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# Quad Cities Nuclear Power Station Steam Dryer Replacement Meeting

May 4, 2005

# Agenda

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| | |
|---|---|
| • Introduction<br>– Purpose<br>– Timeline | J. Meister |
| • Extended Power Uprate (EPU) Extent of Condition/ Flow Induced Vibration | B. Porter |
| • New Steam Dryer<br>– Design Strategy/Process Overview<br>– Design<br>– Loading<br>– Stress Analyses<br>– Instrumentation | K. Moser/<br>G. DeBoo |
| • Startup Test Plan | B. Strub |
| • Quad Cities (QC) Operational Plans | R. Gideon |
| • Regulatory Commitments/Interactions | K. Jury |
| • Dryer Weld Issues | J. Meister |
| • Conclusions | T. Tulon |

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# Introduction

Jim Meister
Vice President – Nuclear Services

# Purpose

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- Summarize information provided to NRC during technical meetings
- Overview the startup and operational plans for QC1 and QC2
- Support QC operation at EPU

# Timeline

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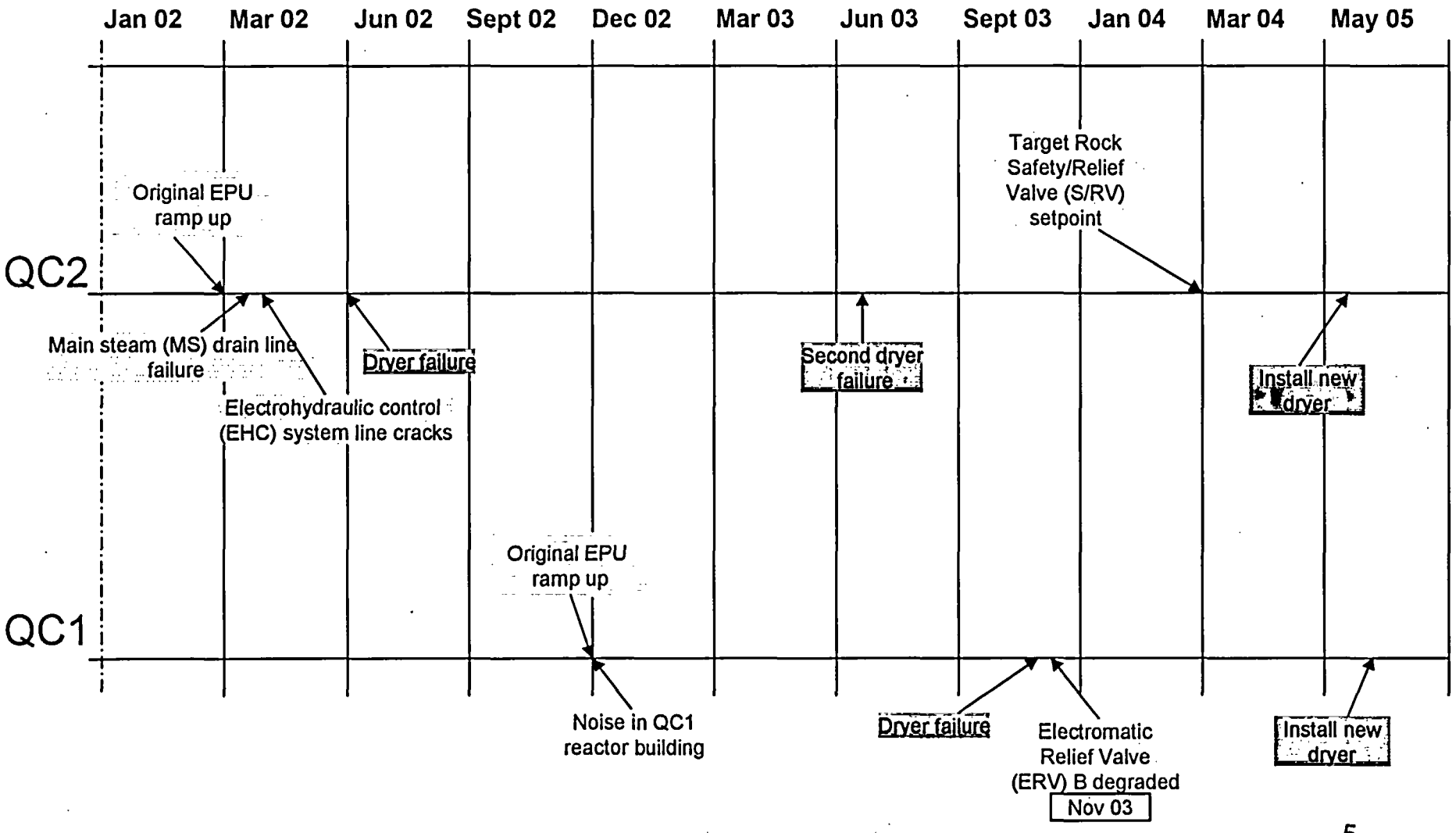

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# EPU Extent of Condition/Flow Induced Vibration

Bill Porter
Engineering Manager
Quad Cities Nuclear Power Station

# Actions

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- Established a comprehensive plan that included three teams to identify actions to prevent future EPU concerns
  - Steam Dryer Team
  - EPU Vulnerability Team
  - Vibration Team
- New steam dryer design and installation
  - QC2 during planned outage scheduled to begin May 9, 2005
  - QC1 during planned outage scheduled for May 28, 2005

# EPU Vulnerability Review

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- Comprehensive evaluation of potential plant equipment vulnerabilities at EPU power
- Scope included balance of plant and safety systems affected by EPU
- Lessons learned and industry input incorporated into the review process
- 101 recommendations included inspections, modifications, preventive maintenance changes, analysis, etc.
- Inspections were performed for QC1 and Dresden Unit 3 (D3) during the first possible refueling outages

# Outage Inspection Results

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- Significant inspection findings at QC
  - Condensate pump impeller cavitation
  - Feedwater sparger bracket support nuts
  - Main steam line (MSL) tie-back support degradation
- Significant inspection findings at Dresden
  - Condensate pump impeller cavitation
  - Shroud head bolt locking pin wear
  - Feedwater heater nozzle crack

# Inspection Results Evaluation

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- Dresden and QC inspections found no vulnerabilities that could result in a challenge to plant safety systems
- Condensate pump impeller cavitation degradation and shroud head bolt wear were the only inspection findings directly attributable to EPU
- Actions completed on approximately 75 issues at D3 and QC1 revealed no immediate challenge to EPU operation
- Upon discovery of issues during the inspections, actions have been or will be taken to preclude challenges to plant operation at EPU
- Inspections and modifications completed during recent outages will ensure reliable operation of the QC units at EPU

# Vibration Evaluation

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- All components are acceptable for full-cycle operation at EPU power with the following exceptions:
  - ERV susceptibility to vibration required upgrades of vulnerable parts
  - Target Rock S/RVs showed vibration wear degradation
- Additional recommendations made to enhance testing, monitoring, and refueling outage inspections
  - Example: Confirmatory vibration testing of Limitorque and Namco limit switches (completed successfully)

# Actions for MSL Vibrations

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- Upgraded actuator components on all ERVs
  - QC2 upgraded in Spring 2004 refueling outage
  - QC1 upgraded in Spring 2005 refueling outage
  - QC2 actuators will be inspected during the planned outage scheduled to begin on May 9, 2005
- Target Rock S/RV bellows cap/setpoint spring upgrade
  - Installed on QC1 during Spring 2005 refueling outage
  - Upgrade will be installed on QC2 during planned outage scheduled to begin on May 9, 2005

