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Quad Cities Replacement Steam Dryer Meeting

August 29 – September 1, 2005

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Introduction

Thomas Roddey
Licensing Engineer

Agenda

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- Introduction
- Opening Remarks
- Quad Cities Unit 2 (QC2) Startup Test Report
- QC1 Startup Test Report
- Engineering Evaluation Summary
- Scale Model Test (SMT)
- Acoustic Circuit Model (ACM) and Refinements
- Main Steam Line (MSL) Strain Gauge Evaluation
- Uncertainty Evaluation
- QC2 and QC1 Load Definition
- Structural Analysis Summary
- QC2 and QC1 Dryer Structural Analysis
- Dresden Steam Dryer Replacement Overview
- Summary and Conclusions
- Open Items
- Closing Remarks

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Opening Remarks

Roman Gesior

Director – Asset Management

Opening Remarks

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- Exelon previously presented the basis for two design loads, startup test plans, startup test results, and load methodology validation for the QC replacement steam dryers
- Results for the steam path data collection during startup testing for both QC units demonstrated a need to perform a detailed load definition and finite element analysis (FEA) to validate structural adequacy at full extended power uprate (EPU) power levels

Opening Remarks (cont.)

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- QC2
  - Refinements to ACM and SMT methodologies are completed or in-progress
  - For QC2 load definition, the modified 930 megawatts-electric (MWe) ACM was used and provided conservative loads
  - Analysis of the overall dryer and skirt demonstrate that the QC2 dryer is structurally adequate for the full range of operation, including EPU power levels
  - Uncertainty analysis for data collection, load definition, and finite element analysis was completed
    - Overall methodology uncertainty was determined to be <5% in the non-conservative direction, with the majority of the uncertainty being in the conservative direction

Opening Remarks (cont.)

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- QC1
  - During data collection on QC1, strain gauge failures required data adjustments to produce load definition inputs; these adjustments were evaluated to be conservative and appropriate
  - For the QC1 dryer load definition, the modified 930 MWe ACM was used and provided conservative loads; skirt load definition used the minimum error ACM, shown to be the best methodology for load definitions to date
  - Analysis of the overall dryer and skirt demonstrate that the QC1 dryer is structurally adequate for the full range of operation, including EPU power levels

Opening Remarks

Summary

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- The engineering design and evaluation approach has been implemented as previously communicated to the NRC
- Results of engineering evaluations demonstrate adequate structural margin for both QC units
- The methodology and approach can also be implemented for the Dresden units

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QC2 Startup Test Report

Brian Strub
Design Engineer
Quad Cities Nuclear Power Station

Instrumented Steam Path

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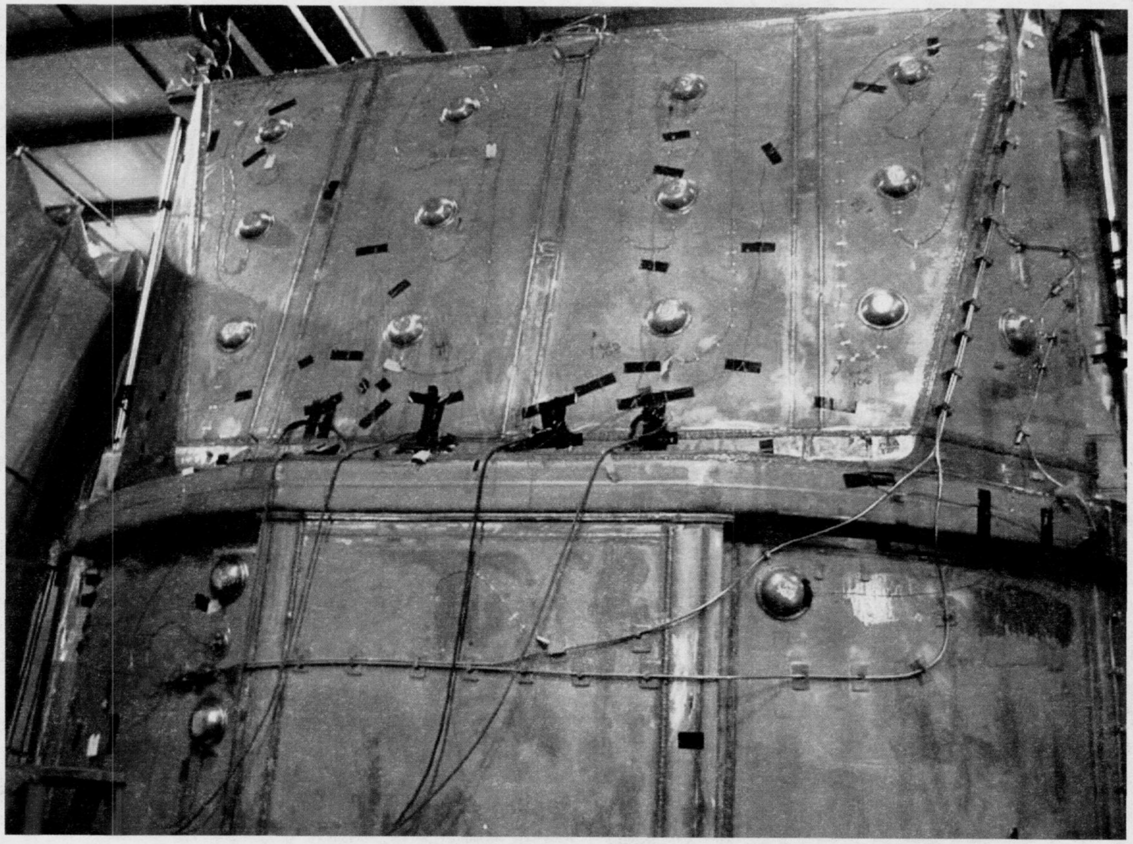
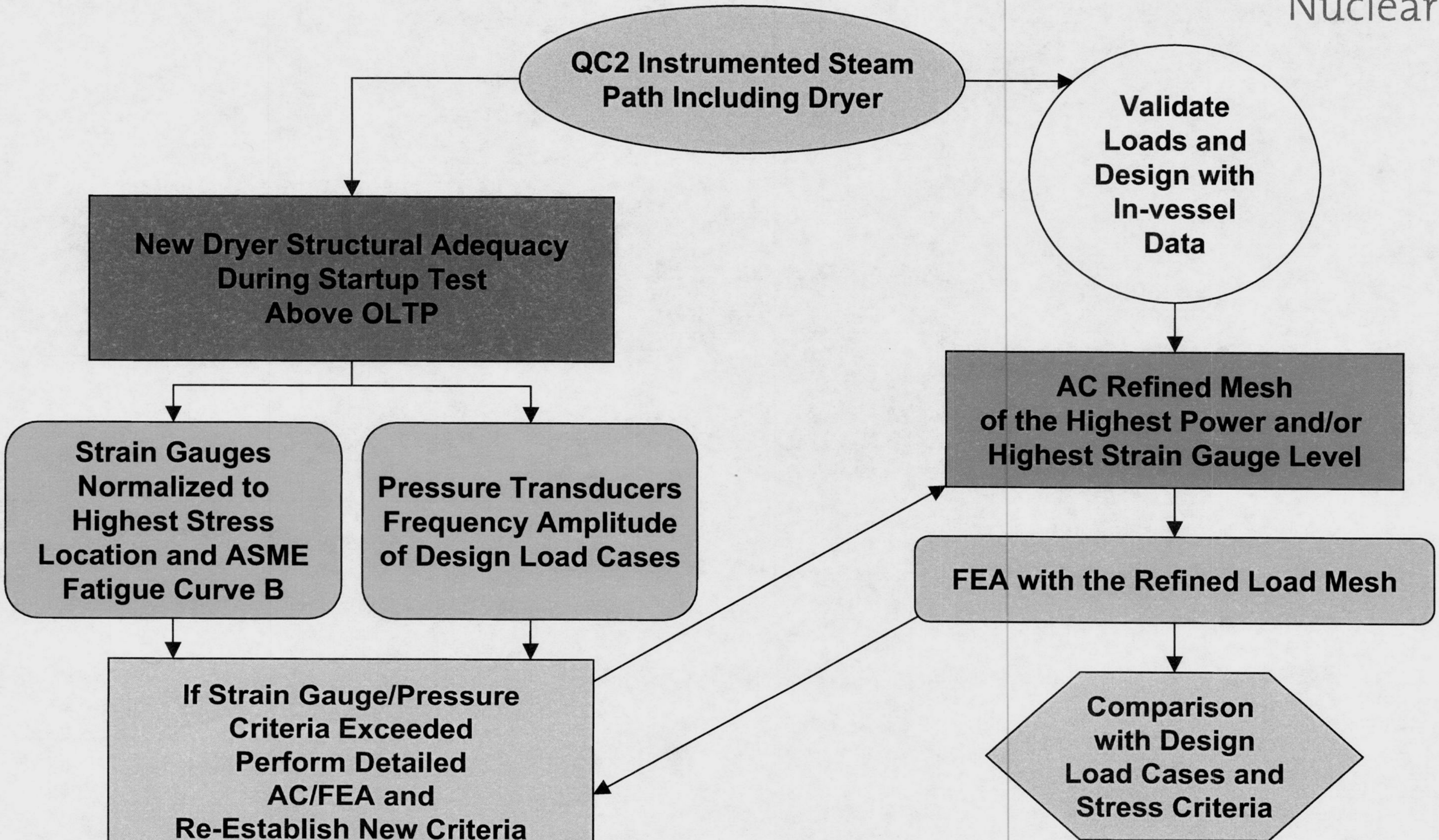


Instrumented New Dryer Face

- Most heavily instrumented dryer in the industry
  - 42 dryer sensors
  - 56 MSL strain gauges
  - 33 MSL accelerometers
- Uses of data
  - Go/no-go criteria
  - Develop actual dryer loads
  - Validate SMT and ACM
  - Validate design load

QC2 Startup Test Strategy



QC2 Data Collection Results

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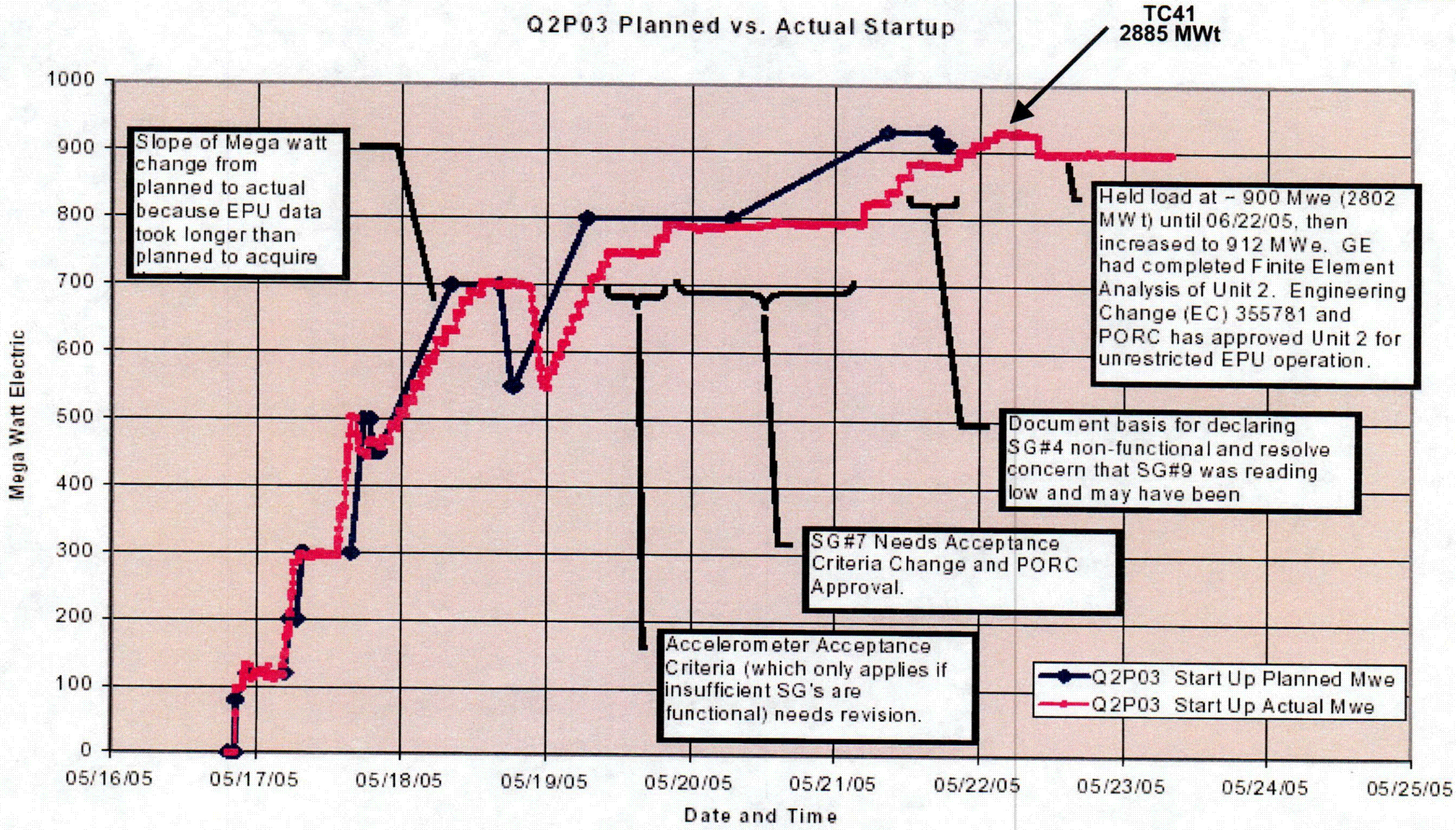

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QC2 Data Collection Results (cont.)

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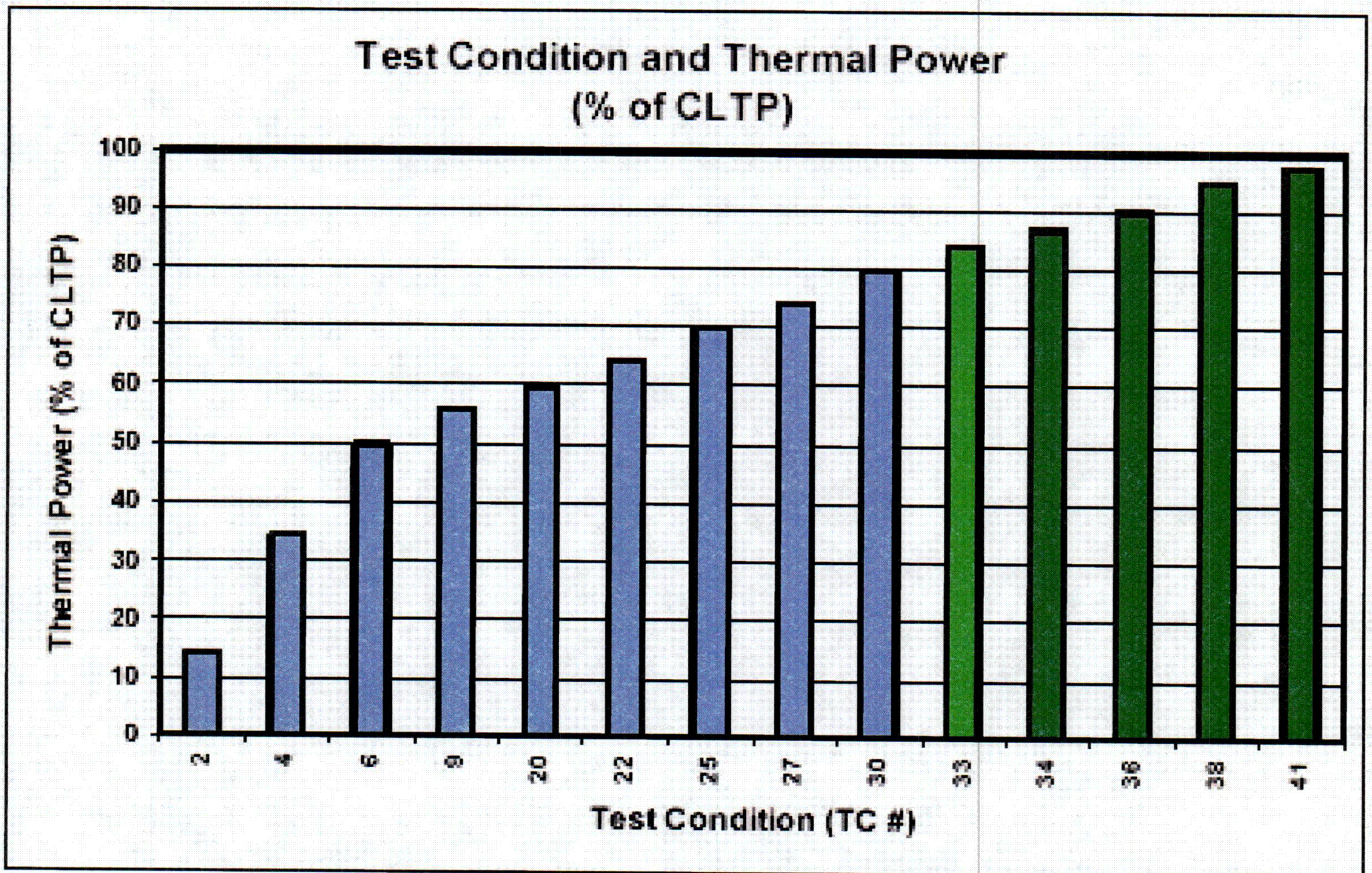

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QC2 Data Collection Results (cont.)

