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General Electric Company
1989 Little Orchard Street, San Jose CA 95125

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Engineering Report

Quad Cities Units 1 and 2 Replacement Steam Dryer Analysis Stress, Dynamic, and Fatigue Supplementary Analyses for EPU Conditions

Principal Contributors:

L. Wellstein
J. Waal

Principal Verifier:
A. Pinsker

Approval: ____________
R. Bodily
Project Manager

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1. EXECUTIVE SUMMARY

The replacement dryers for Quad Cities Units 1 and 2 have been designed, analyzed, fabricated and installed. Analysis showed the replacement dryers to be structurally adequate for EPU loads using the design basis loads [Reference 1] and for plant specific loads at Quad Cities Unit 1 [Reference 2] and Quad Cities Unit 2 [Reference 3] based on loads developed from strain gage measurements from the main steam lines after the replacement dryers were installed in the plant. During the technical meetings with the NRC, held August 29 through September 1, 2005 and on November 8 and 9, 2005, several areas of additional analyses were requested. These additional analyses are:

1. Show that the adjustment in time step, to account for uncertainty in the structural natural frequencies, is adequate to pick up the maximum stress [[ ]],
2. Remove conservatism in the structural analyses and recalculate the design margin for fatigue,
3. Determine the contribution of the skirt loading on the dryer components above the support ring, and
4. Determine the sensitivity of strain gage location and orientation on the finite element analysis results.

Supplemental analyses were performed to address the above-mentioned issues. The analyses and results are presented in this report. The results of the supplemental analyses support continued EPU operation for both Quad Cities Units 1 and 2.

2. Time History Analyses to Account for Dryer Natural Frequency Uncertainty

In previous analyses [References 1, 2, and 3], three time history analyses were performed for each load (QC1 and QC2): +/-10% time shift (which effectively shifts the frequency of the applied loads) and a nominal case. [[

]] Modal participation factors in the X and Y directions (Z load is considered insignificant) are plotted in Figure 2-2. [[

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]] The frequencies defined by the bandwidth divided by two are called the half power points (+/- B/2). The dynamic response, if a mode were exactly at the half power points, is 70.7% of the maximum possible dynamic response. The amplification of the response is calculated according to the following equation [Reference 7]:

$$\frac{D_s}{Q} = \frac{2\zeta}{\sqrt{(1-r^2)^2 + (2\zeta r)^2}}$$

Where:

Ds/Q = actual response/ maximum possible response for the given damping

ζ = damping

r = frequency ratio = forcing function frequency/ natural frequency

[[

]] For a complicated, multi-degree-of-freedom system like the dryer, having a forcing frequency near a natural frequency does not mean that it will produce any significant response since the applied pressure on the dryer may not be distributed in a manner to excite the given mode. Figures 2-4 through 2-11 show trends in the stress intensities as a function of load case for all dryer components, plotted in four groups (Figures 2-4 through 2-7 are for Quad Cities Unit 1 and Figures 2-8 through 2-11 are for Quad Cities Unit 2). Several components did have higher stress intensities in the intermediate runs than were found in the original three cases (nominal, +/-10%). However, these components are all components with high design margins and the increase in stress over the original three cases was just a few percent. It is clear from these plots that there are no significant peaks found with the additional time history analyses. The original three runs (nominal, +/-10%) are sufficient to determine the fatigue stresses in the dryer due to fluctuating loads. Appendix A presents results from four additional time history analyses that confirm this conclusion.

Figure 2-12 shows the maximum possible response for a mode based on how close the mode of interest is to the forcing frequency. This response assumes that the loading is applied in a distribution that will excite the given mode. [[

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Additionally, the dryer component stresses are also comprised primarily of response to these discrete driving frequencies.

Uncertainty of the stress magnitudes for the 6 lowest margin components plus the outer hood components, based on the time history analyses performed versus what the maximum possible stress would be if an infinite number of time steps were analyzed, is summarized in Tables 2-1 and 2-2 for QC1 and QC2, respectively. [[

]] In

all cases, the actual stress change is far lower than the theoretical stress increase expected if a resonance condition existed. [[

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Table 2-1 Quad Cities Unit 1 Dryer: Uncertainty of Stress Intensity of 6 Lowest Margin Components Based on Available Time History Analyses Cases.

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Table 2-2 Quad Cities Unit 2 Dryer: Uncertainty of Stress Intensity of 6 Lowest Margin Components Based on Available Time History Analyses Cases.

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3. Fatigue Design Margin

The design margins presented at NRC meetings in April 2005 and August 2005 were based on stress results reported in References 1, 2, and 3. There is conservatism in some of the reported design margins. Due to the fact that there is uncertainty in the applied fluctuating load, some of the conservatism in the fatigue analysis is identified and removed to show more realistic margins on fatigue. This section will discuss the conservative assumptions used in the analysis and present the design margins with some of these conservatisms removed.

3.1 Dynamic Analysis Approach

The primary dynamic loads of concern on the dryer are the fluctuating acoustic pressure loads during normal operation at EPU levels. These pressures are the loads responsible for the fatigue damage experienced by all four of the original Dresden and Quad Cities steam dryers. The design basis loads, which were used to demonstrate the structural acceptability of the replacement dryer for EPU conditions, are based on both scale model test and in-plant measurements from strain gages on the main steam lines prior to the replacement dryer being installed in the plant. Both sets of pressure loads were generated using an acoustic circuit model (ACM). The fatigue results based on these design basis loads are presented in Reference 1.

To demonstrate acceptable structural margin during EPU operation, plant specific loads were determined using strain gage measurements from main stream lines taken after installation of the new dryers. An acoustic circuit model was used to generate the pressures applied to the dryer surfaces in the finite element analyses. The fatigue results based on these plant specific loads are presented in References 2 and 3.

To account for differences in the dryer natural frequencies between the finite element model and the as-built dryer, three time history analyses were performed for each load case. Since it is not practical to change the finite element model natural frequencies, the frequency of the applied load is changed instead. Shifting the time step used in the analysis, which effectively shifts the frequency of the applied load, produced the three load cases that are referred to as the nominal, +10% and –10% cases.

3.2 Conservatism In Analysis

Several conservative assumptions were used in determining design margin for the dryers in the earlier analyses. The following conservative assumptions were removed from the calculation of the design margins reported here:

1) Fillet weld factors were sometimes applied to stresses that occurred at full penetration welds in References 1, 2, and 3. In the design margin tables presented in this report, the appropriate weld factors are used in all locations.

2) [[

   ]] Margin presented in this report uses the appropriate damping value as called out in the design specification [Reference 4].

3) [[

   ]] In References 1, 2, and 3 this more restrictive stress limit was conservatively applied to many components. Design margins presented in this report only use the more restrictive fatigue stress limit on components on or near the outer hood across from the main steam lines (outer hood, vane cap flat part, outer vane cap curved part, T-section webs, T-section flanges, and lifting lug guide). Allowable fatigue limits are discussed in Reference 5.

3.3 Dryer Component Revised Design Margin – Original Load Cases

The design margins for all of the dryer components have been recalculated based on revised stresses and stress limits as discussed above in Section 3.2. Table 3-1 lists design margins for Quad Cities Unit 1. Table 3-2 lists design margins for Quad Cities Unit 2. Both Tables 3-1 and 3-2 summarize the margins based on the maximum stresses from the nominal, +10% and –10% time history cases. The loads applied to the dryer finite element model were based on plant measurements taken at a lower power level than EPU. [[

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In Tables 3-1 and 3-2, the six components with the lowest design margin are highlighted. For Quad Cities Unit 1, the lowest design margin is [[ ]]. For Quad Cities Unit 2 the lowest design margin is [[ ]]. However, the Quad Cities Unit 2 analysis did not have loads generated from the CDI minimum error model as the Quad Cities Unit 1 analysis did. The Quad Cities Unit 1 analysis was performed with both the "old" and "new – minimum error" models and the reduction in skirt stress was found to be [[ ]] with the new CDI minimum error model. Therefore, if the Quad Cities Unit 2 analysis was rerun using loads from the CDI minimum error model, an increase in skirt margin of about [[ ]] could be expected. Not counting the skirt, the lowest design margin component for the Quad Cities Unit 2 dryer is [[ ]] margin.

