Exelon Nuclear

Extended Power Uprate (EPU) Vibration Assessment and Vulnerability Review

September 23, 2004

Agenda

Exelon Nuclear

- Introduction
- EPU Vibration Assessment
- EPU Vulnerability Review
- Status of Steam Dryer Load Analysis, Design, Fabrication and Instrumentation
- Closing Remarks

Exelon Nuclear

Introduction

James Meister

Vice President, Nuclear Services

EPU Vibration Assessment

Sharon Eldridge
Corporate Engineering Projects

Topics

Exelon Nuclear

- Vibration Evaluation
- Background
- Original EPU Monitoring Plan
- Vibration Evaluation/Scope
- Purpose, Scope, and Methodology
- Results
- Planned Actions
- Independent Reviews
- Summary

Vibration Evaluation

Exelon Nuclear

- The purpose of the vibration evaluations was to provide assurance that potentially effected components would perform acceptably for at least a full 24 month cycle at EPU full thermal power operation
  - All evaluations and testing are completed except for the Target Rock Safety/Relief Valve (S/RV)
  - Implementation of actions is either planned or complete to support return of Quad Cities (QC) Units 1 and 2 to full EPU power operation
  - Dresden (DR) evaluations support continuation of full EPU power operation

Background
QC Indications

Exelon Nuclear

- Main Steam (MS) low point drain line failed shortly after EPU ramp up (QC2)
  - Forced outage to repair
  - Caused by vibration-induced fatigue
- Electrohydraulic Control system accumulator small bore line cracking (QC2)
- Audible noise due to resonance of reactor building components to MS acoustic frequency (QC1)
- Limitorque limit switch degradation (QC1)
  - Rotor wear due to vibration of fingers
- Electromatic Relief Valve (ERV) actuator degradation (QC1)
  - Caused by higher vibration levels with EPU
- Target Rock S/RV as-found set point 6.8% high (QC2)
  - Other Target Rock S/RVs showed similar wear

Background
Indications

Exelon. Nuclear

- Multiple equipment problems challenged plant operations
  - In some cases, outages were required to resolve/repair identified individual component problems
- Consolidated efforts were established to ensure that no more failures occurred
  - Teams were assembled to address steam dryer, EPU vulnerabilities, and vibration issues

Background

Original EPU Monitoring Plan

Exelon Nuclear

- DR/QC EPU initial vibration monitoring plan was based on industry guidance for piping
  - Utilized accelerometers on large bore piping supports
  - Focused on piping, both large and small bore, to prevent failures
  - Acceptance criteria for piping based on American Society of Mechanical Engineers (ASME) criteria (OM Part 3)
  - Weakness in implementation contributed to failure of MS low point drain line at QC2
- Industry guidance for components was also utilized
  - Pump vibration monitoring conducted
  - Relied on component surveillance testing to ensure acceptability

Vibration Evaluation/Scope

Exelon. Nuclear

- During QC1 dryer repair outage in November 2003, the 3B ERV actuator was discovered with significant damage
  - Root cause investigation was performed
  - A detailed inspection scope was developed and implemented for both QC and DR to determine “extent of condition” and identify any other potentially vulnerable components
- EPU related vibration issues identified as a result of these walkdowns include
  - Remaining 3 ERVs (QC)
  - Limitorque limit switch (QC)
  - Various pipe support mechanical connections (DR/QC)

Vibration Evaluation/Scope (cont.)

Exelon Nuclear

- Based on the walkdown results, accelerometers were installed on susceptible components for data collection and reevaluation
  - MS Isolation Valves (MSIVs)
  - ERVs
  - Various limit switches, including Namco-type on MSIVs
  - SRVs and Target Rock S/RV
  - Valve operators (Limitorques)

Purpose, Scope, and Methodology

Exelon Nuclear

- The purpose of these evaluations was to provide assurance that full EPU thermal power operation would pose no threat to continued equipment operation throughout the remainder of the current fuel cycle or to make specific recommendations required prior to allowing full cycle operation

Purpose, Scope, and Methodology (cont.)

Exelon Nuclear

- Component evaluations used data obtained during ramp to 912 MWe adjusted for expected full thermal power impact
  - The expected impact of future increases to full thermal power (2957 MWt) is a further increase in the measured vibration levels
  - Predicted increase calculated by plotting the available data and extrapolating to full thermal power
  - Each component evaluation included an assessment of any potential effects of increased vibration levels as the unit approaches full thermal power
  - Actual vibration levels will be measured when the units stabilize at full power to confirm the assumptions made

Purpose, Scope, and Methodology (cont.)

Exelon Nuclear

- Component/system responses for full EPU thermal power operation were assessed using:
  - Vibration data collected throughout the available range of power operation
    - Vibration data obtained during ramp up to full EPU power level for each of three units (fourth unit was already at full EPU power)
    - Data was extrapolated and utilized in evaluations
  - Industry operating experience
  - Component failure/Preventive Maintenance (PM) history
  - Analytical modeling
  - Wyle lab testing

Results

General Assessment

Exelon. Nuclear

- Evaluations concluded that all components are acceptable for full-cycle operation at full EPU thermal power with the following exceptions:
  - ERV susceptibility to vibration at QC requires upgrades of vulnerable parts
    - DR ERVs determined to be acceptable based on two factors:
      - As-found inspections of Units 2 and 3 actuators
      - Data evaluations which showed lower vibration levels for DR
  - Target Rock S/RVs show vibration wear degradation at both QC and DR
    - Degradation may impact the lift setpoint
    - Evaluation and testing of the current configuration complete
    - Additional testing of a modified configuration is in progress
- The team identified additional recommendations for enhancements in testing, monitoring, and refuel outage inspections
  - An example is confirmatory vibration testing of Limitorque and Namco limit switches – completed successfully

