ENCLOSURE 5
TENNESSEE VALLEY AUTHORITY
BROWNS FERRY NUCLEAR PLANT (BFN)
UNITS 1, 2, AND 3

TECHNICAL SPECIFICATIONS (TS) CHANGES TS-431 AND TS-418 - EXTENDED POWER UPRATE (EPU) OPERATION - STEAM DRYER STRESS REPORT BROWNS FERRY NUCLEAR PLANT UNITS 1, 2, AND 3 STEAM DRYER STRESS, DYNAMIC AND FATIGUE ANALYSES FOR EPU CONDITIONS

(NON-PROPRIETARY VERSION)

Attached is **Non-Proprietary** General Electric Report No. GE-NE-0000-0053-7413-R0-NP, "Browns Ferry Nuclear Plant Units 1, 2 and 3 Steam Dryer Stress, Dynamic and Fatigue Analyses for EPU Conditions."

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Browns Ferry Nuclear Plant Units 1, 2 and 3 Steam Dryer Stress, Dynamic and Fatigue Analyses for EPU Conditions

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ACRONYMS AND ABBREVIATIONS

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

1. EXECUTIVE SUMMARY

Tennessee Valley Authority's Browns Ferry Nuclear Plant (BFN) Units 1, 2, and 3 are 251" diameter BWR/4 plants with the BWR/4 slant hood steam dryer. Structural analyses of the steam dryer were performed using a full three-dimensional finite element model of the BFN1 dryer in support of the Unit 1 restart and Extended Power Uprate (EPU) programs for Units 1, 2, and 3. The analyses consisted of time history dynamic analyses, frequency calculations, and stress and fatigue evaluations. Predictions of the fluctuating pressure loads on the dryer were developed in GE's scale model test (SMT) facility for use as input to the fatigue analysis. The scale model test loads were processed using an acoustic circuit model by Continuum Dynamics Inc. (CDI) to develop the detailed dryer pressure loads for the time history analyses. In addition, ASME Code based load combinations were also analyzed using the dryer finite element model. This report summarizes the dynamic, stress and fatigue analyses for the BFN Units 1, 2, and 3 steam dryer at original licensed thermal power (OLTP) and EPU conditions based on scale model test data.

The acceptance criterion used in the evaluation to predict fatigue susceptibility of the individual components was the ASME fatigue limit peak stress intensity greater than 13,600 psi. The load definitions based on the SMT methodology are conservative due to the nature of the boundary condition modeling in the test apparatus and due to the amplitude scaling used to bound the uncertainties in the SRV resonance frequency range. Due to the conservative nature of the SMT-based pressure loads, the analysis predicted that the majority of the steam dryer components are not vulnerable to fatigue at the OLTP conditions; however, there are a few locations that are at or near the fatigue stress limit. The 3/8-inch thick outer cover plate and manway cover are attached with ¼-inch fillet welds. These welds are considered undersized and could lead to fatigue initiation at EPU conditions and will be reinforced as part of the EPU modifications. The results of the evaluation based on the ASME load combinations and associated stress acceptance criteria show acceptable stress margins for all operating conditions: normal, upset and faulted. The analyses show that the outer hood and cover plate locations are also regions of higher stress at EPU conditions. Therefore, it is recommended that actions be taken to further evaluate the fluctuating stresses prior to extending power to 120% OLTP. Proposed modifications to improve the stress margins at these locations are identified in this report.

The stress analysis results for OLTP demonstrate that the BFN dryer stresses are generally below the fatigue endurance level screening criteria. When conservative stress concentration factors (SCF) are applied to address local stress intensification, a few dryer components are predicted to exceed the endurance level.

The Unit 1, 2, and 3 dryers have operated at OLTP for a period of eleven (11) to fifteen (15) years. Additionally the Unit 2 and 3 reactors have operated at 105% OLTP for over six (6) years. Dryer inspections conducted throughout these operating periods have identified no unusual damage due to flow-induced vibration. Inspection has revealed some dryer tie-bar damage and drain channel cracking. Necessary modifications have been implemented to address these issues. The overall BFN dryer experience is representative of the fleet experience for BWR/4 slant hood dryers operating at stretch and EPU power levels.