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Table 3-1 QC1 EPU Design Margins Based on Nominal, +/- 10% Cases

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Table 3-2 QC2 EPU Design Margins Based on Nominal, +/- 10% Cases

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3.4 Additional Dynamic Analyses

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]] This supplementary work and the results from it are discussed in Section 2.0 and Appendix A.

3.5 Dryer Component Design Margin – Including Additional Load Cases

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]] For each component, the load case that produced the highest stress intensity is highlighted. These stresses do not have any weld factors applied nor have they any solid model results included. These tables are to show which runs produced the highest stress in a given component. Figures 2-4 through 2-7 show stress intensity as a function of load case for Quad Cities Unit 1. Figures 2-8 through 2-11 show stress intensity as a function of load case for Quad Cities Unit 2. These figures are graphical representations of how each component maximum stress intensity varies with increased or reduced time step size. These figures show ANSYS stress intensity output without weld factors or solid model results included. The purpose of Figures 3-4 through 3-11 is to show trends in the stresses in the various components of the dryer (plotted in four groups) as the time step is varied in the time history analyses. The final stresses, scaled up to EPU levels, with the appropriate weld factors, damping values, and solid model disposition are shown in Tables 3-5 and 3-6 for Quad Cities Unit 1 and Unit 2, respectively. The percentage decrease in design margin for any component where the stress intensity is higher from any of the additional cases [[ ]] is also reported in Tables 3-5 and 3-6. [[

]] Therefore, it can be concluded that the original three cases (nominal, +/-10%) are sufficient to address FIV fatigue stresses in the dryer components.

Table 3-3 QC1 Dryer Shell Element Stress Intensity Summary Based on All Cases [[ ]] (No Weld factors or Solid Model Results)

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Table 3-4 QC2 Dryer Shell Element Stress Intensity Summary Based on All Cases [[ ]] (No Weld factors or Solid Model Results)

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**Table 3-5 QC1 EPU Design Margins Based on All Cases (+/-10% range, [[
]])**

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Table 3-6 QC2 EPU Design Margins Based on All Cases (+/-10% range, [[ ]])

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4. Summary of Skirt/ Dryer Load Contribution on Dryer Component Stresses

The Quad Cities Unit 1 time history analyses in Reference 2 were performed using the QC1D loads for the [[ ]] dryer and the QC1B loads for the [[ ]] skirt. For this study, two additional time history cases were run using the QC1D nominal loads [[ ]] [Reference 9]. The first case, called the "skirt only" case, had loads only applied to the skirt (including the support ring) and the second case, called the "dryer only" case, had loads only applied to the upper portion of the dryer (above the support ring). The purpose of this study is to determine the contribution of the skirt loads on the upper dryer components (above the support ring). The maximum stress intensity at each component for both additional cases is shown in Table 4-1. The six lowest margin components are highlighted.

Table 4-1 Stress Intensity Summary for Skirt and Dryer Loaded Separately

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Since these stresses occur at different times and locations (in some cases), additional information was taken from the time history results for the 6 most limiting components. The time and location that produced the maximum stress in each component for the "dryer only" case was used to find the stress in that component from the "skirt only" case. The same thing was done for the time and location of maximum stress from the "skirt only" case to come up with the corresponding stresses from the "dryer only" case. These results are shown in Table 4-2. All stress intensity results are at 2887 MWt. The scaling to EPU is not needed since the percent contribution from the skirt and dryer will remain the same for either power level.

Table 4-2 Percentage of Stress from Skirt Loading for 6 Minimum Margin Components Based on Both "Dryer Only" and "Skirt Only" Load Cases

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[[

]] The maximum stress in all cases, with the exception of the cross beams, occurs at the time when the skirt contribution to the total stress is small. The skirt load, although significantly over-predicted, does not contribute substantially to the total stress on most of the low margin components. The loading from the upper portion of the dryer provides the largest contribution to the maximum stress intensities of the lowest margin dryer components.

[[

]] Based on Reference 10, the skirt loading is over predicted by at least a factor of 2. The cross beam design margin can be recalculated based on the percent of the loading coming from the skirt and reducing the stress contribution coming from the skirt by a factor of 2. The skirt load contribution on the dryer components was analyzed for the nominal load case only. The maximum stress in the cross beams occurred at the +10% case. There will be some variability in results for the various frequency shift cases in the time history analyses. However, the similarity in the dryer dynamic response for all of the time history cases indicates that the percent of the skirt load affecting the cross beam stress will not vary very much from case to case. The cross beam stress from Table 3-1 is recalculated as follows:
[[

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5. Dryer Strains

5.1 Strain Gage Measurements Versus Analytical Results

Strain gage measurements from the Quad Cities Unit 2 replacement dryer were compared with strains from the finite element analysis in Reference 3. The strains from the analytical model were recalculated based on the most recent finite element model revisions to the trough and closure plate and are presented in Tables 5-1 and 5-2. The calculated strains shown in Tables 5-1 and 5-2 are from the finite element model node closest to the actual strain gage on the dryer. In all strain gage locations the measured strains are lower than the maximum analytically determined strains (maximum of the three cases: nominal, +/-10%). In the skirt, the measured strains are an order of magnitude lower than the analytical results. This indicates that the loads applied in the finite element model to the Quad Cities Unit 2 skirt are very conservative.

Table 5-1 Strain Range: Measured Versus Analytical (Revised Finite Element Model Results)

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Table 5-2 Peak Strains: Measured Versus Analytical (Revised Finite Element Model Results)

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5.2 Strain Sensitivity to Orientation and Location of Gages

5.2.1 Strain Gage Study

Additional strains were extracted from the finite element time history analyses to perform a sensitivity study showing the effect of strain gage orientation and location on the dryer strain at three strain gage locations. For each of the three strain gages used in this study, the node from the finite element model closest to the strain gage location on the dryer is identified. Figure 5-1 shows the locations on the dryer where the five working strain gages are located. For this study, strain gages S5, S7, and S9 are used. Figures 5-2, 5-4, and 5-6 show the location of the strain gage in relation to the nearest node in the finite element model. Figures 5-3, 5-5, and 5-7 show the adjacent nodes in the finite element model used in this study. These adjacent nodes are labeled "A" through "J", where the center node, labeled "E" is the node closest to the actual strain gage. [[

]] Strains from the finite element time history analyses at each deviated location were compared to the node closest to the strain gage location, named location "E". Also, the strains at each of the locations was determined for a + or – 10 degree rotation and compared with the location "E" strain with zero rotation.

The results for three strain gage locations (S5, S7, and S9) are presented here and in more detail in Appendix B.

5.2.2 Sensitivity Study Results and Conclusions

Strain Gage S5

[[

]] Since the installed location of S5 is in between locations E, F, H and J (see Figures 5-2 and 5-3), the focus should be concentrated at these locations. Table 5-3 shows the linearly interpolated strain range values at the actual strain gage location and within the tolerance that the gage was applied to the dryer (+/- 0.5 inch). [[

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Table 5-3 Interpolated Finite Element Strain Range Results for Strain Gage 5

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Strain Gage S7

[[

]] Since the installed location of S7 is in between locations A, B, D and E (see Figures 5-4 and 5-5), the focus should be concentrated at these locations. Table 5-4 shows the linearly interpolated strain range values at the actual strain gage location and within the tolerance that the gage was applied to the dryer (+/- 0.5 inch). [[

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Table 5-4 Interpolated Finite Element Strain Results for Strain Gage 7

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Strain Gage S9

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]] Since the installed location of S9 is located in between locations B, C, E and F (see Figures 5-6 and 5-7), the focus should be concentrated at these locations. Table 5-5 shows the linearly interpolated strain range values at the actual strain gage location and within the tolerance that the gage was applied to the dryer (+/- 0.5 inch). [[

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Table 5-5 Interpolated Finite Element Strain Results for Strain Gage 9

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6. Conclusions

There are four subjects addressed in this report: 1) adequacy of the 10% interval between time history analyses and an uncertainty on the stress results based on the interval used in the Exelon replacement steam dryer analyses, 2) dryer component fatigue design margin, 3) the skirt load contribution on the dryer component stresses, and 4) sensitivity of strain gage location and orientation.

