

Generator Rotor and Steam Dryer Meeting

Dresden Nuclear Power Station
December 2, 2004

Opening Remarks

Danny Bost
Site Vice President
Dresden Nuclear Power Station

Purpose

- Discuss cause of generator rotor cracking, corrective actions, and monitoring plans
- Discuss steam dryer inspections, modifications, and causal factor analysis
- Outline the basis for extended power uprate (EPU) operation
- Describe ongoing actions and proposed NRC interactions

Agenda

- Opening Remarks
- Generator Rotor
- Steam Dryer
 - Background Information
 - Inspection Results
 - Quad Cities/Dresden Comparison
 - Causal Factor Analysis
 - Ongoing Actions
 - Planned Interactions
 - Bases for EPU Operation
- Closing Remarks

Danny Bost

Mark Kanavos

Jim Meister

Danny Bost

Generator Rotors

- We understand the causes for generator rotor cracking
- We have repaired the Dresden Unit 3 (D3) generator rotor and are completing repairs for Dresden Unit 2 (D2)
- We have developed a monitoring plan

Steam Dryers

- Recent inspections and analytical results confirm lower dryer loads at Dresden compared to Quad Cities (QC)
- Cover plate cracking on D3 dryer occurred in an area previously identified as a high stress location in analytical models, and was subject to cold spring
- Cover plate cracking for both units initiated at sites with evidence of lack of fusion (root cause ongoing) – corrective actions preclude future deficiencies

Steam Dryers (cont.)

- Structural improvements through the design modifications provide additional confidence for both Dresden units
- Substantial evaluation efforts continue – modeling capabilities continue to improve
- Both units can safely return to full power operations
- Propose ongoing meetings with NRC to discuss progress and results
 - Fall 2005 meeting following the D2 outage will include discussion of impact on D3, including a potential mid-cycle inspection

Generator Rotor

Mark Kanavos
Site Engineering Director
Dresden Nuclear Power Station

Generator Rotor

Purpose

- Discuss rotor issue timeline and inspection findings
- Discuss root and contributing causes
 - Oscillating torsional loads (cause)
 - Fretting due to keyway design (contributing cause)
- Summarize corrective actions for Dresden
- Describe monitoring to determine source of oscillating loads

Generator Rotor

Issue Timeline

- May 2004 – D2 bearing vibrations begin adverse trend
- June 2004 – Vibration monitoring equipment connected to D2
- July 2004 – D3 vibration recognized as increasing since May
- August 2004
 - X-Y proximity probes installed on D2 and D3
 - Flux probe and soft foot tests performed on D2
 - D2 shutdown to repair cracked foot support rail
- September 2004
 - Thermal sensitivity test performed on D3
 - Flux probe test performed on D3
 - D2 and D3 foundation surveys conducted
 - Vibration monitoring equipment connected to D3
 - D2 shutdown to correct soft feet and align machine
- October 2004
 - D3 shutdown for Fall 2004 refueling outage – 13” crack found at “D” coupling
 - D2 subsequently shutdown and a similar 10” crack was found

Generator Rotor

2004 Rotor Inspection Findings

- Fretting at initiation site weakened area in coupling
- Original coupling design produced stress risers
- 45° angle of crack indicates torsional loads as the cause of crack growth
 - Metallurgical evaluation indicates that crack growth started and stopped ~200+ times
 - 6 months of increasing vibration suggests intermittent torsional loading
- Conclusion – crack propagation was caused by intermittent oscillating torsional loads above the material fatigue endurance limit
 - Results to be shared with fleet and industry

Generator Rotor

Intermittent Oscillating Torsional Loads

- D2 and D3 cracks show >200 beach marks
 - Each beach mark indicates an occurrence that the fatigue limit was exceeded by torsional loads
- If the oscillating torsional loads were applied constantly, then the shaft would have failed in less than 2 days
- Potential causes include: switchyard events, breaker reclosures, line faults, and cycling of large loads

