ENCLOSURE 2

Attachment 11

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Quad Cities Unit 1 Replacement Steam Dryer Stress and Fatigue Analysis at EPU Power Level of 2957 MWt Based on Measured EPU Conditions

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ACRONYMS AND ABBREVIATIONS

Item	Short Form	Description
1	ACM	Acoustic Circuit Model used by CDI to predict pressure loads on the dryer based on measurements taken from main steam line strain gages.
2	ASME	American Society of Mechanical Engineers
3	BWR	Boiling Water Reactor
4	EPU	Extended Power Uprate
5	FEA	Finite Element Analysis
6	FEM	Finite Element Model
7	FFT	Fast Fourier Transform
8	FIV	Flow Induced Vibration
9	GE	General Electric
10	GENE	General Electric Nuclear Energy
11	Hz	Hertz
12	IGSCC	Intergranular Stress Corrosion Cracking
13	Mlbm/hr	Millions pounds mass per hour
14	CDI	Continuum Dynamics, Inc.
15	MSL	Main Steam Line
16	MW	Megawatt Thermal
17	NA	Not Applicable
18	NRC	Nuclear Regulatory Commission
19	OBE	Operational Basis Earthquake
20	OLTP	Original Licensed Thermal Power
21	Pb	Primary Bending Stress
22	Pm	Primary Membrane Stress
23	psi	Pounds per square inch
24	Ref.	Reference
25	RMS	Root-Mean-Squared
26	RPV	Reactor Pressure Vessel
27	SCF	Stress Concentration Factor
28	SRSS	Square Root Sum of Squares
29	SRV	Safety Relief Valve

1. EXECUTIVE SUMMARY

In 2002 Quad Cities Unit 2 first developed fatigue cracks in the cover plate portion of the steam dryer after the plant had been operating at extended power uprate (EPU). The result of the root cause evaluation showed the primary factor for this event was high cycle loadings on the dryer. Additional fatigue cracking was observed in 2003 and 2004 in the cover plate and outer hood portions of the repaired Quad Cities and Dresden steam dryers. A replacement dryer was designed to withstand these flow induced vibration loads. The design loads for the replacement dryer were based on time history analyses using acoustic circuit loads from both in-plant steam line data and scale model test (SMT) data at less than EPU conditions. The results of the analyses performed using the design loads are in Reference 17, which established that the replacement dryer components are not vulnerable to fatigue at EPU conditions.

As part of the replacement dryer program, the replacement dryer and main steam lines in Unit 2 were instrumented for the purpose of measuring the pressure loads acting on the dryer and for benchmarking the load prediction and measurement methodologies. In addition, the main steam lines in Unit 1 were instrumented for the purpose of calculating the pressure loads acting on the Unit 1 dryer. This report summarizes the structural analysis performed to demonstrate the adequacy of the replacement steam dryer design using Continuum Dynamics Inc. (CDI) predicted loads based on main steam line strain gage measurements obtained during the Unit 1 startup with the replacement dryer.

Finite element analyses were performed using a full three-dimensional model of the Exelon replacement dryer comprised of shell elements to determine the most highly stressed locations associated with EPU. The analyses consisted of time history dynamic analyses, frequency calculations, and stress and fatigue analyses. The acoustic circuit model by CDI, which was driven by strain gauge measurements on the main steam lines, was used to develop the dryer pressure loads for the time history analyses. In addition, ASME Code based load combinations were also analyzed using the finite element model. Where necessary, the locations of high stress identified in the time history analyses were further evaluated using solid finite element models to more accurately predict the stresses at these locations.

This report summarizes the dynamic, stress and fatigue analyses that demonstrate the Exelon replacement steam dryer is structurally adequate for EPU conditions based on plant measurements taken at Quad Cities Unit 1 during EPU operation of the replacement dryer. The replacement dryer satisfies both the fatigue limit and the

ASME Code limits for normal, upset and faulted events at EPU conditions (Reference 1).