[[

]] This study shows that the original three runs (nominal, +/-10%) are adequate to address FIV fatigue on the dryer components. Additionally, an uncertainty based on the frequency shift for the analysis runs was determined for both QC1 and QC2. [[
]]

Strain gage sensitivity to both location and orientation was studied in detail at three strain gage locations (S5, S7, and S9). Results of this study showed that, when looking at the four nodes closest to the actual strain gage location, the maximum analytical strain range always bounds the measured strain range. These strain gage results show that the loads applied to the dryer in the time history analyses are conservative. In addition, the analytically derived strains using [[ ]] damping exceed the measured strains at all strain gage locations. These strain comparisons show that the [[ ]] damping used in the time history analysis is appropriate and conservative.

[[

]] The dryer has significant design margin, which is confirmed by the strain gage results. Additional analysis is presented in this report that demonstrates improved design margins for 2 of the 6 lowest margin components for QC1. [[
]]

The contribution of the skirt loading to the upper dryer components is evaluated for QC1 and the skirt contribution for all of the lowest margin components, with the exception of the cross beams, is found to be small. Therefore, the stresses in these components are not due to the over prediction in the skirt loading used in the dryer analyses.

The results of all of the structural analyses performed in References 1, 2, and 3, as well as these supplementary studies show that the Quad Cities Units 1 and 2 replacement steam dryers are structurally adequate for continued EPU operation.

7. References

1 "Quad Cities Units 1 and 2 Replacement Steam Dryer Analysis Stress, Dynamic, and Fatigue Analyses for EPU Conditions," DRF GE-NE-0000-0034-3781, Section GE-NE-0000-0039-4902, Revision 0, April 2005.

2. "Quad Cities Unit 1 Replacement Steam Dryer Stress and Fatigue Analysis Based on Measured EPU Conditions," DRF GE-NE-0000-0043-5391, Section GE-NE-0000-0043-9157, Revision 1, August 2005.

3. "Quad Cities Unit 2 Replacement Steam Dryer Stress and Fatigue Analysis Based on Measured EPU Conditions," DRF GE-NE-0000-0043-3105-01, Section GE-NE-0000-0043-3119, Revision 0, July 2005.

4. "Steam Dryer Design Specification (DS)," 26A6266, Rev 3 and "Design Specification Data Sheet (DSDS)", 26A6266AB, Rev.5, GENE 0000-0038-5717, Rev. 0.

5. "Fatigue Stress Threshold Criteria For Use in the Exelon Replacement Steam Dryer", GENE 0000-0034-6079, DRF Section 0000-0034-8374, Rev 0, October 2004.

6. "LMS, Quad Cities New Design Steam Dryer Methodology for Stress Scaling Factors Based on Extrapolation from 2885 MWt to 2957 MWt of Unit #2/Dryer #1 Data, Revision 2", GENE 0000-0046-8129-02-P, Rev. 1, December 2005

7. "Structural Dynamics: An Introduction to Computer Methods", by Roy R. Craig, Jr. John Wiley & Sons, 1981.

8. Trough mesh refinement Analysis, DRF 0000-0045-4374, DRF Section 0000-0048-3692.

9. Additional post processing from DRF 0000-0043-0470, DRF Sections 0000-0043-0471 (QC1D [[ ]]), 0000-0043-6786 (QC1B [[ ]]).

10. "An Assessment of the Uncertainty in the Application of the Modified 930 MWe Acoustic Circuit Model Predictions for the Replacement Quad Cities Units 1 and 2 Steam Dryers", AM-2005-012, Rev 1.

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Figure 2-1 Dryer Natural Frequency Distribution in the range of 140 Hz to 170 Hz

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Figure 2-2 Dryer Modal Participation Factors in the range of 140 Hz to 170 Hz

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Figure 2-3 Effective Mass Versus Frequency

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Figure 2-4 Stress Intensity as a Function of Load Case for Various QC1 Components (Group 1)

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Figure 2-5 Stress Intensity as a Function of Load Case for Various QC1 Components (Group 2)

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Figure 2-6 Stress Intensity as a Function of Load Case for Various QC1 Components (Group 3)

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Figure 2-7 Stress Intensity as a Function of Load Case for Various QC1 Components (Group 4)

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Figure 2-8 Stress Intensity as a Function of Load Case for Various QC2 Components (Group 1)

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Figure 2-9 Stress Intensity as a Function of Load Case for Various QC2 Components (Group 2)

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Figure 2-10 Stress Intensity as a Function of Load Case for Various QC2 Components (Group 3)

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Figure 2-11 Stress Intensity as a Function of Load Case for Various QC2 Components (Group 4)

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Figure 2-12 Percent of Maximum Theoretical Dynamic Response as a Function of Time Step Interval

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Figure 5-1 Strain Gage Locations in Finite Element Model

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Figure 5-2 Strain Gage S5 Location in Finite Element Model

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Figure 5-3 Strain Locations In Finite Element Model Near Strain Gage S5

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Figure 5-4 Strain Gage S7 Location In Finite Element Model

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Figure 5-5 Strain Locations In Finite Element Model Near Strain Gage S7

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Figure 5-6 Strain Gage S9 Location in Finite Element Model

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Figure 5-7 Strain Locations In Finite Element Model Near Strain Gage S9

Appendix A Time History Additional Run Details

Four additional time history analyses for Quad Cities Unit 1 were preformed to demonstrate the conclusion that no significant peaks were missed during the original three time history analyses presented in References 1, 2, and 3. [[

]] The same figures for Quad Cities Unit 1 presented in this report (Figures 2-4 through 2-7) are presented again in this appendix with the locations of potential peaks identified (Figures A-1 through A-4). Additional runs were performed to determine if there were any missed peaks. The results of these runs are presented in Table A-1.

Table A-1 QC1 Dryer Shell Element Stress Intensity Summary Based on All Cases (+ 4 additional) [[ ]] (No Weld factors or Solid Model Results)

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Table A-1 shows no significant peaks found with the additional four runs. For each component, the load case that produced the highest stress intensity is highlighted. The stresses highlighted in purple are the stress intensities that increased in these additional four analyses over the previous nine runs. The maximum change in stress intensity for the components that had any increase is summarized in Table A-2.
[[
]] These changes are not considered significant. These results support the conclusions of the report that there were no significant peaks missed in the original time history analyses documented in References 1, 2, and 3. These results and conclusions for the four additional runs made for Quad Cities Unit 1 apply to Quad Cities Unit 2 as well.

Table A-2 Increase in Stress Intensity due to Four Additional Runs (ANSYS output, no weld factors, [[ ]] or solid model disposition)

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Figure A-1 Additional Time History Analyses Based on QC1 Component Group 1 Results

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Figure A-2 Additional Time History Analyses Based on QC1 Component Group 2 Results

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Figure A-3 Additional Time History Analyses Based on QC1 Component Group 3 Results

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Figure A-4 Additional Time History Analyses Based on QC1 Component Group 4 Results

Appendix B Strain Gage Sensitivity Study Details

Additional strains were extracted from the finite element time history analyses to perform a sensitivity study showing the effect of strain gage orientation and location on the dryer strain at three strain gage locations. For each of the three strain gages used in this study, the node from the finite element model closest to the strain gage location on the dryer is identified. Figure 5-1 shows the locations on the dryer where the five working strain gages are located. For this study, strain gages S5, S7, and S9 are used. Figures 5-2, 5-4, and 5-6 show the location of the strain gage in relation to the nearest node in the finite element model. Figures 5-3, 5-5, and 5-7 show the adjacent nodes in the finite element model used in this study. These adjacent nodes are labeled "A" through "I", where the center node, labeled "E" is the node closest to the actual strain gage. [[

]] Strains from the finite element time history analyses at each deviated location were compared to the node closest to the strain gage location, named location "E". Also, the strains at each of the locations was determined for a + or – 10 degree rotation and compared with the location "E" strain with zero rotation.