Results

ERV Components

Exelon Nuclear

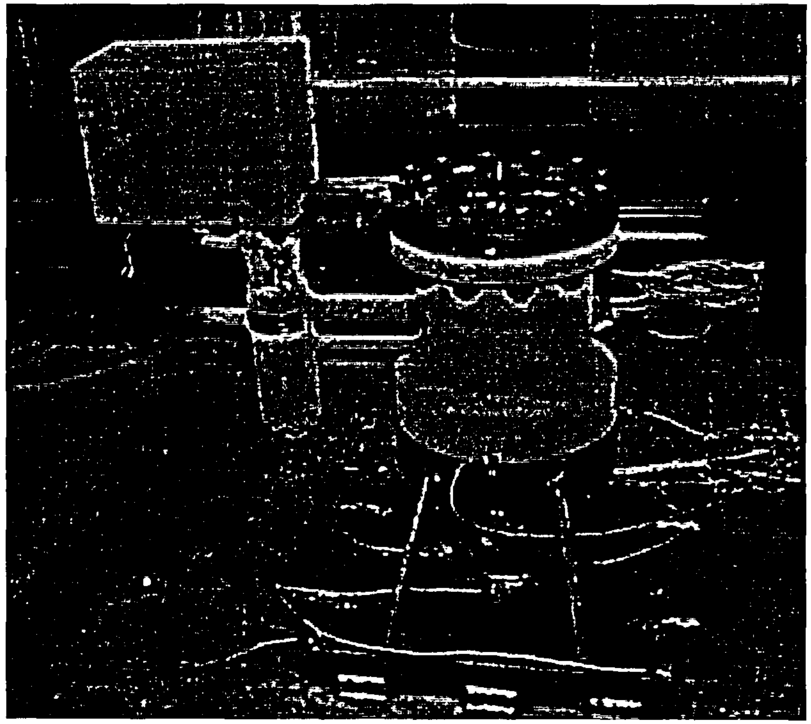
- ERV response for full EPU power operation was evaluated using:
  - Vibration data throughout the range of power operation
  - Component failure history
  - Analytical modeling
  - Vibration testing of original ERV and proposed modification

- These evaluations validated proposed modifications to improve the ERV response to vibrations at full EPU thermal power and provided assurance of ERV operability for a full 24 month fuel cycle
  - Modification consists of replacing internal actuator parts with hardened materials

Results
ERV Components (cont.)

Exelon. Nuclear

- The four ERVs have virtually identical assemblies, which consist of the main ERV valve body, pilot valve, and solenoid actuator
- Detailed finite element models were completed for the ERVs
  - Analytical natural frequencies and mode shapes were compared to frequency content of the measured vibration data
  - Modal test results were also used to validate the model
  - Analysis utilized in determination of root cause of the 3B ERV failure



Results

ERV Components (cont.)

Exelon Nuclear

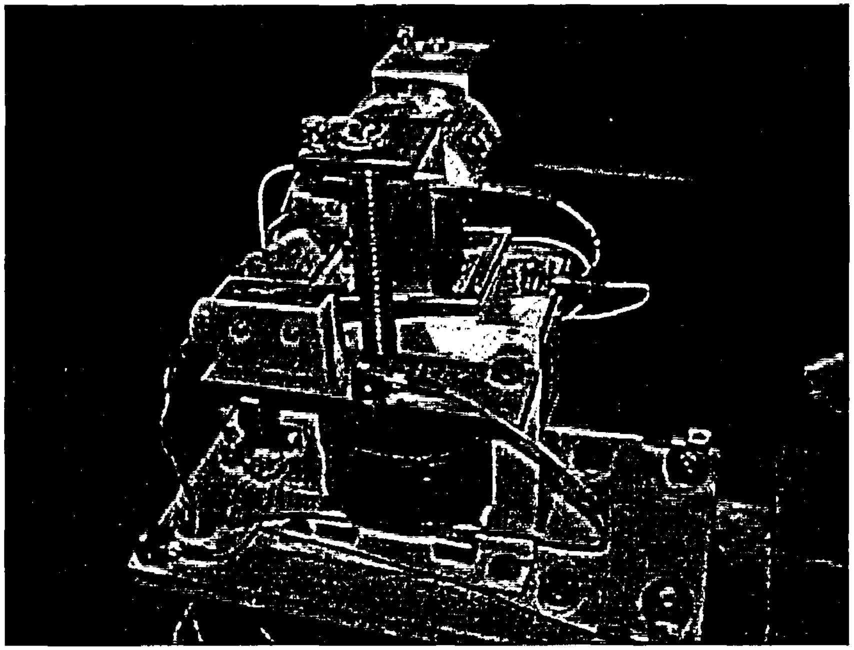
- Testing performed at Wyle labs to determine/confirm failure mode and to test proposed modifications
  - Modal test performed on QC1 as-built configuration to validate and adjust finite element model
  - Over 50 individual tests performed to validate wear mechanism and proposed valve/actuator modifications