2. INTRODUCTION AND BACKGROUND

2.1 Dryer Design Bases and Historical Development

The function of the steam dryer is to remove any remaining liquid in the steam exiting from the array of axial flow steam separators. GE BWR steam dryers use commercially available modules of dryer vanes that are enclosed in a GE designed housing to make up the steam dryer assembly. The modules or subassemblies of dryer vanes, called dryer units, are arranged in parallel rows called banks. Four to six banks are used depending on the vessel size. Dryer banks are attached to an upper support ring, which is supported by four to six steam dryer support brackets that are welded attachments to the RPV. The steam dryer assembly does not physically connect to the shroud head and steam separator assembly and it has no direct connection with the core support or shroud. A cylindrical skirt attaches to the upper support ring and projects downward forming a water seal around the array of steam separators. Normal operating water level is approximately mid-height on the dryer skirt. During refueling the steam dryer rests on the floor of the equipment pool on the lower support ring that is located at the bottom edge of the skirt. Dryers are installed and removed from the RPV using the reactor building crane. A steam separator and dryer strongback, which attaches to four steam dryer lifting rod eyes, is used for lifting the dryer. Guide rods in the RPV are used to aid dryer installation and removal. BWR steam dryers typically have guide channels or upper and lower guides that interface with the guide rods.

Wet steam flows upward from the steam separators into an inlet plenum, horizontally through the dryer vane banks, vertically in an outlet plenum and into the RPV dome. Steam then exits the reactor pressure vessel (RPV) through steam outlet nozzles. Moisture (liquid) is separated from the steam by the vane surface and the hooks attached to the vanes. The captured moisture flows downward under the force of gravity to a collection trough that carries the liquid flow to drain pipes and vertical drain channels. The liquid flows by gravity through the vertical drain channels to the lower end of the skirt where the flow exits below normal water level. The outlet of the drain channels is below the water surface in order to prevent reentrainment of the captured liquid.

GE BWR steam dryer technology evolved over many years and several product lines. In earlier BWR/2 and BWR/3 dryers, the active height of the dryer vanes was set at 48 inches. In BWR/4 and later steam dryer designs the active vane height was increased to 72 inches. Perforated plates were included on the inlet and outlet sides of the vane banks of the 72-inch height units in order to distribute the steam flow uniformly through the bank. The addition of perforated plates resulted in a more uniform velocity over the height of the vanes. The performance for BWR/4 and dryer designs was established by testing in steam. The replacement dryer designed for Quad Cities and Dresden incorporates the performance features of the latest steam dryer designs along with structural design enhancements to better withstand the pressure loading that can result in fatigue crack initiation.

Most of the steam dryer is located in the steam space, with the lower half of the skirt extending below normal water level. These environments are highly oxidizing. All of the BWR/2-6 steam dryers are welded assemblies constructed from Type 304 stainless steel. The Type 304 stainless steel used in BWR/2-6 steam dryers was generally purchased with a maximum carbon content specification of 0.08% (typical ASTM standard). Therefore, the weld heat affected zone material is likely to be sensitized during the fabrication process making the steam dryer susceptible to intergranular stress corrosion cracking (IGSCC). Temporary welded attachments may have also been made to the dryer material that could result in unexpected weld sensitized material. Steam dryer parts such as support rings and drain channels were frequently cold formed, also increasing IGSCC susceptibility. Many dryer assembly welds included crevice areas at the weld root, which were not sealed from the reactor environment. Cold formed 304 stainless steel dryer parts were generally not solution annealed after forming and welding. Because of the environment and material conditions, most steam dryers have exhibited IGSCC cracking. The replacement dryer design specified materials and fabrication processes that will reduce the susceptibility of the dryer to IGSCC cracking compared to the original dryer.

Average steam flow velocities through the dryer vanes at OLTP conditions are relatively modest (2 to 4 feet per second). However, the outer hoods near the steam outlet nozzles are continuously exposed to steam flows in excess of 100 feet per second. These steam velocities have the potential for exciting acoustic resonances in the steam dome and steam lines, provided appropriate conditions exist, resulting in fluctuating pressure loads that act on the dryer.

The dryer is a Class I Seismic but non-safety related component and performs no safety functions. The steam dryer assembly is classified as an "internal structure" per ASME Boiler and Pressure Vessel Code, Section III, Subsection NG. Therefore the steam dryer needs only to be analyzed for those faulted load combinations for which loss of structural integrity of the steam dryer could interfere with the required performance of safety class equipment (i.e., generation of loose parts that may interfere with closure of the MSIVs) or affect the core support structure integrity (shroud, top guide, core support and shroud support).