The results and conclusions for the strain gage study at three strain gage locations (S5, S7, and S9) are presented in Section 4 and additional details are presented in this appendix. For each strain gage location two tables are presented. The first table for each strain gage (Tables B-1, B-3, and B-5) shows strain values as a function of location and orientation for each of the three time history cases (nominal, +/-10%). The second table for each strain gage (Tables B-2, B-4, and B-6) shows the percent variance from the non-rotated "E" location (or node closest to the strain gage) for each node in terms of location and orientation. [[

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Table B-1 Strain Gage S5 Location: Finite Element Strain Values as a Function of Location and Orientation

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Table B-2 Strain Gage S5 Location: % Variation in Finite Element Strain Values as a Function of Both Location and Orientation

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Table B-3 Strain Gage S7 Location: Finite Element Strain Values as a Function of Location and Orientation

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Table B-4 Strain Gage S7 Location: % Variation in Finite Element Strain Values as a Function of Both Location and Orientation

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Table B-5 Strain Gage S9 Location: Finite Element Strain Values as a Function of Location and Orientation

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Table B-6 Strain Gage S9 Location: % Variation In Finite Element Strain Values as a Function of Both Location and Orientation

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Attachment 2

Exelon Response to NRC Open Issues Concerning the Quad Cities Units 1 and 2 Replacement Steam Dryers (Non-Proprietary)

ATTACHMENT 2

Exelon Response to NRC Open Issues Concerning the Quad Cities Units 1 and 2 Replacement Steam Dryers (Non-Proprietary)

NON-PROPRIETARY NOTICE

This is a non-proprietary version of Attachment 1 to Exelon letter RS-05-179, which has the proprietary information removed. Portions of the document that have been removed are indicated by an open and closed bracket as shown here [[ ]].

During the November 8 and 9, 2005, meeting, Exelon discussed the actions taken, and planned, to address the open items regarding the EPU restart for Quad Cities, Units 1 and 2, resulting from the August 29 - September 1, 2005, technical meeting with the NRC. Following the November 8 and 9 meeting, the NRC provided a summary of the open items and their status.

Open Issue #1

> Why does the ACM under predict pressures at specific locations on the Quad Cities Unit 2 steam dryer, and what impact does this under prediction have on the uncertainty of the stress analysis?

Status of Open Issue #1

> With respect to Open Item 1, the licensee discussed its development of uncertainty (random and bias) terms for its steam dryer analysis, including MSL strain gage uncertainty (5.03%), pressure instrument uncertainty (2.9%), pressure instrument phenomenological bias (-3 to -8%), ACM low frequency bias (3% peak-to-peak and 0.4% RMS), and ACM methodology bias (7.8% RMS, -0.5% peak-to-peak, and 13.1% RMS for the 135-160 Hz range). The licensee considered that the -0.5% bias uncertainty based on the peak-to-peak data was appropriate for its "modified 930 MWe" version of the ACM. The licensee combined these uncertainties to calculate a total uncertainty of 6.3% for its steam dryer analysis. The NRC staff noted that the ACM over predicted the loading for some portions of the Quad Cities Unit 2 steam dryer (such as the skirt region) and under predicted the loading for other portions of the steam dryer (such as the middle portion of the outer hood slanted plate). The licensee considered the loads obtained from the skirt pressure measurement locations close to the hood to be indicative of loads on the bottom of the steam dryer hood. The staff also noted that the ACM under predicted the measured pressure load in some portions of the frequency range of primary interest (150 to 170 Hz). As a result, the staff raised a question as to the impact of the uncertainty for the ACM methodology resulting in the actual stress being higher than calculated by the ACM on the dryer hood in the frequency range of interest. The staff believed that this question could be addressed by calculating an ACM uncertainty considering the loads acting on the hood region only (sensors P1-P12) for RMS, peak-to-peak, and pressures between frequencies of 135 and 160 Hz. The licensee indicated that it would consider using the more conservative ACM bias uncertainty (discussed in Exelon AM-2005-012) associated with loads at frequencies between 135 and 160 Hz. Upon combining the ACM uncertainty with other uncertainties in the stress analyses, the margins to the stress limits could be determined for the steam dryer components and evaluated for appropriate action. The licensee stated that it would address this question regarding ACM uncertainty with regard to the available stress margin for the steam dryer components at Quad Cities.

Exelon Response to Open Issue #1

In response to the NRC questions concerning the impact of acoustic circuit model (ACM) uncertainty, Exelon performed additional calculations to investigate the uncertainty associated with the Modified 930 MWe ACM pressure time histories. Specifically, Exelon performed an ACM uncertainty calculation based on the frequency content between 135 Hz and 160 Hz. Examination of the dryer pressure and strain gage measurements has demonstrated this frequency range dominates the pressure loads acting on the dryer and the stress response of the dryer components, excluding the skirt. Consequently, the uncertainty calculation is focused on ensuring the ACM accurately predicts pressures in this frequency range.

Exelon Report AM-2005-12, "An Assessment of the Uncertainty in the Application of the Modified 930 MWe Acoustic Circuit Model Predictions for the Replacement Quad Cities Units 1 and 2 Steam Dryers," (i.e., Enclosure 1) was revised to include Appendix B, which contains specific information describing how the additional uncertainty calculations were performed. These uncertainty calculations examined two cases. Case 1 examined the uncertainties for 22 pressure sensor locations, including the pressure sensors on the upper and lower parts of the dryer. Case 2 examined the uncertainties for only the 15 pressure sensors on the outer hood. The second case was evaluated because these sensors measured the largest pressures acting on the dryer. Additionally, prior uncertainty evaluations have clearly demonstrated that the ACM significantly over-predicts pressures measured on the lower part of the dryer (i.e., the skirt). By only including the 15 pressure sensors on the outer hoods, the calculated uncertainty is biased to ensure ACM pressure predictions accurately represent the pressure magnitudes and distributions on the outer hoods where the pressures are greatest.

The results obtained from Case 2 are applicable to the dryer hoods above the support ring and would be conservative in application to the lower part of the dryer, such as the skirt. As such, Exelon selected the results from Case 2 as the most appropriate to be used in calculation of the overall ACM uncertainty for the dryer. Considering the over-predicted pressures for the skirt, this uncertainty will not be applied to the dryer skirt components. The computed uncertainties for Case 2 were 14.91% for peak pressure uncertainty, and 16.81% for a root mean square (RMS)-based uncertainty. The peak pressure uncertainty was comprised of a bias term, equal to 9.1%, and a random uncertainty term, equal to 5.81%. The RMS-based uncertainty was comprised of a bias term, equal to 11%, and a random uncertainty term, equal to 5.81%.

In determining the dryer response to pressure loads with very discrete frequency content, as seen in the measured pressures, it is important to ensure that the predicted peak pressures bound those of the measured pressures rather than ensuring the RMS pressures are bounded. Using the RMS values would not ensure that the pressure time history drives the dryer components to the measured peak pressures at the discrete frequencies measured. As such, Exelon selected the peak pressure uncertainty value of 14.91% as the most representative for the dryer components, excluding the skirt. The Case 2 uncertainty of 14.91% was used in the dryer design uncertainty and margin analysis described in the response to Open Issue #2. This dryer design and uncertainty analysis is contained in Exelon Report AM-2005-020, "Quad Cities Replacement Dryer Design Uncertainties and Margins for Units 1 & 2," Revision 0 (i.e., Enclosure 2).