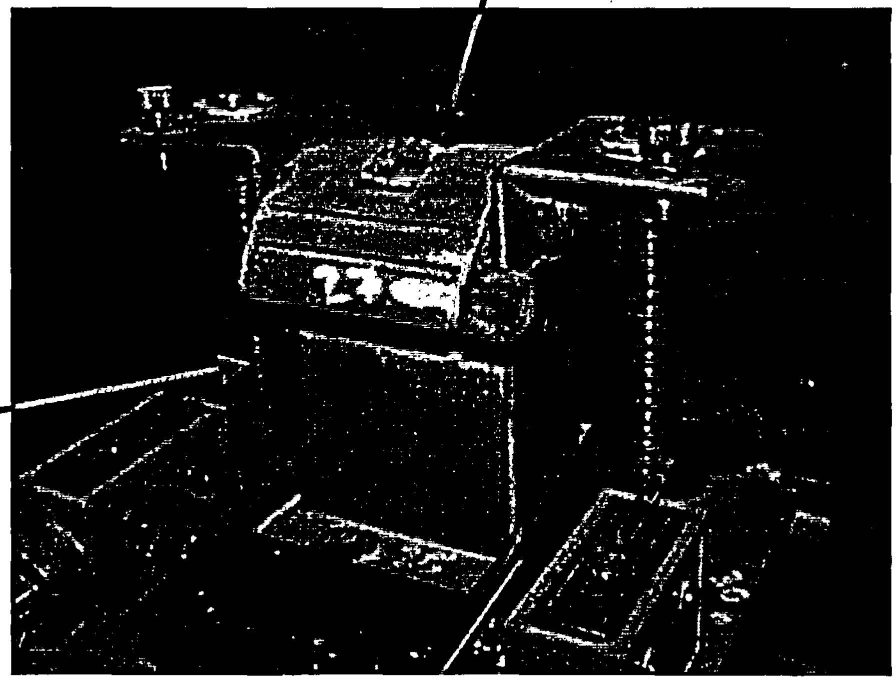
- Wear mechanism is a result of a local structural mode of the solenoid plunger assembly
  - Response due to assembly floating on spring