2.2 Quad Cities and Dresden EPU Dryer Experience

Exelon has experienced dryer cracking and failures at each of the Quad Cities and Dresden units following implementation of EPU. The first dryer failure, loss of the lower horizontal cover plate at Quad Cities Unit 2, occurred in June 2002 after about three months of EPU operation. The root cause of this failure was determined to be high cycle fatigue due to a high frequency fluctuating pressure load. The second dryer failure, also at Quad Cities Unit 2, occurred in May 2003 after a little more than a year of total EPU operation. This failure consisted of severe through-wall cracking in the outer hood, along with cracking of vertical and diagonal internal braces and tie bars. The root cause of this failure was determined to be high cycle fatigue due to fluctuating pressure loads [[
]]. The internal gussets for the diagonal braces created a local stress concentration where the fatigue cracking had initiated. Hood cracking was observed at all four outer hood gusset locations. In October 2003, the dryer at Dresden Unit 2 was inspected following a full two year cycle at EPU conditions. Incipient cracking was observed in the outer hoods at all four diagonal brace gusset locations. In November 2003, Quad Cities Unit 1 experienced a hood failure similar to the one that occurred in May 2003 at Quad Cities Unit 2, again after about a year of EPU operation. Following this failure, Dresden Unit 3, which had been operating at EPU for a little more than one year, was shut down and the dryer inspected. Dresden Unit 3 exhibited the same incipient cracking at the outer hood gusset locations as was observed in Dresden Unit 2. In all of these cases, the root cause was determined to be high cycle fatigue due to the fluctuating pressure loads at EPU conditions.

Cracking has also been observed in some of the repairs and modifications that were made to the dryers following these failures. This type of cracking has also been observed to varying degrees in the dryers in all four units. During the March 2004 refueling outage, inspection of the repairs in the Quad Cities Unit 2 dryer showed cracking in the hood plate at the tips of the external gussets on the outer hoods. In November 2004, cracking was observed at one end of the weld between the lower horizontal cover plate and support ring in the Dresden Unit 3 dryer. The lower horizontal cover plate had been replaced in response to the initial 2002 Quad Cities failure as part of the EPU modifications for the dryer. In November 2004, an inspection of the Dresden Unit 2 dryer revealed cracking in the same lower horizontal cover plate weld, this time near the base of one of the external gussets. Recently, a crack was found in this same weld at Quad Cities Unit 1 during a March 2005 inspection, again at the base of one of the external gussets. This cracking experience highlighted the importance of local stress concentrations in determining the fatigue life of the structure. In addition, several of the dryers are beginning to experience fatigue cracking in the perforated plate inserts installed in each dryer as part of the EPU implementation modifications. Tie bar repairs have also experienced cracking. This experience demonstrates the uncertainty in the useful life of the repairs and modifications performed on the original Quad Cities and Dresden steam dryers.

2.3 Motivation for Additional FIV and Structural Analysis

The experiences at Quad Cities and Dresden demonstrated the need to better understand the nature of the loading and the dynamic structural response of the steam dryers during normal operation. The expense involved with inspection and repair of the dryers for the extended life of the plants provide motivation for determining the loads acting on the dryers and quantifying the stresses in the dryers at EPU conditions. GE and Exelon have initiated development programs to determine the fluctuating pressure loads acting on the dryer in order to confirm the continued acceptability of operating the current dryers and for use in designing a replacement dryer that will be able to accommodate the loading during EPU operation without experiencing cracking.

Based on these needs, this evaluation was initiated to perform the comprehensive structural assessment for the replacement dryer design to assure that it could operate at EPU conditions. The loads affecting the steam dryer were determined and used as input to a three-dimensional finite element model of the Exelon replacement steam dryer. Loads considered in the assessment included steady state pressure, fluctuating, and transient loads, with the primary interest in the steady state fluctuating loads that affect the fatigue life of the dryer. Additionally, ASME-based design load combinations were evaluated for normal, upset and faulted service conditions. A detailed finite element analysis using the dryer model subjected to these design loads was also performed. The analytical results identified the peak stresses and their locations. The results of the analysis also included the analytically determined structural natural frequencies for the different key components and locations in the dryer. Hammer tests were performed on the assembled dryer both dry and in water with varying water elevations. Frequencies from the hammer tests compared well with the finite element model frequencies and showed that no changes were required in the model.

The replacement dryer design has incorporated several design features that reduce the likelihood of fatigue cracking (References 3 and 4). These features include moving welds out of high stress locations, reducing the number of fillet welds and increasing the number of full penetration welds, and allowing more flexibility in the tie bar attachments to the dryer banks. This report summarizes the dynamic, stress and fatigue analyses performed based on the in-plant load measurements to demonstrate that this new dryer design is structurally adequate for EPU conditions.

