ATTACHMENT 2

GE Report GENE-0000-0038-6481-01-R1-NP, "Exelon Steam Dryer Dynamic Time History Analyses: Dresden Unit 2 2004 Repair and Dresden Unit 3 2003 and 2004 Repair Dryer Configurations using Loads from Plant Measurements," Revision 1, Non-Proprietary, dated March 2006

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NON-PROPRIETARY VERSION

Exelon Steam Dryer Dynamic Time History Analyses:

Dresden Unit 2 2004 Repair and Dresden Unit 3 2003 and 2004 Repair Dryer Configurations using Loads from Plant Measurements

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Revision History

Revision 1

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1. Introduction

In March of 2002, Quad Cities Unit 2, operated by Exelon, operated at uprated power level up to a maximum of 117% OLTP after its planned refueling outage and began continuous operation at this power level. On June 7, 2002, several anomalous readings related to pressure, water level, steam flow and moisture carryover were detected. Initial evaluation concluded that the steam dryer was operating in a degraded condition. After 34 days of continuous monitoring of Quad Cities Unit 2, the unit was shutdown July 11, 2002 to perform visual inspection of the steam dryer. The inspection revealed that a large portion of one cover plate adjacent to one of the outer bank inlet hoods was missing.

The result of the root cause evaluation showed the primary factor for this event was flow regime instability that resulted in localized, high cycle pressure loadings near the main steam line (MSL) nozzles. The high vibratory stresses from the pressure loading eventually resulted in the high cycle fatigue failure of the cover plate. During the subsequent 10 day unplanned outage, Quad Cities, Unit 2 replaced both damaged and undamaged 0.25-inch cover plates with new 0.5-inch cover plates and the unit was returned to its pre-outage extended power uprate (EPU) operating level. The thicker 0.5-inch cover plate was designed to lower predicted stresses from both the turbulent and resonant loading. The root cause was identified at that time as high cycle fatigue caused by high frequency pressure loading. Subsequently, the cover plates for Quad Cities Unit 1 and both Dresden units were replaced with 0.5-inch plates as well.

In May 2003, Quad Cities Unit 2 experienced a significant increase in steam moisture content while operating at EPU conditions. Inspection during the June 2003 outage found significant through-wall cracks in the outer dryer bank hood coupled with cracking in the outer hood internal braces. Additional fatigue cracking was also observed in some of the tie bars between dryer banks. The primary repair implemented in June 2003 involved removing the upper portion of the 0.5-inch thick outer hood and replacing it with a 1.0-inch thick plate. Additionally, 0.5-inch thick gussets were added to the outer hoods to increase the stiffness. The gussets were attached to the outer hoods one inch below the horizontal weld seam connecting the 0.5-inch thick plate with the new 1.0-inch thick plate on the outer hood. The diagonal braces in the outer hoods and one vertical brace in the 90-degree outer hood and one vertical brace in the 270-degree outer hood were removed. Rectangular 3-inch by 1-inch bars were welded to the tie bar angles to reduce the stresses. The root cause of the outer hood failure was attributed to low frequency high cycle fatigue.

During the March 2004 refueling outage inspections of the previously repaired Quad Cities Unit 2 steam dryer, fatigue cracks were found at the tops of several gusset welds on the dryer outer vertical hood. One gusset on the 90-degree side and two gussets on the 270-degree side were cracked in the weld between the gusset and the outer hood. These gusset cracks, were found to have traveled into the outer hood material. In addition, cracks were found in the outer hood to support ring weld, tie bar welds and perforated plate L bracket welds. Again, repairs were made to the dryer to restore structural margin. The entire front hood panel was replaced with 1.0-inch thick plate, new taller gussets were added using shop groove welds, and redesigned tie bars were installed. Additionally, specific design criteria were developed based on static analyses to prevent future crack initiation.