Results

ERV Components - Actuator Internals

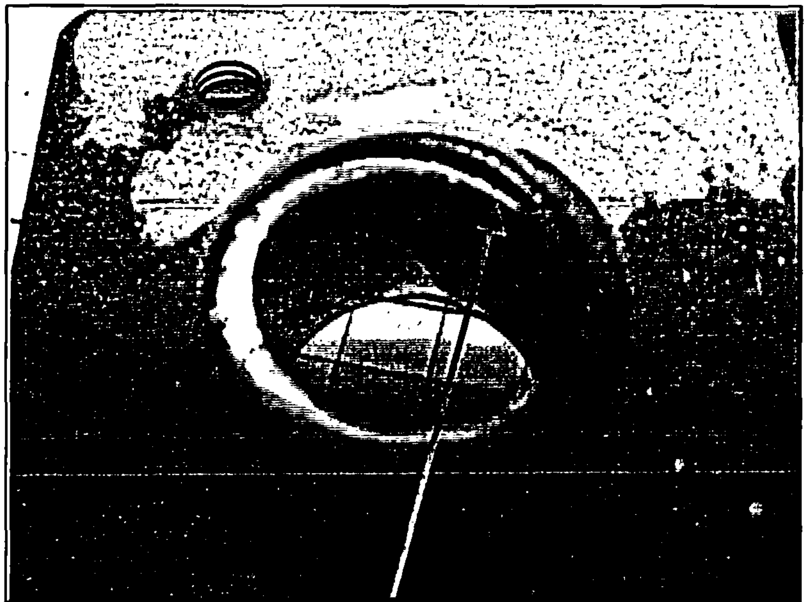
Exelon Nuclear



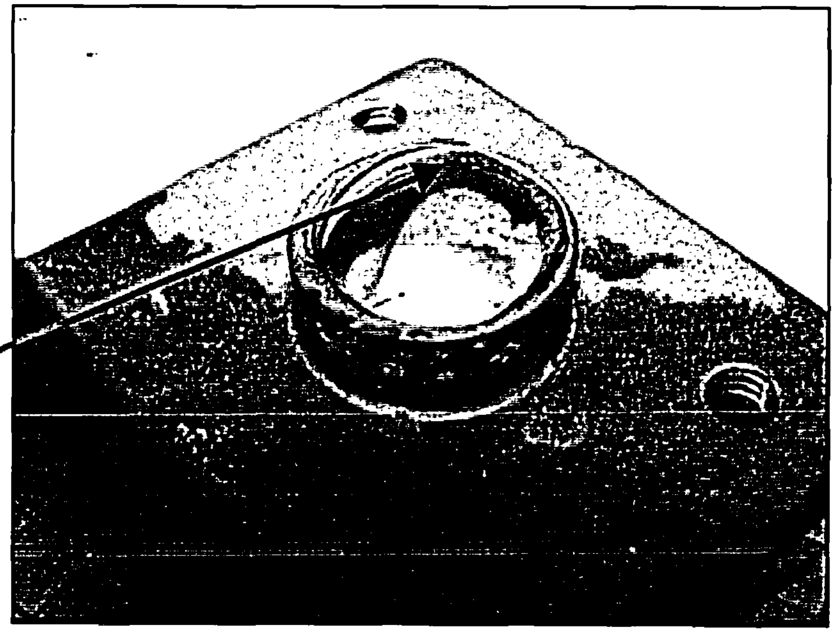


Results
ERV Components - Worn Bushings

Exelon
Nuclear



Brass bushing



Groove worn by spring point

Results

ERV Components - Acceptability

Exelon. Nuclear

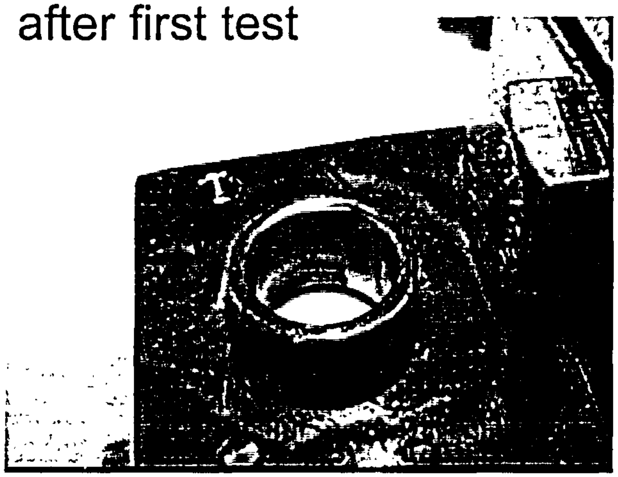
- Mitigation strategies were limited by desire to minimize internal actuator design effects
  - Vulnerable components within the actuator assembly are being modified
    - Material changes implemented for parts which have historically exhibited unacceptable wear
    - Inconel X750 bushings and guide rods being installed
    - Springs are being chamfered to remove hard edges which cause damage
- Endurance testing designed to provide assurance of full cycle operation without unacceptable wear of the affected components
  - Final configuration changes tested for equivalency to 12 months of operation
    - Testing included prolonged aging tests of approximately 8 hours at low frequency (20-70 Hz) and 10 hours at high frequency (70-200 Hz)
    - No measurable wear was observed, therefore it was concluded that a full 24-month cycle of EPU thermal power operation was assured

Results

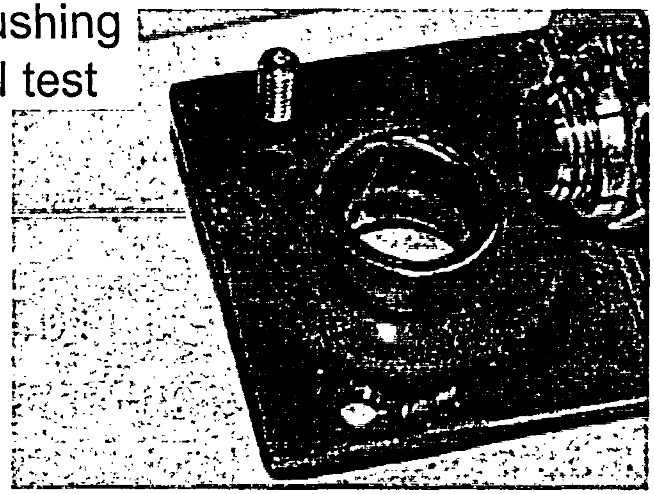
ERV Components - New Bushings/Guide Rods