Generator Rotor

EPU Impacts

- EPU did not cause the rotor cracking
 - 10% torque increase from EPU
 - Pre- vs. post-EPU torque capability of coupling shrink fit was acceptable
 - Torque would not cause fretting by itself
 - Steady state loads did not drive the crack
 - Shaft would fail in <2 days if steady state loading were the cause

Generator Rotor

2004 Rotor Repairs

- Removed cracked end of the rotor shaft and welded in new stub-shaft
- Re-designed rotor shaft keyway to eliminate the stress risers
- Increased shaft torsional capacity with improved coupling shrink fit

Generator Rotor

Going Forward Monitoring Plans



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- Transient Torsional Vibration Monitoring System (TTVMS) was installed on both units
 - Monitors each phase of generator current and voltage
 - Monitors turbine speed at the front standard and “D” coupling
 - If a torsional event occurs, TTVMS will record data
 - Event data will be used to calculate individual and cumulative shaft life usage for each event for comparison to acceptance criteria
- High speed monitoring equipment will be installed in the switchyard to monitor generator output buses for feedback from the transmission system
 - Work with transmission system operator to identify source(s) of events
 - Eliminate source(s) of loading or modify plant to correct the imbalance
- Monitoring will allow Exelon to be proactive in addressing vibrations before cracking develops
 - Technology has been successfully used elsewhere

Generator Rotor

Summary

- Troubleshooting actions were thorough
 - Cracked rotor was identified as a possible cause of vibration
- Root cause analysis is comprehensive
- Shaft and keyway design have been improved
- Cracks were caused by oscillating torsional loads above the fatigue endurance limit of the material
- Torsional and switchyard monitoring equipment is being installed to identify the source of the intermittent loads

Steam Dryer

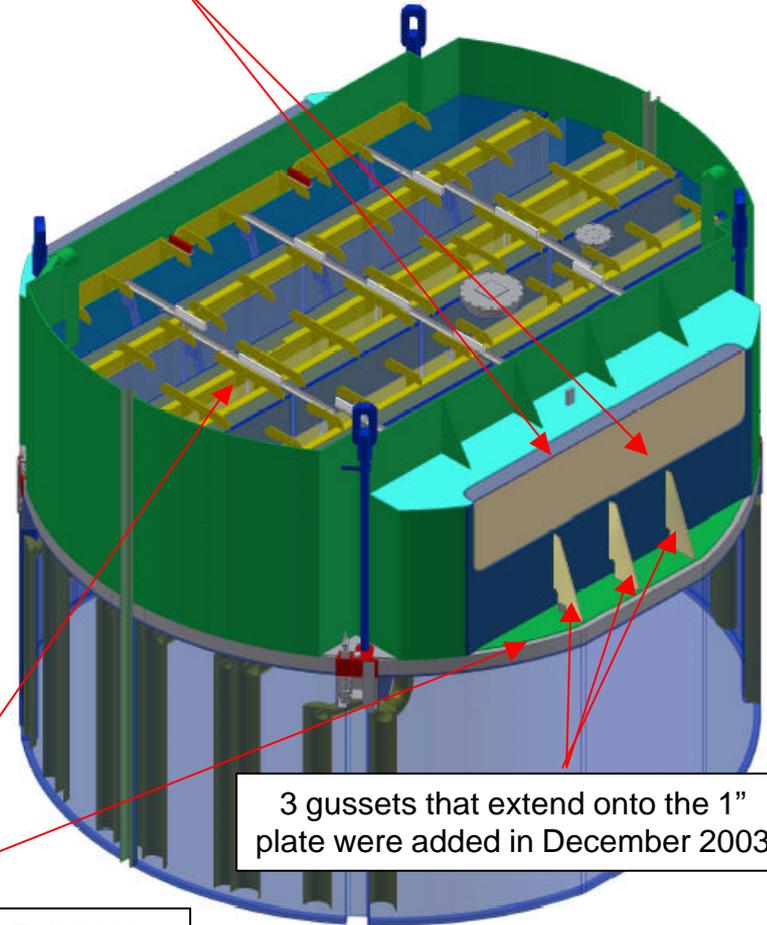
Jim Meister
Vice President
Nuclear Services