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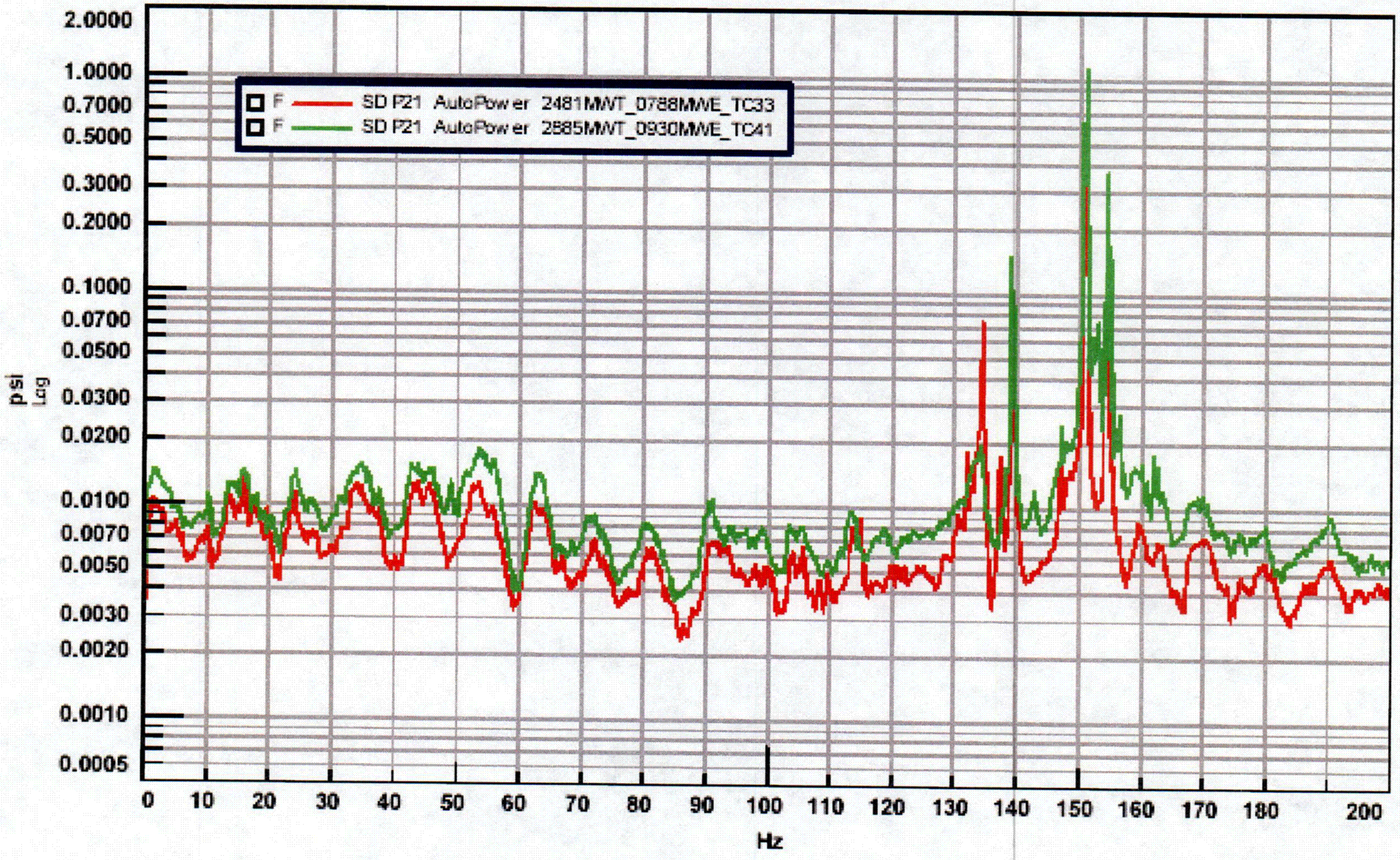

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QC2 Startup

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- Results in startup test report
  - Strain gauge #7 exceeded Level 2 Criteria
    - Full load definition and FEA completed for structural evaluation
  - Pressure data trended
  - Accelerometer data trended
  - Moisture carryover – initially exceeded 0.09% then stabilized below 0.08%
  - Reactor water level – no anomalies noted
  - MSL flow rates – no anomalies noted
  - Feedwater flow – no anomalies noted
  - Steam flow/feedwater flow/reactor power comparison – no anomalies noted

QC2 Data Collection Results (cont.)

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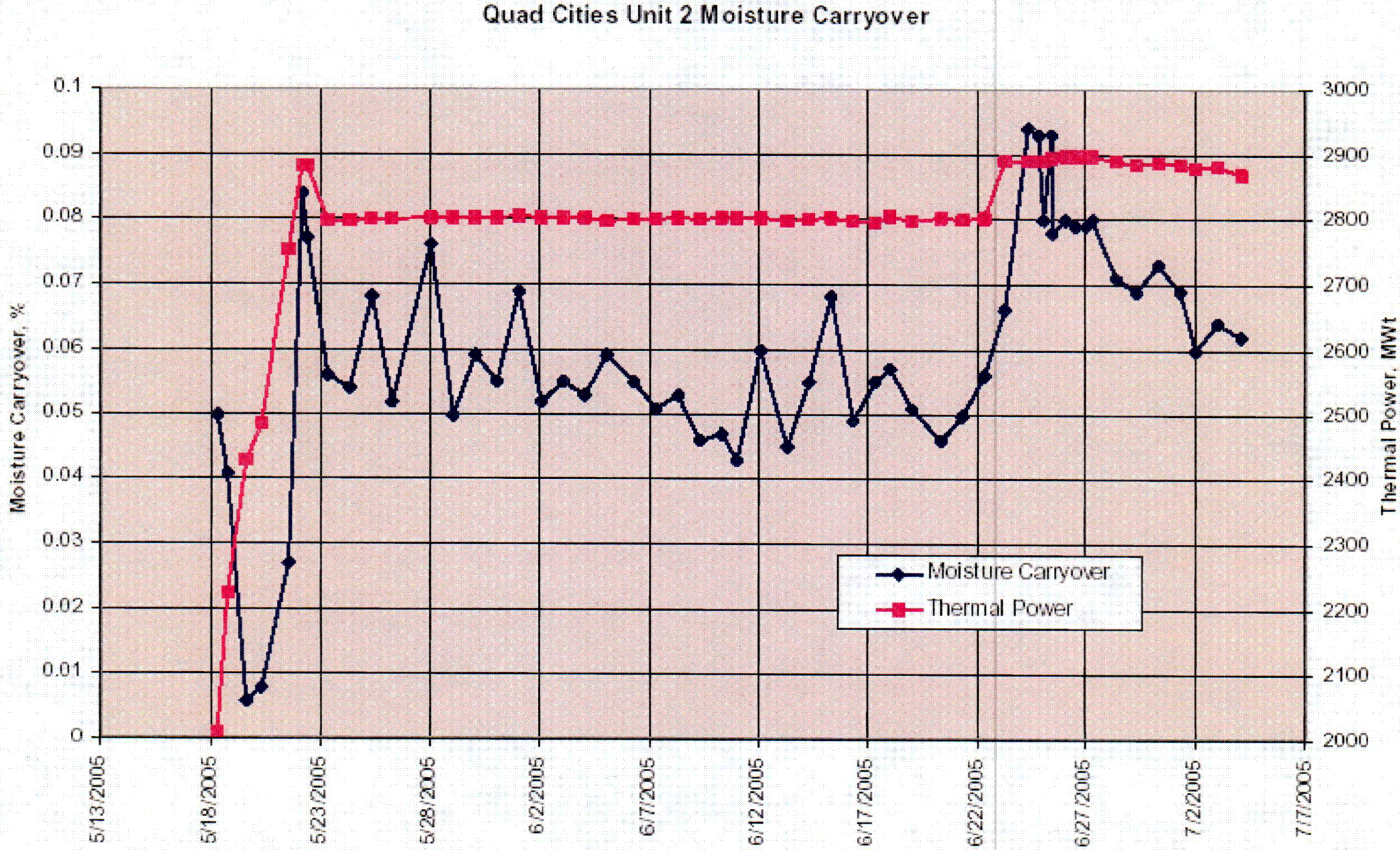

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QC2 Vibration Assessment

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- Acceptability of ERV components at EPU
  - Four new QC2 ERVs have identical assemblies to QC1
  - Valve assembly hardened with X750
  - QC2 vibration levels are bounded – Wiley Labs test qualification data
- High Pressure Coolant Injection (HPCI) system -4 valve operator
  - Vibration data collected shows unit 2 to be bounded based on original evaluation and laboratory qualification testing
- MSIVs
  - Vibration data collected shows QC2 to be bounded, based on original evaluation and laboratory qualification testing
- Small bore piping/feedwater sample probes
  - Meet Exelon Engineering Standard NES-MS-03-04
  - Feedwater probe inspection showed probe was intact
  - New probe: 2" vs. 13"

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QC1 Startup Test Report

Brian Strub
Design Engineer
Quad Cities Nuclear Power Station

QC1 Data Collection

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- MSL strain gauges were re-configured to more closely match the QC2 configuration
- For the first data collection during the QC1 startup following dryer replacement, a total of five strain gauges failed – S3, S6, S11A, S31, and S36

QC1 Data Collection

Strain Gauge Configuration – Startup

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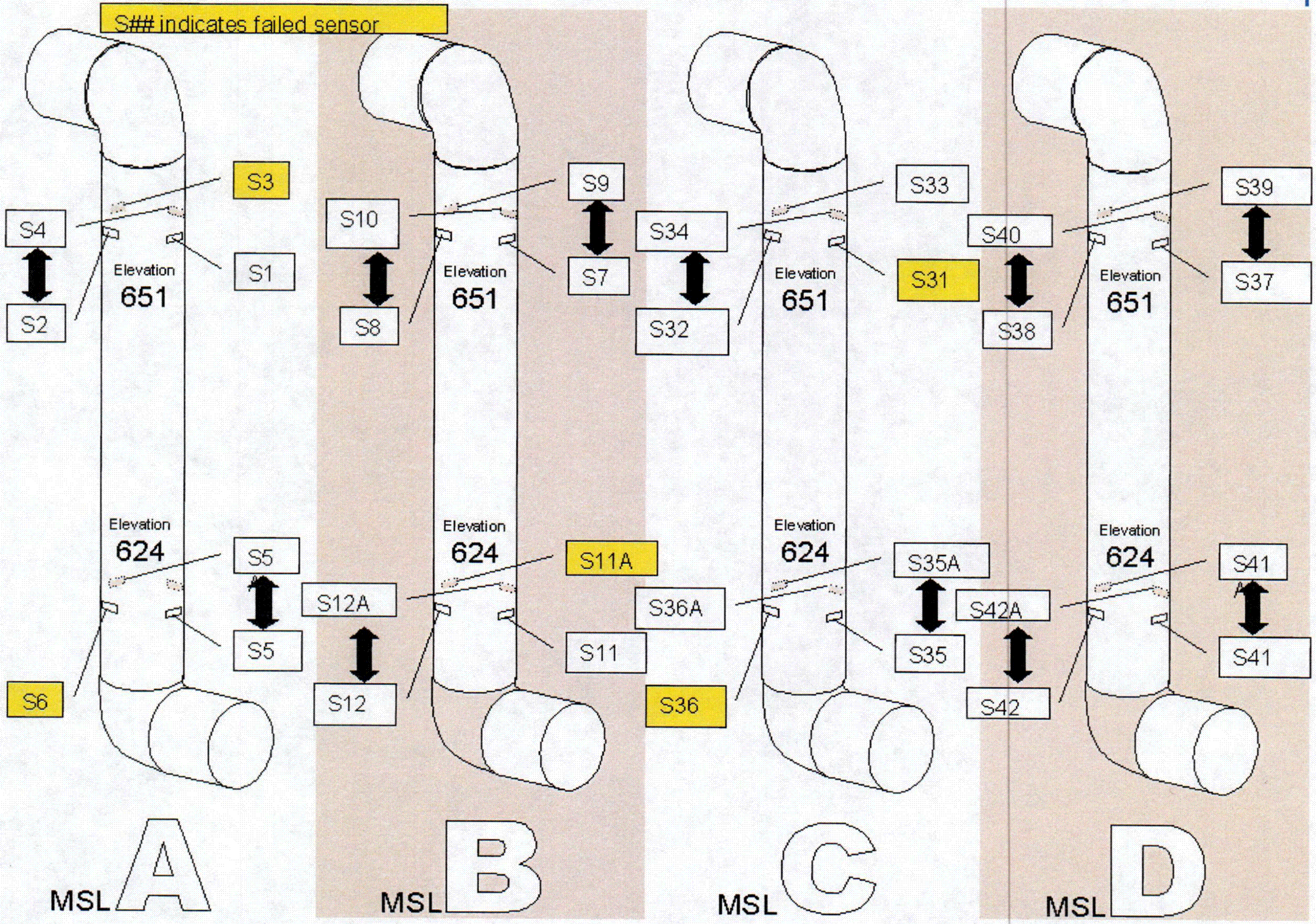

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QC1 Data Collection Results

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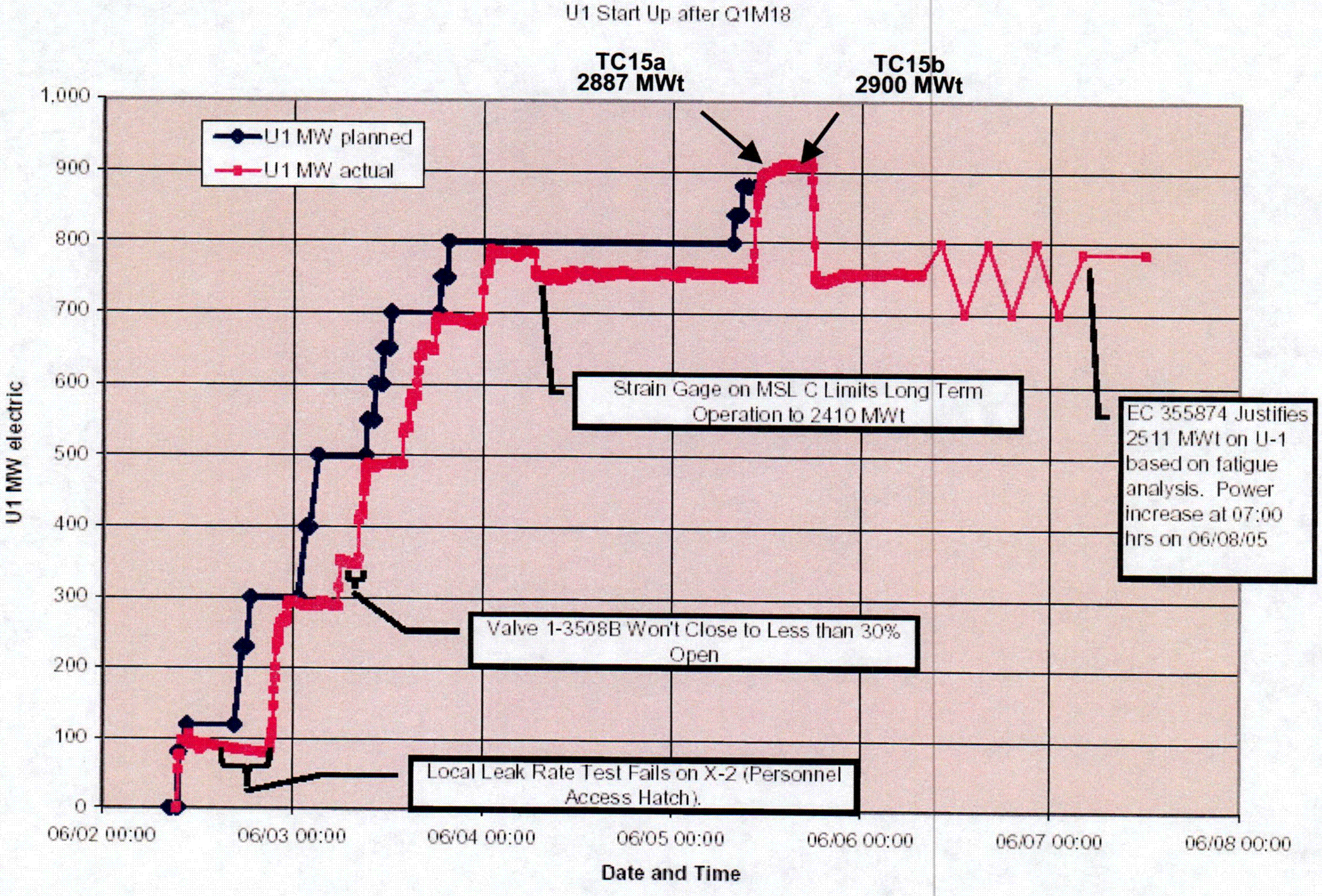

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QC1 Data Collection Results (cont.)