Exelon Nuclear

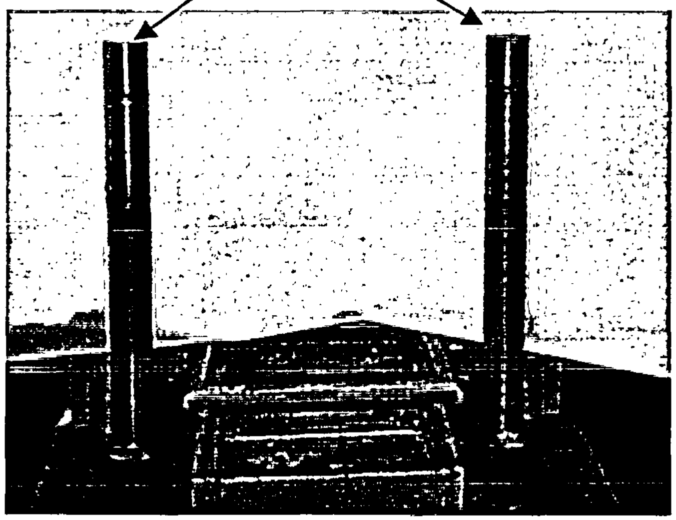
Inconel bushing after first test



Inconel bushing after final test



Inconel guides



Results

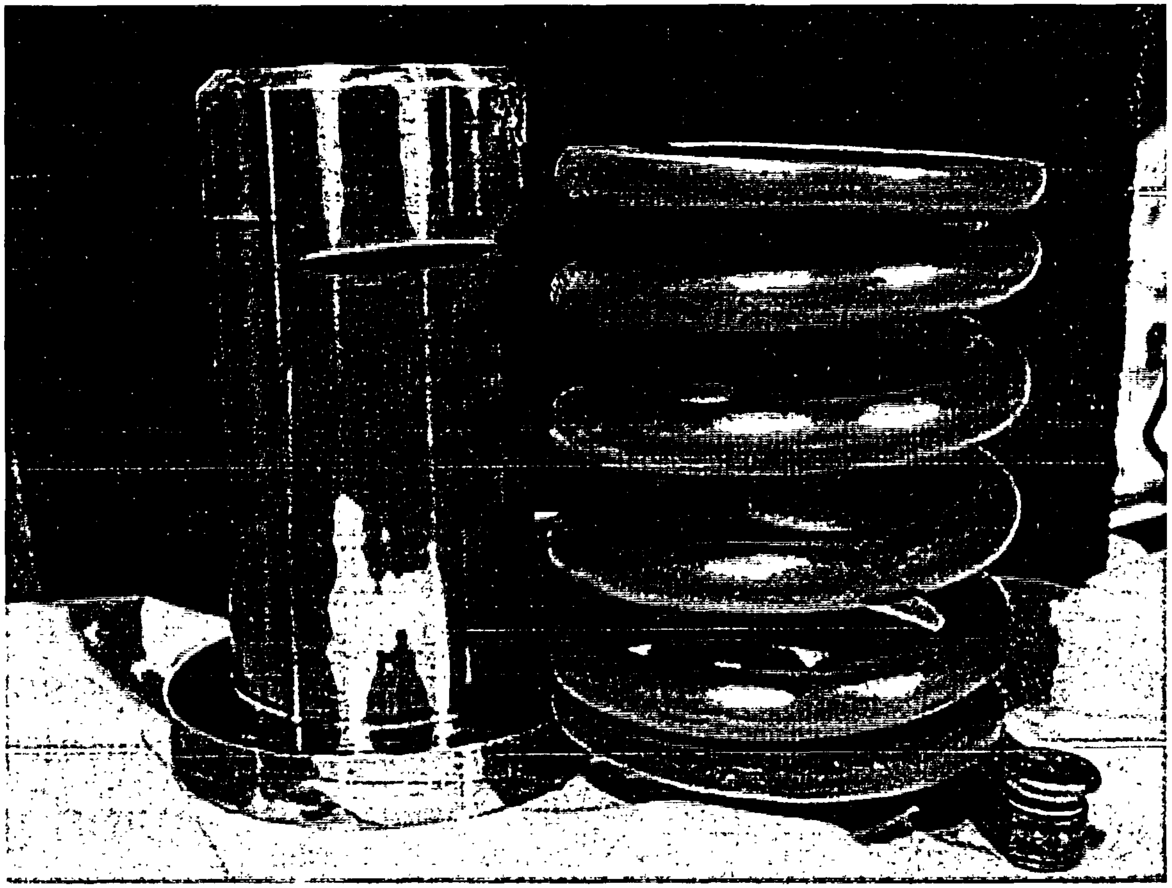
Target Rock S/RV

Exelon Nuclear

- As-found testing on QC Target Rock S/RV resulted in +6.8% lift point
  - Disassembly and inspection determined that wear of the bellows cap caused spring resistance to increase
    - Additional force required = approximately 70 pounds
    - Groove worn in bellows cap caused spring to bind
- Two DR valves tested at –3.6% and –1.4%, one with EPU operating history, one without
- Shaker table testing has been performed to confirm wear phenomena driver
  - Testing produced similar wear to the as-found condition
  - Preliminary conclusion is that the wear is a function of the spring and cap combination and the materials installed
    - Enhanced tolerances and materials on first stage pilot spring and cap combination being evaluated and tested

Target Rock Pilot
Bellows Cap and Spring

Exelon Nuclear



In-service bellows cap and spring

Results

Other Testing

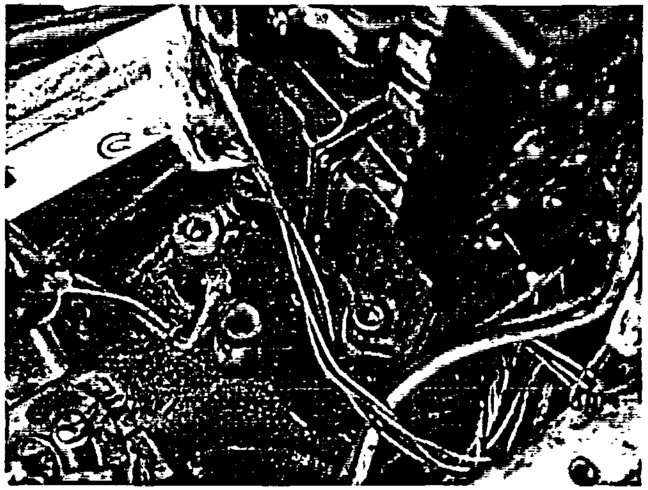
Exelon Nuclear

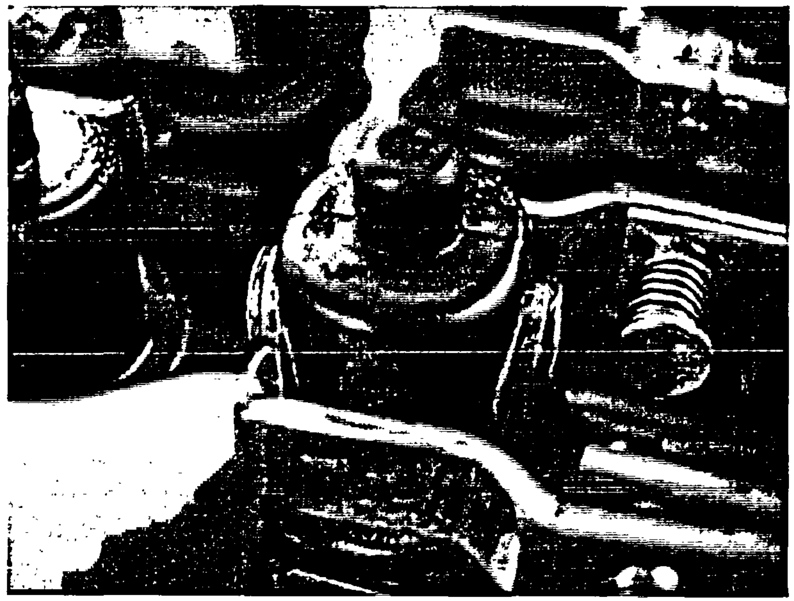
- Namco limit switches tested with plant level data for vibration endurance
  - Results showed acceptable performance
  - Matched previous analytical results

- Limitorque limit switch vibration endurance testing with plant level data
  - Results showed minimal wear for simulated one cycle operation that resulted in no impact to valve function

Results
Other Testing - Limitorque Limit Switch

Exelon. Nuclear





Planned Actions

Exelon Nuclear

- Validate PM scope and frequency for all evaluated components
  - ERV PM changes already implemented
- Replace ERV actuator parts for both DR and QC during future rebuilds
- Inspect ERV actuator internals each cycle until performance is validated
- Perform focused walkdowns during each refuel outage
- Inspect minimum of one MSIV internally each cycle until satisfactory performance is demonstrated

Independent Reviews

Exelon. Nuclear

- Each individual component evaluation was subjected to an independent review
  - The purpose was to ensure that the analytical methods, assumptions, judgment, and conclusions were reasonable
  - Reviews were performed by MPR Associates and Stevenson and Associates personnel
- Conclusions were that the assessments, combined with the planned testing, would provide the desired assurance that evaluated components are capable of performing satisfactorily for a full cycle of EPU full thermal power operation