Background Information

D3 Timeline

- Began EPU operation on November 4, 2002
 - During the Fall 2002 refueling outage, perforated plates were added to reduce moisture carryover
 - Added 1/2" cover plate
 - Steam dryer externals were inspected
- December 2003 steam dryer modification
 - Added 1" partial height front hood face plate
 - Added 3 gussets on both 90° and 270° sides that extended onto the 1" plate
 - Interior and exterior examinations performed in accordance with General Electric (GE) Service Information Letter (SIL) 644

1" inserts added December 2003



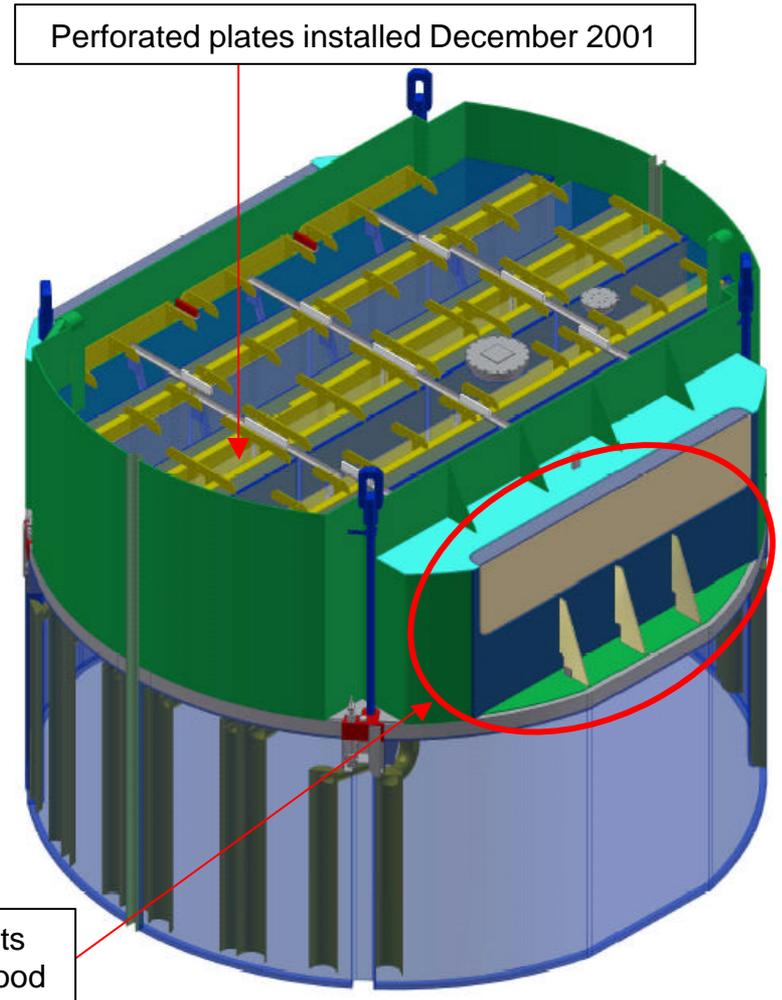
3 gussets that extend onto the 1" plate were added in December 2003