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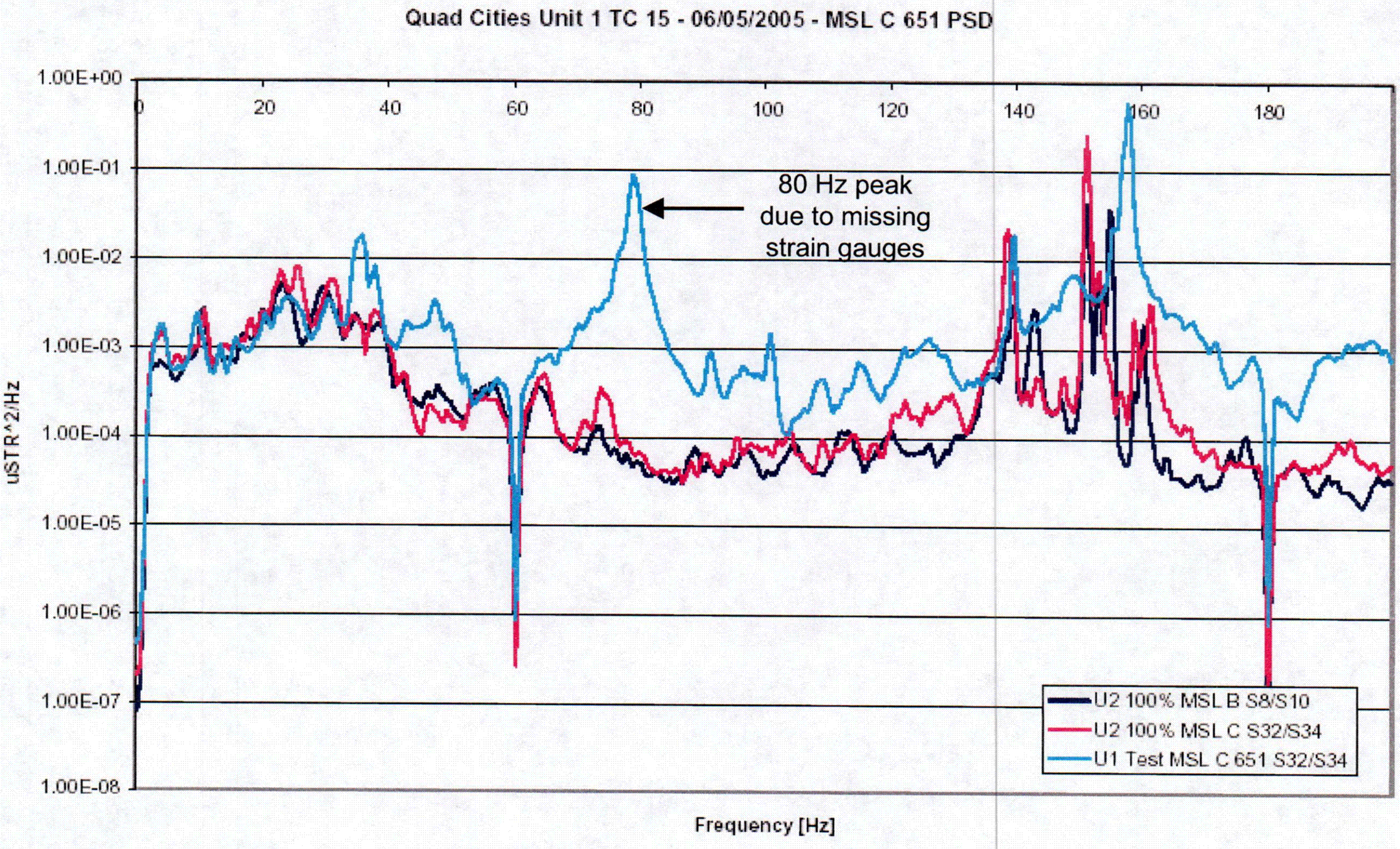

C-07

QC1 Startup

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- Results in startup test report
  - MSL C strain gauge at 651 elevation exceeded Level 1 Criteria
    - Fatigue evaluation completed to allow data collection at Full EPU
  - Moisture carryover – no anomalies noted
  - Reactor water level – no anomalies noted
  - MSL flow rates – no anomalies noted
  - Feedwater flow – no anomalies noted
  - Steam flow/feedwater flow/reactor power comparison – no anomalies noted

QC1 Vibration Assessment

Exelon Nuclear

- Acceptability of ERV Components at EPU
  - 4 QC1 ERVs have identical assemblies to Unit 2
  - Valve assembly hardened with X750
  - Unit 1 vibration levels are bounded by testing – Wiley Labs test qualification data
- HPCI 4 Valve Operator
  - Vibration data collected shows QC1 to be bounded based on original evaluation and laboratory qualification testing
- MSIVs
  - Vibration data collected shows QC1 to be bounded based on original evaluation and laboratory qualification testing
- Small bore piping/feedwater sample probes
  - Meet Exelon Engineering Standard NES-MS-03-04
  - Feedwater probe inspection showed probe was intact
  - New probe: 2" vs. 13"

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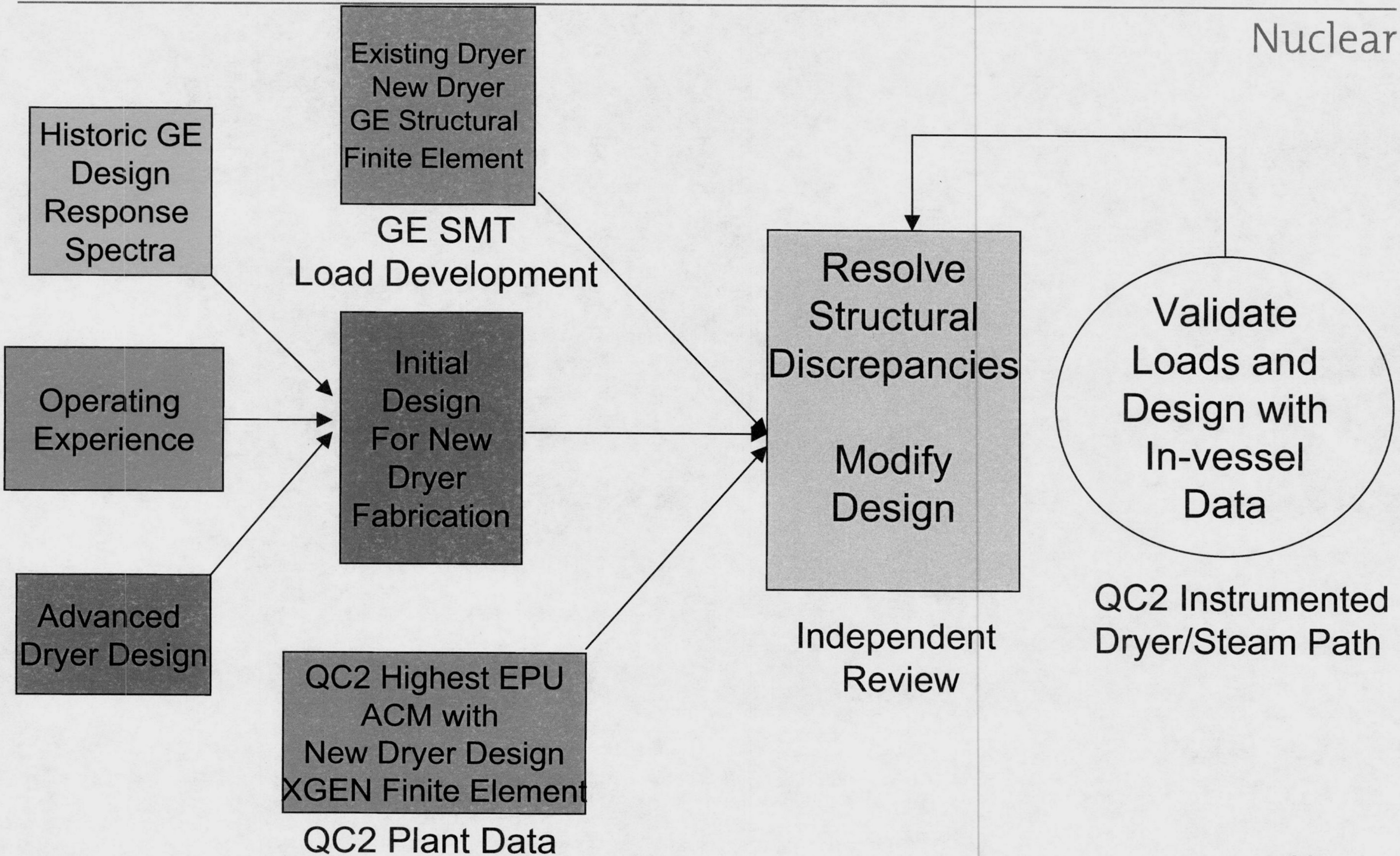
Engineering Evaluation Summary

Keith Moser

Asset Management Engineer

New Dryer Design Strategy



Engineering Evaluation
Summary (cont.)

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- New dryer design loads:
  - QC1 SMT
  - QC2 In-plant loads – ACM
    - Actual QC2 steam dryer pressure measurements had enough difference from design loads (see figure on next page) to require a new load definition based on QC2 startup data and detailed FEA
- SMT
  - Comparisons show conservative correlation up to 135 Hz
  - GE/Exelon pursuing QC2 model refinement
- ACM
  - Model refinements completed based on QC2 instrumented steam path
    - Detailed load cases have been created for QC2 and QC1 based on ACM
- FEA
  - Modeling improvements made to better match as-built conditions – QC1
  - Results show both QC2 and QC1 are structurally acceptable for EPU operation

QC2 Data Collection Results (cont.)

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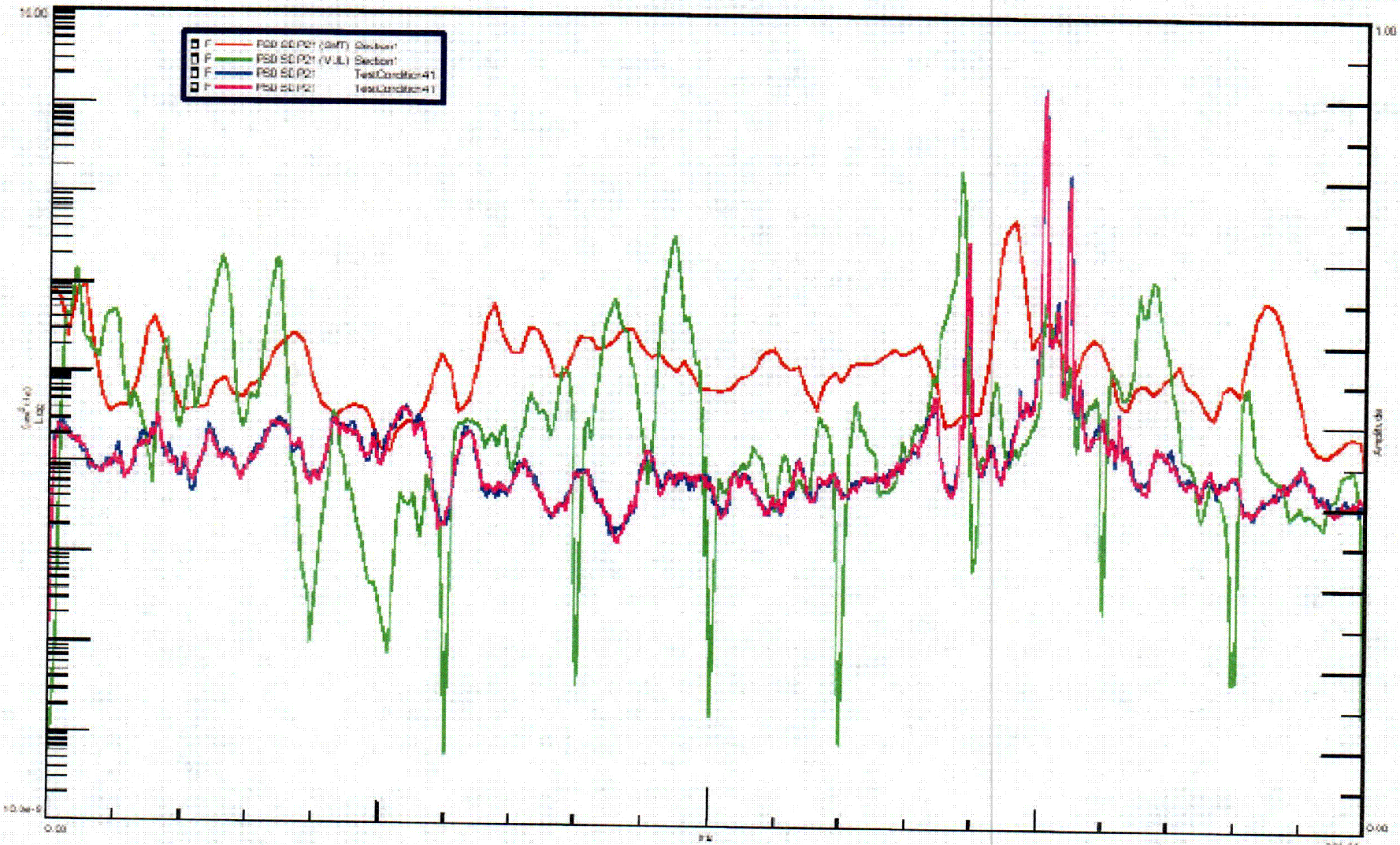

P21 Spectral Overlay with SMT and VUL at TC 41

C-08

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SMT

Daniel Sommerville

General Electric

This presentation contains information that is proprietary to General Electric

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ACM and Refinements

Kevin Ramsden
Senior Staff Engineer

Exelon Nuclear

- QC2 instrumented steam path provided a validation of load definition models
  - As planned, Exelon provided the MSL strain gauge data to Continuum Dynamics, Inc. (CDI) at 790 MWe and 930 MWe without providing the 6 key pressure transducer data on the dryer until the first ACM predictions were made.
    - At both power levels, a refinement to the model was made to better match the data and Exelon's acceptance criteria
    - The end result was the Modified 930 MWe ACM that was used for QC2 dryer/skirt and QC1 dryer load definition
  - After the initial ACM refinements were completed, the data from all 26 dryer pressure transducers were provided to CDI to develop the best ACM
    - The first AC model was a least squares approach with the 26 pressure transducers
    - The next refinement involved including the MSL strain gauge data, which resulted in the minimum error ACM
      - This was used for the QC1 FEA of the dryer skirt

ACM – Refinements

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- First ACM – QC2 790 MWe evaluation
  - Model parameters set to values used for QC2 new dryer design load
  - Only in-plane MSL strain gauges were used for inputs
    - Resulted in additional frequency content when compared to actual pressure transducer results on the dryer
- Second ACM – QC2 790 MWe evaluation
  - Most significant change was to use both sets of MSL strain gauge pairs as input
  - Additional changes to the model included the following:
    - 60 Hz spike was filtered from the MSL strain gauge data
    - Damping was adjusted at the steam-water interface, steam dome, and MSLs
    - Acoustic speed of sound was adjust to 1484.33 feet per second (ft/s) in accordance with ASME steam tables at 1000 pounds force per square inch absolute (psia)

ACM – Refinements (cont.)

