Exelon Nuclear

# 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

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- 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

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|---|---|
| • Opening Remarks | Danny Bost |
| • Generator Rotor | Mark Kanavos |
| • Steam Dryer | Jim Meister |

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

# Generator Rotors

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- 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

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- 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.)

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- 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

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- 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

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- 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

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- 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

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- 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

Exelon Nuclear

- 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

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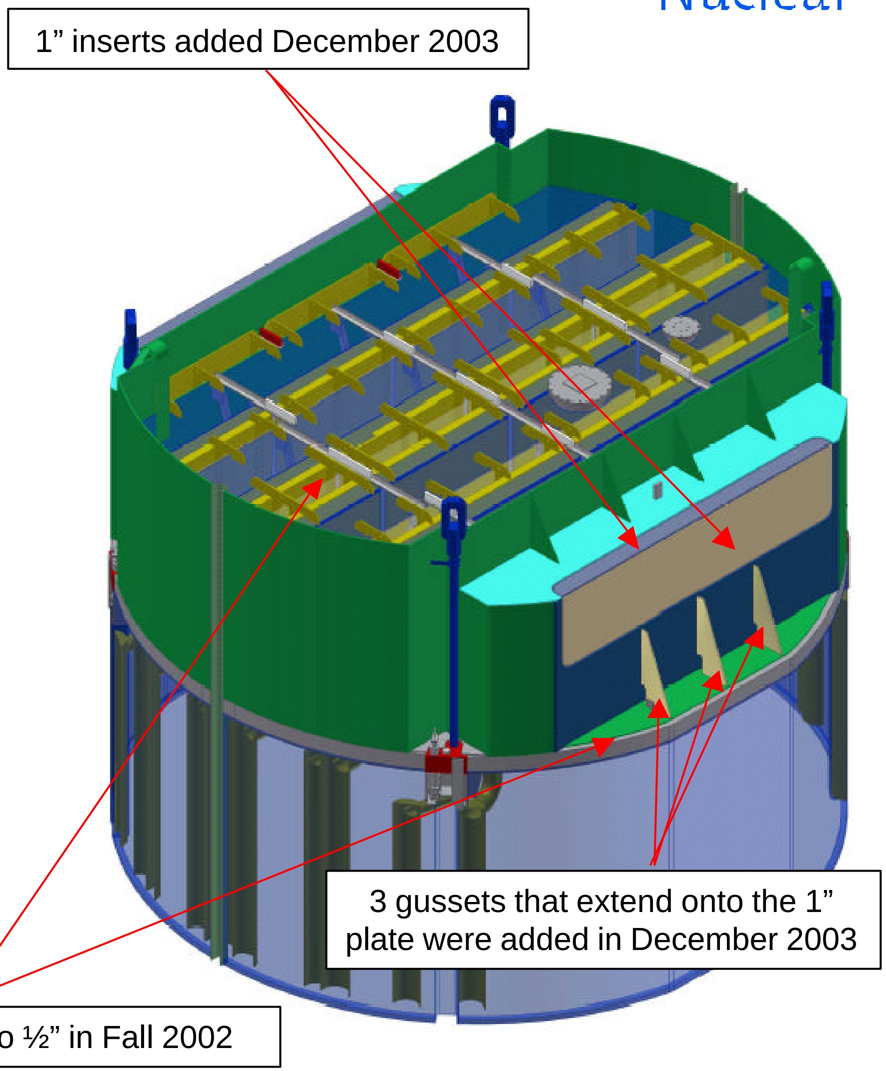
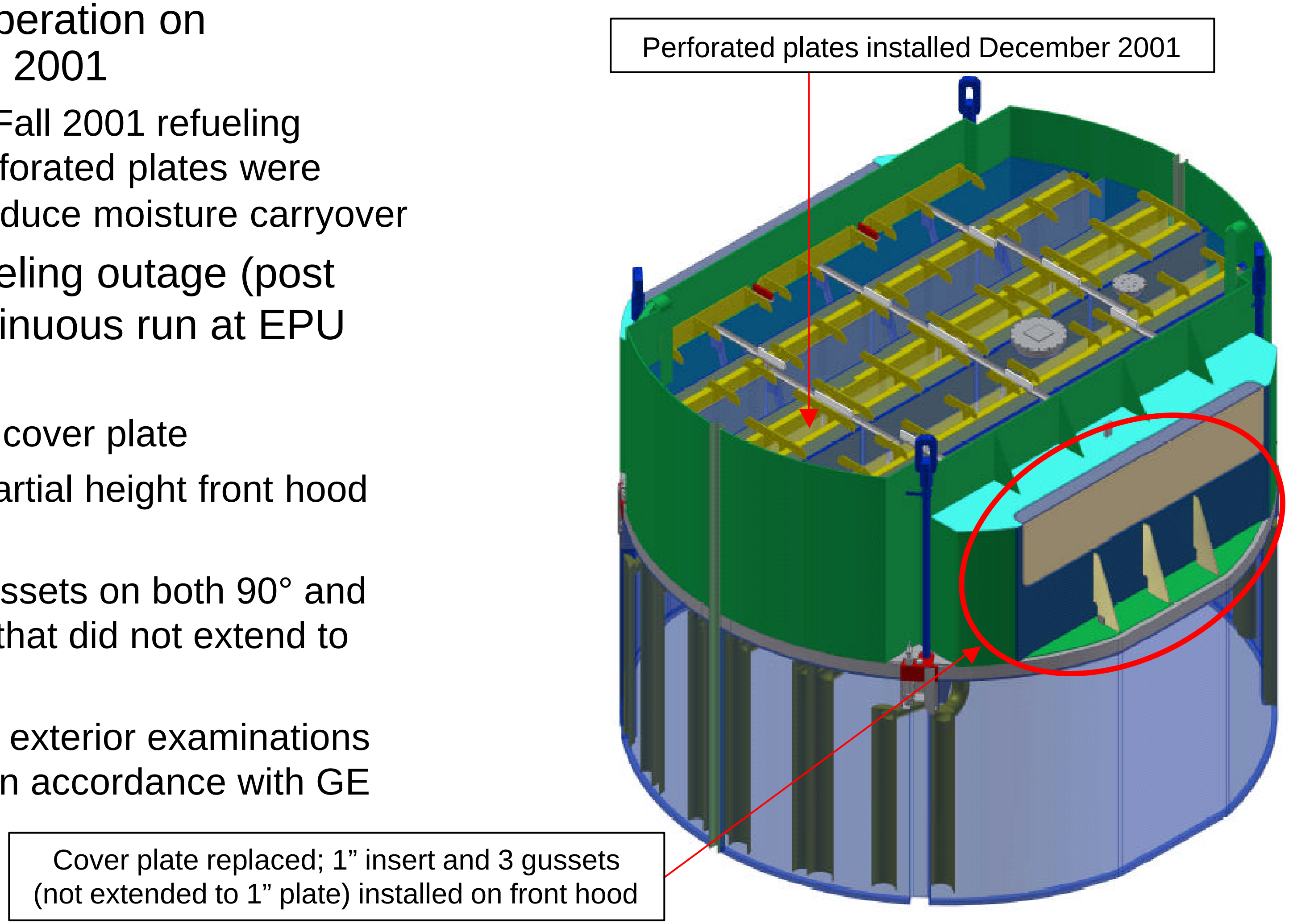
- Began EPU operation on November 4, 2002
  - During the Fall 2002 refueling outage, perforated plates were added to reduce moisture carryover
  - Added 1/2” cover plate
  - Steam dryer externals were inspected
- December 2003 steam dryer modification
  - Added 1” partial height front hood face plate
  - 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