Insert/cover plate size increased to 1/2" in Fall 2002

Background Information

D2 Timeline

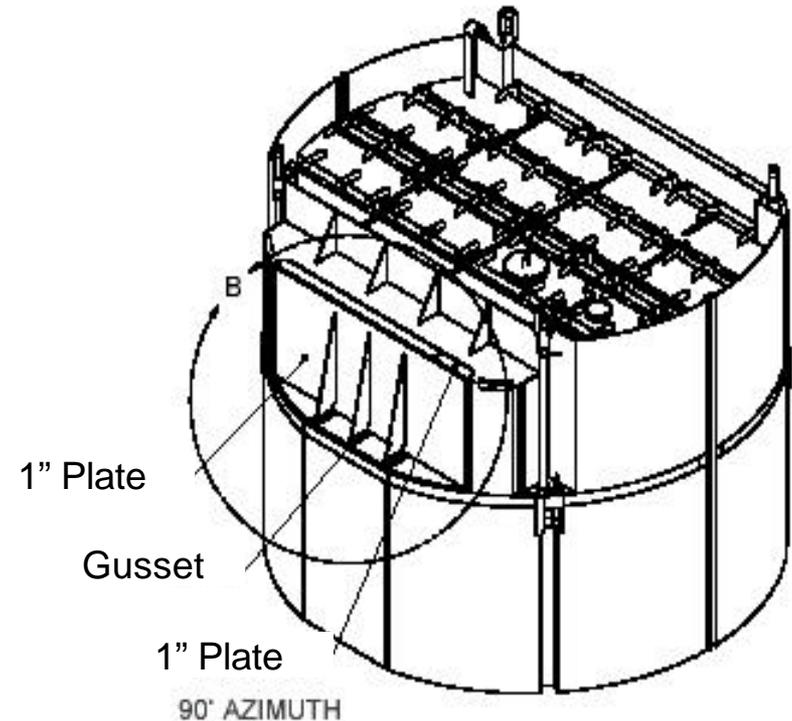
- Began EPU operation on December 26, 2001
 - During the Fall 2001 refueling outage, perforated plates were added to reduce moisture carryover
- Fall 2003 refueling outage (post 690 days continuous run at EPU power)
 - Added 1/2" cover plate
 - Added 1" partial height front hood face plate
 - Added 3 gussets on both 90° and 270° sides that did not extend to the 1" plate
 - Interior and exterior examinations performed in accordance with GE SIL 644



Background Information

Preplanned Modifications

- Replace front vertical plate and corresponding section of horizontal plate with 1" plate on both outer hoods
 - Retain section on each end for attachment weld
 - Vertical welds are ½" groove welds
 - Top and bottom horizontal welds are ½" fillet welds
- Install ½" thick gusset to ~6" from top of vertical plate
 - Taper to 1" at tip
 - Groove welded to vertical plate in shop
 - Weld continues around tip
 - Round extension piece to connect gusset to lower cover plate
- Increase the cover plate to ring weld (R2) to ½"
- Dryer stresses reduced by approximately 2.5 times through modifications



Background Information

Dryer Analytical Methods



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- Analytical teams consist of experts in numerous technical fields from a variety of sources
- Scale model test
 - Load set for finite element analysis (FEA) of dryer modification
 - Identify acoustic source(s) of dryer loads
- Acoustic circuit analysis
 - Used scale model test to validate acoustic circuit analysis
 - Demonstrated correlation of acoustic circuit analysis to scale model test
 - QC2 pre-EPU and post-EPU load definition provided for FEA
 - Developed scaling of loads between units

Background Information

Dryer Analytical Methods (cont.)

- FEA (time history from QC2 plant data)
 - Original design pre-EPU – high stress locations identified – below material endurance
 - 2003 dryer modification – high stress locations identified – above material endurance
- Empirically established load limits
 - Identified locations where cracking has occurred at D/QC units
 - Evaluated stresses at these locations based on shell element model with computational fluid dynamics loadings
 - Established design limit based on stresses at locations that have not experienced cracking
 - Used methodology to evaluate modification design