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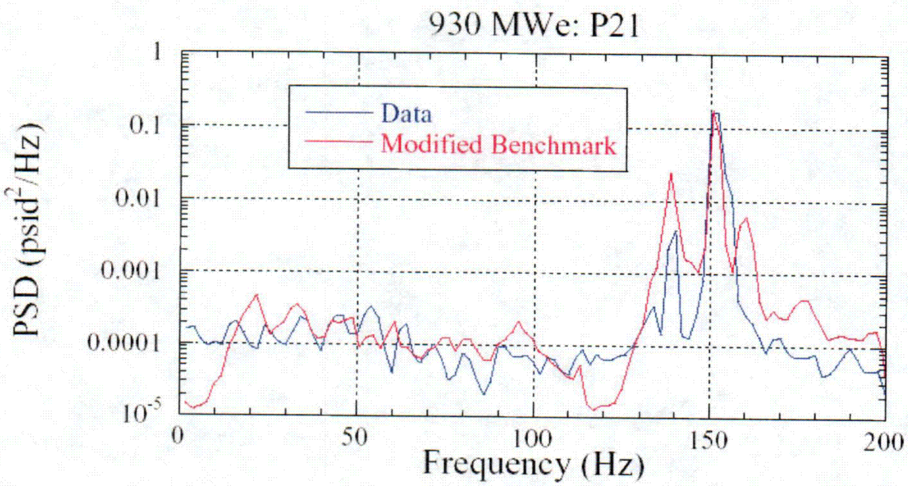
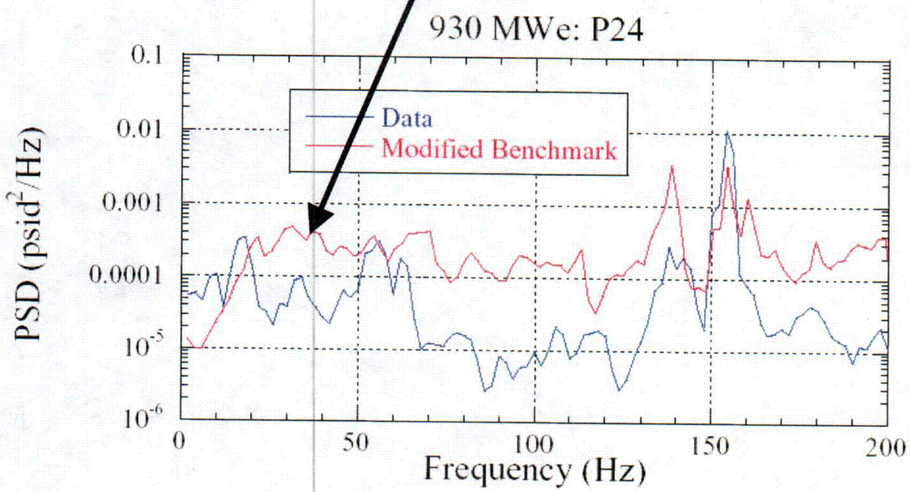
- Third ACM – QC2 930 MWe evaluation
  - Same model as the 2nd QC2 790 MWe evaluation
    - Under-predicted P-21
- Fourth ACM – QC2 930 MWe evaluation
  - Damping in the MSLs was increased by 20%
    - Resulted in the prediction for P-21 to be within the pre-defined acceptance criteria
    - Skirt loads were over-predicted at the skirts natural frequency





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ACM – Refinements (cont.)

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- Fifth ACM – QC2 930 MWe evaluation
  - 26 steam dryer pressure sensors used as input
  - Previous model parameter for Helmholtz solution from fourth ACM evaluation remained the same
  - The approach was to minimize the error by using a least squares methodology as outlined below

$$\text{Error}(\omega) = \sum_{n=1}^{26}[P_{pred}(\omega) - P_{data}(\omega)]^2$$

Where: ω = Frequency

- This methodology resulted in over-predictions at frequencies which create dynamic structural responses on dryer components

ACM – Refinements (cont.)

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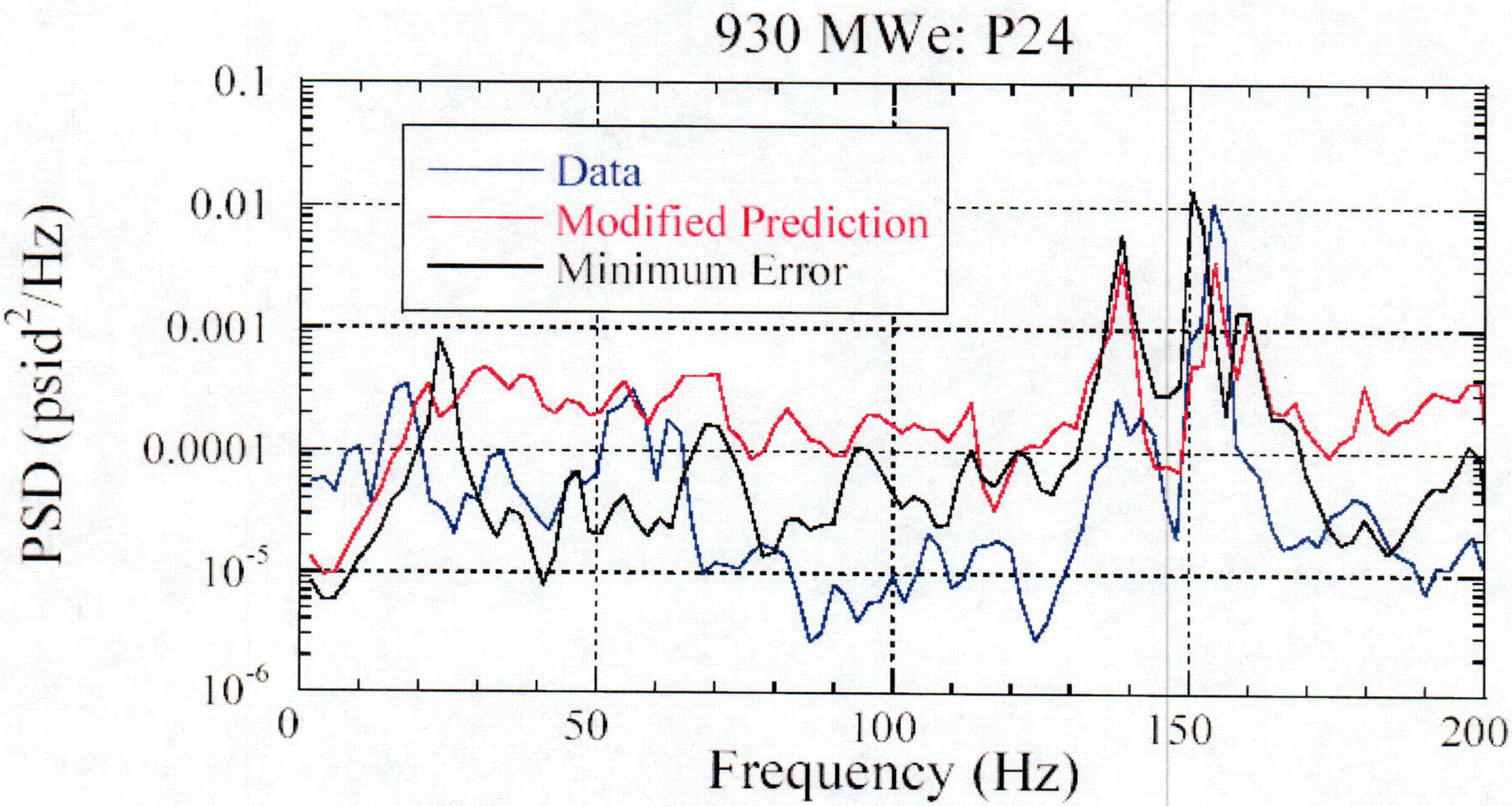
- Minimum error – QC1 skirt evaluation
  - Sixth ACM – QC2 930 MWe evaluation
    - To improve the QC2 least squares approach using 26 steam dryer pressure transducers, the sixth model used eight MSL strain gauge locations and 26 steam dryer pressure transducers as drivers for the model
    - The steam dome Helmholtz solution was refined to more accurately compute the skirt loads

$$\text{Error} = \sum_{\omega=0}^{\Omega} \sum_{N=1}^{27} W\left[P_{pred}(\omega) - P_{data}(\omega)\right]^2$$

ACM – Refinements (cont.)

- Minimum error ACM comparison to modified 930 MWe ACM and dryer data for the skirt P24 sensor



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ACM – Minimum Error (cont.)

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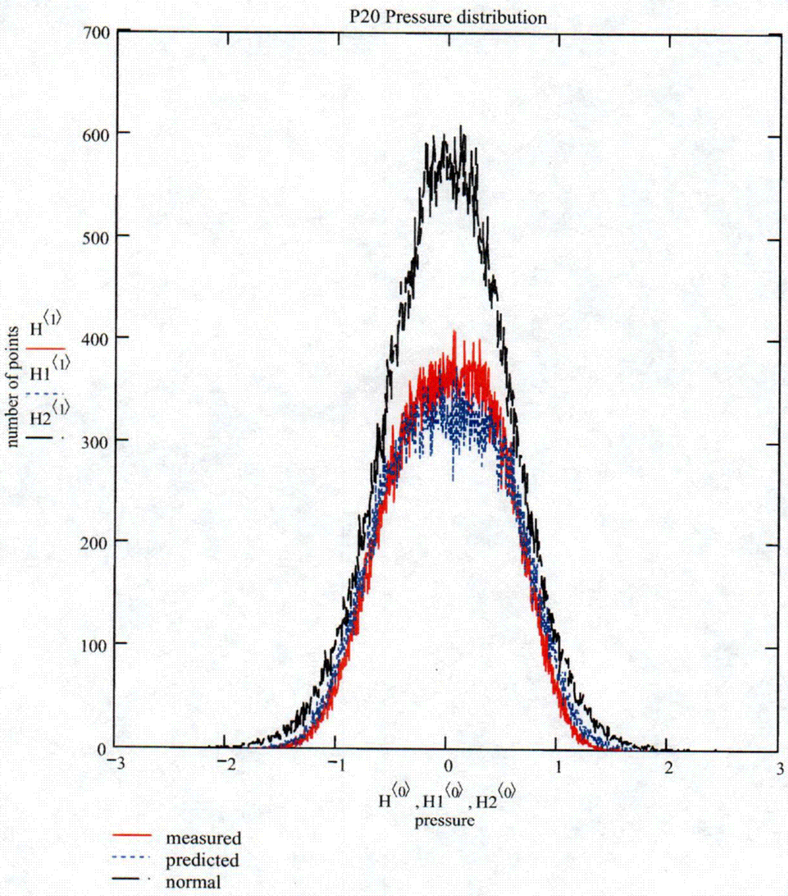

- Pressure distribution
  - Performed histograms of pressures, irrespective of time
  - Compared histograms to Gaussian distributions
    - See Figure for P20
  - Determined that pressure distributions can be represented by a normal distribution
  - Used statistical evaluation
    - Data population capture
    - Confidence levels

C-11

ACM – Minimum Error (cont.)

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- Pressure distribution results
  - Two-sided 95-95 tolerance limit equals 1.96 x standard deviation
    - 95% of the total population is captured with a 95% confidence level
  - 18 of the 26 pressure locations meet 95-95 tolerance limit
    - P7 is slightly below the 95-95 tolerance limit
    - P14/P26 are located inside the dryer and under-predictions produce conservative results as this yields a higher pressure differential on the dryer face
    - P16/P26 and P27 are in low pressure areas with very low pressure oscillations
      - not significant to the dryer structural response
    - P2/P11 meet 95-90 tolerance limit

ACM – Minimum Error (cont.)

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- Conclusions for the minimum error ACM
  - The pressure distribution can be represented by Gaussian distribution functions
  - With two exceptions, 95-95 confidence limits were met at significant locations
  - The two exceptions meet a 95-90 confidence limit
  - A more representative skirt loading has been achieved with this ACM
  - This load methodology is acceptable for the entire dryer
    - Used to confirm stresses on QC1 skirt are acceptable
  - The load methodology with resulting damping values for MSLs, steam dome, and steam-water interface developed on the instrumented steam path for QC2 can be used for QC1, D2, and D3

ACM Methodology

Typical Uncertainties

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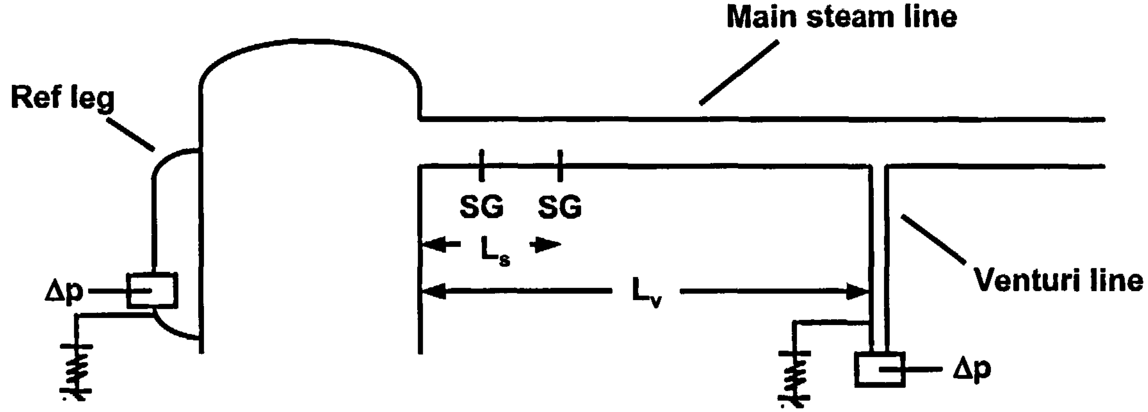

Uncertainty Source	Typical Uncertainty	Typical Sensitivity to Steam Dryer Load
Strain gauge measurement	5-10%	0.6
Reference leg/venturi DP measurement	5%	
Instrumental line transfer function	177% or less	
Pressure uncertainty due to compliance	25% or less	
Instrument location	Up to 50%	

ACM Validation
Parameter Changes: QC2 Data

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Data Set for Evaluation	Steam/Water Interface Ratio	Steam Dome Damping Ratio	Steam Line Damping Ratio	Acoustic Speed Ratio	Input Data	Average Error on RSD of RMS	Comments
790 MWe Blind	0.93	20.0	0.0	1.08	8 strain gages: in-plane pairs only	4 pressure sensors: 0.136	After receipt of dryer data: P3, P12, P20, P21
790 MWe Modified	1.0	4.0	1.5	1.0	8 strain gages: average all pairs, filter 60 Hz	4 pressure sensors: 0.359	Trial and error to meet acceptance criteria on P3, P12, P20, P21
930 MWe Blind	1.0	4.0	1.5	1.0	8 strain gages: average all pairs, filter 60 Hz	4 pressure sensors: 0.113	After receipt of dryer data: P3, P12, P20, P21
930 MWe Modified	1.0	4.0	1.8	1.0	8 strain gages: average all pairs, filter 60 Hz	4 pressure sensors: 0.130	Trial and error to meet acceptance criteria on P3, P12, P20, P21
Least Squares Dryer Data	1.0	4.0	Not Applicable	1.0	27 pressure sensors	4 pressure sensors: 0.095	Singular Value Decomposition (SVD) to minimize error*
Least Squares All Data	1.0	1.0	1.0	1.0	8 strain gages: average all pairs, filter 60 Hz + 27 pressure sensors	4 pressure sensors: 0.152	SVD to minimize error*

* W. H. Press, S. A. Teukolsky, W. T. Vetterling and B. P. Flannery. 1992. Numerical Recipes in FORTRAN: The Art of Scientific Computing (Second Edition). Cambridge University Press.