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# New Steam Dryer

Keith Moser/Guy DeBoo
Asset Management Engineers

# New Dryer Design Strategy

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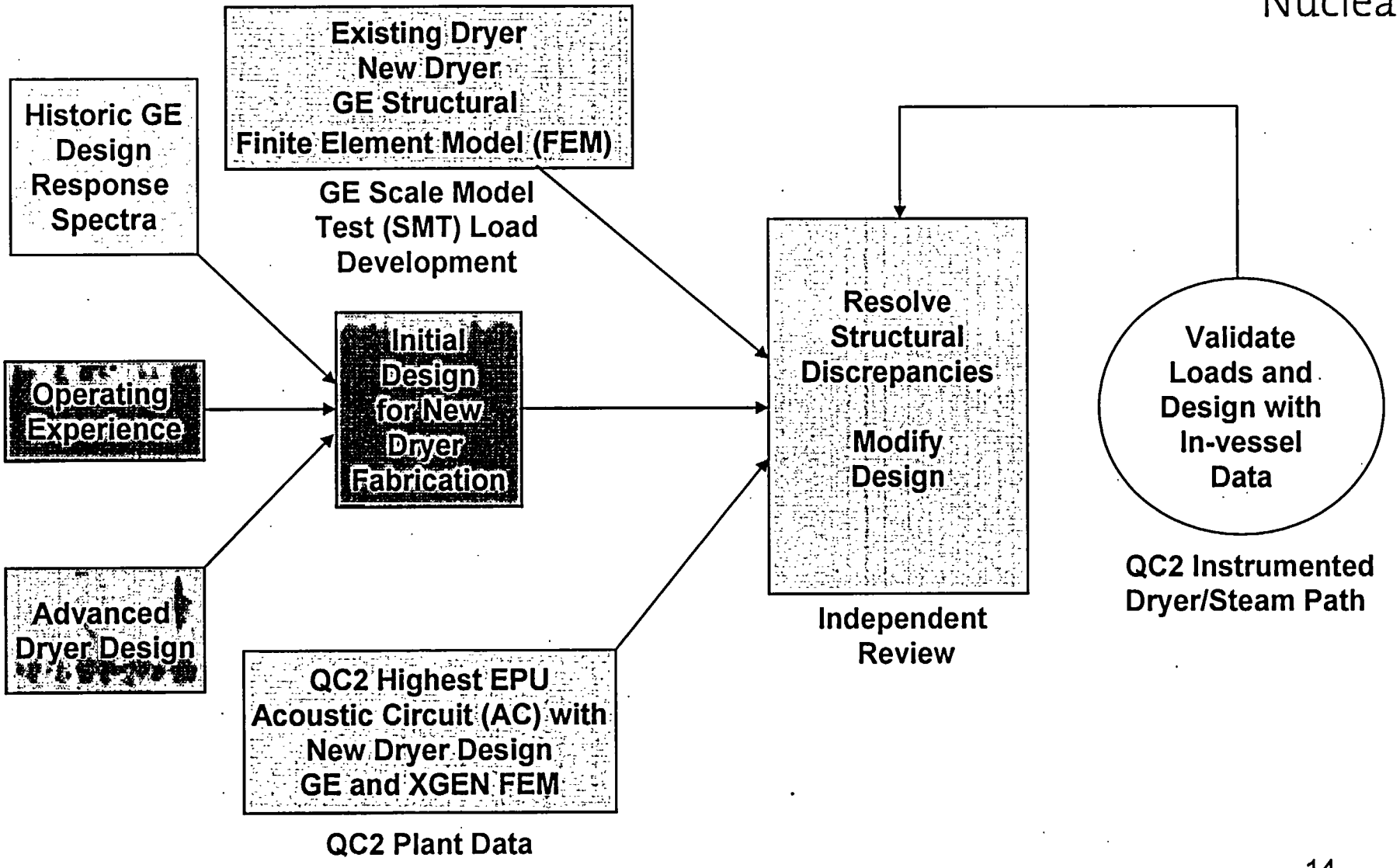

# New Dryer Design Overview

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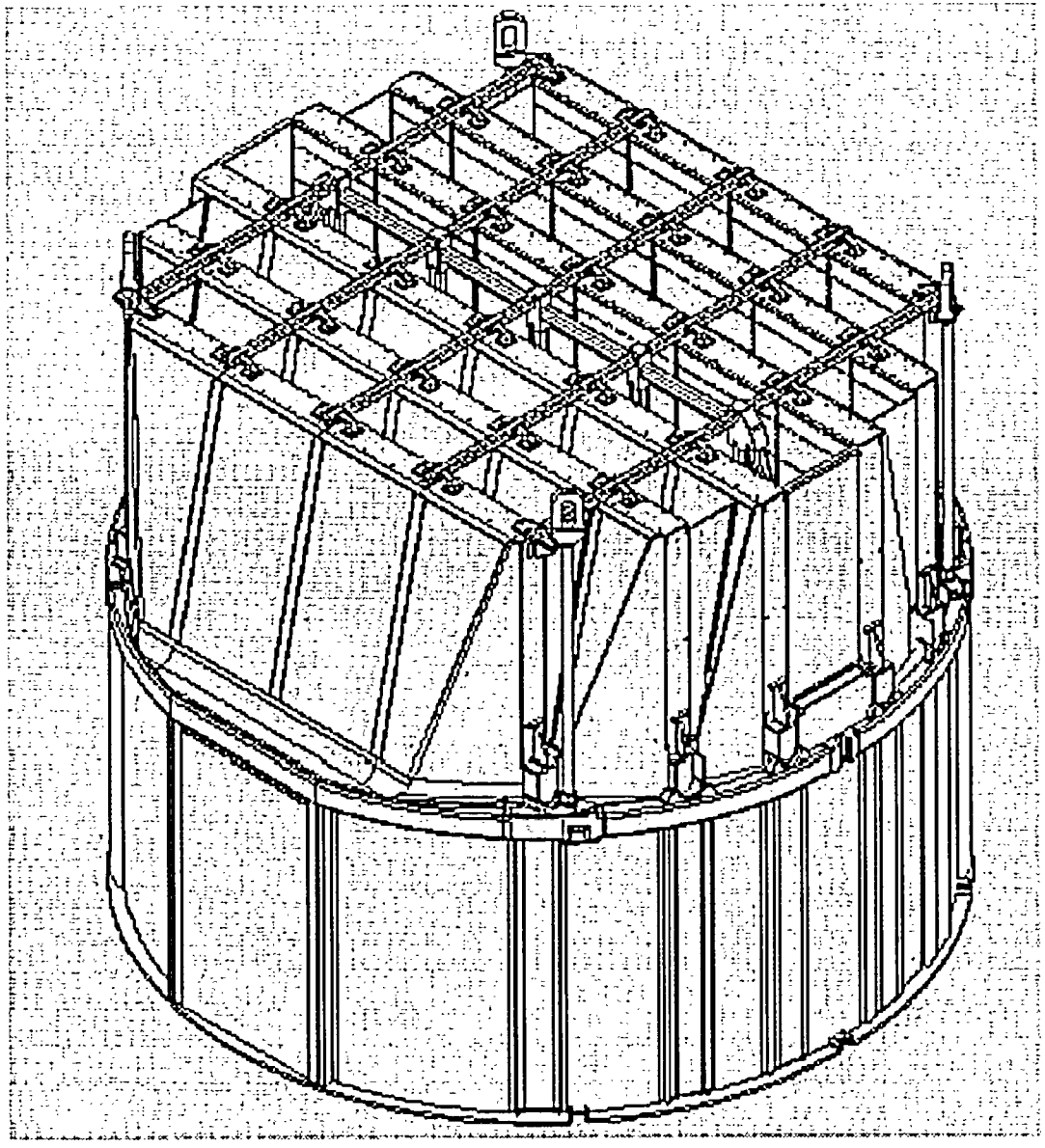

# Design Guidelines and Objectives

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- Design a structurally robust dryer
  - Solid gussets between dryer banks
  - Tied beam structures (top and bottom)
  - Skirt plate thickness increased from 0.25" to 0.375"
  - Outer hood thickness increased from 0.5" to 1.0"
- Design a vibration-tolerant dryer (i.e., eliminate "hard points")
- Minimized the number of welds in high-stress and high-fatigue areas
  - Use machined parts and extruded beams
- Locate welds in accessible areas that can be inspected
- Use full penetration welding where possible

# New Dryer Design

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# New Dryer Design (cont.)

