Theory

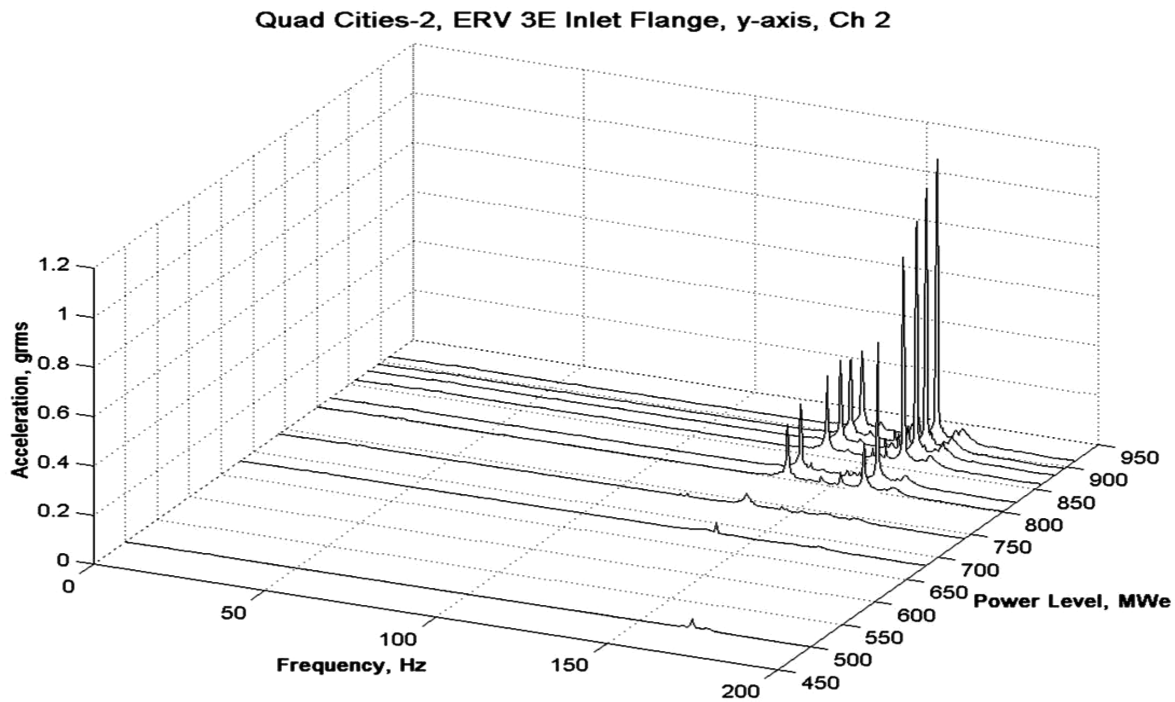


- The addition of the ASB increases the effective length (L) of the standpipe decreasing the frequency (f) of the acoustic standing wave
- The vortex shedding frequency remains unchanged at the same power level, but when the acoustic and vortex shedding frequencies are no longer coupled, resonance does not occur
- The decrease in the acoustic frequency lowers the velocity at which the vortex shedding will excite the acoustic standing wave (i.e., the acoustic signal occurs at lower plant power levels)
- The addition of screen mesh material inside the ASB introduces a damping medium that absorbs the energy of the standing wave
- The end result is a reduced acoustic pressure oscillation that occurs at a lower point in power operation

ASB Modification

What Frequency Is Causing Degradation to the ERVs?

Exelon Nuclear



The majority of degradation on the ERVs is caused by acoustic signals in a frequency range of 150 – 160 Hz