Concurrently, inspections were performed at the other Exelon BWR/3 unit steam dryers. Repairs based on the 2003 Quad Cities Unit 2 analyses were implemented. However, in October of 2004, during a planned outage at Dresden Unit 3, a through-wall crack in the cover plate-to-support ring weld was discovered at the cover plate corner. Static analysis showed that when the short repair gussets and thicker top portion of the outer hood were installed in the Dresden and Quad Cities plants after the June 2003 discovery of cracks in the outer hood, the maximum stress in the cover plate moved outward from the center of the cover plate near the outer hood to the corner of the cover plate where the crack was discovered. Time history analyses later confirmed this conclusion. All dryer failures were initially analyzed using static and quasi-static methods as well as frequency analyses. To better address dynamic loading issues, a response spectrum approach based on enveloping pressure time histories from three plants was employed. However, these loads were found to be overly conservative; there was also a concern that the assumed loading was generic and not plant specific.

This report describes the dynamic time history analyses performed on the Dresden steam dryers for different repaired configurations. The loading used for these analyses came from plant data measurements from the MSLs. Continuum Dynamics, Inc. (CDI) processed these MSL gauge measurement/ venturi instrumentation line measurements through acoustic circuit analyses to develop pressures on all surfaces of the dryer, both internal and external. Using this data, time history analyses have been performed on the 2003 and 2004 dryer repair configurations for Dresden Unit 3 and the 2004 Dresden Unit 2 repair configuration. This report then correlates results with the unrepaired and repaired steam dryer failure behavior.

2 Summary

Finite element analyses were performed to evaluate the original and repaired dryer configurations. The full dryer shell model, used in previous Quad Cities and Dresden dryer evaluations [References 3 and 4], was modified to reflect the June 2003 and March 2004 repaired configurations of the Dresden Unit 3 dryer (both Dresden Units have the same configuration for 2004, which is their current configuration). The

2004 repair configuration was analyzed using loading from two sources: 1) Dresden Unit 2 plant data, and 2) Dresden Unit 3 plant data.

A summary of maximum stress intensities for each dryer configuration and loading is shown in Table 2-1. These stress values are taken directly from ANSYS output. In the previous static analysis for the 2004 repair, stresses in all critical locations affected by the repair were below the design criterion of [[ ]] The design criterion stress intensity limit of [[ ]] force per square inch (psi) was based on a [[

]] accounted for any stress concentration not accounted for in the shell finite element model of the full dryer, weld quality, and load uncertainty. In the time history analyses reported here, the purpose is to demonstrate that the pressure time history loads from plant data results predict the past dryer failures for the 2003 repair configuration for Dresden Unit 3 2003 and show that the current 2004 repair is acceptable for both Dresden units. [[

]] [Reference 10]. This alternating stress is then compared with the fatigue curves and a determination is made whether failure would occur at each location with the results summarized in Table 2-2. The time history results match very well with the observed failures in the Exelon steam dryers.

Table 2-1 Comparative Summary of Stress Intensities from Time History Analyses for Different Dresden Dryer Configurations: Unaltered ANSYS results

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Table 2-2 Failure Predictions based on Time History Analyses for Different Dryer Configurations and Loading Conditions

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3 Dynamic Analysis Approach

3.1 Dynamic Loading, Pressure Time Histories

These analyses used data collected from both Dresden units. The plant data was taken from strain gauge readings on the MSLs for Dresden Unit 2. For Dresden Unit 3, the plant data was from a combination of strain gauge and venturi instrumentation line data. The plant data was processed in acoustic circuit analyses by CDI to determine the pressure differentials on all external and internal surfaces of the dryer that experience fluctuating pressure during normal plant operation.

Pressures are applied to dryer components, represented by shell elements in finite element models. A different finite element model was used for each dryer configuration. A time step of [[ ]] was used. For the Dresden 2 analysis presented in this report, modal superposition was used with a constant damping value of [[ ]] [Reference 13]. For the Dresden 3 analyses, direct integration was used with Rayleigh constants resulting in a nominal 0.5% damping.

3.2 Stress Recovery Methodology

An ANSYS macro was written to sweep through each time step at every element on each component of interest to determine the time and location of the maximum stress intensity. ANSYS maximum stress intensity results from this macro are presented in Table 2.1.