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# New Dryer Design Load Strategy

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SMT
QC1 AC
Refined Load

EGC Benchmark of AC Model
to SMT for Load Refinement Using
In-vessel Dryer Microphones
Produced Acceptable Results

GE FEA Benchmark
Against Dryer Damage
Original Dryer Pre-EPU – Damage Predicted
2003 Repaired Dryer EPU – Damage Predicted

New Dryer QC1 SMT Load Case
Tends to Over Predict Loads

AC Analysis
QC2 In-Plant MSL Strain Gauge
Venturi Instrument Line

XGEN Finite Element Analysis (FEA)
Benchmark Against Dryer Damage
Original Dryer Pre-EPU – Borderline
2003 Repaired Dryer EPU – Damage Predicted

New Dryer Shape
Analytically Inserted
Into 3-D Steam Dome
Volume for AC

New Dryer QC2 In-plant Load Case
Results in Peak Loads Higher than SMT

# Benchmarking
## Load Definition Methodology

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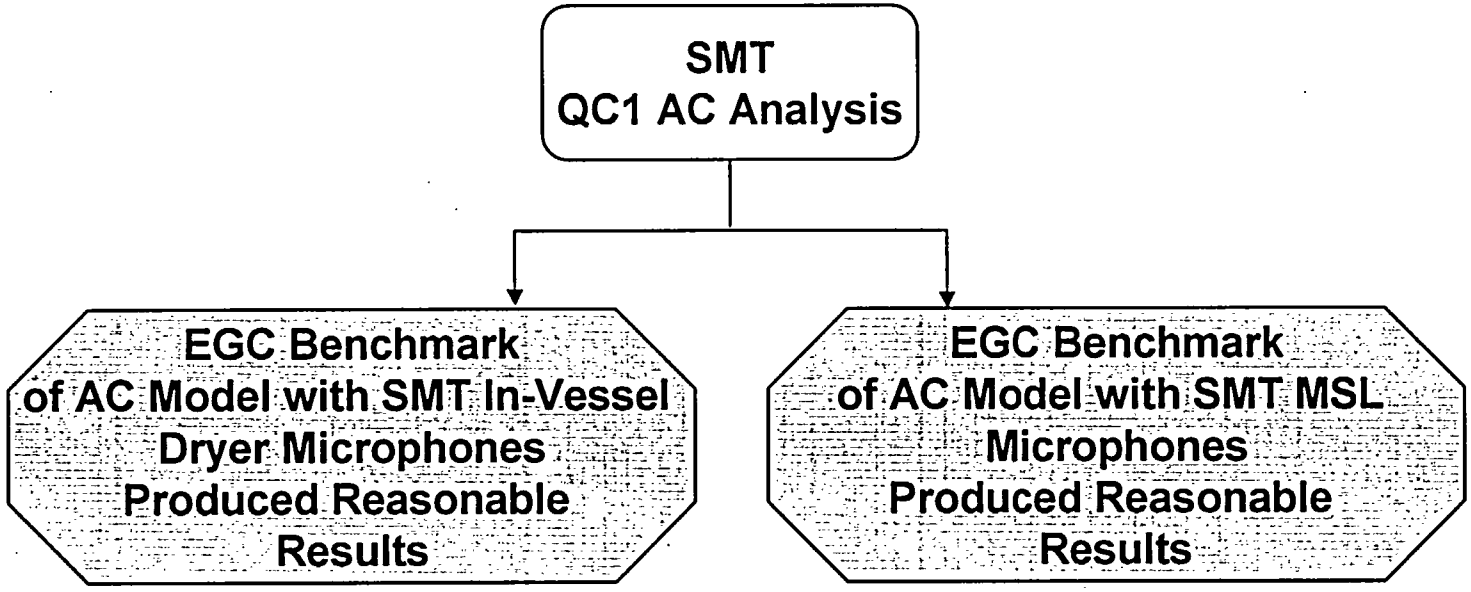

# Benchmarking
## Planned Benchmarking

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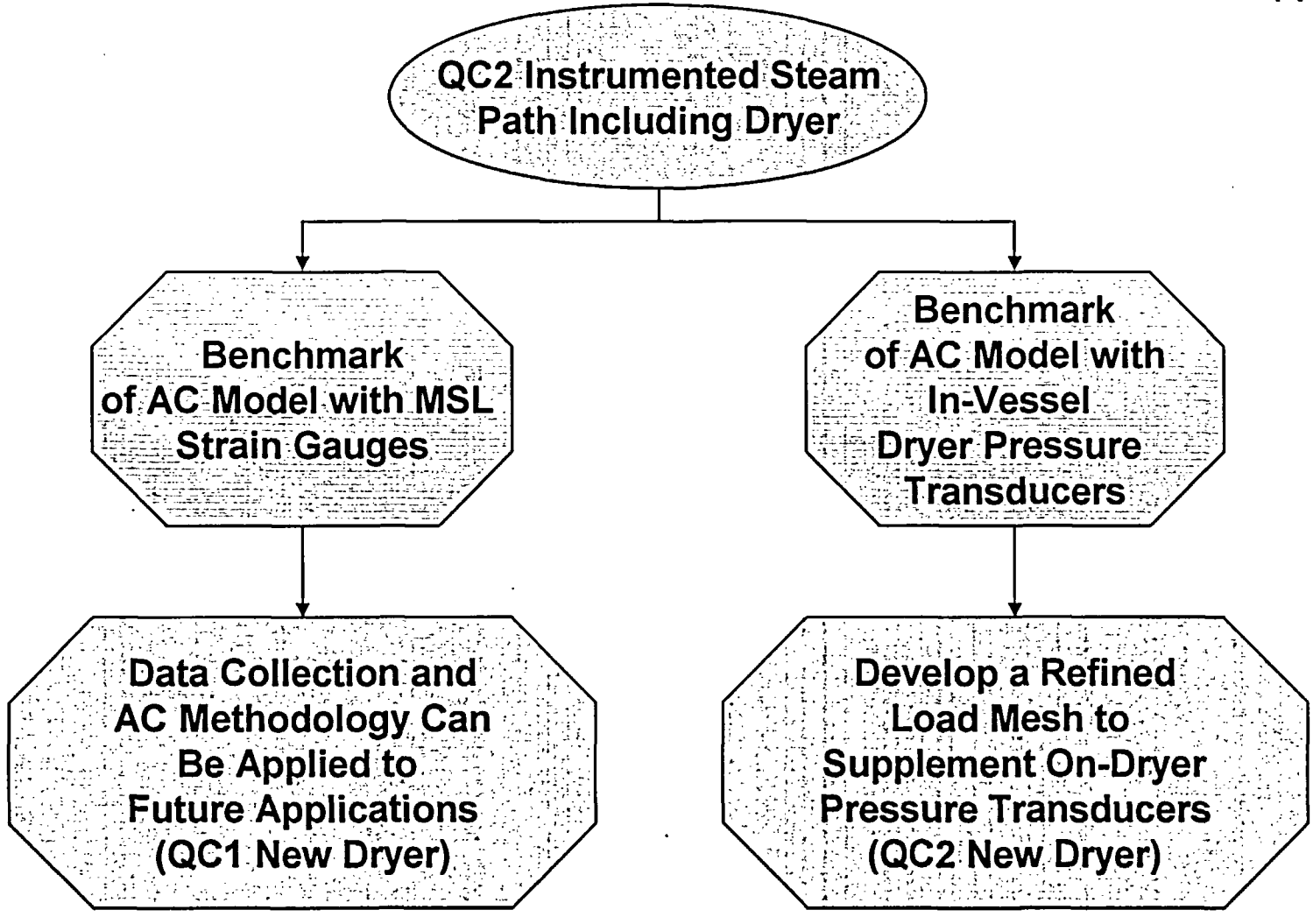