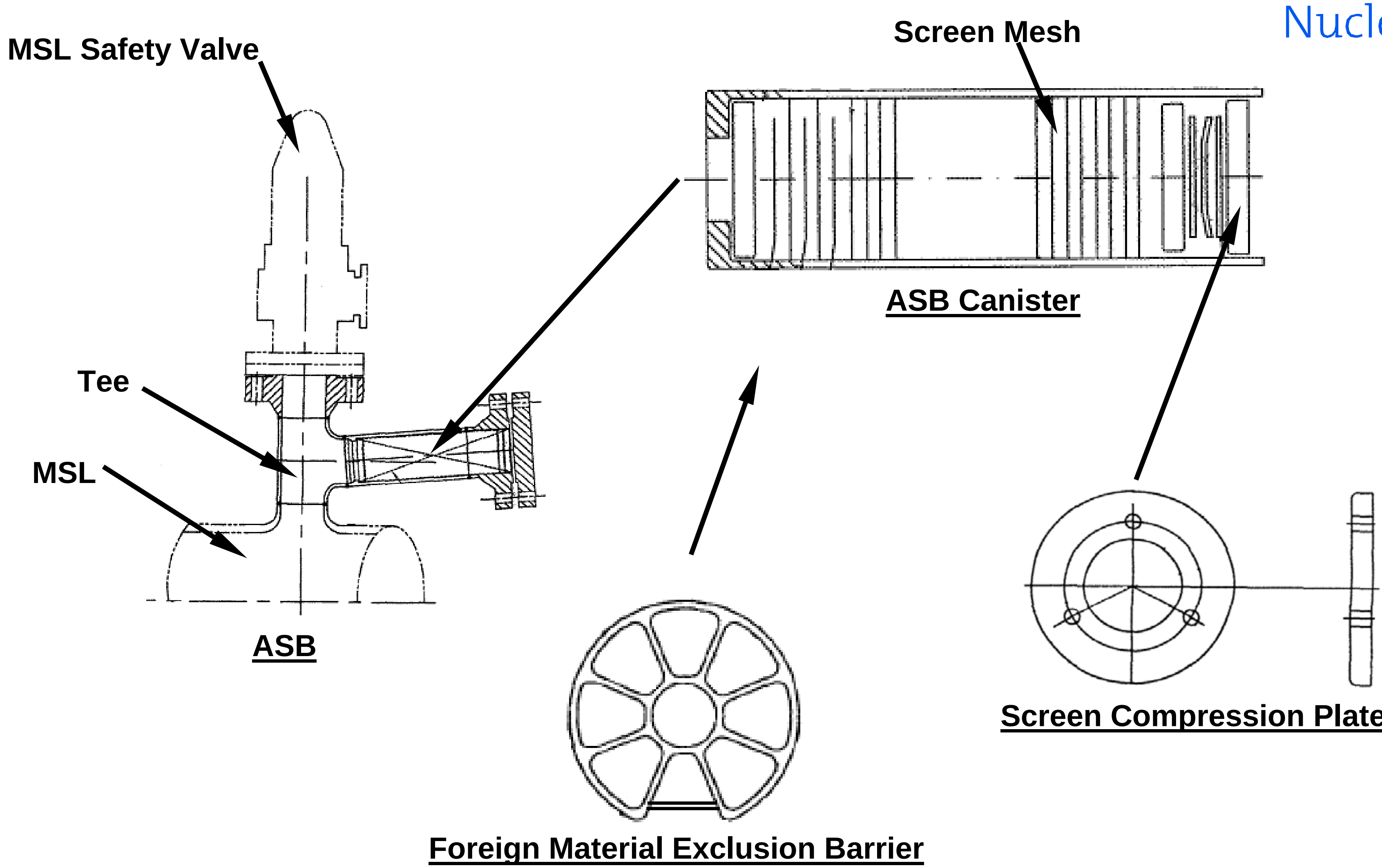
ASB Modification

Exelon Nuclear

- Rigorous test plan has confirmed ASB performance
  - Scale model testing has demonstrated expected frequency shift and amplitude reduction
  - Standpipe acoustic characteristics and mesh effectiveness validated by full scale resonance test
  - Shaker table testing confirmed vibration endurance
  - Full flow testing demonstrated no adverse impact on ERV/MSSV performance
- Further verification will occur during planned startup testing