4 Material Properties

The dryer assembly was manufactured from solution heat-treated SS304 conforming to applicable ASTM standards at the time of manufacture. The repair plate is made from SS316L. Minimum of SS304L and 316L properties were used to conservatively envelop the properties of the original components and the repair plate. The applicable properties are shown in Table 4-1.

Table 4-1 Properties of SS304L and SS316L [Reference 6]

Material / property	Room temperature 70°F	Operating temperature 545°F
SS304L		
S_y, Yield strength, psi	25000	15940
S_u, Ultimate strength, psi	70000	57440
E, Elastic modulus, psi	28300000	25575000
SS316L		
S_y, Yield strength, psi	25000	15495
S_u, Ultimate strength, psi	70000	61600
E, Elastic modulus, psi	28300000	25575000

5 Design Criteria

For the purpose of determining whether failure would be predicted, at those locations that failed in the field, the stresses calculated based on the plant pressure time history loads are compared to the fatigue curves from the American Society of Mechanical Engineers (ASME) Code [Reference 11]. Figure I-9.2.2 of ASME Section III [Reference 11] provides the fatigue threshold values for use in the evaluation of stainless steels. Since most of the dryer failure locations are at welds, Curve C is conservatively used in this evaluation (13.6 ksi is the endurance limit). If the calculated alternating stress is below 13.6 kilo-pounds per square inch (ksi), then fatigue crack initiation is not expected at this location. The ASME Code fatigue curve includes a factor of 2 over the mean fatigue failure curve at the high cycle end. Any peak stress above 27.2 ksi (13.6 X 2) would be expected to cause crack initiation. Since there is wide variability in fatigue data, any peak stress which falls between the standard design endurance limit of 13.6 ksi and 27.2 ksi would be assumed to have some probability of crack initiation. These will be the criteria for determining if these loads predict the actual failures experienced in the field.

6 Dynamic Analyses

Time history analyses were performed using ANSYS Version 6.1 [Reference 9] and Version 8.1 [Reference 10]. The modal superposition method was used for the Dresden Unit 2 time history analysis and direct integration method was used for both of the Dresden Unit 3 time history analyses described in this report. The results from both modal superposition and direct integration should be very similar for the same load. Time history loads from CDI were provided for nodes every [[ ]] on the outer banks, every [[ ]] on the inner banks just inboard of the outer banks and every [[ ]] for the inner most hoods. The analyses used a code developed by General Electric Nuclear Energy to read the CDI load files into ANSYS. This program converted the given pressure to nodal forces on all the surfaces where the dryer experiences a pressure drop during normal operation. The time history runs were two seconds in duration. Time history analyses were performed on the following dryer configurations and loading as discussed in Section 3:

1. 2003 repair dryer with Dresden Unit 3 plant data at EPU
2. 2004 repair dryer with Dresden Unit 3 plant data at EPU
3. 2004 repair dryer with Dresden Unit 2 plant data at EPU

6.1 Finite Element Models

A different finite element model (FEM) was used to analyze each dryer configuration. Reference 12 describes in detail the different dryer finite element models for each of the plants and the models used in previous repair analyses. A brief description of the models for the original dryer, the 2003 repair configuration, and the 2004 repair configuration is included in this section.

6.1.1 Original Dryer

The unrepaired dryer configuration finite element model is shown in Figure 6-1.

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6.1.2 2003 Dresden 3 Repair Dryer

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[Reference 1]. The diagonal braces were removed from the outer banks during the 2003 dryer repair. Two vertical braces were also removed from the outer banks during the 2003 dryer repair, one on each side of the dryer. These changes are incorporated in the full dryer finite element model.

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]] The 2003 repair configuration used in this analysis is the Dresden Unit 3 configuration with the short gussets welded to the outer hood above the weld seam at the 1.0-inch thick repair plate. This model is shown in Figure 6-2.

6.1.3 2004 Repair Dryer

For this configuration, which applies to Quad Cities Unit 2, Dresden Unit 2 and Dresden Unit 3, the front vertical portion of the outer hood is now 1.0-inch thick and the short, 30-inch high gussets have been replaced with tall 53-inch high gussets, which are welded to the outer hood and come within 6 inches of the top of the outer hood. This model is shown in Figures 6-3 thru 6-5. [[

]] The boundary conditions are shown in Figure 6-6.