# Load Definitions

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# SMT Apparatus

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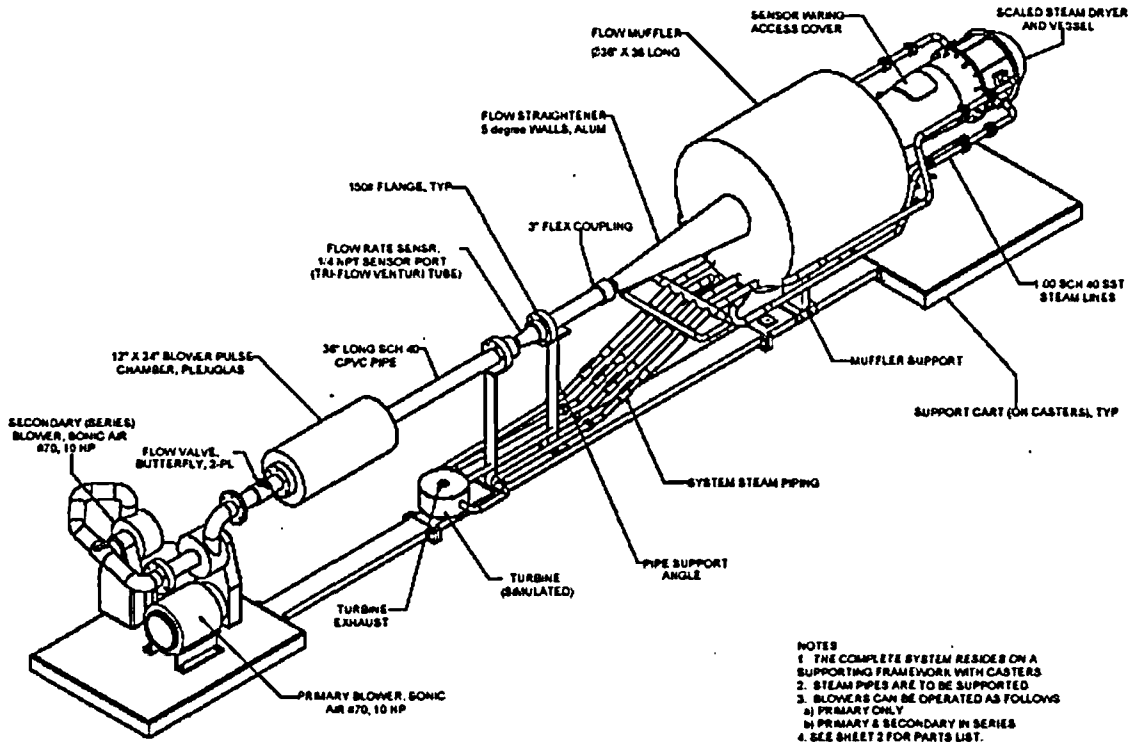


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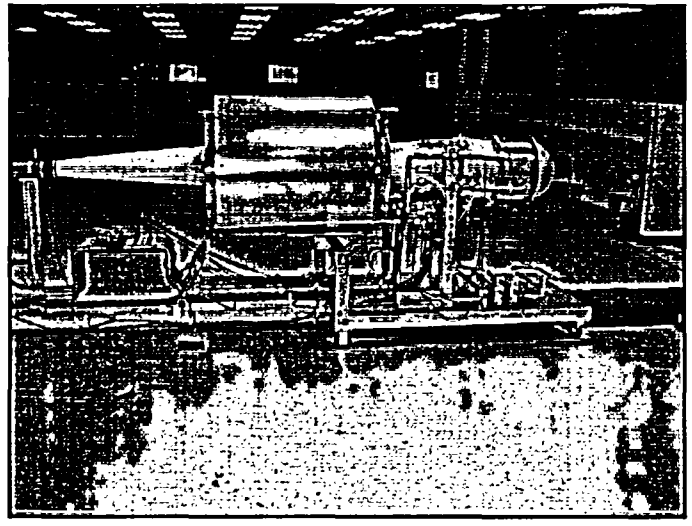

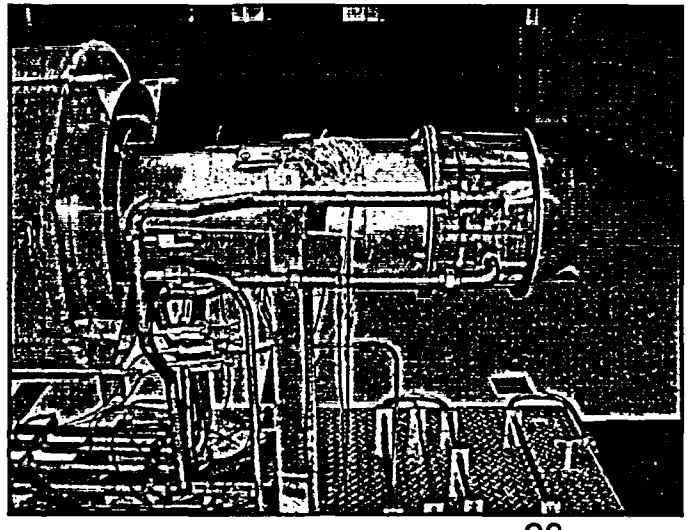

# Tests Performed for QC Dryers

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- Baseline
  - Original and new dryers
- Source identification
  - Original and new dryers
- Characterization
  - New dryer
- Sweep tests and dwell tests performed for both dryer designs
  - Sweep Test: Flow is increased at a constant rate
  - Dwell Test: Flow is held constant

# Potential Loading Sources

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- Several potential sources were evaluated using SMT and AC model
- Acoustic loads are the predominate source of flow induced vibration loading for the steam dryer
- Fluid-structure interaction (FSI)
  - Analysis showed that if FSI were to occur on the new dryer structure, it would tend to reduce the acoustic loads
- Turbulent buffeting vibration
  - Produces a broad band appearance
    - Previous in-plant and SMT results have distinct peak frequencies
    - Turbulent vibration accounts for less than 10% of QC dryer loads
- Independent review team and industry experts challenged and concurred with conclusions

# Source Identification Tests

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# QC1 Source Testing Results
## Summary

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# Flow Induced Vibration Mechanism

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# Conclusions

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- Acoustic induced vibration is dominant flow induced vibration excitation mechanism
- Source of acoustic loads are complex and driven by interactions of steam path components
- SMT methodology is a viable tool to predict fluctuating pressure loads on steam dryers
- In-plant loads provide higher peaks
- Both loading conditions create a conservative load definition