Summary

Exelon. Nuclear

- The vibration evaluations performed provide assurance that potentially effected components will perform acceptably for at least a full 24 month cycle at EPU full thermal power operation
  - All evaluations and testing are completed except for the Target Rock S/RV
  - Implementation of actions is either planned or complete to support return of the QC units to full EPU power operation
  - DR evaluations support continued full EPU power operation

Exelon.[SM]
Nuclear

EPU Vulnerability Review

Mohammad Molaei
Dresden Engineering Programs Manager

Topics

Exelon Nuclear

- Mission and Goals
- Process Used
- Systems Reviewed
- Summary Statistics
- Potential Vulnerabilities and Actions
- Outage Scope
- Conclusions
- Summary

Mission and Goals

Exelon Nuclear

- Mission – identify potential EPU-related vulnerabilities for DR and QC, and actions to prevent failures induced by these vulnerabilities
- Goals – reduce/eliminate operational challenges, as measured by:
  - Licensee Event Reports
  - Engineered safety features actuations
  - Reactor scrams
  - Plant power derates
  - Unplanned entries into Technical Specifications
  - Operator work-around challenges (increases risk of one of the above events)
  - Unexpected accelerated degradations (that increases risk of one of the above events)
  - Significant loose/lost parts

Process Used
Power and Safety Systems

Exelon. Nuclear

- Power Systems
  - Phase I - Data Collection
  - Phase II - System Level and Component Evaluation
  - Phase III - Vulnerability Assessments and Recommendations
- Safety Systems
  - Event input verification
  - Task report output implementation validation
  - Effect of power operation at EPU condition on safety components
- Both power systems and safety systems were selected based on EPU impact
- Safety systems reviews were scenario-based
- A total of 42 power systems and 10 safety systems were reviewed

Process Used
Technical Rigor

Exelon Nuclear

- Utilized multiple industry organizations
- For the purpose of this review, every component in the plant was assumed to be susceptible to failure, unless proven otherwise
- Evaluated changes in operating parameters-EPU for 4 units
  - Flow rate, temperature, pressure, radiation level, vibration level, and wear rate
- Utilized process of elimination at system and component levels
- Identified potential vulnerabilities due to the changed parameters
- Developed actions to address the potential vulnerabilities
- Results were challenged in multiple stages, by various teams

Systems Reviewed
Power Systems

Exelon Nuclear

- Reactor Recirculation and Vessel Internals
- Main Steam
- Off Gas
- Feedwater
- Feedwater Level Control
- Condensate
- Condensate Booster
- Condensate Demineralizer
- Main Generator
- Generator Hydrogen Cooler
- Stator Cooling
- Isolated Phase Bus Duct
- Instrument Air
- Reactor Building Closed Cooling Water
- Turbine Building Closed Cooling Water
- Spent Fuel Pool Cooling
- Shutdown Cooling/Residual Heat Removal
- Radwaste
- Circulating Water
- Reactor Building Equipment Drain
- Turbine Building Equipment Drain
- Hydrogen Addition
- Zinc Injection
- Service Water
- Reactor Water Clean Up
- Nuclear Instrumentation
- Control Rod Drive
- Reactor Building Ventilation
- Turbine Building Ventilation
- Control Room HVAC
- Extraction Steam
- Heater Drain
- Misc. Heater Vents and Drains
- Turbine Oil
- Main Turbine
- EHC
- Main Condenser
- On-Site Power
- Off-Site Power
- Process Radiation Monitoring
- DC Power
- Main Generator Exciter

Systems Reviewed

Safety Systems

Exelon Nuclear

- Automatic Depressurization System (ADS)
- Containment
- Core Spray (CS)
- Emergency Diesel Generator (EDG)
- High Pressure Coolant Injection (HPCI)
- Isolation Condenser (IC)
- Low Pressure Coolant Injection (LPCI)/Residual Heat Removal (RHR)
- Reactor Core Isolation Cooling (RCIC)
- Standby Gas Treatment
- Standby Liquid Control

Summary Statistics

Exelon. Nuclear

- 101 total actions
  - 60 outage physical work activities
  - 9 non-outage physical work activities
  - 32 analysis/study/PM reviews
- Applicability
  - 27 Exelon-specific actions
  - 74 potential General Electric (GE) fleet lessons learned
- Action categories
  - 43 inspections
  - 42 PM reviews
  - 17 modifications
  - 9 studies
  - 28 analyses

Potential Vulnerabilities and Actions

Exelon Nuclear

1. Increased FW flow has increased the fatigue loading on some vessel internals, which may require more frequent inspections of susceptible components
   - Perform a one-time visual inspection of the shroud head bolt locking pin window for evidence of wear
   - Perform a one-time visual inspection of a sample of separator stand pipe weld to the shroud head
   - Perform a one-time visual inspection of the feedwater sparger end bracket pin

Potential Vulnerabilities and Actions (cont.)

Exelon Nuclear

2. Increased core differential pressure (d/p) has changed jet pump flows and consequently the loading on jet pump support components; these components will require accelerated inspections
   - Establish the value of the appropriate parameter at which slip joint bypass leakage initiates jet pump vibration
   - Accelerate the Boiling Water Reactor Vessel Internals Project (BWRVIP)-41 required inspection of the restrainer gate wedges for evidence of wear

Potential Vulnerabilities and Actions (cont.)

Exelon Nuclear

3. Changed operating conditions has increased wear, which will require implementation of enhanced PMs
   - Accelerate generator PM due to increased heat and stress
   - Increase Recirculation pump/drive motor/motor generator set PMs due to increased duty and speed; alternate option is to review business case for adjustable speed drives
   - Enhance valve internals and actuator PMs in the affected systems due to increased temperature and modified vibration amplitudes/ frequencies
   - Replace one MS high flow switch in each MS line, inspect for signs of degradation and adjust PM accordingly
   - Inspect Offgas condenser division plate bypass valve
   - Perform eddy current testing of a sample of unstaked tubes at edge staked region of the main condenser

Potential Vulnerabilities and Actions (cont.)