3. Dynamic Analysis Approach

3.1 Dynamic Loading Pressure Time Histories

The primary dynamic loads of concern on the dryer are the fluctuating pressure loads during normal operation. The fluctuating pressure loads are responsible for the fatigue damage experienced by the original and repaired steam dryers at all four Dresden and Quad Cities plants. As part of the replacement dryer program, main steam lines in Unit 1 were instrumented for the purpose of better defining the pressure loads acting on the dryer. Pressure measurements from the steam lines (inferred from strain gauge measurements on the piping) were used in CDI's acoustic circuit model to estimate the pressures acting on the dryer (References 5 and 5A). These measurements were taken at a power level of 2887 MWt. This load definition is basically the same as the "in-plant" load case in Reference 17; however, the steamline strain gauge placement was improved to provide a more accurate determination of the pressure in the steamline and the acoustic circuit model was refined based on the pressures measured by sensors mounted directly on the steam dryer on Unit 2. Additional details on the CDI acoustic circuit model are provided in Reference 6D. The pressure predicted from the CDI acoustic circuit model were applied as time history forcing functions to the structural finite element shell model of the dryer (Figure 3-1). Two sets of loads (referred to as QC1D and QC1B) were used in this analysis and are discussed in detail in Section 6.2.1.

3.2 Stress Recovery and Evaluation Methodology

The entire shell finite element model was divided into components with every element assigned to a component. An ANSYS macro was written to sweep through each time step on every component to determine the time and location of the maximum stress intensity. [[

]]. ANSYS maximum stress intensity results from this macro are presented in Table 6-1. In most cases these stresses from the shell finite element model meet the GENE fatigue design criteria of 10800 psi (References 1 and 7). In some locations that do not meet this criteria, solid element finite element models from Reference 17 are used and combined with hand calculations to determine more accurate stresses (Table 6-3) such as for the cross beams and support ring. Solid models (Reference 17) are used to more accurately determine the stress state using forces and moments extracted from the shell model. Solid modeling of the weld attachment to the support ring gave a better representation of the local weld geometry and flexibility and thus resulting in more accurate stresses.

At high stress locations away from the outer hood (i.e., inner hoods), an alternate criteria was used as described in Section 5.1. [[
]], justified in Reference 18.

4. Material Properties

The dryer assembly was manufactured from solution heat-treated Type 316L and 304L conforming to the requirements of the material and fabrication specifications (Reference 3). ASME material properties were used (Reference 8). The applicable properties are shown in Table 4-1.

Table 4-1 Properties of SS304L and SS316L

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

5.1 Fatigue Criteria

The fatigue evaluation consists of calculating the alternating stress intensity from FIV loading at all locations in the steam dryer structure and comparing it with the allowable design fatigue threshold stress intensity. The recommended fatigue threshold stress intensities that were developed specifically for the replacement dryer are the following (Reference 7):

1) The acceptable conservative fatigue threshold value of 10,800 psi is to be used as the baseline criterion. It should be used at all critical locations that include the outer hood as the maximum acceptable value for the stress intensity amplitude.

2) The higher ASME Code Curve C value of 13,600 psi may be used in specific cases. However, its use must be technically justified.

The fatigue design criteria for the dryer is based on Figure I-9.2.2 of ASME Section III (Reference 9), which provides the fatigue threshold values for use in the evaluation of stainless steels. A key component of the fatigue alternating stress calculation at a location is the appropriate value of the stress concentration factor. The shell finite element model of the full dryer is not capable of predicting the full stress concentrations in the welds. Therefore, additional weld factors are applied to the maximum stress intensities obtained from the shell finite element time history analyses at all weld locations (Reference 10). The stress intensities with the applied weld factors are then compared to the fatigue criteria given above.

5.2 ASME Code Criteria for Load Combinations

Table 5-1 ASME Code Stress Limits

Service level	Stress category	Class 1 Components Stress limits (NB)	
			Stress Limit, KSI
Service levels A & B	P_m	S_m	14.4
	$P_m + P_b$	$1.5S_m$	21.6
Service level D	P_m	Min(.7S_u or 2.4 S_m)	34.56
	$P_m + P_b$	1.5(P_m Allowable)	51.84

Legend:

P_m: General primary membrane stress intensity
P_b: Primary bending stress intensity
S_m: ASME Code stress intensity limit
S_U: Ultimate strength

6. Fatigue Analysis

Time history analyses were performed using ANSYS Version 8.1 (Reference 11). The direct integration time history method was used for all of the cases described in this report. [[

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A Rayleigh damping of 2% was used in all of the time history analyses. This was justified based on Reference 19. Knowledge of the significant frequencies that contribute to the total response is used to define the appropriate alpha and beta Rayleigh damping coefficients for the time history direct integration finite element analyses. [[

]] This is justified based on Reference 18 and the hammer test results (Reference 12).