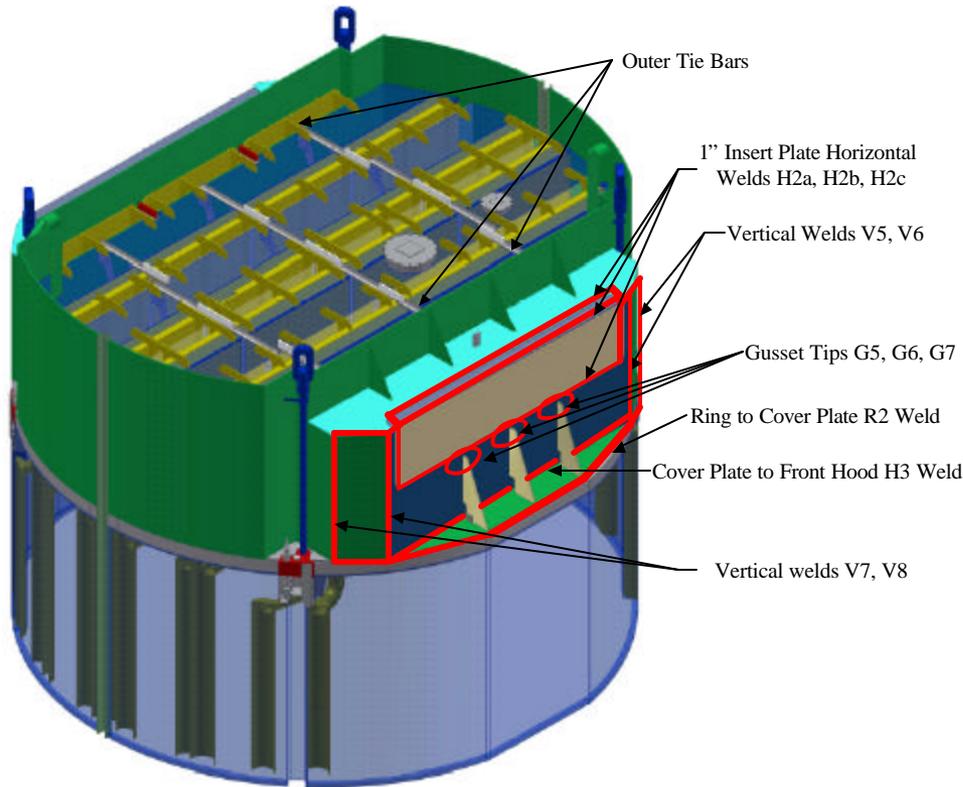
Inspection Results

2004 D3 Inspection Scope/Results

- Best effort VT-1 and VT-3
 - Approximately 1100 dryer inspection points
 - Satisfies recommendations described in GE SIL 644, Revision 1
 - Includes areas of dryer previously inspected on QC2
- 16 total indication notification reports (INRs) identified
 - 12 were dispositioned as acceptable for additional service or stop-drilled
 - No measurable crack growth from previously identified indications
 - Two required minor repair
 - Remaining two INRs were not previously seen in the industry
 - Missing startup instrumentation pipe – subsequently retrieved from moisture separator
 - Cover plate to dryer support ring crack
 - No concerns for structural integrity or loose parts within reactor vessel

Inspection Results

2004 D2 Inspection Scope/Results



- Based on D3 inspection results, an inspection of D2 was performed
- Inspected areas where loose parts could be generated or the structural integrity of the dryer could be threatened
 - All high stress welds identified in GE SIL 644, Revision 1
 - Welds in areas modified in 2003
 - Outer tie bars
 - Startup instrumentation piping
 - Interior inspections of the illustrated welds
- One INR identified – cover plate to dryer support ring crack

Quad Cities/Dresden Comparison

Unit Inspection Comparison



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- Severity and magnitude of cracking identified on the Dresden steam dryers has been considerably less significant than that previously identified at QC
- Number of observed indications has increased over time due to the expansion of areas examined on the steam dryers and improved inspection techniques
- Inspection results demonstrate the efficacy of previous repairs
 - Previously identified indications have shown no measurable crack growth
- Inspections and analytical work continue to support our conclusion that Dresden is different from QC in both the loading and its effect on the dryers

Causal Factor Analysis

D3 Flaw Evaluation

- Boat samples from four symmetrical locations were taken and analyzed
 - Only one of four locations was cracked
 - Other locations did not show any weld abnormalities
- Fillet welds were undersized at all four locations
- Cracking occurred in a location confirmed to be in a high stress region by the FEA
 - Fatigue cracking occurred only at this one location and was not seen in the other boat samples
- Root cause and contributing factors
 - Margin for load uncertainty was not adequate
 - Fillet weld was undersized with a small lack of fusion defect
 - Higher than nominal residual stresses (i.e., cold spring) reduced fatigue life