6.2 Stress Analysis Results

The maximum stresses from the time history analyses are summarized in Table 2-1. For the 2003 Dresden Unit 3 dryer configuration, applied pressure at the following times are plotted: 1) maximum pressure [Figure 6-7] and 2) minimum pressure [Figure 6-8]. Figures 6-9 through 6-14 show plots of stresses in the outer hood, inner hood, top hood, cover plate, base plate, and gussets are shown in. More detailed post processing of the cover plate stress intensities at locations near the corners and the gusset attachments are included in this report. Figure 6-15 shows the locations on the cover plates where stresses are recovered. Figures 6-16 and 6-17 show the stress intensity versus time for the cover plate corner locations and figures 6-18 and 6-19 show the stress intensity versus time for the cover plate gusset attachment locations at the support ring. Table 6-1 below gives a detailed listing of stress intensity at the cover plate locations shown in Figure 6-15.

For the 2004 Dresden Unit 3 dryer configuration, applied pressure at the following times are plotted: 1) maximum pressure [Figure 6-20], 2) minimum pressure [Figure 6-21], and 3) maximum stress intensity in the outer hood [Figure 6-22]. Plots of stresses in the outer hood, inner hood, top hood, cover plate, base plate, and gussets are shown in figures 6-23 through 6-28.

For the 2004 Dresden Unit 2 dryer configuration, applied pressure at the following times are plotted: 1) maximum pressure [Figure 6-29], 2) minimum pressure [Figure 6-30], and 3) maximum stress intensity in the outer hood [Figure 6-31]. Plots of stresses in the outer hood, inner hood, top hood, cover plate, base plate, and gussets are shown in figures 6-32 through 6-39. In addition, plots showing how the stress intensity attenuates with distance from the maximum stress locations are shown for the outer hood [Figure 6-33] and the cover plate [Figure 6-37]. This information is used in determining the nominal stress intensity in the region directly around the maximum stress location for the fatigue evaluation.

Table 6-1 Dresden Cover Plate Stress Intensity Summary

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7 Fatigue Assessment

Peak stress intensities were determined by using a nominal stress at a location near the maximum stress intensity from the finite element analysis and multiplied by the appropriate SCF from Reference 10. Reference 10 states that for nominal stress intensity from a shell finite element model, a factor of [[ ]] is to be used for double fillet welds (fillet welds on both sides of a plate) and a factor of [[ ]] is to be used for a single fillet weld. The nominal stress intensity was conservatively determined by selecting the stress [[ ]] away from the maximum stress location. In all cases, this stress was located between [[ ]] from the maximum nodal stress intensity in the finite element model. Figure 6-33 is an example of how stress intensity attenuates with distance from the maximum stress intensity location. The fatigue evaluation results are shown in Table 2-2. These results also demonstrate that in-plant data loads accurately predict the observed failures in the Exelon steam dryers. The results are very consistent with the actual finite element maximum stress intensity results given in Table 2-1.

8 Conclusions

The time history loads from plant data show good correlation with the field experience. The results using the 2003 configuration for Dresden Unit 3 predict high stresses at the cover plate location where cracking was found. Secondly, the results for the 2004 configuration do not predict any locations having unacceptable stresses for either plant. Additionally, while the Dresden Unit 3 loads produce almost double the stress intensity at the locations of interest in the dryer as compared with the Dresden Unit 2 loads, they do not predict failure at any locations other than those that actually did experience failure in the field for the 2003 dryer configuration.

In summary, the predictions based on plant data from Dresden Units 2 and 3 substantiate that in the 2004 repair configuration, the steam dryers are acceptable for continuous operation at EPU power levels.