6.1 Full Dryer Shell Finite Element Model

The three-dimensional shell model of the replacement dryer is shown in Figures 6-1 through 6-3. The model incorporates super elements for the vane banks, submerged portion of the skirt and tie bar supports. [[

]] The details of the finite element model and associated super elements are contained in Reference 17. For this analysis, the finite element model has been modified from that used in References 17 and 17A as described below.

6.1.1 Model Modification for QC1 Evaluation

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6.2 Dynamic Loads

The primary dynamic loads of concern are the fluctuating pressure loads during normal operation. These are the loads responsible for the fatigue damage experienced by all four of the Dresden and Quad Cities steam dryers. As described in Section 3.1, pressure measurements from the steam lines (inferred from strain gauge measurements) were used in CDI's acoustic circuit model to estimate the pressures acting on the dryer (References 5 and 5A). Two sets of loads were developed (QC1D & QC1B) as explained in Section 6.2.1. Figures 3-1 and 3-1A show the applied load at the time when the pressure is a maximum for each load set.

Note that the loads used in this analysis were based on measurements taken at a power level of 2887 MWt, which is below the EPU power level of 2957 MWt. Consequently, the resulting stress results have been conservatively increased by 10% to account for extension to EPU. [[

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6.2.1 Basis for QC1D and QC1B Loads

CDI has calculated the steam dryer loads for Quad Cities Unit 1 (QC1) based on the measured steam line strain gauge data (Test Condition TC15a) taken during plant start-up in June 2005. This loading was calculated using the same methodology used previously (Reference 6D). This loading is referred to as the QC1D loads and is one of the load sets used as the basis for further confirmation of the design adequacy of the replacement steam dryer at full EPU conditions. The two time histories used in this analysis were generated and transmitted in References 5 and 5A (TC15a_2 for QC1D and TC15a for QC1B).

The evaluation of this QC1D loading (Reference 5) has shown that the loading on the dryer skirt is overly conservative (Reference 6D). The use of overly conservative, unrealistic loads can result in the development of fictitiously high stresses that exceed the ASME Code stress limits. The conservatism of the loads is confirmed by comparison of the FEA results with the as-measured strain gauge data from the gauges on the Unit 2 steam dryer skirt (Section 6.9 of Reference 17A). Thus such level of over conservatism is generally undesirable.

To address the overly conservative skirt loading in the QC1D loading, a second set of loading considered more realistic for the dryer skirt was developed by CDI for QC1. This loading is referred to as the QC1B loads (Reference 5A). This methodology and the evaluation are discussed in an Exelon Report (Reference 6A), where References 6B and 6C describe the differences between QC1D and QC1B. This provides a more reasonable yet still conservative loading (QC1B) that can be used for confirmatory analysis of the dryer skirt.

Thus, if the dryer skirt is shown to meet design requirements for either loading QC1B or QC1D, the design adequacy is considered confirmed. In general, the QC1D loads are used for dryer evaluation. For the dryer skirt, the QC1B loads are used to avoid the unnecessary taxing of the design from the overly conservative QC1D skirt loading.

Note that the dryer skirt response is primarily a function of the lower frequency skirt loading. As an example, Figure 6-16 shows the lateral displacement response spectrum for a selected skirt node (note the low frequency content). As can be seen by referring to Figures 6-15 and 6-16, in the low frequency regime the skirt modes are decoupled from the rest of the structure.

In conclusion, the QC1D loading is used to evaluate the steam dryer except for the skirt, as this load case will provide overly conservative results on the skirt. The QC1B load case is used to evaluate the skirt as it represents a more reasonable yet still conservative loading on the skirt. Using two separate load cases is acceptable because the skirt is considered decoupled from the rest of the dryer based on its unique response as discussed above.