Causal Factor Analysis

D2 Preliminary Flaw Evaluation

- One boat sample was taken and analyzed
 - Crack propagated into cover plate base metal near gusset
 - Crack in cover plate removed during boat sample removal
- Fillet weld leg lengths were adequate
- Fatigue cracking occurred at only this one location
- Preliminary root cause
 - Lack of fusion defect at the crack initiation site

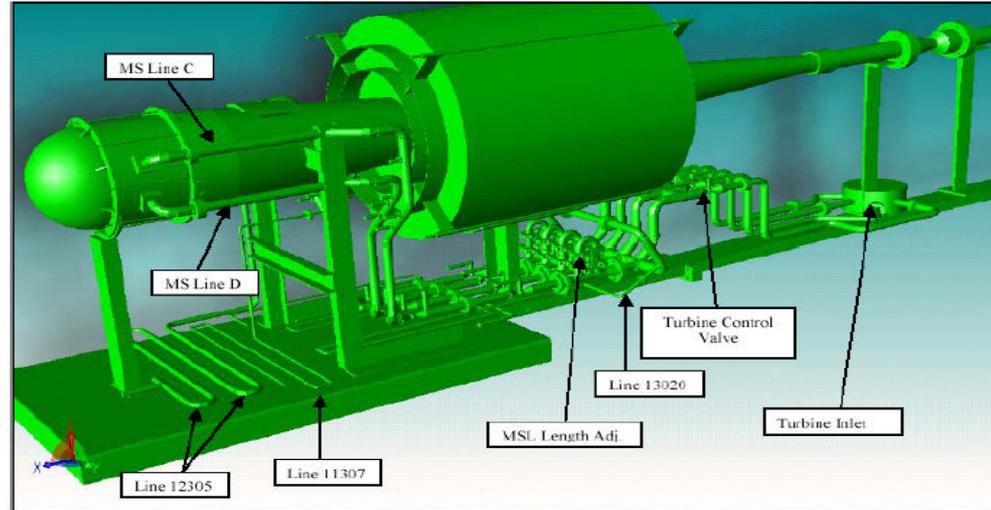
Causal Factor Analysis

Corrective Actions

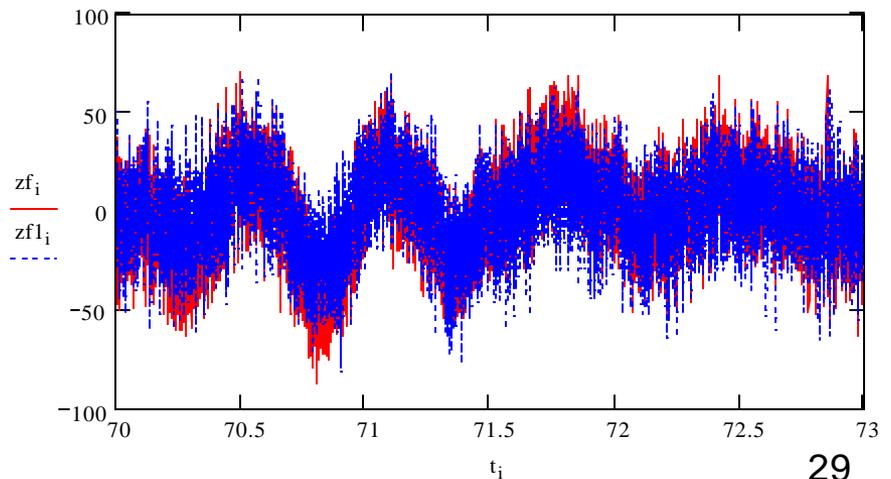
- Stress intensities have been decreased through the modifications
 - Ongoing steps to further refine steam dryer loads
- Increased R2 weld size to 1/2”
- Improved welding process
 - Enhanced briefing with welders stressing importance of weld quality and size
 - Revised weld sequence to minimize fit-up stresses
 - Welder inspection of every pass
 - Periodic supervisory checks of in-progress welds
 - Verified correct weld profile through measurements