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MSL Strain Gauge Evaluation

Karen Fujikawa
Structural Integrity Associates

Overview

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- Data collection for the QC1 startup following the steam dryer replacement had five strain gauges fail
  - S3, S6, S11A, S31, and S36
- Each strain gauge location consisted of four strain gauges installed 90° apart
- Each pair of strain gauges located 180° apart were installed in opposite arms of a Wheatstone bridge (½ bridge configuration)
- The Wheatstone bridge was reconfigured into a ¼ bridge for each location with a failed strain gauge

Overview (cont.)

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- To account for local shell effects, both ½ bridges at each MSL location were averaged together and the resultant strain measurement was converted to a dynamic pressure
- For locations where a strain gauge failed, the resultant strain measurement was determined by combining the ¼ and ½ bridge data
- An evaluation was performed to assess the effect of losing five strain gauges at QC1

Evaluation

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- Due to similarities between QC1 and QC2, the strain gauge measurements can be compared and used to validate combining ¼ and ½ bridge
- Structural characteristics between the two units are comparable
  - MSL pipe characteristics
  - Frequency content and magnitude
  - Time history characteristics (root mean square (RMS), max, min)
  - Relationship between orthogonal planes (i.e., cross spectral density (CSD))
- ¼ bridge data obtained for QC2 was compared to equivalent ½ bridge data

Strain Gauge Locations

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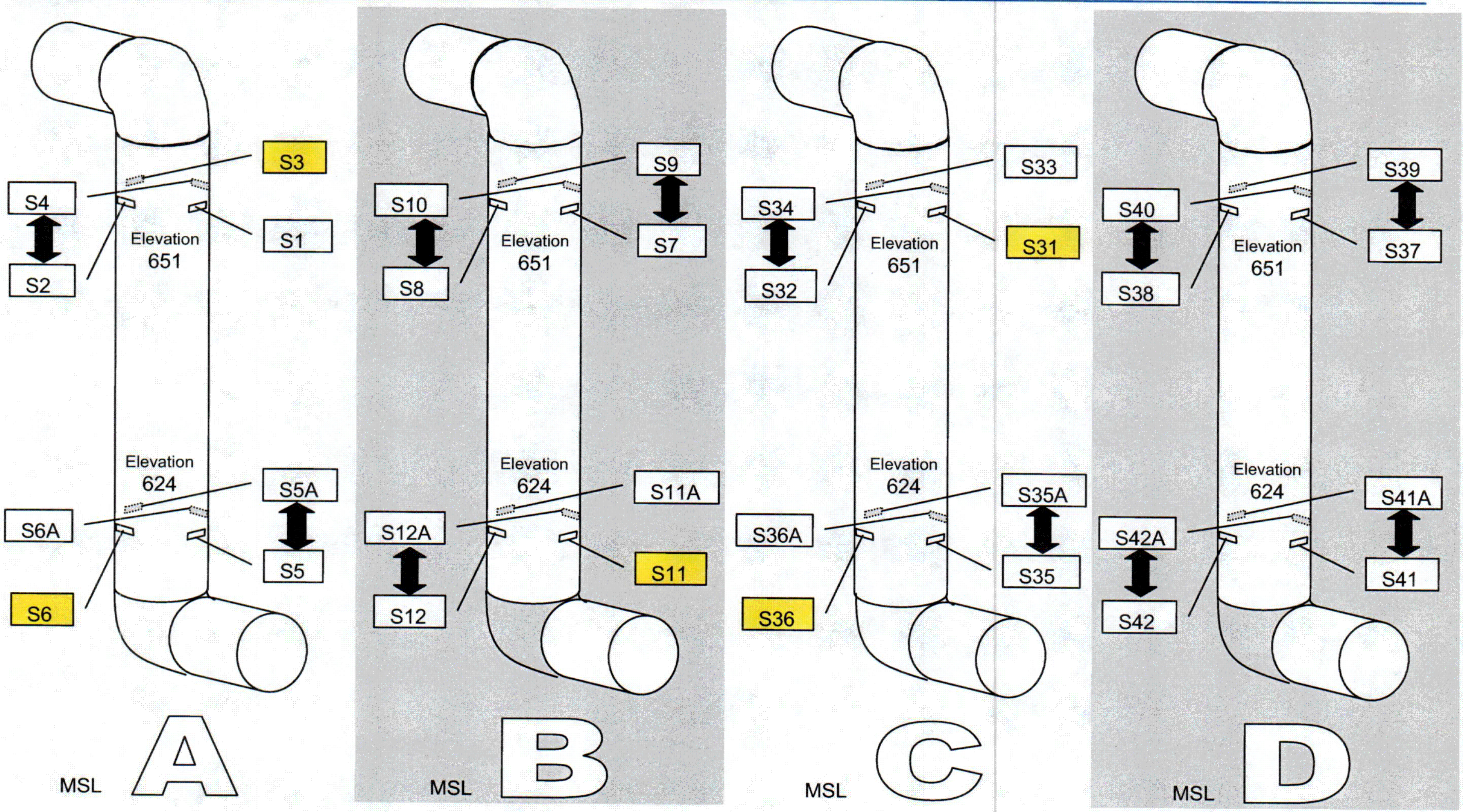

Legend: - Failed SG - Half Bridge

C-12

MSL Pipe Characteristics

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- MSL piping for both units are essentially identical except for some valve locations and the HPCI connection
- Pipe size, material, configuration, and relationship to the reactor pressure vessel are the same
- Dynamic response will be similar; specifically, for a similar excitation, the piping will respond the same and provide similar vibration and acoustic measurements

QC1 and QC2 Spectra Comparison

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- Profiles of the spectra are similar
  - Overall amplitudes across the spectrum are the same except
    - QC1 A651, QC1 C651, QC1 D651 – where each has relatively higher amplitudes at 78.6 Hz and 157.7 Hz
  - Predominant frequencies are similar between the units
    - QC1 frequencies – 23, 78.6, 138.7, and 157.7 Hz
    - QC2 frequencies – 23, 139.2, 150.9, and 154.8 Hz

QC1 and QC2 Spectra – Typical

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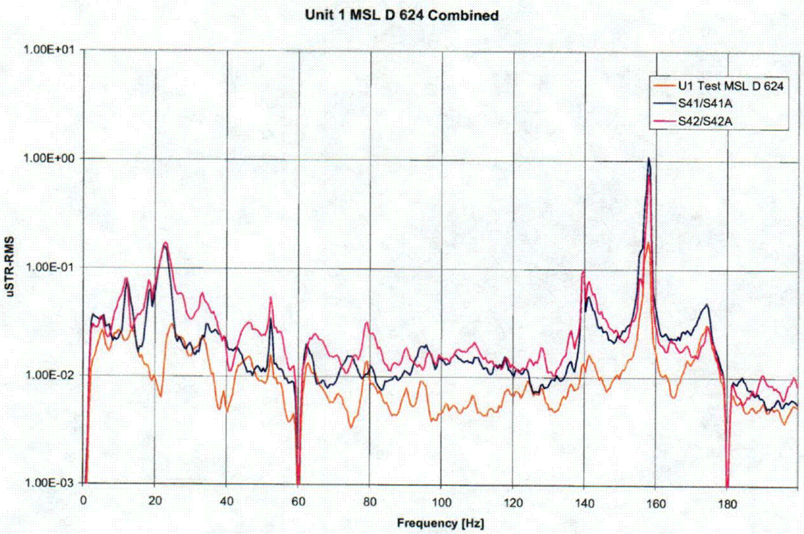
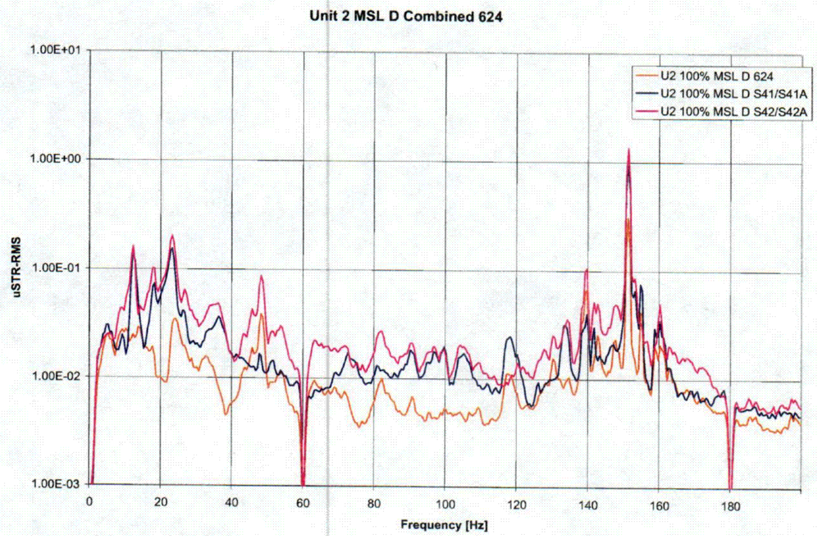
QC1 D624



QC2 D624



Comparison of QC1 and QC2 frequency spectra shows similar frequency content and magnitude

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QC1 and QC2 RMS Comparison

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QC1			QC2		
Description	**RMS**	**RMSavg**	**Description**	**RMS**	**RMSavg**
S1 A651	0.678	———	S1/S3 A651	0.305	———
S2/S4 A651	0.459	0.49	S2/S4 A651	0.422	0.572
S5/S5A A624	0.303	———	S5/S5A A624	0.914	———
S6A A624	0.885	0.876	S6/S6A A624	1.223	1.151
S7/S9 B651	0.242	———	S7/S9 B651	0.323	———
S8/S10 B651	0.361	0.216	S8/S10 B651	0.416	0.333
S11 B624	0.314	———	S11/S11A B624	0.319	———
S12/S12A B624	0.353	0.34	S12/S12A B624	0.337	0.399
S33 C651	0.401	———	S31/S33 C651	0.25	———
S32/S34 C651	1.11	0.69	S32/S34 C651	0.593	0.593
S35/S35A C624	0.371	———	S35/S35A C624	0.272	———
S36A C624	0.444	0.33	S36/S36A C624	0.399	0.319
S37/S39 D651	0.256	———	S37/S39 D651	0.449	———
S38/S40 D651	0.397	0.237	S38/S40 D651	0.572	0.344
S41/S41A D624	1.382	———	S41/S41A D624	1.151	———
S42/S42A D624	1.036	0.325	S42/S42A D624	1.512	0.427
	RMSavg	0.438		**RMSavg**	0.517
Total rms	8.993		**Total rms**	9.456	
RMS Avg	0.562		**RMS Avg**	0.591	
RMS IP avg	0.493		**RMS IP avg**	0.498	
RMS OP avg	0.631		**RMS OP avg**	0.684	

Comparison of QC1 and QC2 shows the difference is less than 18%

QC1 and QC2 RMS Comparison (cont.)

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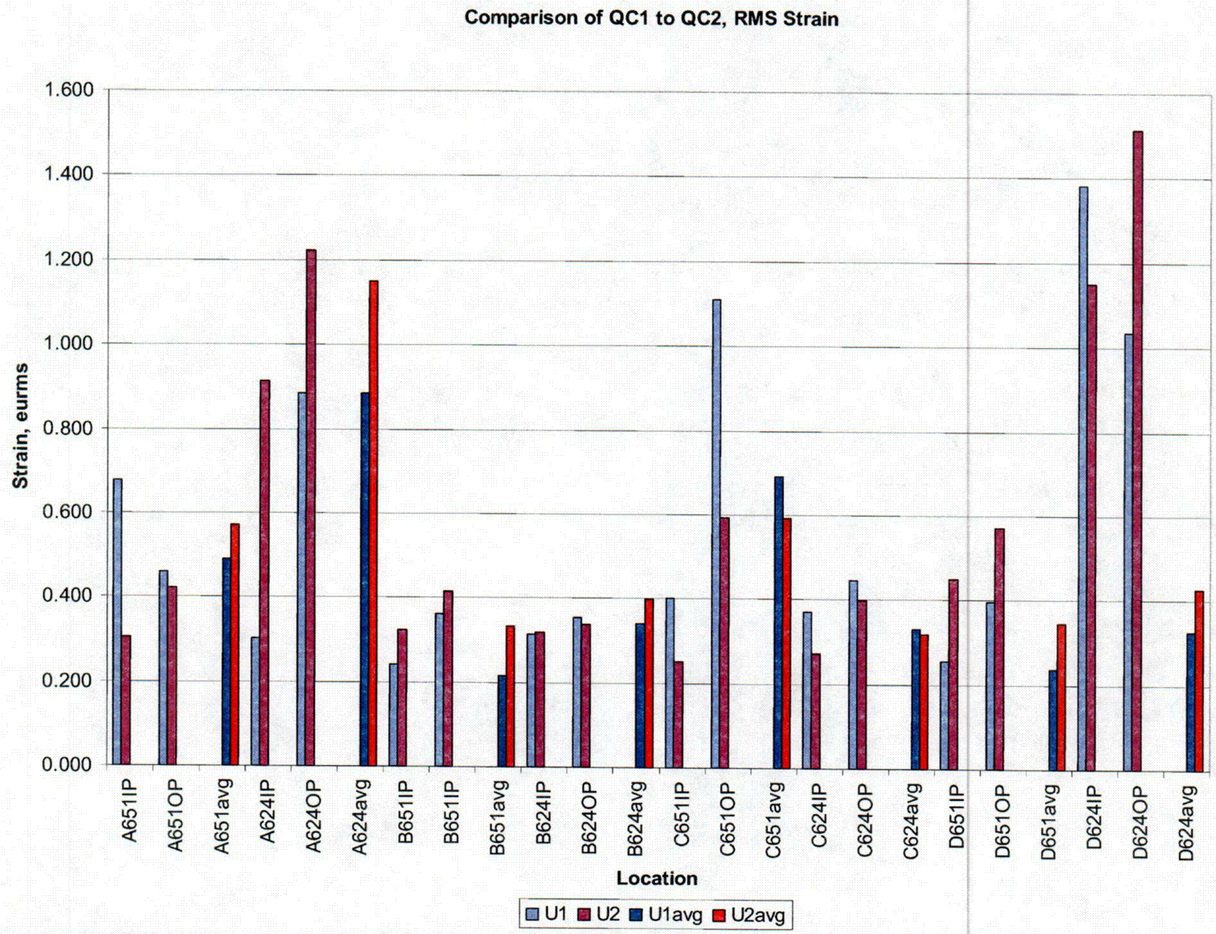