6.3 Frequency Content of Loads

The frequency content of the Quad Cities in-plant loads is shown in Figures 6-4 and 6-4A. [[

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6.4 Modal Analysis

Frequency calculations were performed with the dryer supported from the RPV dryer support brackets. The support was modeled by fixing all translational degrees of freedom at the dryer support bracket interface. The entire dryer was surveyed for the component natural frequencies. However, the focus of the assessment was on the outer dryer surfaces. These calculated component natural frequencies for the skirt are shown in Figures 6-5 through 6-11. [[

]]

6.5 Structural Response to Loads

Structural frequency responses for the dryer outer hood and dryer vane caps [[
]] are shown in Figures 6-13, 6-15 and 6-17. The structural response of the skirt is shown in Figure 6-18 for the QC1B load case [[ ]].

[[

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6.6 Stress Results from Time History Analyses

Maximum stress intensity results from ANSYS for all components of the dryer are shown in Table 6-1 [[

]] The stresses are shown in Figures 6-19 through 6-43 for the 2887 MWt power level. [[

]]

More detailed analyses using solid models of the cross beam and support ring were used to show adequate fatigue margin for those components. These models are described in more detail in Reference 17. The stresses, from these QC1D loads, presented in Table 6-2 are lower than those reported in Reference 17. Therefore, the solid model results reported in Reference 17 bound the stresses for QC-1 at 2957 MWt. Solid model results from the design basis loads are shown again, for information, in Table 6-3 of this attachment. The skirt stresses shown in Figure 6-31 are for the 2887 MWt power level and the stress intensities listed in Tables 6-1 and 6-2 include the scaling to 2957 MWt power.

Note, the loads used in this analysis and resulting stress contour plots are based on measurements taken at a power level of 2887 MWt that is below EPU power level of 2957 MWt. Consequently, the resulting stress results have been conservatively increased by 10% to account for extension to EPU. [[

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Table 6-1 Shell Element Model Stress Intensity Summary for Time History Cases

[[

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6.7 Weld Factors

The calculation of fatigue alternating stress using the prescribed stress concentration factors in Subsection NG is straightforward when the nominal stress is calculated using the standard strength of material formulas. However, when a finite element analysis (FEA) approach is used, the available stress component information is very detailed and requires added guidance (Reference 10) for determining a fatigue alternating stress intensity to be used in conjunction with the ASME Code S-N design curve. The replacement steam dryer welds are analyzed using FEA. Reference 10 provides the basis for calculating the appropriate fatigue factors for use in the S-N evaluation to assess the adequacy of these welds based on the FEA results. Figure 6-44 summarizes the Reference 10 criteria. For the case of full penetration welds, the recommended SCF value is 1.4. In this case, the finite element stress is directly multiplied by the appropriate SCF to determine the fatigue alternating stress intensity. The recommended SCF is 1.8 for a fillet weld when the FEA maximum stress intensity is used. Various studies have shown that the calculated fatigue alternating stress using this alternate approach at a fillet weld correlates with that using a nominal stress and a SCF of 4.0 (Reference 14). An alternative approach involves extracting forces and moments from the shell finite element model near the weld and calculating a nominal stress. This nominal stress would then have a factor of 4.0 applied for a fillet weld. Figure 6-44 shows a chart [[

]]

Note that the above discussion of stress concentration effects (SCF's, fatigue factors, weld factors) only applies to the fatigue evaluation. SCF, "fatigue factor," and "weld factor" are used interchangeably. These terms do not refer to 'weld quality factors' from ASME Subsection NG for primary stress evaluation used in Section 7.0 of this report.

Table 6-2 Maximum Stress Intensity with Weld Factors

[[

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Table 6-3 Components with High Stress Intensity and Disposition

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6.8 Disposition of High Stress Locations

The high stress components for QC1 Load Combinations requiring special disposition are summarized in Table 6-3. Details of the disposition are described as follows:

[[

]]. Therefore, the crossbeams and support ring are considered acceptable.

6.9 Fatigue Analysis Results

The fatigue analysis results are a compilation of shell finite element model, solid model, and stress ratioing of previous results (Table 6-3) for assessing the acceptability of the steam dryer against the fatigue design criteria. [[

]]. The maximum stresses directly from the ANSYS shell finite element analysis are summarized in Table 6-1. The stresses [[ ]] are summarized in Table 6-2. The components requiring additional evaluations are summarized in Table 6-3. The fatigue evaluation results including use of previous solid models (Reference 17), different damping values, and an alternate fatigue limit in areas away from the outer hood are summarized in Table 6-4. All components listed meet the fatigue design allowables.