# Finite Element and Stress Analyses

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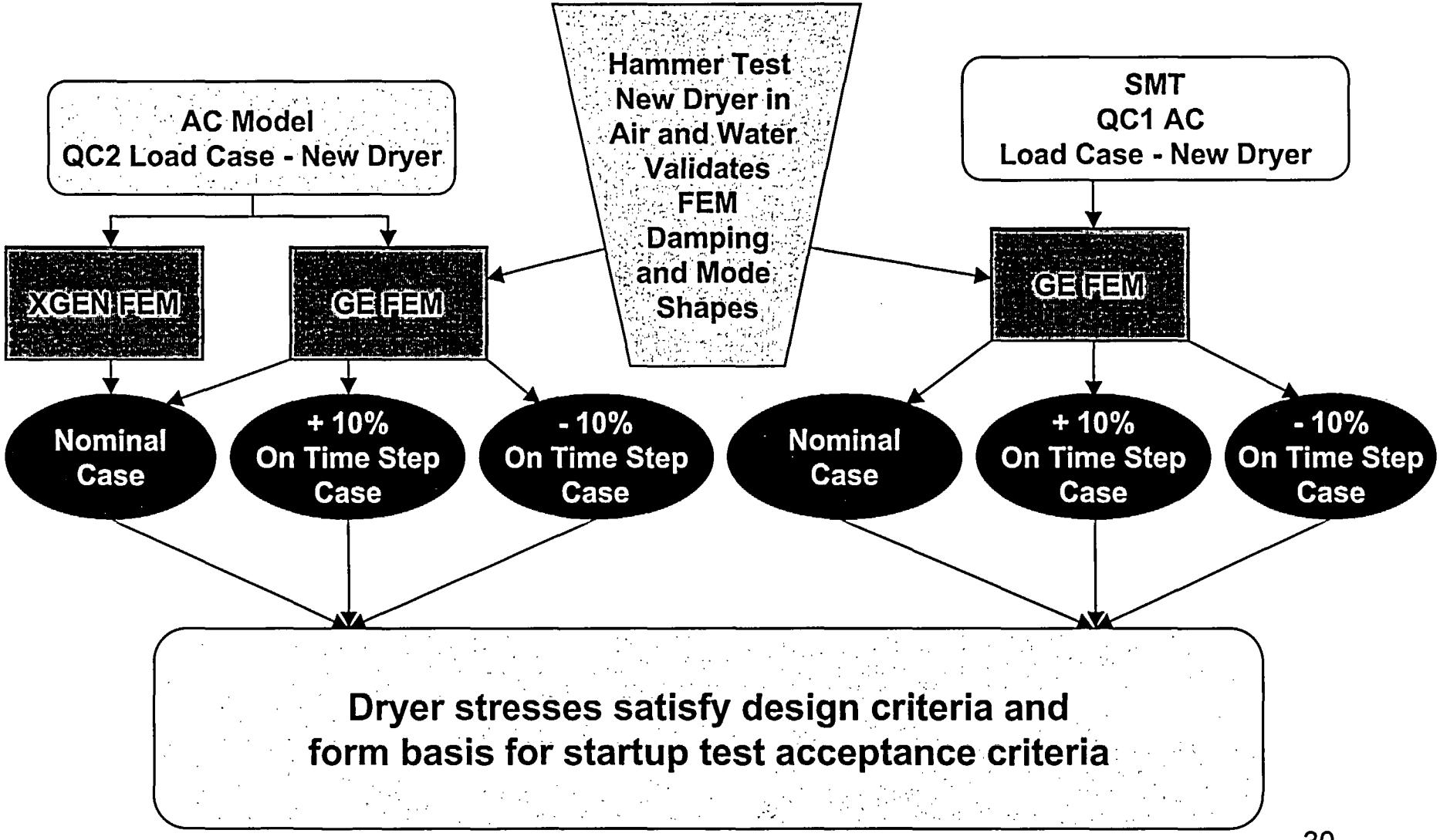

# Dryer Model
## Full Model Without Super Elements

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# Fatigue Analysis Summary

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# ASME Code Case
## Stress Margins

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# Structural Analysis Conclusions

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- New dryer is structurally adequate for EPU conditions
- New dryer meets the design fatigue limits for EPU conditions
- New dryer meets the ASME Code limits for all service levels (i.e., normal, upset, and faulted)

# XGEN FEM

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# XGEN FEM (cont.)

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# XGEN FEM (cont.)

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- XGEN FEM is a reasonable representation of the structural characteristics of the new dryer
- XGEN stress results are within the design stress endurance limits
- Stress results are generally lower and compare well to the equivalent GE stress levels
- XGEN analysis results provide a reasonable verification of the GE analysis results
- XGEN analysis results provide confidence that the new dryer is acceptable for EPU operation

# Hammer Test
## Purpose

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- Obtain actual (as-built) dynamic characteristics of the new dryer
  - Modal frequencies
  - Mode shapes
  - Modal damping
- Validate new dryer FEM
- Confirm critical damping for FEA

# Hammer Test
## Excitation/Response Points

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# Hammer Test Results

## Hammer Test vs. FEA Frequencies

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# Hammer Test Results
## Conclusions

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# Instrumentation

# Dryer Instrumentation
## Purpose

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- Define the steam dryer pressure loading
  - Pressure sensors placed at predicted high pressure locations
  - Locations from previous operating experience
- Verify adequacy of the new steam dryer design
  - Strain gauges located to ensure stress is consistent with predictions
  - Accelerometers located to ensure displacement trends are not unexpected and to provide data in the event of strain gauge failures
- Identify steam dryer properties (e.g., frequency, damping)
  - Impact testing on steam dryer
- Gain insights regarding the source(s) of loading
  - Sensors on MSLs for input to AC model
- Benchmarking

# Use of Collected Data

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- Validate structural adequacy of QC2 dryer
  - Compare strain gauge results to criteria developed from FEA for dryer structural integrity at EPU power
  - Validate that the design load for new QC2 dryer is bounding
  - Use FEM to compare stress results from pressure transducers to design calculations
- Benchmark predictive tools
  - Sensors on the dryer and MSLs are the most comprehensive to date
    - AC with MSL and water reference leg data will be compared against in-vessel data points
    - SMT data will be benchmarked against QC2 data
    - GE/LMS International acoustic FEM will be benchmarked against the QC2 data

# Sensor Selection and Placement
## New QC2 Dryer

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# Sensor Selection and Placement
## MSLs

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| MSL Sensor Locations Inside Drywell | |
|---|---|
| **Location** | **Strain Gauges** |
| MSL - A | 10 |
| MSL - B | 10 |
| MSL - C | 16 |
| MSL - D | 10 |
| | **Overall Total: 46** |

Notes:

- MSL "C" was selected for additional instrumentation because of the HPCI system piping connection
- Strain gauges used to benchmark the AC analysis will include four circumferential strain gauges to measure the pressure oscillation at four 90° circumferential locations at the 651' and 621' elevations
- 10 additional strain gauges on MSL piping outside of the drywell

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# Startup Test Plan

Brian Strub
Design Engineer
Quad Cities Nuclear Power Station

# QC2 Startup Test Strategy

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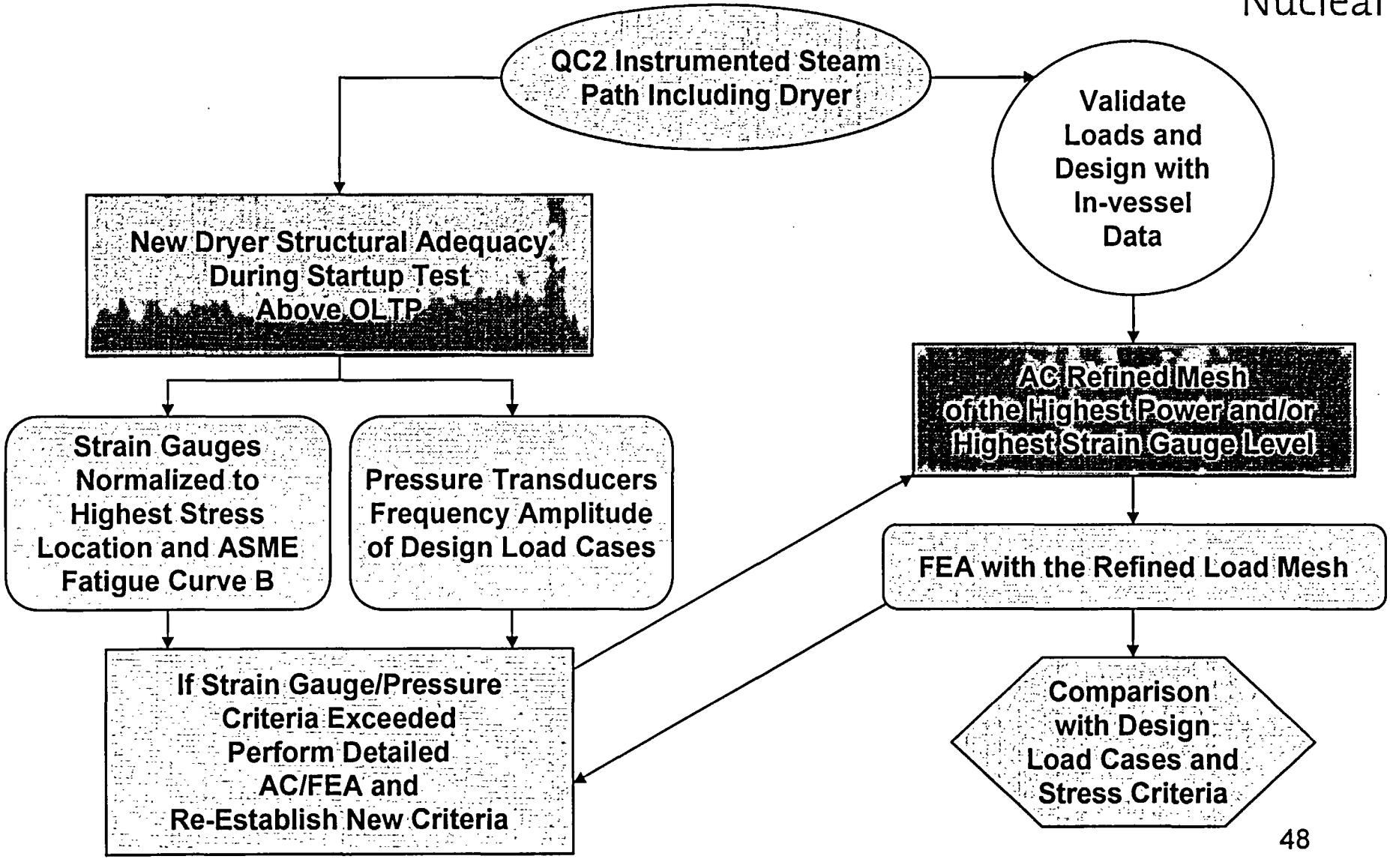