Open Issue #2

If the uncertainty of the individual aspects of the stress analysis (such as the ACM) will not be determined, combined, and applied, what is the end-to-end uncertainty of the entire stress analysis for the steam dryers in Quad Cities, Units 1 and 2?

Status of Open Issue #2

With respect to Open Item 2, the licensee discussed its consideration of the strain gage readings on the Quad Cities Unit 2 steam dryer to strain calculated by the licensee's stress analysis. The licensee determined that the Quad Cities Unit 2 steam dryer experienced less strain than calculated by the stress analysis based on three strain gages installed on the dryer. The staff requested the results of the comparison for each of the Quad Cities Unit 2 steam dryer strain gages. The staff considers that the licensee's comparison of measured strain to calculated strain will be helpful to provide confidence in the capability of the Quad Cities Unit 2 steam dryer to withstand the applied pressure loads. However, differences in responsiveness to applied loads might make this determination not applicable to other steam dryers. Therefore, the individual uncertainty terms for the stress analysis needs to be determined when evaluating the structural capability of other steam dryers. The licensee indicated that it would provide information available for the other strain gages installed on the Quad Cities Unit 2 steam dryer.

Exelon Response to Open Issue #2

Exelon performed additional comparisons of measured strain to calculated strain on the dryer, and documented the results of these additional evaluations in Exelon Report AM-2005-015, " A Comparison of the Cumulative Mean Square Strain in the Application of the Modified 930 MWe Acoustic Circuit Model and FEA to the QC2 TC41 In-Vessel Test Condition," Revision 0 (i.e., Enclosure 3). The intent of this report was to compare the margins obtained when applying the Modified 930 MWe ACM load definition in the Finite Element Model (FEM) for the evaluation of steam dryers with the measurements obtained during the startup tests. The report contains cumulative strain plots for each strain gage attached to the Quad Cities Unit 2 dryer. The plots compare the measured cumulative strain against predicted strain for the nominal and +/- 10% time shifted finite element analyses at each strain gage location (See Figures 1 through 15 of Exelon Report AM-2005-015). The cumulative strain plots show that the predicted strains are considerably larger than the measured strain when considering the three load cases evaluated.

The finite element analysis process used in determining the stresses on the various dryer components assumed the highest of the component stress intensities from each of the three time history load cases (nominal, +10% and –10%). Based on the cumulative strain comparisons presented in Exelon Report AM 2005-015, the Modified 930 MWe ACM, coupled with the finite element analysis process, yields very conservative results when compared to plant measured data, which further supports the Exelon position that the design analysis process provides sufficient margin.

Resolution to NRC concerns that the Quad Cities replacement dryers contain differences in responsiveness to applied loads is provided in the Exelon response to Open Issue #6.

During the November 8 and 9, 2005, meeting, Exelon provided the NRC with an overall dryer design margin analysis by comparing actual dryer strain gage data to values predicted by the finite element analysis used in the structural design of the dryer. However, the NRC noted differences in calculated loads applied to Quad Cities Unit 1 when compared to Quad Cities Unit 2. As such, the NRC was concerned that the margin analysis performed using Quad Cities Unit

2 data might not be applicable to other steam dryers, including Quad Cities Unit 1. Therefore, the NRC requested that Exelon determine individual uncertainty terms in the dryer stress analysis and calculate the margin associated with the structural capability of the Quad Cities Unit 1 steam dryer.

In reviewing the main steam line strain gage data collected during startup of Quad Cities, Units 1 and 2, it is Exelon's position that the loads applied to the Quad Cities Unit 1 steam dryer are bounded by those applied to the Quad Cities Unit 2 dryer. The technical reasons for this position are presented in the Exelon response to Open Issue #8 below. However, in response to the NRC request, Exelon evaluated individual uncertainty terms in the dryer stress analysis and used these values in determining overall design margin for both units. The design margin analysis included the overall uncertainties and bias for the ACM as discussed in Exelon Report AM-2005-012 (i.e., Enclosure 1) along with uncertainties associated with the finite element analyses. Uncertainties associated with the finite element analyses include the model, damping, frequency response, and extrapolation of pressure loads to higher power levels. This analysis was performed for both Quad Cities steam dryers on the six dryer components with the lowest stress margins. The results of this analysis concluded that design margins for the Unit 1 outer hood components range from 26.4% to 65.6% margin in comparison to the design endurance limit of 10.8 ksi. The design margins for the Unit 2 outer hoods range from 39.4% to 71.7% margin in comparison to the design endurance limit of 10.8 ksi. The margins for some internal dryer components are smaller, but all margins are greater than one (1) for both units. The design margin analysis and uncertainty is documented in Exelon Report AM-2005-020.

Open Issue #3

With the modifications to the ACM to best match the Quad Cities Unit 2 steam dryer pressure data at 930 MWe, what is the confidence in the application of the ACM to Quad Cities Unit 1 and Dresden, Units 2 and 3?

Status of Open Issue #3

With respect to Open Item 3, the licensee presented its comparison of measured pressure data to pressure loads calculated by the ACM at 790, 912, and 930 MWe for Quad Cities Unit 2. The comparison suggested that the ACM calculates higher loads at lower power levels at Quad Cities Unit 2. The licensee noted that a comparison of the ACM calculations to measured pressure loads across the Quad Cities Unit 2 steam dryer indicates that the assumed acoustic damping in the steam dome area was too high and the assumed acoustic damping in the skirt region of the steam dryer was too low. The licensee was not aware whether these damping assumptions in the ACM would be corrected. The staff questioned the lack of comparison of frequency peaks for the ACM calculations and actual pressure data. Since the ACM bias uncertainty is frequency dependent, the dynamic behavior of the dryer needs to be evaluated to determine appropriate uncertainties over the specific dryer regions in the frequency ranges of interest. The licensee stated that it would address this question on the frequency dependence of the ACM uncertainty.

Exelon Response to Open Issue #3

To demonstrate the reliability and accuracy of the ACM, Continuum Dynamics Inc. (CDI) performed a third blind benchmark analysis at 2831 MWt using data collected during the Quad Cities Unit 2 startup testing, and documented the results of the evaluation in CDI Technical Note No. 05-37, " Blind Evaluation Of Continuum Dynamics, Inc. Steam Dryer Load Methodology Against Quad Cities Unit 2 In-Plant Data at 2831 MWt," (i.e., Enclosure 4). This report contained power spectral densities (PSDs) for each dryer pressure sensor location. The PSD plots were created using a frequency interval of 1024 samples per second, resulting in low-resolution graphs with wide frequency bands. CDI revised Technical Note No. 05-37 and created PSDs using a more refined frequency interval (i.e., twice the original frequency interval) resulting in higher resolution PSD plots. The revised PSDs clearly show distinct peaks at 151 Hz and 154 Hz. The same peaks appear in the finite element analysis described in GE Report GENE-0000-0043-3105-01, "Quad Cities Unit 2 Replacement Steam Dryer Stress and Fatigue Analysis Based on Measured EPU Conditions," dated July 2005 (i.e., Enclosure 5). The PSDs provided in revised Technical Note 05-37 clearly demonstrate the ability of the ACM to accurately predict frequency spikes in the range of interest. As such, no uncertainty factors due to the ACM frequency prediction need to be considered when assessing the overall uncertainty of ACM load predictions.

Open Issue #4

Is it sufficient to use a +/-10% time step on the frequency spectrum in the stress analysis without considering significant peaks within that range?

Status of Open Issue #4

With respect to Open Item 4, the licensee discussed its evaluation of small spectra increments within the ±10% frequency band in the stress analysis. The licensee found only small increases in stress intensity for various dryer components for the frequency increments within the ±10% frequency band. The licensee calculated the minimum design margin [[ ]] for the Quad Cities Unit 1 steam dryer and [[ ]] for the Quad Cities Unit 2 steam dryer. The licensee plans to provide a written description of its evaluation of the ±10% frequency band. The staff suggested that this evaluation be conducted for 2% and 1% of critical damping. The staff noted that division of the 140 to 170 Hz frequency band into smaller segments showed increases in stress of some dryer components above the values determined at nominal conditions and ±10% frequency intervals. Therefore, the uncertainty of the stress for those dryer components needs to be addressed, along with other analysis uncertainties, as part of the evaluation of adequate stress margin.