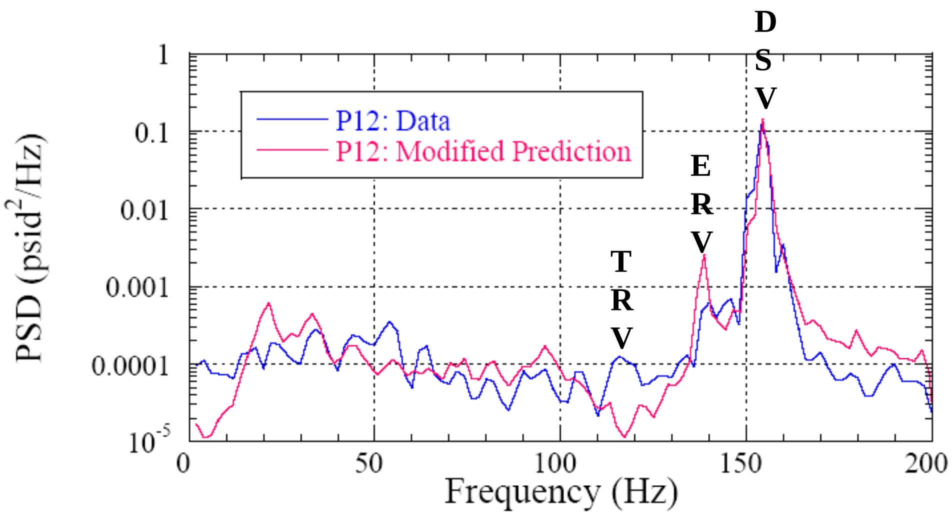
ASB Modification

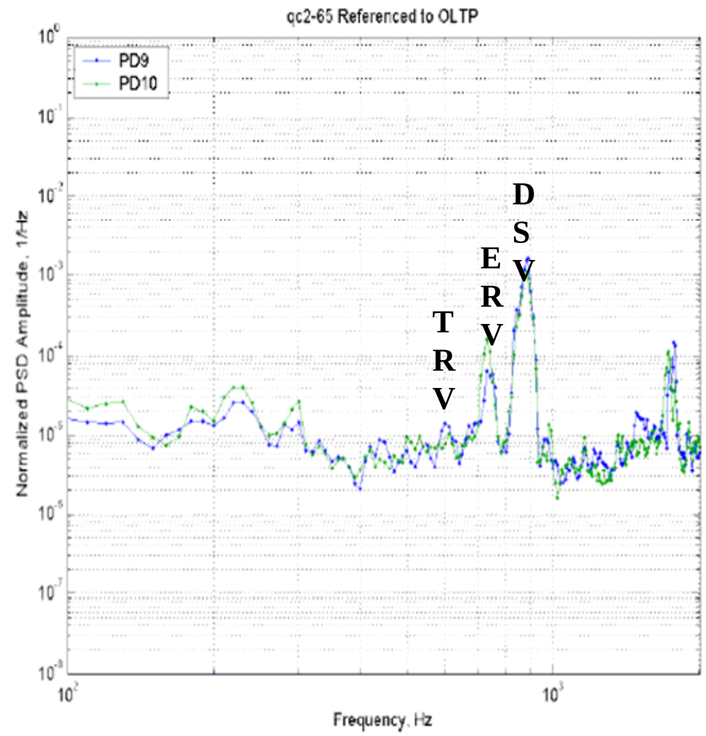
Exelon Nuclear



SMT As-Built Comparison

Exelon Nuclear



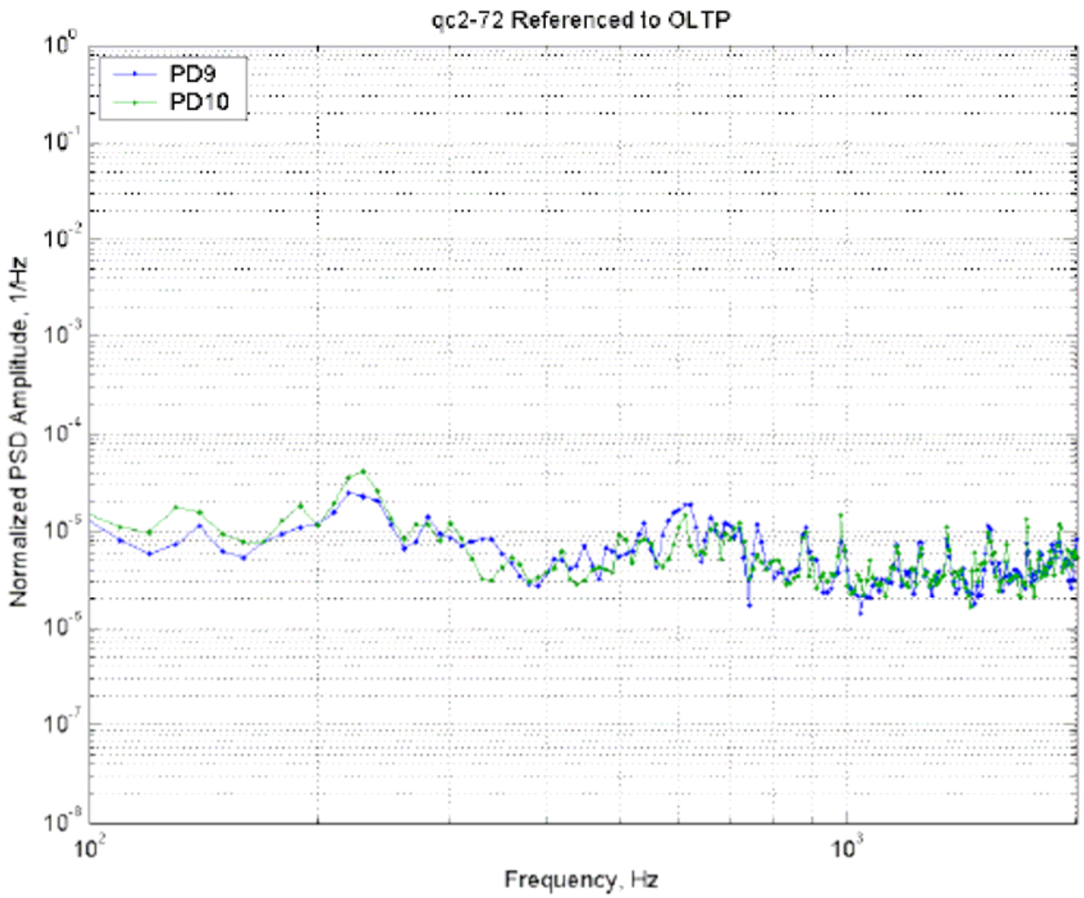


In-plant dryer pressure sensor EPU power

SMT dryer pressure sensor EPU power

Post-ASB Installation

Exelon Nuclear



SMT dryer pressure sensor at EPU with ASBs installed on SV/ERVs

Conclusions

Exelon Nuclear

- Testing has demonstrated that the ASB is effective in reducing the 150 – 160 Hz MSL pressure oscillation to pre-EPU levels
- This reduction will significantly reduce MSL vibrations and steam dryer loads
- A design has been tested and demonstrated robust for MSL application

QC2 Startup Test Plan

Karl Moser

Site Engineering Director

Quad Cities Nuclear Power Station

QC2 Startup Test Plan

Exelon Nuclear

- Startup plan verifies plant parameters and equipment performance remain within established acceptance criteria
- Data will be collected throughout the full range of operation from pre-EPU to EPU conditions
- Power ascension will occur incrementally in a controlled manner
  - Test plan includes 18 plateau test conditions (TCs) starting at approximately 8% thermal power
  - Acceptance criteria provided at specified TCs
- PORC will evaluate test results and authorize continued testing above pre-EPU power (>2511 MWt)
- Following completion of the test plan, power will be returned to pre-EPU, unless all Level 1 and Level 2 criteria are satisfied