# Startup Test Plan
## Approach

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- Power will be raised to OLTP level over a 3.5-day period
  - Data will be taken at 33 Test Conditions (TCs) to this point
  - Three levels of Acceptance Criteria will be evaluated at each power level
    - Plant Equipment Acceptance Limits: Normal alarm points or established equipment operating limitations based upon historical performance data
    - Level 2 Criteria: Not necessarily alter plant operation or test plan, but will initiate an Issue Report (IR)
    - Level 1 Criteria: Initiate an IR and seek immediate resolution; repeat test portion to verify Level 1 can be satisfied; documented resolution within the test procedure (Example: dryer strain gauges)
  - Acceptance Criteria for dryer measurements (Go/No-Go decision)
- Power will then be raised to EPU level over a 29-hour period (TCs 34-41)

# Startup Test Plan
## Approach (cont.)

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- Actions during the 24-hour hold at 2511 MWt (i.e., OLTP)
  - During both steady state operation and while turbine valves are stroked:
    - Collect data on the 33 MSL component accelerometers
    - Collect data on the 42 dryer data acquisition system (DAS) instruments and the 56 MSL strain gauges
    - Collect data on the reactor steam dome pressure transducers, control valve positions, and MSL pressure transducers
  - Obtain equipment vibration levels utilizing handheld vibration instruments on small bore piping and local instrument racks
  - Perform core performance monitoring (core thermal limits)

# Startup Test Plan
## Approach (cont.)

Exelon Nuclear

- Actions during the 24-hour hold (cont.)
  - Stroke Main Turbine valves for testing
  - Determine moisture carryover
  - Perform system and equipment monitoring (i.e., computer points and operator rounds data)
  - Obtain control room and local in-plant readings
  - Perform reactor parameters monitoring:
    - 25-point moving averages method has identified past dryer issues
    - Parameters include reactor pressure, reactor level, MSL flows, and steam flow versus feed flow mismatch
  - Provide MSL strain gauge data to CDI and Corporate Engineering for blind benchmark of AC model
  - Present collected data to the Plant Operations Review Committee (PORC); obtain approval from PORC to continue power ascension to EPU levels if there are no unresolved issues

# Startup Test Plan
## Dryer Acceptance

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- Dryer issues would be detected by:
  - Monitoring critical reactor parameters (25-point moving average of reactor pressure, reactor level, MSL flows, and steam flow versus feed flow mismatch)
  - Sampling and trending moisture carryover from 75% power to full power; the dryer design criterion is 0.1%
  - Dryer instrumentation:
    - Strain gauges indicating above Level A Criteria
    - Sudden change in pressure sensors
    - Sudden change in accelerometers

# Startup Test Plan
## Approach (cont.)

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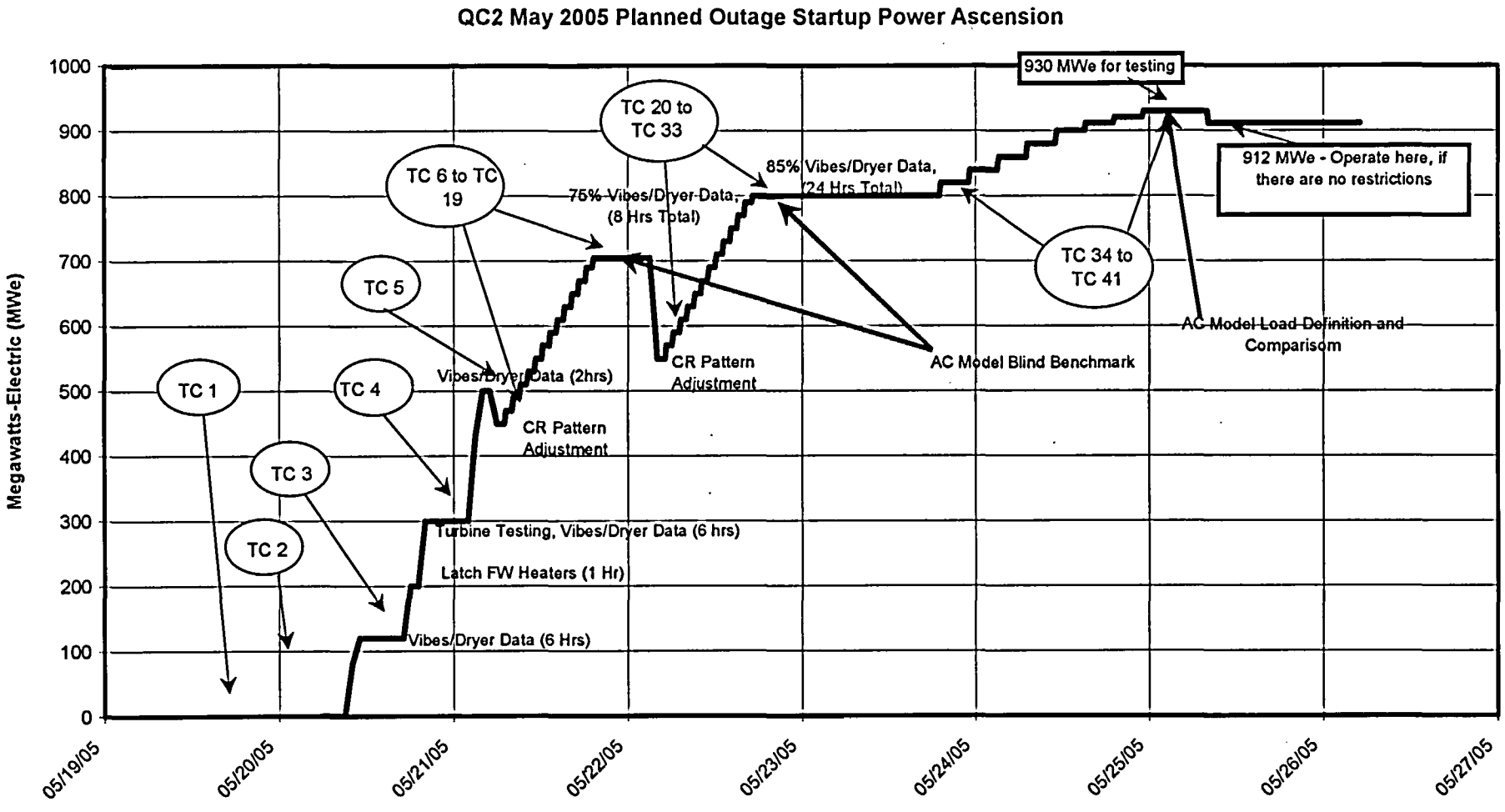