Exelon Response to Open Issue #4

GE revised GE Report GENE-0000-0046-5358-01, "Quad Cites Units 1 and 2 Replacement Steam Dryer Analysis Stress, Dynamic, and Fatigue Supplementary Analyses for EPU Conditions," Revision 1 (i.e., Enclosure 15) to include a written description of the +/-10% frequency band. In response to an NRC concern that the +/-10% frequency shifts used in the finite element analysis could miss an intermediate peak in the 140 Hz to 170 Hz range, GE performed additional time history analyses to account for the dryer FEM frequency uncertainty. Additional analyses using time history shifts [[ ]] were performed for both the Quad Cities dryers. The dynamic response of the dryer components showed little variation for the time shifted finite element analyses. For the Quad Cities Unit 1 dryer, more refined time history shifts [[ ]] were performed to confirm that a maximum response for some dryer components had been calculated. The results of the additional time history analyses clearly show that there is no structural resonance condition in the 140 Hz to 170 Hz peak load frequency range.

To provide additional confidence that the maximum stress intensities were predicted, an uncertainty analysis of the finite time shifts was performed for the six lowest margin components. Details of the methodology are provided in Section 2 of GE Report GENE-0000-0046-5358-01. Separate uncertainty values for the dryer components were provided for the Quad Cities Unit 1 and Unit 2 dryers. These uncertainty values were used in the overall design margin analysis discussed in the response to Open Issue #2 above.

Open Issue #5

How significant is the omission of low frequency pressure loads on the steam dryer by the ACM?

Status of Open Issue #5

With respect to Open Item 5, the licensee presented its evaluation of the omission of low frequency loads by the ACM through filtering low frequency loads (less than 20 Hz) from the measured pressure data obtained by the four sensors on the Quad Cities Unit 2 steam dryer nearest the MSL nozzles. The licensee determined that the omission of low frequency loads resulted in a small negative bias (about 3%) in the pressure loads calculated by the ACM on the steam dryer. Further, the licensee reported that the skirt is the only component in the Quad Cities Unit 2 steam dryer with modal frequencies less than 20 Hz, and that the strain measured in the skirt is an order of magnitude lower than the strain calculated by the finite element model. The licensee acknowledged that this evaluation only applies to the replacement steam dryers for Quad Cities Units 1 and 2. In response to an NRC staff question, the licensee evaluated five other points to determine that the low frequency loads represented only a small percentage (less than 3% in all but one parameter comparison) of the total pressure load. When this evaluation is documented, the NRC staff will consider the licensee to have satisfied this open item regarding the omission of low frequency loads by the ACM when calculating the pressure loads on the steam dryer. The 3% bias in the calculated pressure loads from the omission of low frequency loads by the ACM needs to be considered in assessing the impact of uncertainties in the stress analysis on the confidence in the structural integrity of the steam dryer.

Exelon Response to Open Issue #5

When determining the effect that the omission of low frequency loads would have on the dryer structural analysis, Exelon originally determined that the omission of low frequency loads resulted in a small negative bias (about 3%) in the pressure loads calculated by the ACM on the steam dryer. This original analysis included data from four pressure transducers located on the dryer hood opposite of the main steam line nozzles. The intent was to capture the locations with the highest known loads. At the request of the NRC, the analysis was revised to include five additional points located across the dryer surface, including the skirt. The results of this analysis are provided in Attachment 1 of Exelon Report AM-2005-011, "Quantifying the Effects Associated with the Acoustic Circuit Model Omission of Low Frequency Loads," Revision 1 (i.e., Enclosure 7). The refined analysis also results in a small negative bias (about 3%) in the pressure loads calculated by the ACM on the steam dryer when considering the entire range of frequencies.

It is clear from the cumulative mean strain comparisons provided in Exelon Report AM-2005-015, and as summarized in Exelon Response to Open Issue #2, that the low frequency loads are not contributing to the response of the dryer components other than the skirt. This measured response is the result of the structural characteristics of the dryer and the applied low frequency load content. Since the dryer's response is completely dominated by the high frequency load content (as seen in the cumulative mean strain comparisons and the frequency response of other dryer components, except the skirt), the effect of this low frequency load content uncertainty is overwhelmed by the uncertainty determined for the high frequency load content, as described in Exelon Response to Open Issue #1. This is discussed in Exelon Report AM-2005-012.

Open Issue #6

Are the differences in the resonance response of the Quad Cities, Units 1 and 2, steam dryers during the hammer tests significant?

Status of Open Issue #6

With respect to Open Item 6, the licensee presented a comparison of the hammer tests for the Quad Cities Units 1 and 2 steam dryers. The staff pointed to an apparent higher response of the Quad Cities Unit 1 steam dryer in the 150 to 170 Hz frequency range. In particular, the staff noted the responsiveness of the 270º hood of the Quad Cities Unit 1 steam dryer. The staff indicated the importance of identifying significant frequency bands, including supporting the frequency differences between the hammer test and plant conditions. In that the licensee considers it not reliable to extrapolate the hammer test results showing low structural damping (<1% of critical damping) to reactor operating conditions, the staff believed it important to evaluate the sensitivity of the steam dryer stresses to structural damping so that the effect of damping on structural integrity of the steam dryer can be determined. The resulting uncertainties need to be considered along with other uncertainties in evaluating the stress margin for steam dryer components. The licensee stated that it would address these staff questions.

Exelon Response to Open Issue #6

GE and LMS performed additional analytical work related to the hammer test results for the Quad Cities replacement steam dryers. As a result of the additional efforts, LMS revised report GENE-0000-0045-9761-01, "Quad Cites New Design Steam Dryer - Dryer #1, Dryer #2 and Finite Element Model Outer Hood Frequency Response Functions Extension to 200 Hz," which was originally submitted to the NRC in a letter dated October 28, 2005. Enclosure 8 provides the revised report, and results of the additional evaluations are documented in Attachment. The additional analytical work demonstrated that the replacement steam dryers are dynamically similar to the FEM in the frequency range of interest. The difference in amplitudes for the frequency response functions (FRFs) indicates that the FEM response bounds both replacement steam dryers for the frequencies of interest when the load input time step variation of the stress analysis is taken into account. Differences in FRF amplitudes of the replacement dryers, with respect to acceleration per force, are not scalable to amplitude differences in the FEM stress or strain responses, and the differences in strains between the two dryers cannot be predicted based on the acceleration per force FRFs. The minor amplitude differences between the FRFs for the steam dryers are attributable to test-to-test variations and to structure-to-structure variations (e.g., differences in weld sequences). Using time step shifts in the stress analysis load inputs captures the peak amplitudes in the frequency range of interest. The time step variation ensures that the frequency content of the load applied to the FEM produces the highest amplitude response for the dryer components. The additional hammer test analyses have concluded that FEM demonstrates higher FRF amplitudes than either replacement steam dryer in the frequency range of interest. Consequently, the stress margin analysis has included the uncertainty associated with the dryer response to the time step shifts; however, no additional uncertainty is included for the FEM response amplitudes.

Exelon does not believe that further evaluations using 1% and 2% damping are necessary. The technical bases for this position are contained in GE Report GE-NE-0000-0048-1485-01, "Damping Value for Steam Dryer Hood Focused on a Single Frequency Regime," (i.e., Enclosure 6). The damping values used are appropriate based on the following considerations from this document.