Ongoing Actions

- FEA of modified dryer using QC loads
- Performed scale model tests
 - Validated acoustic circuit analysis
 - Convergence is being reached between actual dryer loads and analytical predictions
 - Further refinement will be obtained through main steam line (MSL) data



Plot of Filter SMT data (Red) compared to CDI predicted data (Blue) - First Benchmark Data Point M21



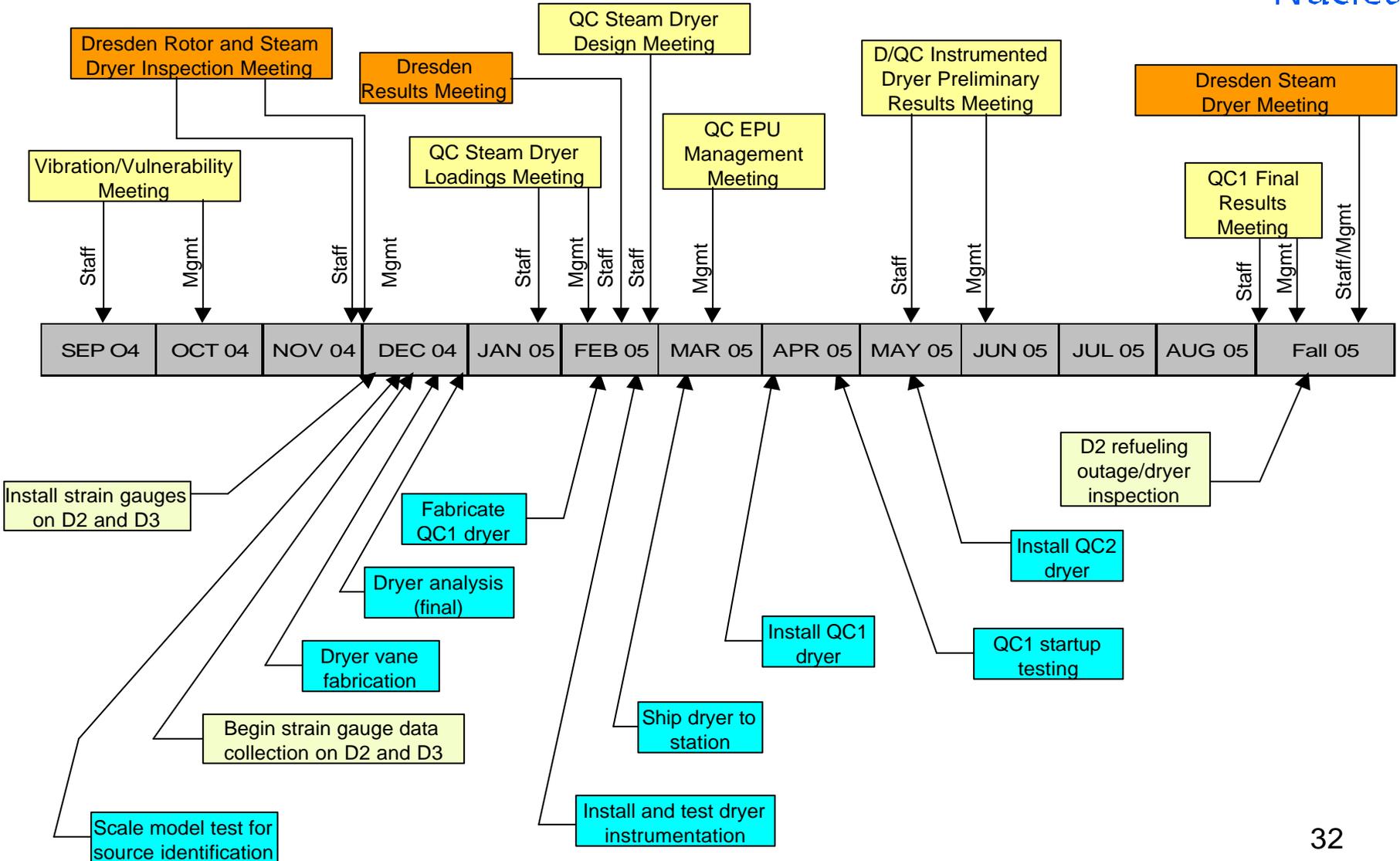
Ongoing Actions (cont.)