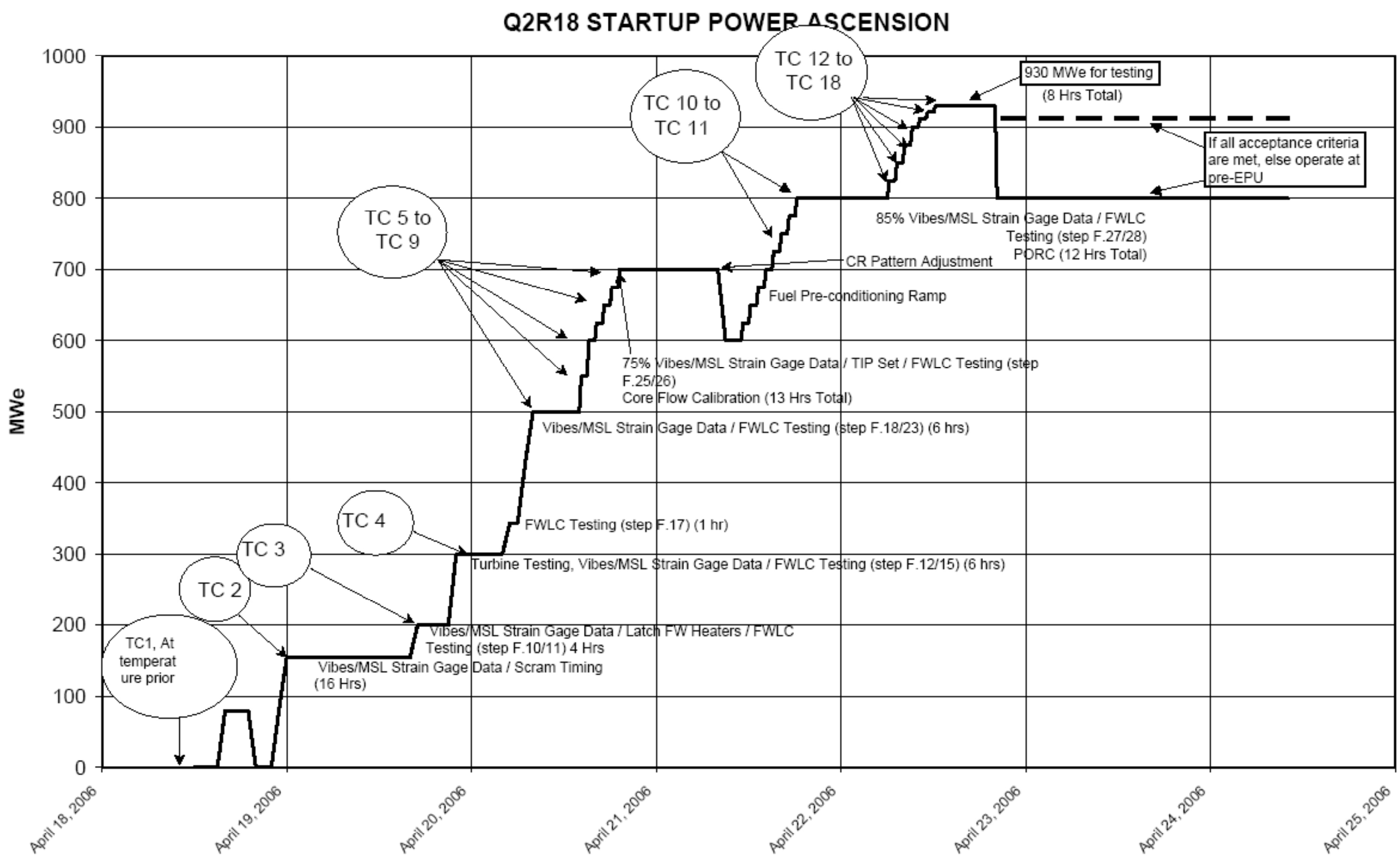
QC2 Startup Test Plan

Exelon Nuclear

- Vibration data will be collected using installed strain gauges and accelerometers located on the MSLs and associated components
  - Additional instrumentation will be installed during the upcoming QC2 refueling outage
- Throughout the power ascension, vibration data will be compared to pre-established acceptance criteria (AC)
  - AC validated at TC 2, 4, 5, 9, 11, and 18
  - Level 1 criteria established to ensure plant safety
    - If exceeded, power will be returned to a level where the AC is known to be met based on prior testing until formal engineering evaluation is completed
  - Level 2 criteria are associated with design expectations
    - If exceeded, testing may continue if authorized by the Test Director and Plant Manager