# Background Information

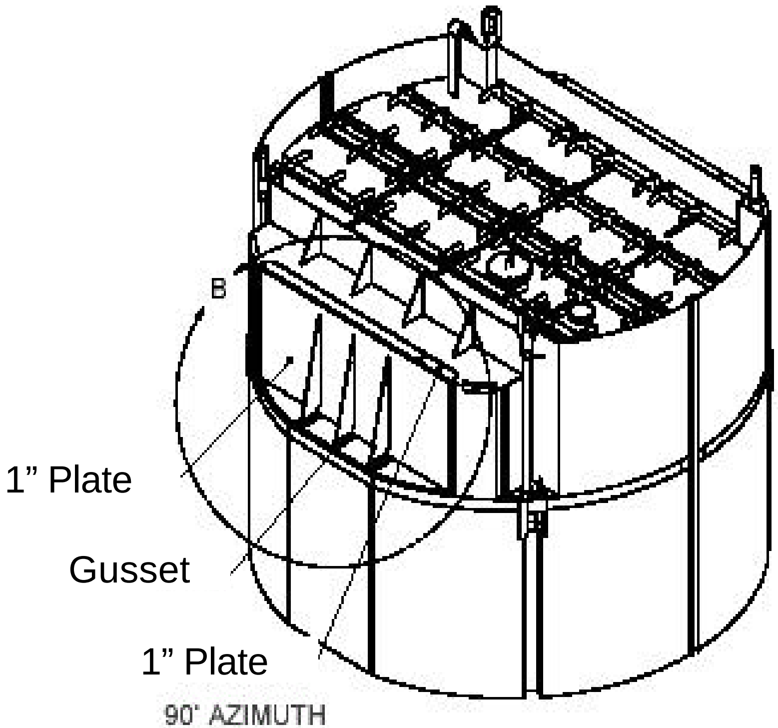
## D2 Timeline

- 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.)

Exelon Nuclear

- 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

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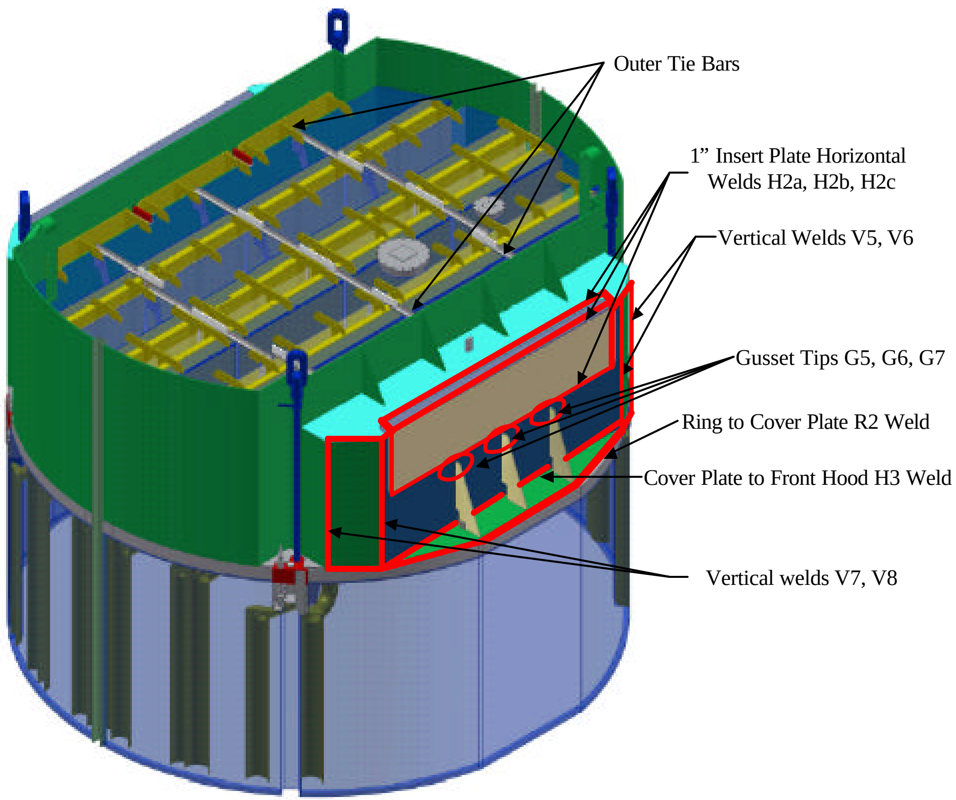
- Best effort VT-1 and VT-3
  - Approximately 1100 dryer inspection points
  - Satisfies recommendations described in GE SIL 644, Revision 1
  - Includes areas of dryer previously inspected on QC2
- 16 total indication notification reports (INRs) identified
  - 12 were dispositioned as acceptable for 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