QC1 RMS values are comparable to QC2

C-14

RMS Comparison by Elevation

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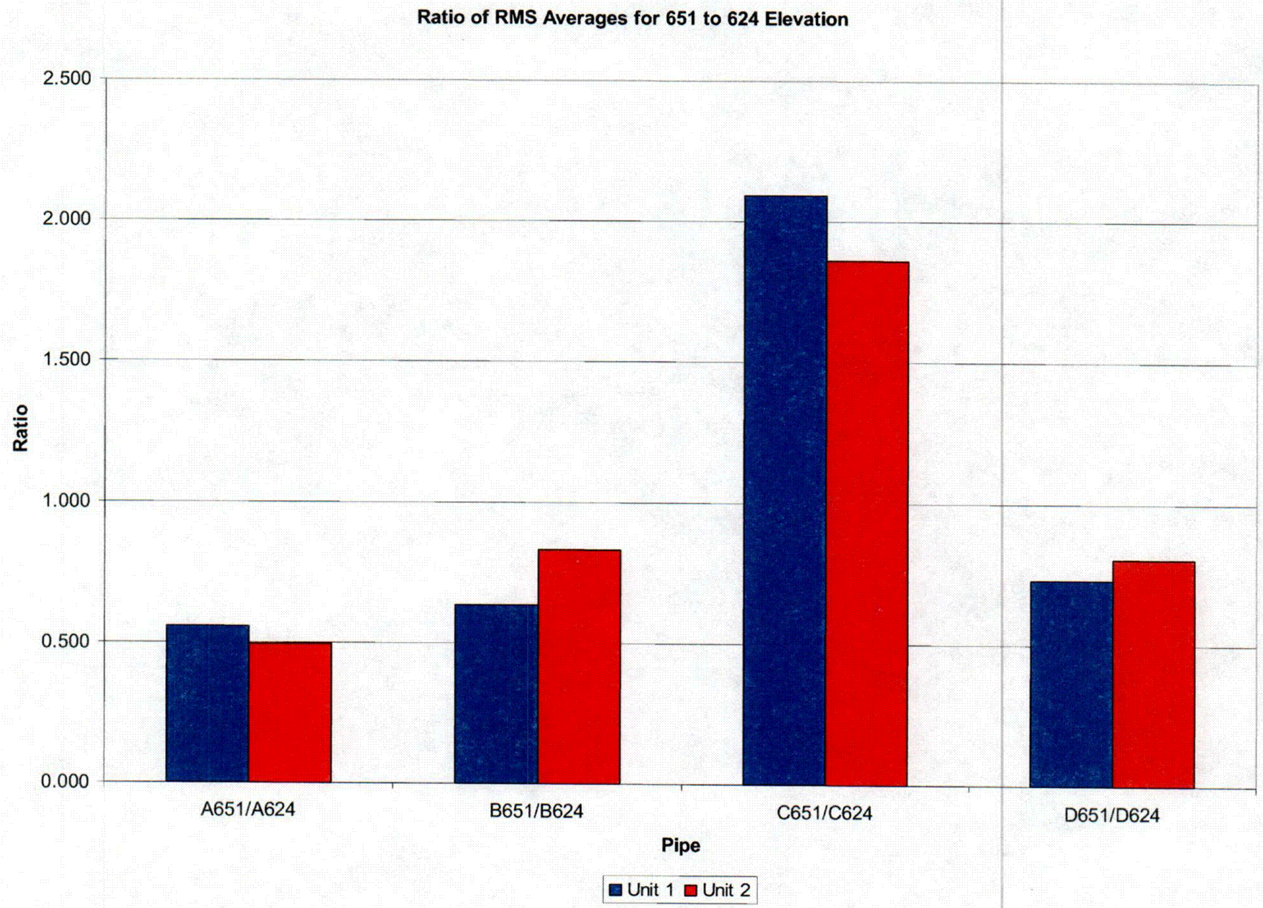

Ratio of RMS values are similar for QC1 and QC2 at each elevation

C-15

CSD Comparison

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- The CSDs were calculated for both units
- A CSD was calculated from the power spectral density (PSD) of each orthogonal bridge pair and graphed as magnitude and phase versus frequency
- Results show that, with the exception of A651, the phase is relatively close in amplitude in the 10 – 40° range

CSD Evaluation

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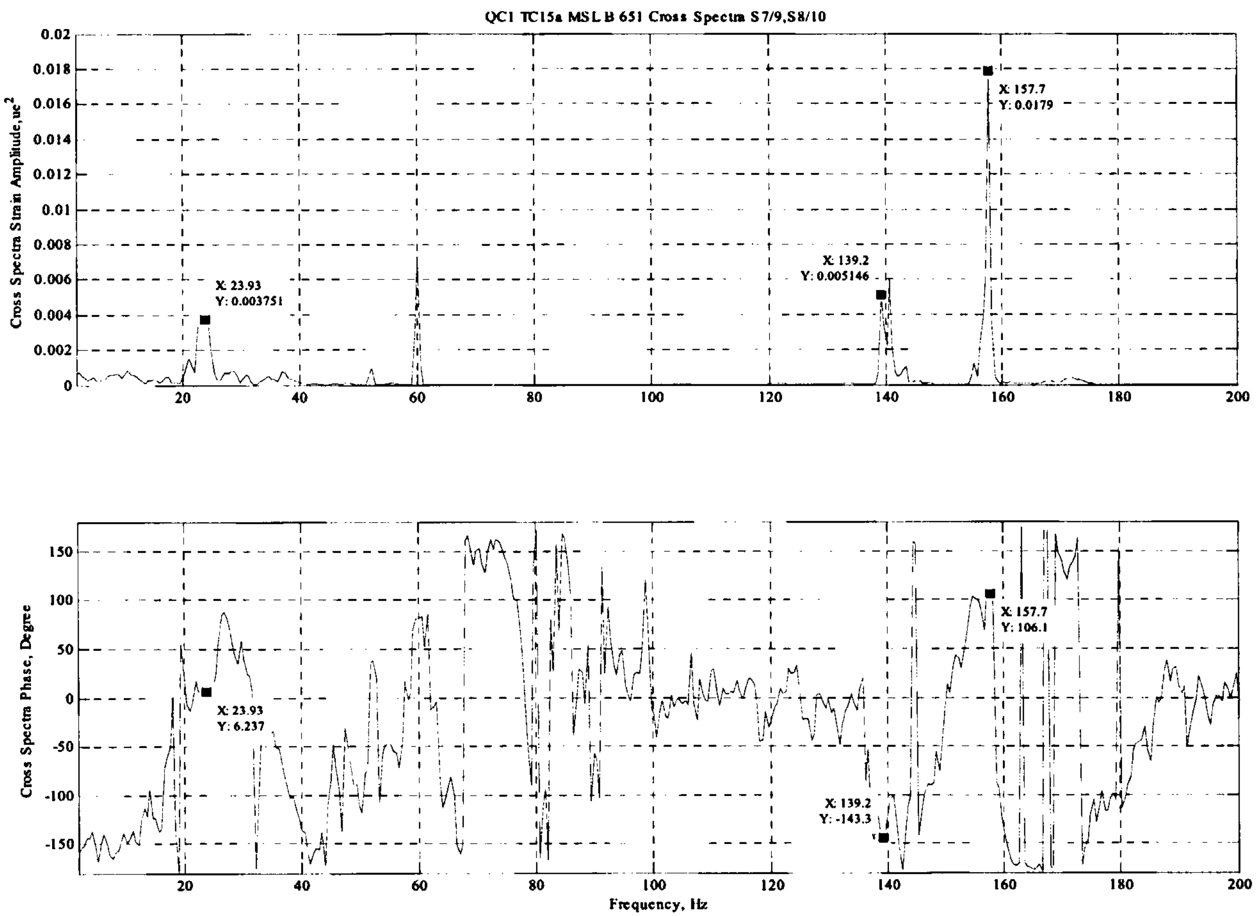

Typical QC1 Phase Relationship

CSD Evaluation (cont.)

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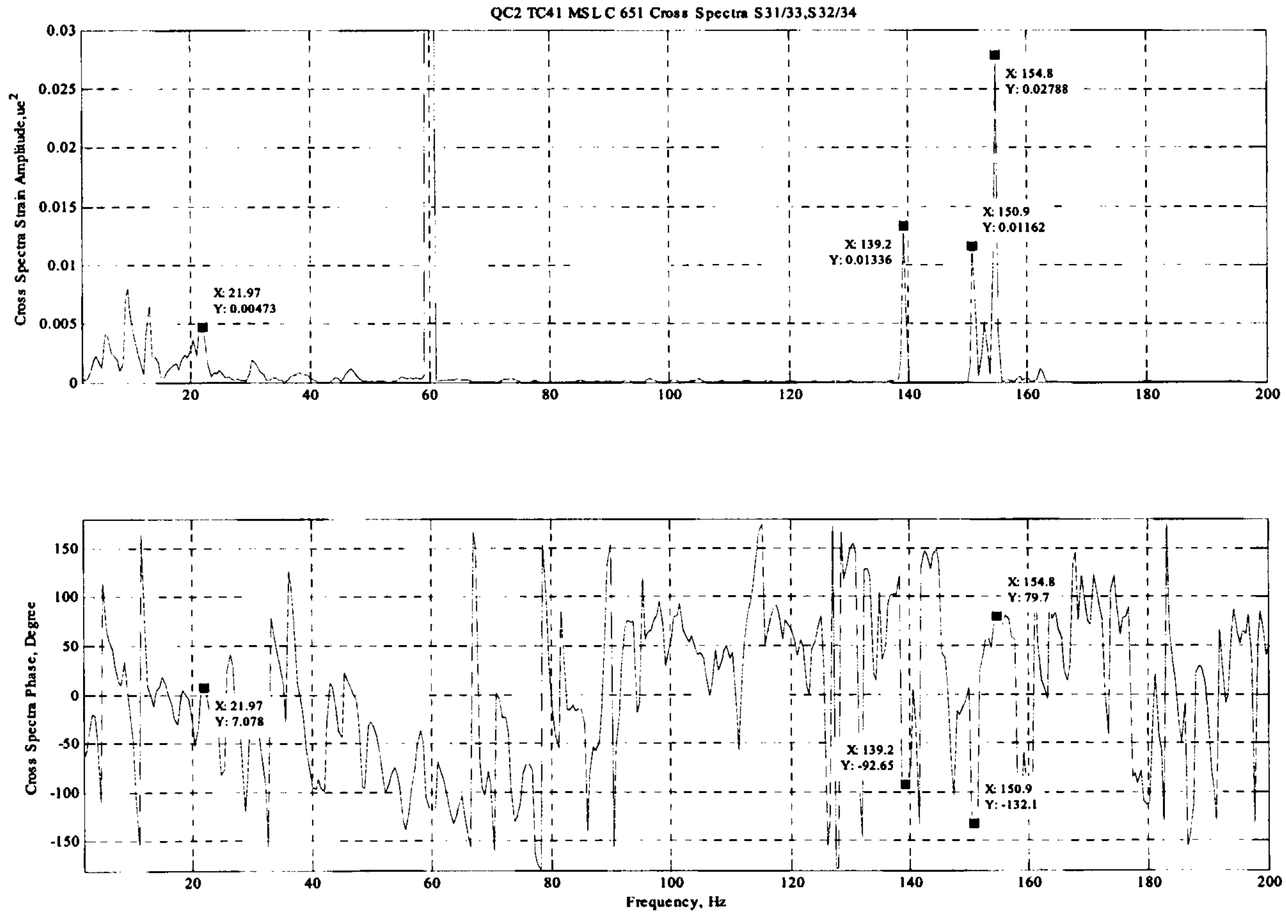

Typical QC2 Phase Relationship

Phase Comparison

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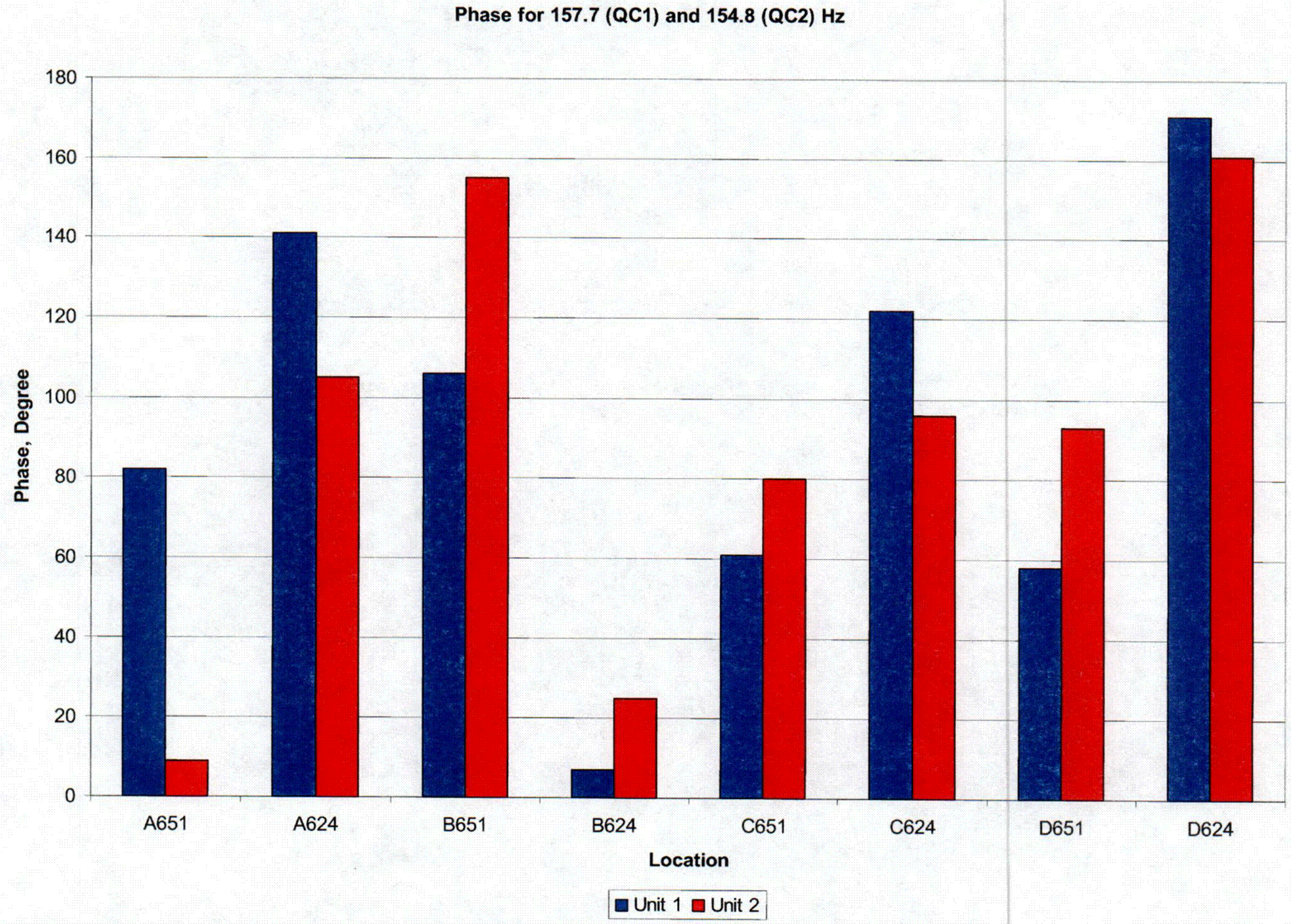

Phase relationship is consistent between the two units

C-16

¼ and ½ Bridge Comparison

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- ¼ bridge data was obtained for QC2 MSL B and C
- Review of the data shows that all strain gauges worked for the ¼ bridge test
- Comparison of ¼ and ½ bridge combination to a two ½ bridge combination confirms that the combination with a ¼ bridge is almost identical to the combination with only ½ bridges

¼ and ½ Bridge Comparison (cont.)