- D2 and D3 have installed 4 strain gauges on each MSL
 - Strain gauges provide a direct measurement
 - Strain gauges provide high frequency content up to 200 Hz
 - Measurements will eliminate nozzle phasing assumption for the acoustic circuit analysis
 - Improved accuracy of load definition
- Data will be collected for both units during power ascension and steady state operation
 - Acoustic circuit analysis will generate a load definition at EPU power
 - Dynamic FEA will be completed for the as-modified dryers
 - Will share analysis results with NRC in early 2005
- Ongoing steam dryer performance monitoring will continue
 - Includes monitoring during power ascension

Ongoing Actions (cont.)

- In Spring 2005, the QC1 instrumented steam dryer and MSLs will provide the data correlation for acoustic circuit dryer load prediction
 - Data collected on the MSL strain gauges will be provided to CDI to predict the dryer pressure measurements at instrumented locations
 - In-plant validation for acoustic circuit analysis will be completed shortly after data collection on QC1
 - Will meet with NRC in mid-2005 to present results of analytical work
- Full GE SIL 644, Revision 1 inspection scheduled for Fall 2005 D2 refueling outage
 - Will meet with NRC in Fall 2005 to share D2 inspection results, provide update on analytical results based on latest QC1 instrumented dryer and D2/D3 strain gauge data, and discuss impact on D3, including a potential mid-cycle inspection

Planned Interactions



Bases for EPU Operation

- D2 and D3 steam dryer loading is less than either QC unit
- Inspections confirmed that the 2003 repairs to the outer hood maintained structural integrity
- Causes of cover plate cracks are understood and resolved
- Modification improves outer hood structural capacity
- 2004 outer hood modification will be validated using
 - Acoustic circuit analysis time histories generated for QC2 at EPU conditions
 - Scale model test time histories for QC1 model at EPU conditions
 - Dresden in-plant data from strain gauges on MSLs

Conclusions

- Inspections and analytical work continue to support our conclusion that Dresden is different from QC in both the loading and its effect on the dryers
- Causes of the identified cracking are understood and corrective actions have been implemented or are in progress
- Structural improvements through the dryer modifications provide additional confidence
- Monitoring is in place that provides the capability to identify loss of structural integrity and to take appropriate actions
- Additional instrumentation on Dresden MSLs and QC1 replacement dryer will increase our understanding of loads and stresses
- We continue to enhance our analytical tools to refine our understanding of the loads

Closing Remarks

Danny Bost
Site Vice President
Dresden Nuclear Power Station

Closing Remarks

- Generator rotors
 - Exelon repaired the generator rotors with redesigned keyways and improved torsional capacity
 - Exelon will monitor for torsional loading
- Steam dryers
 - Steam dryer inspections were performed on both units and thorough repairs have been performed
 - D2 and D3 have the new steam dryer outer hood modification which lowers weld stresses by a factor of 2.5
 - As new insights are gained, appropriate actions will be taken as necessary

Closing Remarks (cont.)

- Both units can safely return to full power operations
- Monitoring is in place that provides the capability to identify loss of dryer structural integrity and to take appropriate actions
- Update April 2, 2004, letter detailing bases for EPU operation
- Propose ongoing meetings with NRC to discuss progress and results
 - Fall 2005 meeting following the D2 outage will include discussion of impact on D3, including a potential mid-cycle inspection