Exelon Nuclear




- 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

Exelon Nuclear

- 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

Exelon Nuclear

- 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

Exelon Nuclear

- 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

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- Stress intensities have been decreased through the modifications
  - Ongoing steps to further refine steam dryer loads
- Increased R2 weld size to ½”
- 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

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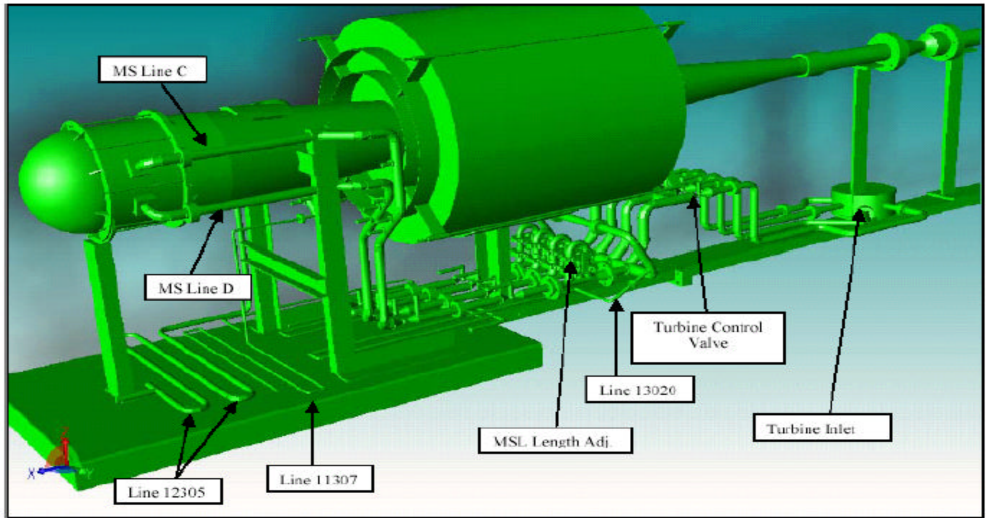
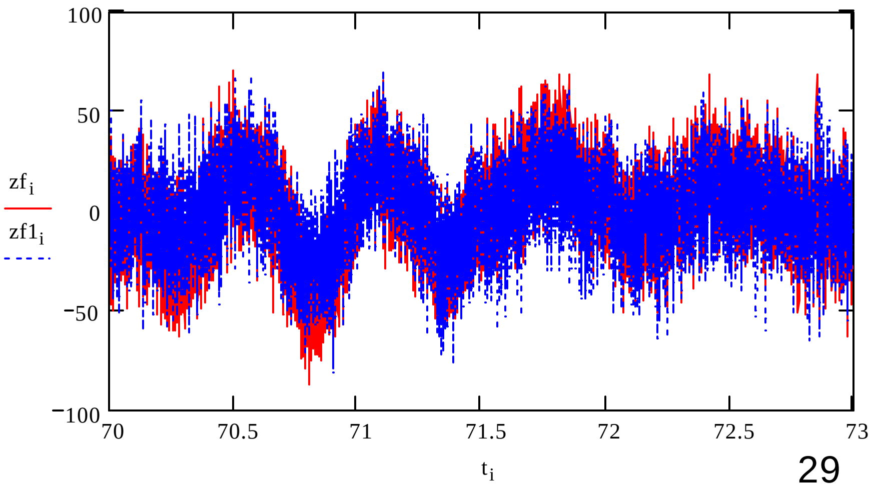
- FEA of modified dryer using QC loads
- Performed scale model tests
  - Validated acoustic circuit analysis
  - Convergence is being reached between actual dryer loads and analytical predictions
  - Further refinement will be obtained through main steam line (MSL) data




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



# Ongoing Actions (cont.)

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- 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