QC2 Startup Test Plan

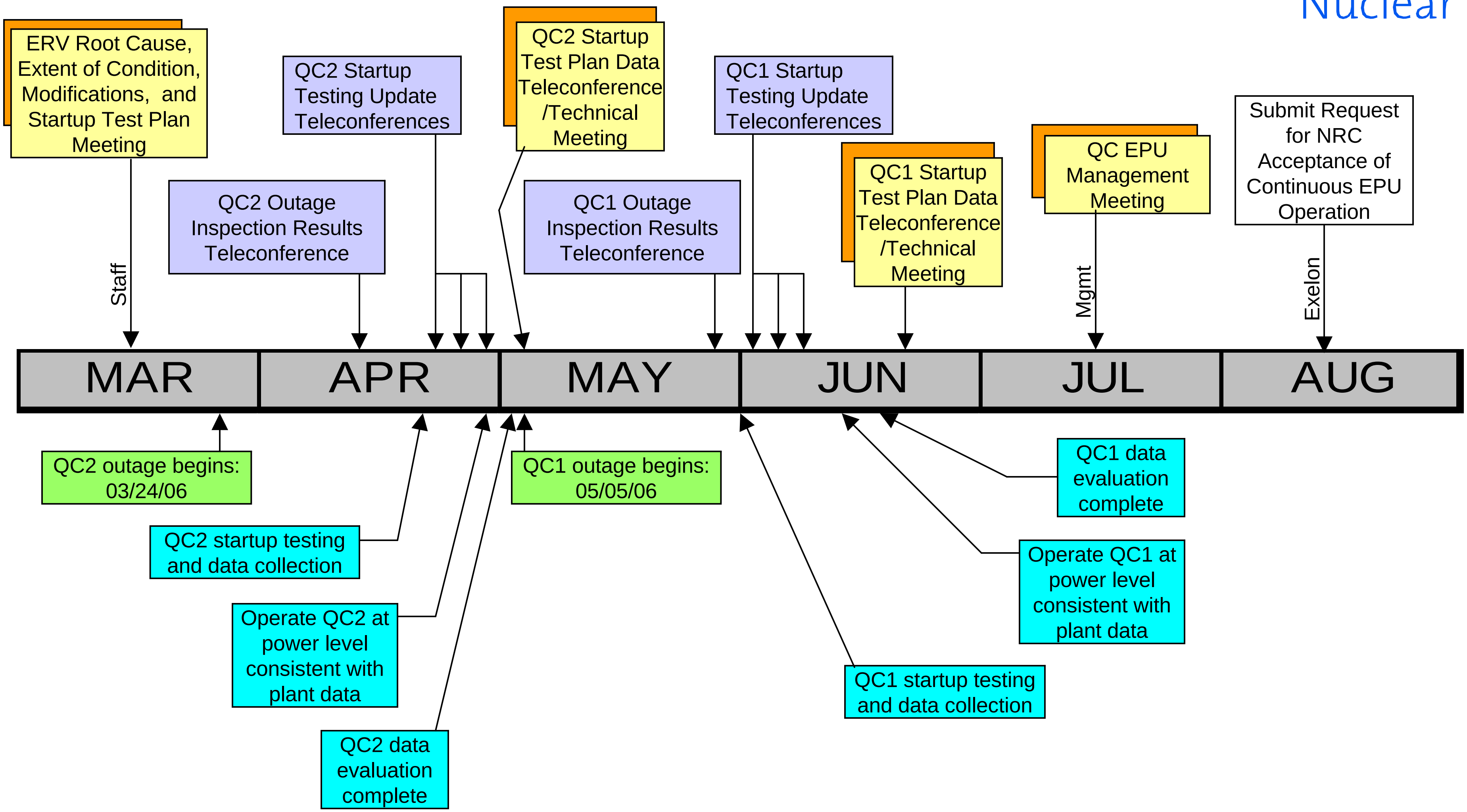
Exelon Nuclear



Planned NRC Interactions

Patrick Simpson
Manager - Licensing

Planned Interactions



Nuclear

Summary and Conclusions

Randy Gideon

Plant Manager

Quad Cities Nuclear Power Station

Summary and Conclusions

Exelon Nuclear

- Exelon is committed to resolving vibration-related concerns prior to returning QC1 and QC2 to EPU power
- The root cause of the ERV degradation has been identified
- Modifications are planned that will improve ERV actuator performance and significantly reduce MSL vibrations
- A comprehensive EOC evaluation has been performed to evaluate components sensitive to MSL vibration
  - Additional inspections planned during upcoming QC2 refueling outage
- A comprehensive startup testing program will confirm ASB performance by monitoring vibration levels on key MSL components
- The NRC will continue to be updated through normal communication channels