Exelon Nuclear

4. Increased flow (Feedwater (FW), MS, Stator Cooling) and Recirculation pump speed results in increased vibration on the system piping and components
   - Perform a one-time inspection of the internals of Stator Cooling temperature controller
   - Install flex hoses on all cooling lines to the condensate and condensate booster pump bearing and the reactor feed pump seals
   - Obtain vibration data and perform a one-time inspection of electrical connections/mechanical linkages subject to turbine control vibrations
   - Perform one-time vibration measurements at various designated power levels on susceptible small bore FW piping
   - After Recirculation pump speeds are increased to levels not previously attained, inspect the Recirculation loop flow sensing lines and other small-bore piping in the drywell

Potential Vulnerabilities and Actions (cont.)

Exelon. Nuclear

5. Elimination of the standby FW and condensate pumps and operation of these pumps at non-optimum flow conditions has introduced gradual component degradation
   - Perform a one-time boroscope examination of all 4 condensate pump impellers during the next outage
   - Install proxy probe or ultrasonic flow measuring device to attain enhanced performance monitoring for condensate and booster pumps
   - Assess the feasibility of operating at full EPU power with two reactor feed pumps and three condensate/condensate booster pumps combination
   - For current operating configuration, perform analysis and validation testing to identify optimum operating conditions to start and stop condensate/condensate booster and feedwater pumps
   - Increase the PM frequency for reactor feed pump seal replacement from the current 4 years to 2 years

Potential Vulnerabilities and Actions (cont.)

Exelon Nuclear

6. Effect of increased FW and condensate flow on balance-of-plant valves and internal components must be assessed
   - Perform sizing calculation for the condensate/condensate booster min flow valve to verify margin at the new design pressure and temperature
   - Perform sizing calculation for the high pressure (HP) and low pressure (LP) heater inlet, outlet and bypass motor-operated valves to verify margin at the new design pressure and temperatures
   - Evaluate the temperature element thermowells in the condensate, condensate booster, and FW systems to assess potential concern with erosion and vortex shedding failure vulnerability; also assess the hydrogen and oxygen injection quills
   - Redesign and install the condensate, condensate booster, and FW system sample probes

Potential Vulnerabilities and Actions (cont.)

Exelon Nuclear

7. Increased FW flow has increased the effects of flow accelerated corrosion (FAC)
   - Determine the cause of the higher than expected condensate influent iron concentration in DR3; inspect LP heater casing for effects of corrosion
   - Measure pipe wall thickness at susceptible locations such as orifices and pressure control valves to validate the EPU assumptions in the FAC program
   - Evaluate the outage template for control rod vacuuming and increase frequency if there is evidence of increased iron concentration
   - During scheduled hydraulic control unit overhauls, inspect the inlet and outlet filters to determine if they are experiencing increased plugging
   - Institute programmatic FW heater and flash tank non-destructive examination (NDE) inspections on a three-cycle frequency

Potential Vulnerabilities and Actions (cont.)

Exelon Nuclear

8. Known system deficiencies were not corrected prior to EPU implementation resulting in more pronounced operational challenges
   - Restore original design margin and eliminate abnormal operating condition for the heater drain system
   - Perform main condenser tube cleaning and waterbox de-sludging if monitoring parameters indicate the presence of scale or debris
   - Resolve the overpressure condition on LP heaters and the drain coolers, consistent with system design and relief valve setpoint conditions
   - Develop analytical model for FW Level Control System to better predict post-transient reactor vessel water levels, considering various pump combinations and power levels

Potential Vulnerabilities and Actions (cont.)

Exelon Nuclear

9. Post-EPU operating and analytical margins have been reduced
   - Re-evaluate the reactor heat balance and Thermal Kit using plant-specific parameters and confirm consistency between reactor and turbine heat balances
   - Identify systems or analyses with limited margin post-EPU and evaluate/implement actions to increase margin as appropriate
   - Monitor cross-around relief valves for leakage after any pressure transient within the turbine boundary
   - Re-evaluate task report recommendation to operate with full Offgas condenser condensate flow (procedure change)

Outage Scope

Exelon Nuclear

- Inspection
  - In-vessel visual inspections
  - Boroscopic inspections
  - Internal valve inspections
  - Walk-downs
  - NDE inspections
  - Eddy current testing
  - Temperature controller and relay inspections
  - MSL flow d/p switch replacement/analysis
- Modifications:
  - Sample probes
  - Flex hoses
  - 2x1 welds
  - Orifice resizing
  - Data recorders

Conclusions

Safety Systems

Exelon Nuclear

- Functions of safety systems remain uncompromised
- Design inputs used in analyses are conservative due to the 5th unit model; however, the 5th unit model results in artificially low calculated margin in some cases
- Analyses results have been adequately implemented with the exception of changing RHR motor lube oil at QC
- Some documentation deficiencies were discovered during the review that are being resolved through the corrective action program
- Identify systems or analyses with limited margin post-EPU and evaluate/implement actions to increase margin as appropriate

Conclusions
Power Systems

Exelon. Nuclear

- Found no vulnerabilities that could result in an immediate challenge to plant operation
- 101 actions were identified to improve operating margin and prevent future failures
- Most of the actions address accelerated equipment aging or wear due to EPU

Summary

Exelon Nuclear

- Rigorous and comprehensive review was conducted
- Extensive corrective actions were developed during the review
- While vulnerability to vibration-induced failure remains our focus, review did not find any challenge to plant operation due to EPU
- Vulnerability review relied on EPU assessment, previously addressed, for evaluation of vibration effects on MS piping and components

Summary (cont.)