Table 6-4 Fatigue Analysis Results Summary

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7. ASME Code Load Combinations

The objective of this evaluation is to determine the effect on the ASME load combination calculations as a result of the new (post-installation of new dryer) FIV loads from the in-plant nominal and +/-10% frequency calculations for the EPU power condition, (QC1D). Also included in this evaluation is a review of stresses in the trough longitudinal weld areas [[ ]].

The inputs for this evaluation are the original ASME load combinations (References 17 and 17A), and the new FIV loads (stresses) as shown in Reference 22A. The new FIV stresses include a multiplication factor of 1.1 to address full EPU conditions.

The ASME load combination evaluations contained in Reference 23 and reported in Reference 17A, are utilized in this evaluation. Because the only loads that changed were the FIV loads contained in the spreadsheet, "QC1D_Stress_Comp.xls" (Reference 22)] modified from Reference 23, the existing load combinations were evaluated to demonstrate that the allowable stress criteria were still being met. [[ ]]. In all other cases, because the FIV loads determined from the pre-installation analysis (Reference 17)] or QC2A analysis (Reference 17A) are greater than the new loads, re-evaluation is not required.

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Note, the dryer finite element model from References 17 and 17A was modified slightly for this analysis. [[

]]

Results from Table 7-2 show that all stresses for the ASME Load Combinations meet the specified allowable stress criteria [[

]] The ASME Code combination results are summarized in Table 7-3.

[[

]].

Table 7-1 ASME Load Combinations

Load Case	Service Condition	Load Combination	Notes
A	Normal	DW + DPn ± FIVn	
B1	Upset	DW + DPn + TSV1 ± FIVn	
B2	Upset	DW + DPn + TSV2	1
B3	Upset	DW + DPu ± FIVu	2
B4	Upset	DW + DPn ± OBE ± FIVn	
D1A	Faulted	$DW + DPn + [\ SSE^2 + AC1^2\ ]^{1/2} \pm FIVn$	3
D1B	Faulted	$DW + [\ DPf1^2 + SSE^2\ ]^{1/2}$	3, 4
D2A	Faulted	DW + DPn + AC2 ± FIVn	
D2B	Faulted	DW + DPf2	4

Notes:

1. In the Upset B2 combination, FIVn is not included because the reverse flow through the steam lines will disrupt the acoustic sources that dominate the FIVn load component.
2. The relief valve opening decompression wave load (acoustic) associated with an inadvertent or stuck-open relief valve (SORV) opening is bounded by the TSV acoustic load (Upset B1); therefore, the acoustic phase of the SORV load need not be explicitly evaluated or included in the Upset load combination B3.
3. Loads from independent dynamic events are combined by the square root sum of the squares method.
4. In the Faulted D1B and D2B combinations, FIVn is not included because the level swell in the annulus between the dryer and vessel wall will disrupt the acoustic sources that dominate the FIVn load component.

AC1 = Acoustic load due to Main Steam Line Break (MSLB) outside containment, at the Rated Power and Core Flow (Hi-Power) Condition.
AC2 = Acoustic load due to Main Steam Line Break (MSLB) outside containment, at the Low Power/High Core Flow (Interlock) Condition.
DW = Dead Weight

DPn = Differential Pressure Load During Normal Operation
DPu = Differential Pressure Load During Upset Operation
DPf1 = Differential Pressure Load in the Faulted condition, due to Main Steam Line Break Outside Containment at the Rated Power and Core Flow (Hi-Power) condition
DPf2 = Differential Pressure Load in the Faulted condition, due to Main Steam Line Break Outside Containment at the Low Power/High Core Flow (Interlock) condition
FIVn = Flow Induced Vibration Load (zero to peak amplitude of the response) during Normal Operation
FIVu = Flow Induced Vibration Load (zero to peak amplitude of the response) during Upset Operation
OBE = Operating Basis Earthquake
SSE = Safe Shutdown Earthquake
TSV1 = The Initial Acoustic Component of the Turbine Stop Valve (TSV) Closure Load (Inward load on the outermost hood closest to the nozzle corresponding to the TSV closure)
TSV2 = The Flow Impingement Component (following the Acoustic phase) of the TSV Closure Load; (Inward load on the outermost hood closest to the nozzle corresponding to the TSV closure)

Table 7-2 ASME Code Combinations: Stress Summary Levels A and B

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Table 7-2 (cont'd) ASME Code Combinations: Stress Summary Level D.