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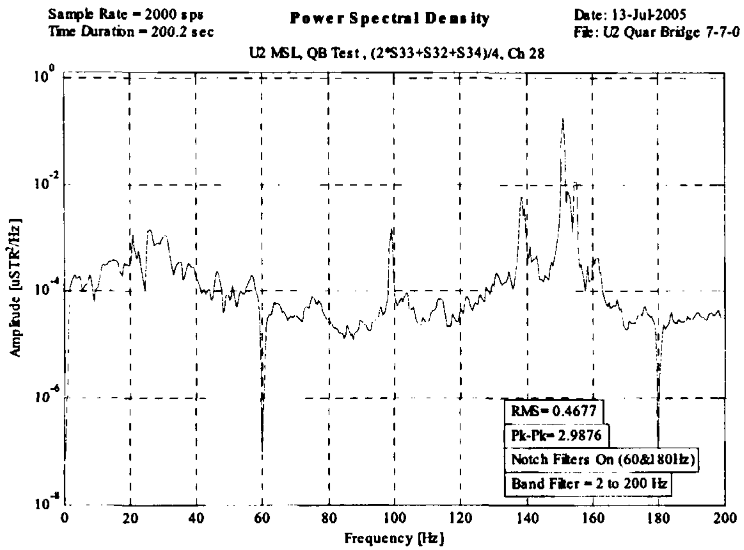
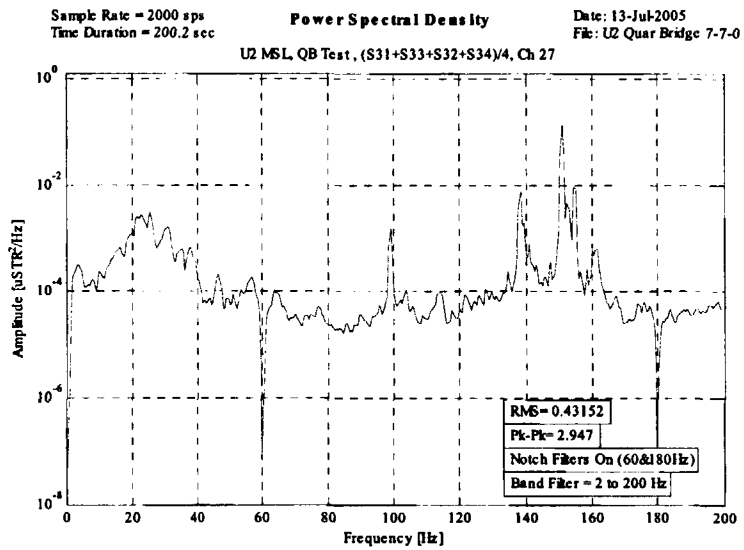
QC2 C651 Avg(¼,½)



QC2 C651 Avg(½,½)



Comparison of ¼ and ½ bridge shows similar frequency content and magnitude

Conclusions

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- Based on similarities between QC1 and QC2 MSLs and the strain gauge data, both units appear to be similar in both the pressure excitation of the piping and the response to the loading
- The consistency provides a measure of the quality of the data for both units
- Consistencies between the MSL strain data shows that, even with some structural differences, both units appear to respond the same due to the pressure excitation of the piping

Conclusions (cont.)

Exelon Nuclear

- Review of the QC2 ¼ bridge data confirms the combination of a ¼ bridge and a ½ bridge produces results that are almost identical to the averaged two equivalent ½ bridge results

Strain Gauge Uncertainty

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- Uncertainty analysis consists of the uncertainty of the strain-to-pressure calculation and the measurement system
- Overall uncertainty is determined by a square-root-of-the-sum-of-the-squares (SRSS) method, used from random error
  - Nominal pressure is calculated
  - New pressure is recalculated by changing each variable by the amount of potential error, one variable at a time
  - Difference between the nominal pressure and the new pressure is squared, summed, and the square root taken of the result

Strain Gauge Uncertainty (cont.)

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- Actual pipe thickness were obtained via ultrasonic testing (UT) measurement
- Uncertainty calculated as 5.03%

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Nuclear

Uncertainty Evaluation

Kevin Ramsden
Senior Staff Engineer

Uncertainty Evaluation

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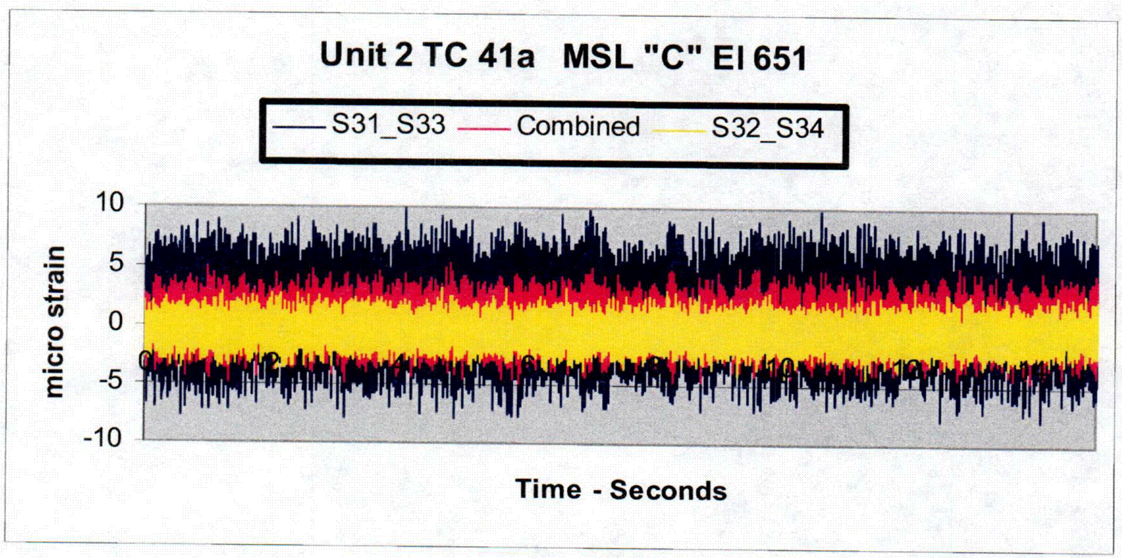
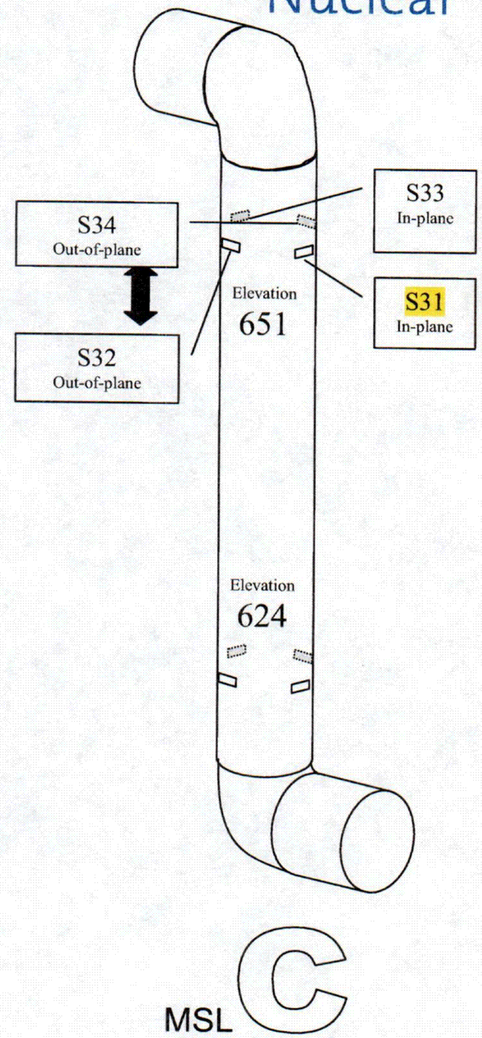
- Sources of uncertainty
  - Measurement accuracy of the strain gauges
  - Accuracy of the ACM
  - Measurement accuracy of the QC2 pressure measurements used for validation of the ACM
  - Accuracy for the finite element model (FEM)

Uncertainty Evaluation (cont.)

Exelon Nuclear

- Strain gauge measurements
  - Wall thickness of the pipe
    - UT measurements made at QC2/QC1 for most accurate results
  - Strain gauge measurements – two functioning pairs
    - Assessed to be 5.03%
  - MSL pipe structural response
    - Two functioning pairs of strain gauges yield more accurate results
    - Loss of in-plane strain gauges results in conservative input for load definition





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Uncertainty Evaluation (cont.)

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- Measurement accuracy of dryer pressure instruments
  - 3.9% absolute measurement uncertainty
  - 2.9% relative measurement uncertainty
    - Relative measurement uncertainty is the most appropriate value to apply, since variations form the mean are the measurements of interest
- Dome vs. flush mounted pressure instruments
  - Dome mounted sensors tend to over-predict by 3% to 8%
  - Wind tunnel testing showed that dome mounted sensors contain the appropriate frequency content
  - Since the trend is toward over-prediction, no additional uncertainty correction is needed for dome mounted sensors

Uncertainty Evaluation (cont.)

Exelon Nuclear

- ACM uncertainties
  - Minimum error ACM
    - Uncertainty evaluated at 3.6% for the applied pressure on the dryer face
  - Modified 930 MWe ACM
    - Tends to over-predict pressures, especially at the skirt natural frequency

Statistical Comparison of Min Error and Modified 930MWe ACM

Sensor	*RMS pressure psi*	*Min pressure psi*	*Max pressure psi*
P-3 min err	0.603	-1.894	1.971
P-3 mod 930	0.682	-2.262	2.193
P-12 min err	0.625	-1.94	1.906
P-12 mod 930	0.659	-1.751	1.848
P-20 min err	0.541	-1.648	1.738
P-20 mod 930	0.605	-1.977	1.994
P-21 min err	0.638	-1.974	2.026
P-21 mod 930	0.804	-2.289	2.337
P-24 min err	0.288	-1.129	1.016
P-24 mod 930	0.251	-1.034	0.986

Uncertainty Evaluation (cont.)

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- FEM uncertainties
  - FEM is based on detailed as-built dryer geometries
    - Specific uncertainty associated with the FEA analysis calculation has not been determined due to the complexity of the model
    - Sensitivity analysis of performing varying time step by +/- 10% and using the most conservative results covers the potential for uncertainties
  - Comparison of the measured strain gauge response to the predicted strains based on the ACM load and FEA shows results are generally bounding

Uncertainty Evaluation (cont.)

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Uncertainty Terms in Unit 2 Dryer Analysis

Uncertainty Term	***Absolute Effect %***	***Effect on Analysis***
Strain Gage Measurement	5.02	+/- 3.6% based on minimum error model sensitivity
Strain Gage Failure Impact	N/A	N/A
Pressure Sensor Measurement	3.9 Absolute 2.9 Relative	+/- 2.9%
Pressure Sensor Phenomenological	N/A	+3 to +8%
ACM Uncertainty		Modified 930 MWe ACM used for Unit 2 analysis is conservative compared to minimum error model, particularly in skirt region and front hood
Structural FEA		Bounding values selected based on +/-10% time step sensitivity cases, plus other attributes of FEA noted in section 2.4

Net Effect		Range: underpredict by 3.5% to overpredict by 14.5%
		• Plus conservatism introduced by use of modified 930 MWe ACM
		  • QC2 Dryer/Skirt
		  • QC1 Dryer

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QC2 and QC1 Load Definition

Guy DeBoo
Asset Management Engineer

QC2 Load Definition

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- Steam path data collected at Test Condition 41 (TC41)
  - 930 MWe
  - 2885 MW-thermal (MWt)

- ACM used for load definition
  - Modified 930 MWe ACM
    - As noted previously, this ACM tends to over-predict load especially at the skirts natural frequency

QC2 Load Definition

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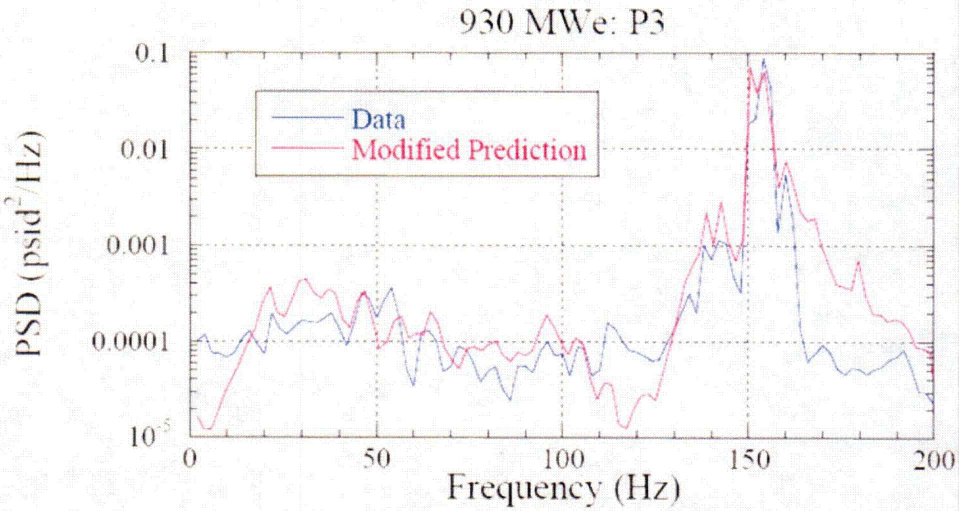
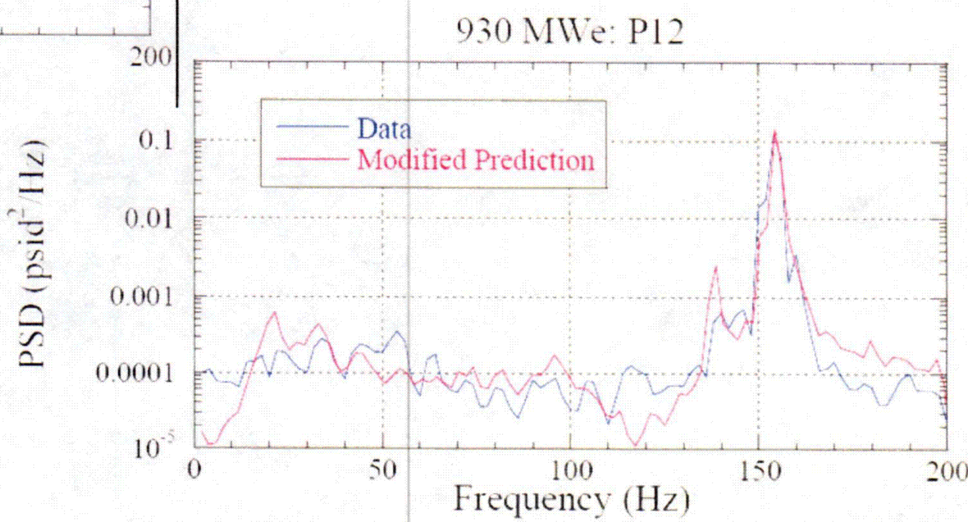
- Examples of modified 930 MWe ACM margins





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QC1 MSL Data Collection

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- Additional MSL strain gauges were installed to more closely match the QC2 configuration
- For data collection during the QC1 startup following dryer replacement, a total of five strain gauges failed – S3, S6, S11A, S31, and S36
- Startup test maximum power achieved
  - TC15a: 2887 MWt
  - TC15b: 2901 MWt
  - Minimal difference in maximum-minimum strains
- QC1 input to ACM used TC15a data

QC1 AC MSL Data Input

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- All available MSL strain measurements at each location were used to define the pressure
- As discussed previously, due to reduced number of strain gauges, data was corrected for non-relevant signals at 80 Hz
  - Results of QC2 first acoustic circuit assessment at 790 MWe
    - 80 Hz frequency amplitude was higher using a strain gauge pair
  - In-vessel instrumentation on QC1
    - High speed pressure data was recorded for the vessel level instrument taps (59A and 59B) located in the dryer skirt region
      - This data provided an understanding of the acoustic pressure field in the vessel
      - 80 Hz was not a predominate frequency
  - MSL instrumentation on QC1
    - MSL C elevation 624
    - Strain gauge data showed little 80 Hz contribution
    - Accelerometers were installed on the MSL C electromatic relief valve (ERV)
      - Accelerometers had little 80 Hz amplitude
  - 80 Hz $\pm$ 4Hz reduced to a level consistent with MSL D

QC1 AC Load Definition

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- First load case (TC15a) was based on minimum error ACM
  - The only adjustment was to combine S33 with strain gauge pair S32/S34 at the MSL C 651 elevation
  - This load case was used to structurally evaluate the skirt on QC1
- Second load case (TC15a_2) was based on the modified 930 MWe ACM
  - Combined functional individual strain gauges with strain gauge pairs for those locations with damaged strain gauges
  - Adjusted the remaining 80 Hz amplitude to equal MSL D
  - This load case was used to structurally evaluate the dryer and vessel brackets
- Third load case (TC15a_3) was based on minimum error ACM
  - Combined functional individual strain gauges with strain gauge pairs for those locations with non-functioning strain gauges
  - Adjusted the remaining 80 Hz amplitude to equal MSL D
  - This load case was compared to the first load case to demonstrate the TC15a load was bounding