# Startup Test Plan
## Planned Data Measurements

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- 42 dryer sensors recorded on GE DAS
- Three reactor steam dome pressure sensors and four pressure measurements at the MSL flow venturis recorded on high speed recorders
- Four control valve positions recorded on high speed recorder
- Strain gauges on MSLs in drywell/heater bay recorded on DAS
- 33 accelerometers on MSLs in drywell recorded on tape drives
- System equipment parameters recorded by computer points and Operator rounds (approximately 1000 data points)
- Handheld measurements for vibration levels and local temperatures
- Trending strain gauge from previous power levels
  - Direct reading
  - Fast Fourier Transform (FFT)
- Trending accelerometers
  - Direct reading
  - FFT

# Applying Acceptance Criteria

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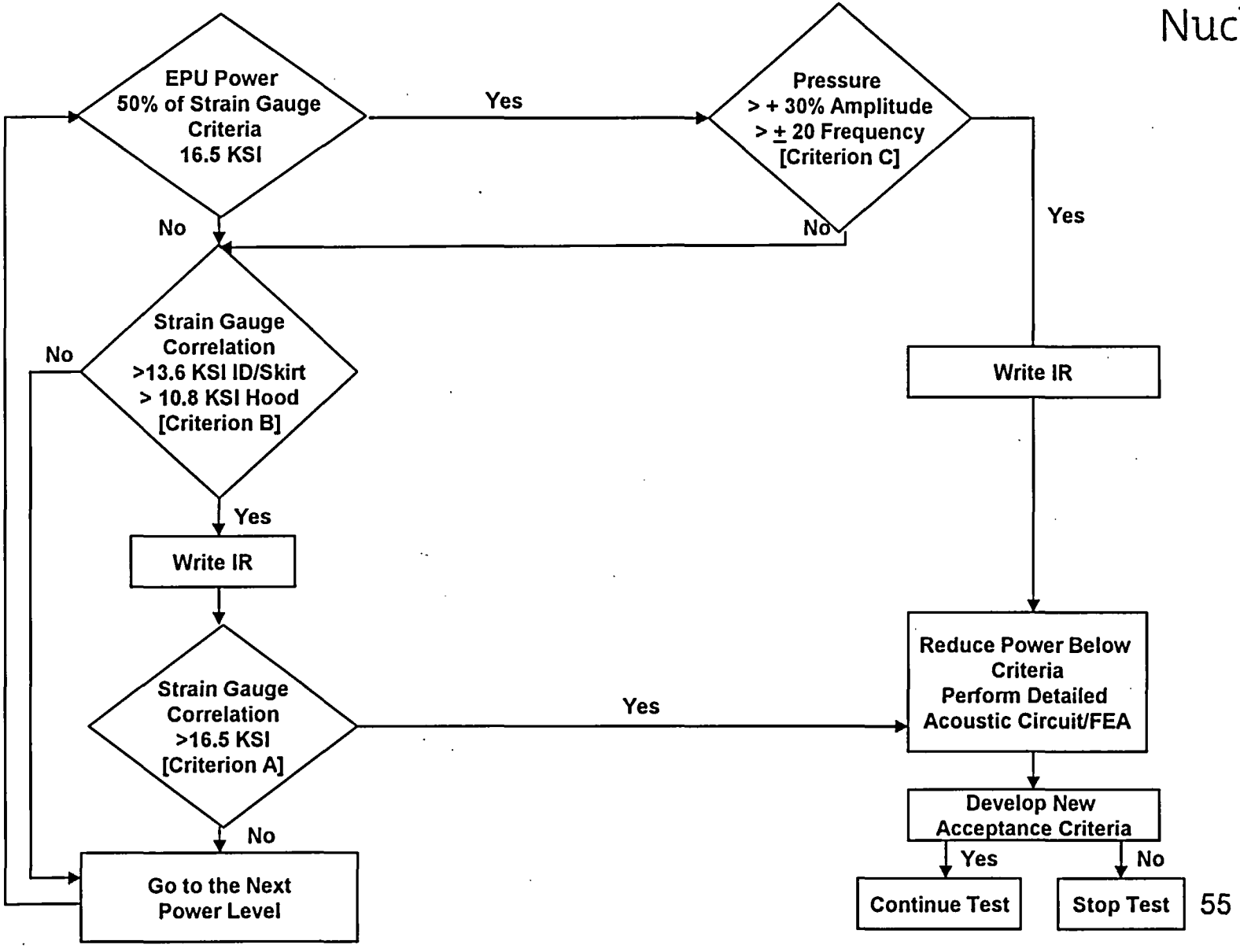

# Startup Test Plan
## Dryer Acceptance

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- The dryer will have four Acceptance Criteria:
  - Criterion A – Dryer strain gauges indicate that the peak dryer stress levels have reached ASME Fatigue Curve "B" for infinite component life (16,500 psi)
  - Criterion B – Dryer strain gauges indicate that the peak dryer stress levels have reached 10,800 psi for outside dryer components, or 13,600 psi for inside dryer components
  - Criterion C – Six pressure gauges on the steam dryer (i.e., actual plant pressure data) will be compared to two load case frequencies and amplitudes; load cases are the SMT and QC2 data from power accession to EPU power levels in August 2004
  - Criterion D – If less than the minimum number of strain gauges are functioning, then accelerometer criteria will be used as a backup

# Startup Test Plan
## Dryer Acceptance (cont.)

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- Criterion C will be implemented above 2511 MWt if the strain gauges reach 50% of Criterion A
- In addition, strain gauge and accelerometer results will be trended during power ascension based on direct readings and FFT analysis
- Moisture carryover will be sampled and trended during the approach to full power (new dryer design criterion is 0.1%)

# QC2 May 2005 Planned Outage
## Startup Power Ascension

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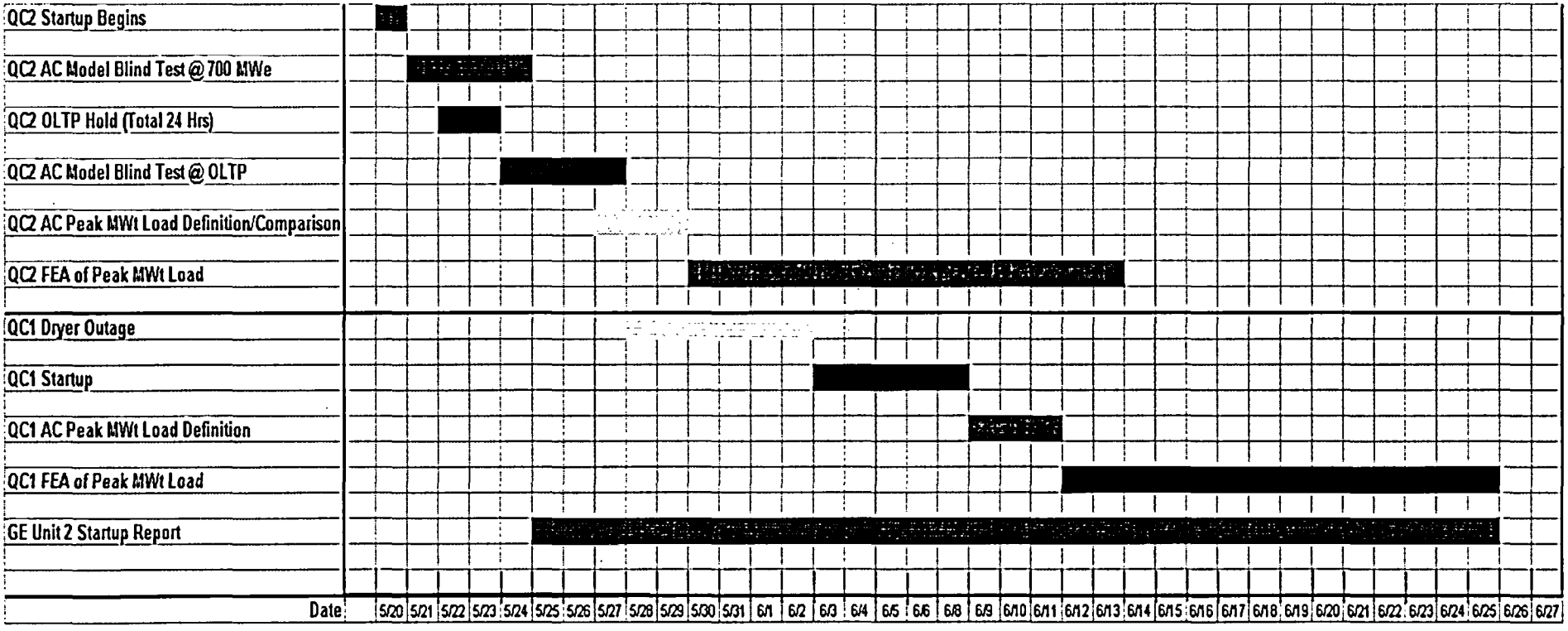