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Table 7-3 ASME Code Margins

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8. Conclusions

The fatigue evaluation of the dryer was based on time history analyses from acoustic circuit model loads using in-plant steam line measurements. The loads were run for nominal and +/-10% frequency shifts. Results of all three fluctuating pressure cases show that the replacement dryer is structurally adequate from a fatigue standpoint at EPU conditions. All locations in the steam dryer are below the design fatigue allowable stress limit as defined in the GENE Design Criteria (Reference 1). All stresses from the ASME service level A (normal), B (upset), and D (faulted) loads are within the ASME Code allowable stress limits for primary stresses. Based on these results, the Quad Cities Unit 1 replacement dryer is structurally adequate for EPU (2957 MWt) conditions.

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Figure 3-1 Maximum Applied Pressure (QC1D Loads)

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Figure 3-2 Maximum Applied Pressure (QC1B Loads)

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Figure 6-1 Replacement Dryer Shell Finite Element Model

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Figure 6-1A Dryer Skirt Water Elements for Superelement Generation

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Figure 6-1B FEA Model, Modified Components for Mounting Block

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Figure 6-1C FEA Model Changes at Trough Attachment to Outer Hood

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Figure 6-1D FEA Model, Closure Plate with Stiffener

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Figure 6-2 Dryer Finite Element Model Boundary Conditions

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Figure 6-3 Finite Element Model without Super Elements

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Figure 6-4 Load Frequency Content – Hood & Vane Cap (QC1D Loads)

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Figure 6-4A Load Frequency Content - Skirt (QC1B Loads)

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Figure 6-5 Skirt Frequency: [[ ]]

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Figure 6-6 Skirt Frequency: [[ ]]

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Figure 6-7 Skirt Frequency: [[ ]]

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Figure 6-8 Skirt Frequency: [[ ]]

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Figure 6-9 Skirt Frequency: [[ ]]

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Figure 6-10 Skirt Frequency: [[ ]]

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Figure 6-11 Skirt Frequency: [[ ]]

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Figure 6-12 Outer Hood Frequency: [[ ]]

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Figure 6-13 Frequency Response QC1D –10%: Hoods & Vane Cap

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Figure 6-14 DELETED

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Figure 6-15 Frequency Response QC1D Nominal: Hoods & Vane Cap

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Figure 6-16 Frequency Response QC1D Nominal: Skirt

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Figure 6-17 Frequency Response QC1D +10%: Hoods & Vane Cap

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Figure 6-18 Frequency Response QC1B +10% Case [[ ]]: Skirt

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Figure 6-19 Time History Stress Intensity Results: Vane Cap Flat Portion

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Figure 6-20 Time History Stress Intensity Results: Outer Hood

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Figure 6-21 Time History Stress Intensity Results: Tie Bars

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Figure 6-22 Time History Stress Intensity Results: Frames

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Figure 6-23 Time History Stress Intensity Results: Troughs

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Figure 6-24 Time History Stress Intensity Results: Gussets

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Figure 6-25 Time History Stress Intensity Results: Vane Cap Curved Part

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Figure 6-26 Time History Stress Intensity Results: Inner Hoods

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Figure 6-27 Time History Stress Intensity Results: Closure Plates

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Figure 6-28 Time History Stress Intensity Results: T-Section Webs

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Figure 6-29 Time History Stress Intensity Results: T-Section Flanges

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Figure 6-30 Time History Stress Intensity Results: Vane Bank Outer End Plates

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Figure 6-31 Time History Stress Intensity Results: [[ ]]

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Figure 6-32 Time History Stress Intensity Results: Cross Beams

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Figure 6-33 Time History Stress Intensity Results: Support Ring

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Figure 6-34 Time History Stress Intensity Results: Trough Ledge

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Figure 6-35 Time History Stress Intensity Results: Trough Brace Gusset

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Figure 6-36 Time History Stress Intensity Results: Inner Trough Brace

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Figure 6-37 Time History Stress Intensity Results: Vertical Support Plates

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Figure 6-38 Time History Stress Intensity Results: Center Support Gussets

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Figure 6-39 Time History Stress Intensity Results: Center Plate

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Figure 6-40 Time History Stress Intensity Results: Trough End Stiffeners

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Figure 6-41 Time History Stress Intensity Results: Gusset Shoe at Cross Beams

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Figure 6-42 Time History Stress Intensity Results: Frame to Cross Beam Gussets

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Figure 6-43 Time History Stress Intensity Results: Lifting Lug Guide

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Figure 6-44 Weld Factors to Use with Finite Element Results