QC1 AC Loads
Minimum Error ACM

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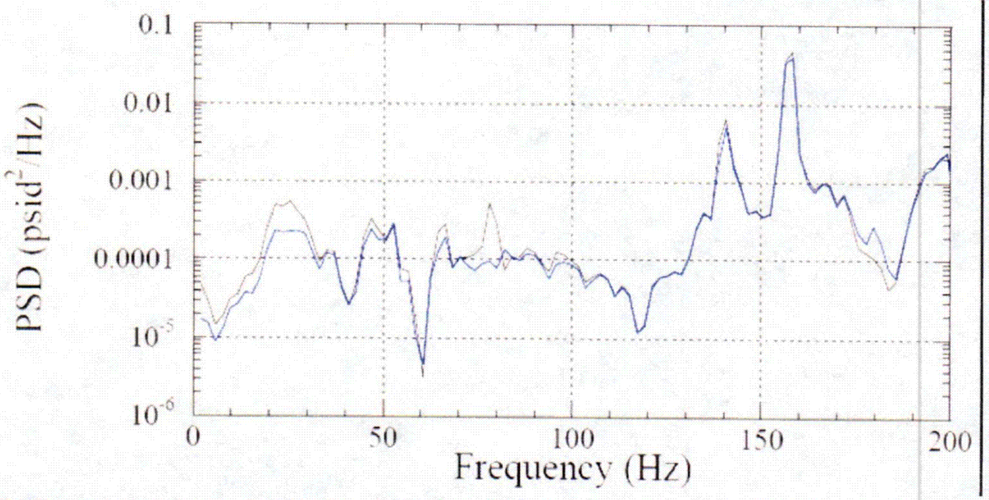
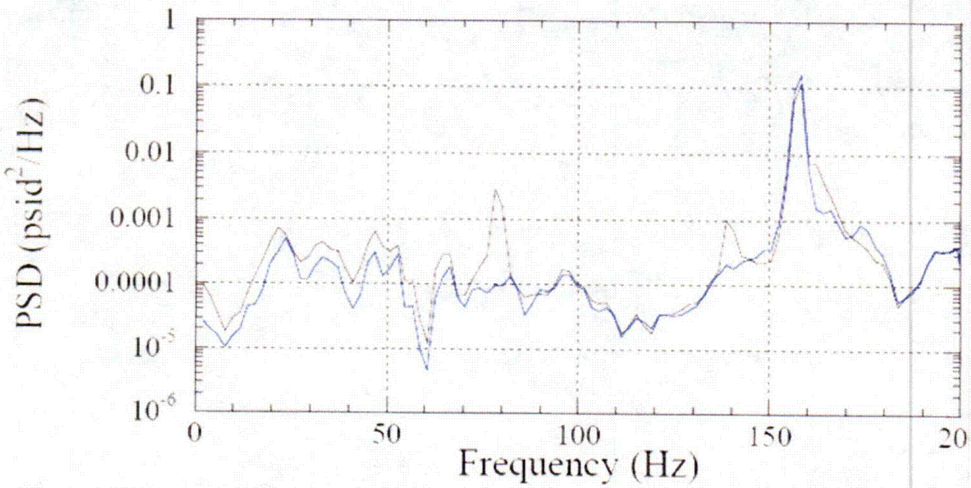


PSD comparison between TC15a (black curve) and TC15a_3 (blue curve) for pressure sensor number P3.



PSD comparison between TC15a (black curve) and TC15a_3 (blue curve) for pressure sensor number P12.

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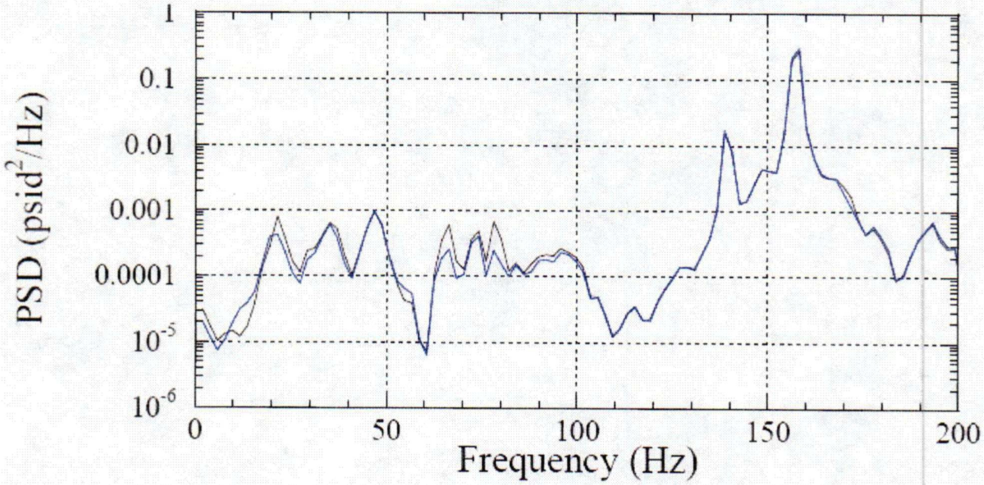
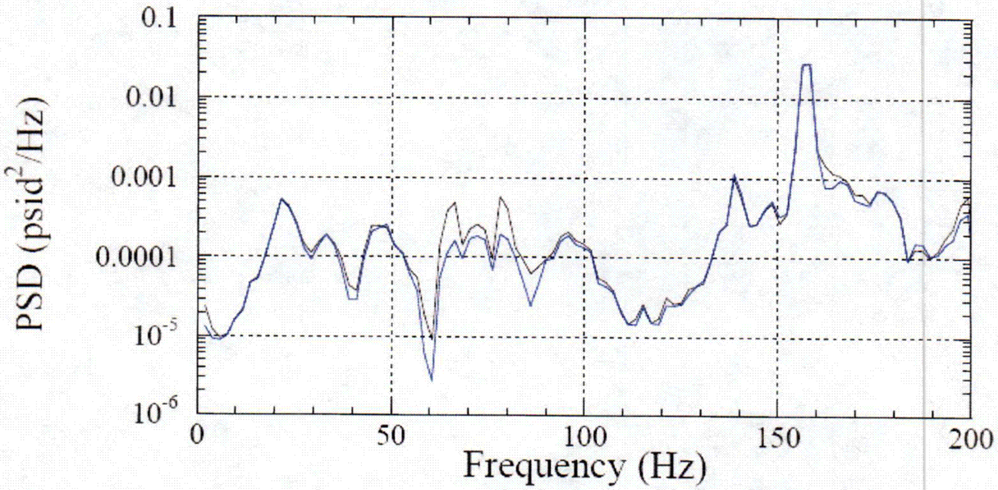
QC1 AC Loads
Minimum Error ACM (cont.)



PSD comparison between TC15a (black curve) and TC15a_3 (blue curve) for pressure sensor number P20.



PSD comparison between TC15a (black curve) and TC15a_3 (blue curve) for pressure sensor number P21.

C-20

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Structural Analysis Summary

Guy DeBoo

Asset Management Engineer

Time History Analysis Methodology

Summary

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- FEA methodology used was generally the same as the methodology used for dryer design analyses
- Three time history analyses are run for each load case: nominal, +10%, and –10% frequency shifts
- Fatigue analysis performed using weld factors applied to time history analysis results
- Disposition of high stress locations using
  - Local solid finite element models with forces extracted from the full shell model
  - Increased damping to 4% for skirt and vane banks
- Minor shell model changes for QC1 FEAs

FEA Presentation

Exelon Nuclear

- QC2A FEA
  - Flow induced vibration (FIV) pressure time histories from TC41 at 2885 MWt
  - Frequency content: load and structural response
  - Strain gauge comparison: measured vs. FEA results
  - Analysis results: fatigue, ASME cases, vessel bracket
- QC1B and QC1D FEA
  - FIV pressure time histories from TC15a at 2887 MWt
  - Model differences from QC2 and April evaluations
  - Frequency content: load and structural response
  - Analysis results: fatigue, ASME cases, and vessel bracket

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QC1 and QC2 Dryer Structural Analysis

Leslie Wellstein
General Electric

Exelon Nuclear

The next 13 slides contain information that is proprietary to General Electric

Dryer Model
Full Model without Super Elements

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FEM Boundary Conditions

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Full Model with Super Elements

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QC1 and QC2 Replacement Dryer
Time History Analyses

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QC2 FEA

Maximum Differential Pressure =

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QC2 Loads
Frequency Content

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QC2 Frequency Domain Response

Nominal Loads: Outer Hood

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QC2 Frequency Domain Response

Nominal Loads: Skirt, Vane Bank Top and End

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Strain Gauge Locations

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Strain Comparison

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Measured vs. Analytical (QC2A FEA, % Damping)

Strain Comparison
Hood with % Damping

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QC2 Time History Analysis

Design Margins

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QC2 ASME Code Case
Stress Margins

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QC2 Structural Analysis
Conclusions

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- Replacement dryer and support bracket meet the design fatigue limits for EPU conditions
- Replacement dryer and support bracket meet the ASME Code limits for all service levels (normal, upset, and faulted)
- QC2 replacement dryer is structurally adequate for EPU conditions

QC1 Analysis Model Changes

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- Skirt
  - Super element water mass was reduced to account for the steam separators
- Mounting blocks
  - Shell elements were added to more accurately represent the mounting blocks, and the stiffness was increased for some existing shell elements at the mounting block locations
- Trough attachment to the outer hood
  - Trough attachment to the outer hood closure plate at the mounting block locations was modified to more accurately represent the connection between the outer hood closure plate and the drain trough
- Closure plate
  - Angle attachment (flange) on the closure plate was added to the model

QC1 FEA

Exelon Nuclear

- QC1D acoustic load used for the dryer
  - Loads from the same ACM as TC15a_2, which predicts skirt strains an order of magnitude higher than those measured on QC2
- QC1B acoustic load used for the skirt
  - Loads from minimum error ACM (i.e., load case TC15a)

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Closure Plate Flange

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Mounting Block

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Trough Attachment to Outer Hood Closure Plate

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QC1D FEA Load Input

Maximum Differential Pressure =

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QC1B FEA Load Input

Maximum Differential Pressure =

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QC1 Load Frequency Content

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QC1 Frequency Domain Response
Nominal Loads: Outer Hood

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QC1 Frequency Domain Response

QC1 +10% Loads: Skirt

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QC1 Time History

Design Margins

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QC1 ASME Code Case
Stress Margins

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QC1 Structural Analysis

Conclusions

Exelon Nuclear

- Replacement dryer and support bracket meet the design fatigue limits for EPU conditions
- Replacement dryer and support bracket meet the ASME Code limits for all service levels (normal, upset, and faulted)
- The QC1 replacement dryer is structurally adequate for EPU conditions

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Dresden Steam Dryer Replacement Overview

Dan Pappone
General Electric

Going Forward Plan

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- Leverage QC experience
  - QC2 loads and instrumented dryer results generally bound Dresden
- No significant changes to replacement dryer design for Dresden
  - Remove modifications that were not structurally significant
  - Perform structural analyses to confirm Dresden configuration remains acceptable

The next four slides contain GE proprietary information

Components Considered for Removal

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Components Considered for Removal (cont.)

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Components Chosen for Analysis

Modified Center Reinforcement Plates (Due to Frame Removal)

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Other Modifications

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- Outer tee to vane cap doubler plates
- Fillet full penetration welds on the closure plate weld between the vane bank end plate and trough
- Increase load capacity of jacking bolts (under evaluation)
- Modify vane bank perforated plates

Load Definitions for Dresden

Exelon Nuclear

- FIV
  - Use QC2A load definition for FIV during normal operation
- ASME load combinations per dryer design specification
  - Use QC loads for
    - FIV (normal, upset)
    - Static differential pressure (normal, upset, faulted)
    - Acoustic, flow impact (upset, faulted)
  - Use Dresden loads for seismic evaluation
    - Operational Basis Earthquake (OBE)
    - Safe Shutdown Earthquake (SSE)

FIV Load

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- QC2A FIV load case is applicable to Dresden
  - Plant operating conditions, vessel geometry, dryer geometry are the same
    - Minor internal modifications to dryer do not affect dryer pressure loading
  - Difference in load definition due to differences in MSL configuration

The next six slides contain GE proprietary information

Source Identification from SMT

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MSL Configuration Comparison

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MSL Configuration Comparison (cont.)

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MSL Configuration Comparison
(cont.)

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Branch Line Comparison

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Branch Line Comparison (cont)

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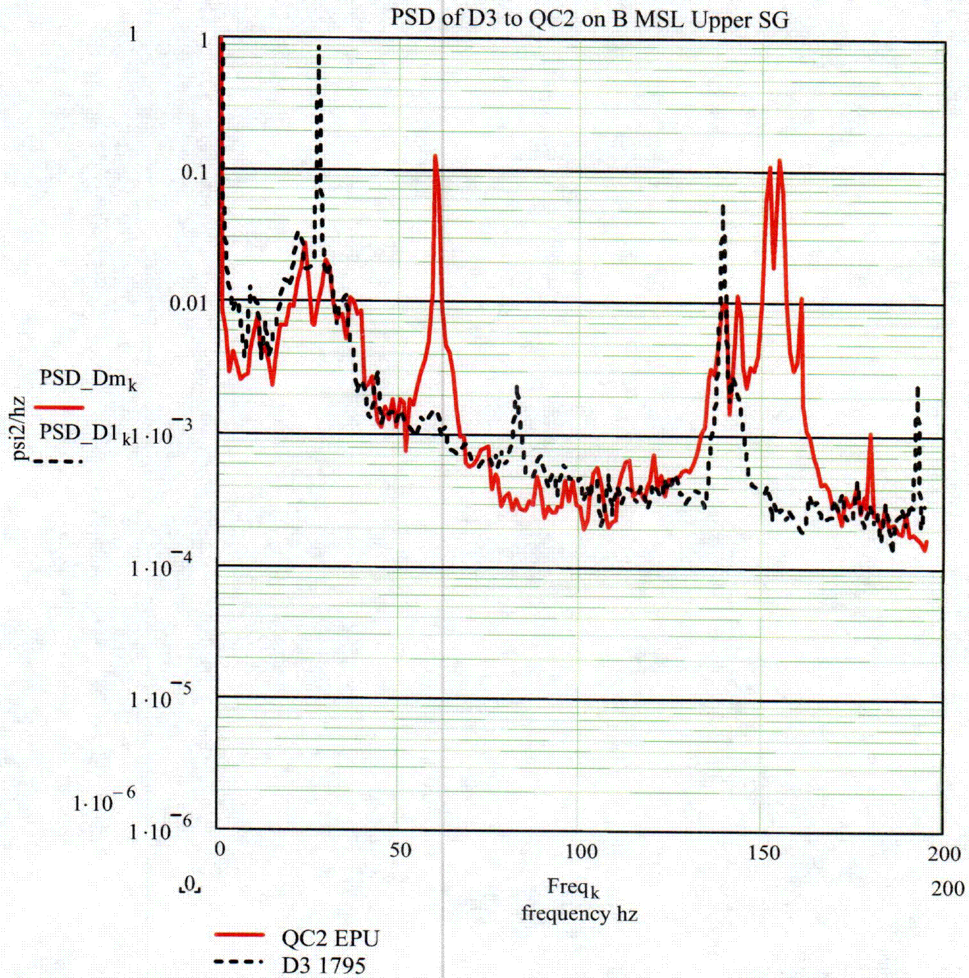
Branch Line Comparison (cont)

- Upper steamline strain gauge comparison
  - Red: QC2 at EPU
  - Black: Dresden Unit 3 at 1795 MWt (~60%)



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FIV Load Conclusion

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- QC and Dresden FIV load on dryer expected to be the same in low and middle frequency ranges
- QC EPU RV resonance bounds Dresden RV resonance during power ascension
- QC FIV load is applicable to Dresden

ASME Load Combinations

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- Use same loads as QC for
  - FIV (normal and upset)
  - Static differential pressure (normal, upset, and faulted)
    - Same geometry and operating conditions
  - Acoustic/flow impact (upset and faulted)
    - Same geometry and operating conditions
    - Same turbine stop valve closing time
- Use Dresden loads for seismic evaluations
  - OBE
  - SSE

Exelon Nuclear

Summary and Conclusions

Roman Gesior
Director – Asset Management