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# QC Operational Plans

Randy Gideon
Plant Manager
Quad Cities Nuclear Power Station

# QC2 Operational Plan

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- Shutdown for QC2 dryer replacement outage on May 9, 2005
  - Outage duration expected to be ~ 10 days
  - Upgrade Target Rock S/RVs
  - Replace dryer
  - Install dryer instrumentation, cabling, and DAS
  - Install MSL strain gauges
  - Confirm instrumentation operation prior to restart

# QC2 Operational Plan (cont.)

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- Execute Startup Test Plan
  - Expect to be at OLTP (2511 MWt) ~ May 21
  - Confirm AC analysis results demonstrate loads are within expected ranges ~ 3 days after OLTP reached
  - Expect to reach full EPU power (2957 MWt or 930 MWe) ~ May 23
    - Operate at this level 5 – 8 hours to collect data
  - Return to 912 MWe ~ May 24
  - Confirm dryer qualification through FEA of instrumented dryer pressure gauge information
- Operate remainder of cycle at 912 MWe, within any limitations identified during startup testing
  - Requires NRC acceptance
  - Continue to monitor strain gauge data throughout the cycle as thermal power increases due to environmental factors to confirm dryer stress is bounded by analytical predictions

# QC2 Operational Plan Basis

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- Rigorous steam dryer qualification provides confidence in integrity during EPU operation
  - Design philosophy that minimizes flow induced vibration susceptibility
  - Diverse loads applied to conservatively bound uncertainty
    - QC1 SMT
    - QC2 in-plant loads
  - Diverse and comprehensive FEMs conservatively bound analysis uncertainty
    - Solid models
    - Weld evaluations
  - Load frequency sensitivity analysis to address model uncertainties
    - Each model run with nominal and +/- 10% shift in time step
  - Hammer test reduces uncertainty in as-built dryer frequency and damping

# QC2 Operational Plan Basis (cont.)

Exelon Nuclear

- Startup Test Plan
  - Instrumented dryer data to confirm analysis load inputs (e.g., frequency and amplitude)
  - Dryer strain gauge data to confirm stress levels remain bounded by predictions
  - MSL strain gauges will be used as an input to AC loads to ensure dryer loads are within expected ranges
  - Dryer data will be trended to address unexpected changes in key monitored parameters (e.g., pressures, accelerations, and strains)
  - If Criterion A limits are exceeded, power will be reduced

# QC2 Operational Plan Basis (cont.)

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- Startup Test Plan (cont.)
  - Monitor reactor parameters for timely identification of issues
  - Other plant equipment will also be monitored to identify adverse conditions (e.g., ERVs, Target Rock S/RV, C MSL, C MSIV, and HPCI valve actuator)
  - Moisture carryover will continue to be monitored in accordance with established protocols and frequencies

# QC1 Operational Plan

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- Outage to replace dryer planned for last week of May 2005
  - Outage duration expected to be ~ 6 days
- Startup Test Plan similar to QC2 (no dryer instrumentation installed)
  - Power ascension to 912 MWe
  - MSL strain gauges will be installed to confirm, using AC analysis, that dryer loads are within expected ranges
- Other plant equipment will also be monitored to identify adverse conditions (e.g., ERVs, Target Rock S/RV, B MSL, B MSIV, HPCI valve actuator)
- Power operation for remainder of cycle at 912 MWe if no limitations identified during startup test or from QC2 instrumented dryer results
  - Requires NRC acceptance

# QC1 Operational Plan Basis

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- QC1 dryer qualification is equally as robust as QC2
- Same design as QC2
  - Hammer test confirmation
- Empirical data shows that QC1 and QC2 loads are similar
- SMT loads used for new dryer design based on QC1 configuration
- AC analysis methodology will be verified using the QC2 data prior to exceeding OLTP for QC1
- MSL strain gauge data will be acquired
  - AC analysis will be performed to confirm dryer loads are consistent with those used in FEA

# QC Operational Plan Basis (cont.)

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- Conclusions
  - Conservative design
  - Extensive evaluations
  - Detailed startup test plans
- EGC has taken the necessary steps for safe EPU operation of QC

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# Regulatory Commitments/ Interactions

Keith Jury
Director, Licensing and Regulatory Affairs

# Regulatory Commitments
## QC1 and QC2

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- After dryer replacement, EGC will continue to conduct daily monitoring of moisture carryover and other key reactor and plant parameters while operating at full power
  - If indications of dryer damage or structural integrity concerns are identified, power will be reduced to OLTP and the issue will be evaluated and dispositioned in accordance with the corrective action process
- Operation at EPU power levels will continue while detailed evaluations of the instrumented data are performed, if the Startup Test Plan acceptance criteria (i.e., go/no-go decisions) are met
  - Operational and analytical insights/results will be shared with the NRC on an on-going basis during periodic updates
  - Detailed evaluations will be completed within 60 days of data collection at 930 MWe
  - EGC will submit the test results within 60 days and meet with the NRC technical staff and management to discuss these results prior to the end of August 2005
  - EGC will obtain NRC acceptance for continuous EPU operation of QC2

# Regulatory Commitments
## QC1 and QC2 (cont.)

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- During the Spring 2006 refueling outage for QC2:
  - EGC will perform a general visual inspection of the RPV internals, steam, and feedwater systems, including inspection and disassembly if needed of the most susceptible components, which include ERVs
  - EGC will conduct an inspection of the QC2 dryer using BWRVIP inspection guidance
- Commitments for QC1 will parallel those for QC2

# Regulatory Commitments
## D2 and D3

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- EGC will use the unbiased MSL strain gauge data from the QC2 instrumented dryer to evaluate the AC model
  - Appropriate action will be taken in response to the application of the test results to the Dresden dryers
- EGC will compare the predicted QC2 dryer loads, developed using the AC model and MSL strain gauge data, with the actual QC2 loads obtained from the instrumented dryer
- EGC will discuss the results of this comparison with the NRC during the July/August meetings; areas to be discussed include:
  - Results of the collected QC2 instrumented dryer data evaluations,
  - Results of SMT of the QC1 steam dryer, and
  - The decision and its basis regarding SMT of the D2 and D3 dryers

# Regulatory Commitments
## D2 and D3 (cont.)

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- During the Fall 2005 refueling outage for D2:
  - EGC will perform a general visual inspection of the RPV internals, steam, and feedwater systems, including inspection and disassembly if needed of the most susceptible components, which include ERVs
  - EGC will conduct an inspection of the D2 dryer using BWRVIP inspection guidance vice GE Service Information Letter 644, Revision 1
  - EGC will attempt to locate and retrieve the lost D2 feedwater sample probe

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# Dryer Weld Issues

Jim Meister
Vice President – Nuclear Services

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# Conclusions

Tim Tulon

Site Vice President

Quad Cities Nuclear Power Station