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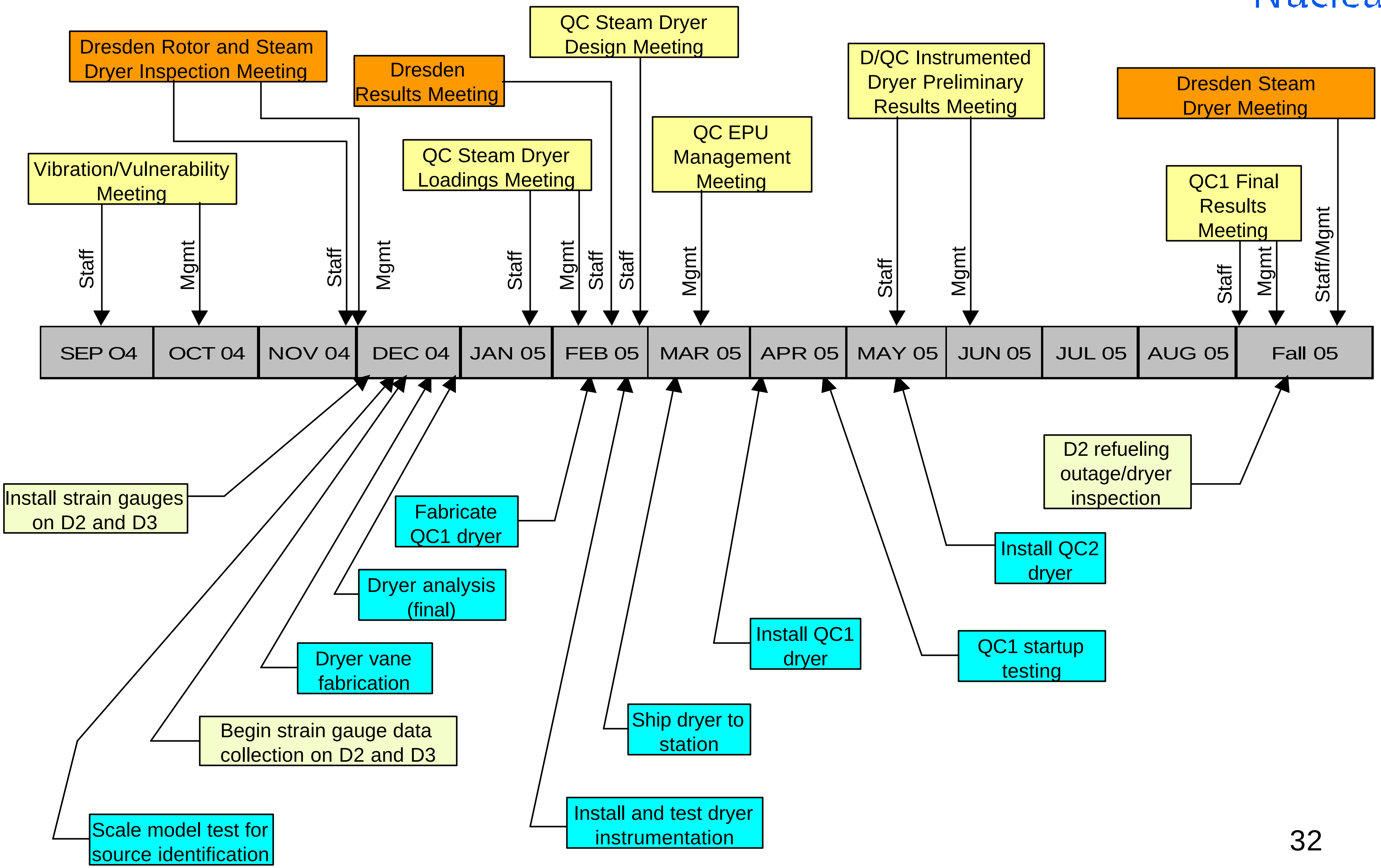

# Bases for EPU Operation

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- 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

Exelon Nuclear

- 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

Exelon Nuclear

- 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.)

Exelon Nuclear

- 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