1. Steam dryer strain response measurements taken on an overseas BWR-5 reactor plant, using data collected during rapid closure testing of turbine stop valves and main steam isolation valves, show critical damping within the range used to evaluate the structural response of QC replacement steam dryers.
2. Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," recommends critical damping values of 2% and 4% for welded structures, such as a steam dryer, for the Operating Basis Earthquake and Safe Shutdown Earthquake analyses, respectively. Although the recommended damping values are specifically for dynamic seismic analysis, no prohibition exists for use of these values for other dynamic loading analysis, as long as the guidelines for the maximum combined stress response due to static, seismic, and other dynamic loading are satisfied. The recommended values, based on an air environment at room temperature, were estimated for a steam environment at reactor operating conditions.
3. Damping values were determined from data collected during the hammer testing of both Quad Cities replacement steam dryers. The damping values at the actual reactor operating condition, and under fluid flow induced dynamic loads, should be much larger than the hammer test measured damping values. The increase in damping resulting from the reactor environment was calculated and determined to be significantly greater than the damping measured during the hammer test. The difference in strain levels between the hammer test load and the flow-induced vibration operating loads was also evaluated, and demonstrated basis for increased damping for the operating load strain levels. This evaluation has determined the percent critical damping at 150 Hz would be greater than the 2% Raleigh damping used in the finite element analyses.
4. Using Raleigh damping for the dryer hood, the finite element analysis predicted strains closely match and/or exceed the measure strain responses.

In addition to the bases provided above, GE Report GE-NE-0000-0046-5358-01 (i.e., Enclosure 15) documents a more rigorous comparison of the strains measured on the Unit 2 dryer to those predicted by the FEM. This study calculated the predicted strains at the installed strain gage locations and assessed the variability of the predicted strains associated with the strain gage installation tolerances. The results of this study demonstrated that the finite element analysis predicted results bound those measured on the dryer. Therefore, the damping, as defined, is considered to be conservative. Any reduction in the finite element analysis damping would tend to increase the predicted strains causing the over-predictions to be even larger. Consequently, structural damping is considered to be conservative, as defined, and no additional uncertainty is required for the stress analysis of the dryers.

The uncertainty analysis suggested by the NRC for the stress on dryer components has been completed and discussed in Exelon Response to Open Issue #2.

Open Issue #7

Is the methodology used to extrapolate the loads to 2957 MWt appropriate based on the Quad Cities, Unit 2 steam dryer data?

Status of Open Issue #7

With respect to Open Item 7, the licensee presented its evaluation of sensor data from the Quad Cities Unit 2 steam dryer to develop scaling factors based on power law exponents to extrapolate the steam dryer loading from 2885 MWt (maximum achieved thermal power) to 2957 MWt (maximum licensed thermal power). From its evaluation of the sensor data as the power level neared the maximum achieved MWt conditions, the licensee calculated increased scaling factors for the upper dryer and skirt to extrapolate the stress from 2885 to 2957 MWt. Following the licensee's presentation, the staff pointed to the rapid rise in strain obtained from strain gage S-7 on the Quad Cities Unit 2 steam dryer. The staff also raised questions regarding the significant increase in data from the pressure and strain sensors in the frequency range of 150 to 170 Hz near the maximum thermal power. The licensee stated that it would address these staff questions regarding extrapolation of steam dryer loading.

Exelon Response to Open Issue #7

As a result of the technical meeting held on November 8 and 9, 2005, additional studies were performed on both strain gage and pressure transducer data collected from the Quad Cities Unit 2 steam dryer. Both strain gage and pressure transducer data were analyzed for the full frequency range and for the [[ ]] frequency range. Data was curve fit both for all of the data above 2480 MWt and for only the data at 2780 MWt and above. For comparison, pressure sensors included for the full frequency range were those at the corners of the outer hoods and those near strain gages. All of the pressure sensors on the outer hoods, other upper components, and the skirt were analyzed for the [[ ]] band. The average power law curve fit exponent of the outer hood and upper dryer sensors for power levels above 2480 MWt in the frequency band of [[ ]] is a power exponent [[ ]]. For the curve fit of the [[ ]] frequency band pressure data at 2780 MWt and above, the average power law curve fit exponent was calculated [[ ]]. Both of these values are bounded by the previously reported power exponent [[ ]], which was calculated using strain gages S5, S7, and S9. As such, a power law exponent [[ ]] continues to be used to extrapolate the predicted dryer stresses to 2957 MWt. In performing the analysis using the pressure data at 2780 MWt and above, the highest power law exponent for the pressure range data was determined [[ ]]. GE Report GENE-0000-0046-8129-02, "Quad Cities New Design Steam Dryer - Methodology for Stress Scaling Factors Based on Extrapolation from 2885 MWt to 2957 MWt of Unit #2/Dryer #1 Data," was revised to provide the details of the extrapolation analysis summarized above. The revised report is provided in Enclosure 9, and details related to the revised power exponents are contained in Appendix B of the revised report.

To validate the extrapolation analysis performed by GE, Exelon contracted with CDI to perform an independent extrapolation analysis. This independent analysis utilized main steam line strain gage data collected during startup testing following replacement of the steam dryers on each unit. CDI took the strain gage data from three separate power levels ranging from 2754 MWt to 2887 MWt on Unit 2 and generated load histories using the Modified 930 MWe ACM. The analysis only included loads associated with the frequency distribution of 145 Hz to 165 Hz. This is a similar power and frequency band utilized by GE in the extrapolation analysis described above. Using the results from each power level, CDI then performed a linear extrapolation of the data to determine an extrapolation factor for 2957 MWth. The results were almost identical to those generated by GE as described above. The GE analysis determined a power factor [[ ]] extrapolation to achieve 2957 MWth. The independent CDI analysis determined an extrapolation of 23% to achieve 2957 MWth. This independent analysis is documented in CDI Technical Note No. 05-45, "Extrapolation of QC1 and QC2 Steam Dryer Loads to 2957 MWt," Revision 0 (i.e., Enclosure 10).

To add conservatism to dryer structural margin analysis, an uncertainty factor associated with the load and stress extrapolation has been used in the overall margin analysis described in the response to Open Issue #2. Specifically, an extrapolation uncertainty factor was based on the difference between the power law exponent [[ ]] from the average of the data and the maximum power law exponent [[ ]]. Details are contained in Exelon Report AM-2005-020.

Open Issue #8

Does a comparison of the MSL strain gage data for Quad Cities, Units 1 and 2, support interim EPU operation for Quad Cities Unit 1 until the stress analysis uncertainty issue is resolved?

Status of Open Issue #8

With respect to Open Item 8, the licensee discussed its comparison of MSL strain gage data from Quad Cities Units 1 and 2. The licensee considered the pressure loading suggested by the MSL strain gage data from the two reactor units to be comparable. The staff concluded that the MSL strain gage comparison could not fully demonstrate that similar pressure loading is being applied to the Quad Cities Units 1 and 2 steam dryers. The staff considered the strain measurement data in Figures 6, 18, and 19 in Structural Integrity Associates letter SIR–05-223 to not appear to support a conclusion that differences in the performance of the steam dryers in Quad Cities Units 1 and 2 are only due to loss of single MSL strain gages in Quad Cities Unit 1. The licensee stated that it would address this question with its consultant.

Exelon Response to Open Issue #8

During the November 8 and 9, 2005, meeting, the NRC identified differences between Figures 18 and 19 of Structural Integrity Associates (SIA) Report SIR-05-223, "Comparison of Quad Cities Unit 1 and Quad Cities Unit 2 Main Steam Line Strain Gage Data," Revision 1, (i.e., Enclosure 11) when compared to the Quad Cities Unit 2 plot in Figure 6. The following are clarifications concerning the information contained in the SIA report. Figures 18 and 19 present the Quad Cities Unit 2 main steam line quarter bridge and half bridge strain gage data PSDs in units of micro-strain squared/Hz with data taken at approximately 2868 MWt. The plot in Figure 6 presents the data as Fast Fourier Transforms (FFTs) in units of micro-strain/Hz with data taken at 2887 MWt. Since the information contained in the two separate sets of graphs was taken at different power levels, direct comparisons cannot be made. Comparison of the three sets of figures does not disprove that the data from the two units is comparable given the loss of single main steam line strain gages on Quad Cities Unit 1.