9 References

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13. "Damping Value for Steam Dryer Structural Dynamic Analysis, DRF Section 0000-0034-1855

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Figure 6-1 Original Dryer Configuration Finite Element Model

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Figure 6-2 2003 Repair Dryer Configuration Finite Element Model

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Figure 6-3 2004 Repair Dryer Analysis Model – Support Structure

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Figure 6-4 2004 Repair Dryer Analysis Model – Dryer banks and hoods

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Figure 6-5 2004 Repair Dryer Analysis Model

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Figure 6-6 Dryer Model Boundary Conditions (same for all configurations)

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Figure 6-7 2003 Repair Dryer D3 Plant Loads at EPU: Maximum Applied Pressure at Time = 1.427 Seconds

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Figure 6-8 2003 Repair Dryer D3 Plant Loads at EPU: Minimum Applied Pressure at Time = 1.4305 Seconds

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Figure 6-9 2003 Repair Dryer D3 Plant Loads at EPU: Outer Hoods

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Figure 6-10 2003 Repair Dryer D3 Plant Loads at EPU: Inner Hoods

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Figure 6-11 2003 Repair Dryer D3 Plant Loads at EPU: Top Hoods

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Figure 6-12 2003 Repair Dryer D3 Plant Loads at EPU: Cover Plate

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Figure 6-13 2003 Repair Dryer D3 Plant Loads at EPU: Gussets

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Figure 6-14 2003 Repair Dryer D3 Plant Loads at EPU: Base Plates

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Figure 6-15 2003 Repair Dryer D3: Cover Plate Stress Map

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Figure 6-16 2003 Repair Dryer D3 plant loads at EPU: Cover Plate Corners on 90-degree side of dryer

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Figure 6-17 2003 Repair Dryer D3 plant loads at EPU: Cover Plate Corners on 270-degree side of dryer

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Figure 6-18 2003 Repair Dryer D3 plant loads at EPU: Cover Plate Gusset Locations on 90-degree side of dryer

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Figure 6-19 2003 Repair Dryer D3 plant loads at EPU: Cover Plate Gusset Locations on 270-degree side of dryer

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Figure 6-20 2004 Repair Dryer D3 Plant Loads at EPU: Maximum Applied Pressure at Time = 1.427 Seconds

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Figure 6-21 2004 Repair Dryer D3 Plant Loads at EPU: Minimum Applied Pressure at Time = 1.4305 Seconds

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Figure 6-22 2004 Repair Dryer D3 Plant Loads at EPU: Applied Pressure at Time = 1.531 seconds

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Figure 6-23 2004 Repair Dryer D3 Plant Loads at EPU: Outer Hoods

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Figure 6-24 2004 Repair Dryer D3 Plant Loads at EPU: Inner Hoods

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Figure 6-25 2004 Repair Dryer D3 Plant Loads at EPU: Top Hood

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Figure 6-26 2004 Repair Dryer D3 Plant Loads at EPU: Cover Plate

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Figure 6-27 2004 Repair Dryer D3 Plant Loads at EPU: Gussets

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Figure 6-28 2004 Repair Dryer D3 Plant Loads at EPU: Base Plate

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Figure 6-29 2004 Repair Dryer D2 Plant Loads at EPU: Maximum Applied Pressure at Time = 0.8335 Seconds

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Figure 6-30 2004 Repair Dryer D2 Plant Loads at EPU: Minimum Applied Pressure at Time = 0.467 Seconds

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Figure 6-31 2004 Repair Dryer D2 Plant Loads at EPU: Applied Pressure at Time = 0.528 Seconds

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Figure 6-32 2004 Repair Dryer D2 Plant Loads at EPU: Outer Hood

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Figure 6-33 2004 Repair Dryer D2 Plant Loads at EPU: Outer Hood Stress Intensity Versus Horizontal Distance from Stress Concentration

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Figure 6-34 2004 Repair Dryer D2 Plant Loads at EPU: Inner Hood

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Figure 6-35 2004 Repair Dryer D2 Plant Loads at EPU: Top Hood

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Figure 6-36 2004 Repair Dryer D2 Plant Loads at EPU: Cover Plate

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Figure 6-37 2004 Repair Dryer D2 Plant Loads at EPU: Cover Plate Stress Intensity Versus Horizontal Distance from Stress Concentration

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Figure 6-38 2004 Repair Dryer D2 Plant Loads at EPU: Gussets

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Figure 6-39 2004 Repair Dryer D2 Plant Loads at EPU: Base Plate