Exelon Nuclear

- Considerable knowledge was gained during the review on impact of EPU operation and was shared with the industry
- Safety system review, while focused, confirmed the adequacy of the original licensing analysis for EPU
- Extent of Condition Review concluded that safe and reliable EPU operation is achievable for all DR and QC

Exelon Nuclear

Status of Steam Dryer Load Analysis, Design, Fabrication, and Instrumentation

Keith Moser
Asset Management Engineer

Existing Dryers

Exelon Nuclear

- QC2 EPU data collection - August 11, 2004
  - Achieved slightly over 11.2 Mlbs/Hr FW flow
  - Acoustic circuit analysis continues to support operability conclusion for DR2 and DR3
- DR3 fall 2004 refueling outage
  - Detailed inspection plan of the dryer exceeds GE Service Information Letter (SIL)-644, Revision 1 recommendations
  - Performing dryer repair modification, similar to QC2 spring 2004 refueling outage modification to improve margin

New Dryers

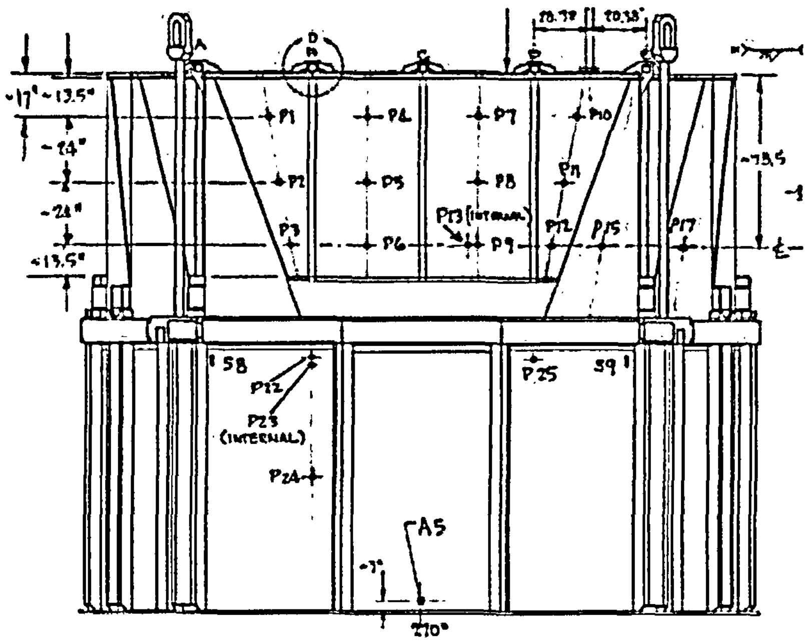
Exelon
Nuclear

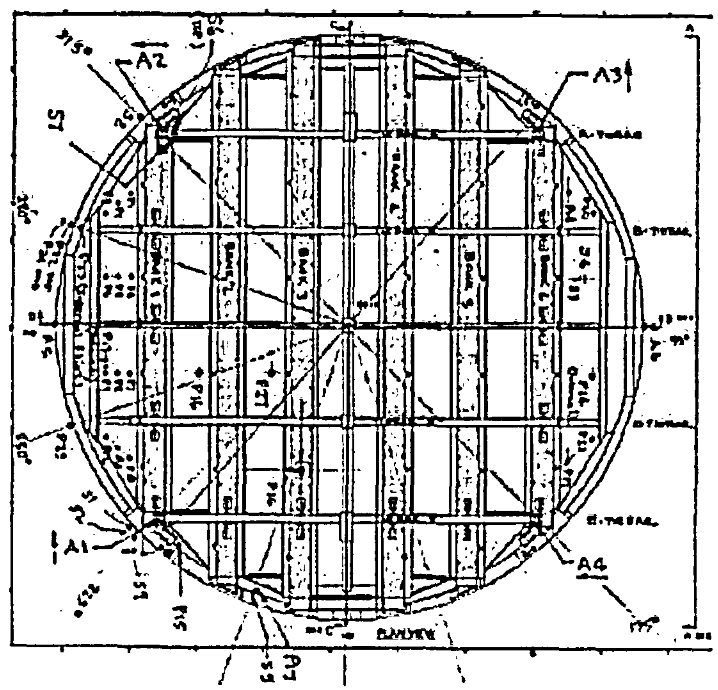
- QC1 dryer design
  - Design review scheduled for mid-October 2004
  - Structural adequacy assessments based on modeled dryer
    - Scale model testing (SMT) of the new dryer
      - Finite element modeling of SMT results
    - Acoustic circuit analysis
      - Benchmark against GE SMT
      - Apply highest QC FW flows to new dryer design
      - Finite element modeling of acoustic circuit results
  - Dryer structural fabrication to start November 2004

New Dryers (cont.)

Exelon Nuclear

- QC1 dryer instrumentation
  - 6 accelerometers
  - 27 pressure sensors
  - 9 strain gauges
  - All four MSLs will have strain gauges





Exelon Nuclear

Closing Remarks

James Meister

Vice President, Nuclear Services

Closing Remarks

Exelon Nuclear

- Exelon is sensitive to EPU related challenges
- Exelon is working closely with GE to understand and manage appropriately the effects of EPU at DR and QC
- Exelon is sharing lessons learned with Institute of Nuclear Power Operators, BWR Owner's Group, and other utilities
- Exelon has performed testing and monitoring to characterize the effects of EPU at DR and QC
- Exelon is taking actions to reduce EPU impacts at DR and QC to acceptable levels
- Exelon remains confident that EPU can be implemented safely and reliably for the long run at DR and QC