The basis for Exelon's conclusion that Quad Cities Unit 2 main steam line strain gage readings generally bound those measured on Quad Cities Unit 1 is supported by the data in Table 2 of the SIA Report. The average of all the strain measurements for Quad Cities Unit 2 are greater than the average of all the Quad Cities Unit 1strain measurements (when comparing average RMS and peak-to-peak data). For individual locations, five out of eight measurements on Quad Cities Unit 2 are greater than Quad Cities Unit 1 for RMS and peak-to-peak. When specifically considering the 150 to 160 Hz frequency range, five out of eight locations on Quad Cities Unit 2 are greater than Quad Cities Unit 1. The only Quad Cities Unit 1 locations not bounded by Quad Cities Unit 2 are locations where strain gage failures occurred on Quad Cities Unit 1. The individual strain gages are measuring the local hoop strains of the pipe shell, which vary around the pipe circumference. These local hoop strains include multiple pipe shell modes of response caused by internal pressure variations and other piping loads. Averaging all of the strain measurements reduces the various circumferential measurements to only the breathing mode hoop strain and mitigates the other shell modes of response. The failure of individual strain gages within a pair on Quad Cities Unit 1 resulted in a hoop strain measurement with more than the pipe breathing mode; consequently, the pressures are over-predicted at these locations. This accounts for the differences between the two units.

These conclusions are additionally supported by Exelon Report AM-2005-005, "Comparison of QC1 and QC2 Vessel Level And MSL Venturi Pressure Tap Dynamic Pressure Response at the

930 MWe Power Level," Revision 1 (i.e., Enclosure 12). Steam line venturi and water level reference leg PSD comparisons demonstrate that Quad Cities Unit 2significantly bounds Quad Cities Unit 1pressures in the 150 to 160 Hz range. This is shown on pages 11 thru 16 of Exelon Report AM-2005-005.

Open Issue #9

> Are the criteria used for strain gages S-5, S-7, and S-9 (outer hood locations) during the recent EPU restart of Quad Cities Unit 2 met with the most recent stress analysis?

Status of Open Issue #9

> With respect to Open Item 9, the licensee presented its evaluation of data from strain gages S-5, S-7, and S-9 in comparison to the acceptance criteria during the Quad Cities Unit 2 restart. The licensee found that the strain gage criteria were met using the most recent analysis. With the impact of structural damping assumptions to be addressed through Open Item 6, the NRC staff considered that Open Item 9 can be closed.

Exelon Response to Open Issue #9

The documentation providing closure to Open Item #9 is provided in GE Report GENE-000-0045-5505-01, "Response to NRC Concern on Quad Cities Steam Dryer Startup Criteria," dated October 2005 (i.e., Enclosure 13).

Open Issue #10

What is the uncertainty of the steam dryer strain gages installed in Quad Cities Unit 2, and how does it impact available margin for steam dryer structural integrity?

Status of Open Issue #10

With respect to Open Item 10, the licensee presented its evaluation of the sensitivity of the strain gages installed on the steam dryer in Quad Cities Unit 2 for location and orientation. Based on its review of strain gages S-5, S-7, and S-9, the licensee found the calculated strain to be higher than the measured strain on the steam dryer. The NRC staff considered the licensee's evaluation to have resolved this open item for Quad Cities Unit 2. Where applicable, the steam dryer strain gage measurement uncertainty needs to be considered in assessing the structural capability margin.

Exelon Response to Open Issue #10

The information presented to the NRC concerning the location and orientation sensitivity of the strain gages installed on the Quad Cities Unit 2 steam dryer is documented in GE Report GENE-0000-0046-5358-01 (i.e., Enclosure 15). The strain gage sensitivity discussed in the GE report was used to determine the end-to-end margin analysis for Quad Cities Unit 2. During the November 8 and 9, 2005, technical meeting with the NRC, Exelon presented the comparison of measured strain gage data on the Quad Cities Unit 2 dryer against predicted strains, and used this analysis to determine the end-to-end margin of the Quad Cities Unit 2 replacement dryer design. Because the Quad Cities Unit 1 replacement dryer did not have strain gages installed to measure actual strains encountered during power operation, a different approach was used to determine the design margin for the Quad Cities Unit 1 replacement dryer. This design margin analysis is described in the response to Open Issue #2, and is contained in Exelon Report AM-2005-020 (i.e., Enclosure 2)

General Discussion

In summarizing its conclusions from the November 8-9 meeting, the NRC stated that, "based on its review of the information provided by the licensee and the discussions during the meeting, several questions remain regarding the licensee's consideration of the impact of uncertainties in the stress analysis and its assumptions on the potential to exceed the allowable stress limits in the Quad Cities steam dryers under EPU conditions. For example, the staff raised questions regarding the consideration of uncertainties associated with the calculation of pressure loads on the steam dryer by the ACM at various locations and frequency ranges; sensitivity of the stress analysis to assumptions for acoustic and structural damping; impact of resonances within the ±10% frequency band; extrapolation of sensor data to maximum thermal power levels in the frequency range of interest; comparison of MSL strain data from Quad Cities Units 1 and 2; and differences in steam dryer responsiveness to pressure loads. The staff noted that the licensee's stress calculations found relatively small margins to the applied stress limits for some parts of the steam dryers in Quad Cities Units 1 and 2. In that the questions associated with the stress analysis uncertainties involve whether the steam dryer stress limits might be exceeded, the staff could not reach agreement with the licensee that the analysis supports long-term EPU operation for Quad Cities."

"The NRC staff considers the questions regarding uncertainties in the steam dryer stress analysis to be less significant for Quad Cities Unit 2 as a result of the pressure sensors and strain gages installed directly on the steam dryer. Further, the licensee will conduct a detailed inspection of the Quad Cities Unit 2 steam dryer during the spring 2006 RFO. With the reliance on the ACM to determine steam dryer loads in Quad Cities Unit 1, the staff considers the questions regarding the steam dryer analysis uncertainties to be more focused on that unit. These questions would also be applicable to the Dresden units."

"The licensee will be providing additional information on the questions associated with several open items from the NRC staff review. In determining the uncertainty for each applicable term in the steam dryer stress analysis, the staff suggested during the November 8-9 meeting that the licensee evaluate the sensitivity of the uncertainty factors in question for the Quad Cities Unit 1 steam dryer with regard to (1) dryer components with the lowest margin and (2) dryer components considered to be the most susceptible to the generation of loose parts (such as the outer hood). The staff also requested that the licensee discuss the location, function, and potential to generate loose parts for each of these analyzed dryer components. Based on this evaluation, the licensee could assess the confidence in the structural integrity of the Quad Cities Unit 1 steam dryer in light of the potential impact of uncertainties on the stress analysis. This information will also help the licensee to determine appropriate long-term plans for Quad Cities and Dresden."

Exelon Response to General Comments

The Exelon responses to Open Issues #2 and #10 provide a comprehensive analysis of the uncertainty for the various factors utilized in the margin analysis of the Quad Cities dryer design. In response to the NRC request that Exelon address the location, function, and potential to generate loose parts for each of these analyzed dryer components, GE performed a failure modes and effects analysis (FMEA) for the six lowest margin components on the dryer. The six lowest margin components analyzed are the drain trough, the inner vane cap curve part, the inner hood, the inner tee section flange, the cross beams, and the trough brace gusset. The analysis identified the potential failure effect for each component and concluded that cracking of associated welds or components themselves would not likely result in a loose part. The most adverse failure effect noted in the analysis was an increase in moisture carry over in the event that the inner hood were to fail. Further details are provided in GE Letter Report GE-ENG-DRY-159, "Review of Failure Modes for Quad Cities Unit 1 Replacement Dryer," (i.e., Enclosure 14).