The fact that no damage has been observed in dryer components predicted to have stresses exceeding the fatigue stress limit is an indication of conservatism in the BFN SMT-based load definition. This conservatism has been carried forward into the analysis for the stress predictions for EPU operating conditions. Carrying forward load-definition conservatism to EPU conditions assures conservative identification of dryer components that may require reinforcement modification, further analysis, or monitoring to assure that the endurance criteria are met under EPU conditions.

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. Six banks are used for the BFN dryers (BWR 4). Dryer banks are attached to an upper support ring, which is supported by four 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 at mid-height on the dryer skirt.

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 steam dryer designs like BFN 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.

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.

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 steamlines, provided appropriate conditions exist, resulting in fluctuating pressure loads that act on the dryer.

The dryer is a passive, non-safety related component that was included in Class I seismic analyses. The steam dryer 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 Browns Ferry Dryer Experience

The operating experience for the three Browns Ferry steam dryers has been typical of the overall BWR fleet experience with no unusual indications. The steam dryer inspection data and disposition of the indications for EPU is summarized in Tables 2-1 through 2-3 for each unit.

BFN1 has been inactive since 1985 and is currently undergoing recovery and restart activities. BFN1 operating experience has been limited to OLTP conditions. Dryer performance has been satisfactory. Limited drain channel weld cracks have been found similar to other BWR plants and will be repaired prior to renewed operations.

BFN2 and BFN3 were restarted at OLTP in 1992 and 1995, respectively. Both units were subsequently uprated to 105% OLTP in 1998. These dryers have operated satisfactorily at OLTP and 105% OLTP. Earlier drain channel cracking had been repaired and reinforced. Subsequent inspections have shown no recurrence of cracking in the repaired welds. BFN3 has experienced limited tie bar cracking. These bars have been replaced with a modified design. The drain channel weld reinforcement and the modified tie-bar design will be implemented into the BFN1 dryer and the analysis of the BFN1 dryer, as described in this report, has simulated this modified BFN1 dryer condition.

Table 2-1: BFNP Unit 1 Steam Dryer Inspection Data and Disposition for EPU

Location	Year	Indication	Disposition for EPU	Reason for Disposition
Drain Channel	Apr-92	Indications reported in three vertical drain channel to skirt fillet welds (Channel 2 right side approximately 12 in. long, Channel 3 left side approximately 10 in. long, Channel 4 right side approximately 14 in. long). In Channel 1 right side a small (less than 1 in. long) indication transverse to the weld. In addition, a broken locking fillet weld and bent support bracket were reported in the 184 degree leveling screw.	Cause: Fatigue (drain channel cracks); Installation or removal (bent support bracket) Welded repairs recommended for three drain channel weld cracks. It was also recommended that all drain channel welds be mitigated (increase 1/8" fillet welds size to 1/4" for at least lower 76 inches. Transverse indication on Channel 1 classified as a scratch.	Reinforcing the welds will reduce the stress.

Table 2-2: BFNP Unit 2 Steam Dryer Inspection Data and Disposition for EPU

Location	Year	Indication	Disposition for EPU	Reason for Disposition
Guide Bracket	May-93	Steam dryer lower guide bracket damage at 180 deg	Cause: Contact with guide rod during installation. Underwater welded repair by divers was done at next outage	Damage unrelated to fatigue or EPU.
Support Ring	Nov-88	Support ring cracks.	Cause: IGSCC. None required	Damage unrelated to fatigue or EPU.
Drain Channel	Nov-88	Cracks were reported in three of eight vertical drain channel welds. Cracking was located in throat of vertical drain channel to skirt 1/8-in. fillet welds. Two of the cracks were approximately 12 inches long and the third was approximately 24 inches long.	Cause: Fatigue Weld repair drain channel cracks, plus mitigation of all drain channel welds (increase 1/8" fillet weld size to 1/4" minimum for at least lower 76" of each vertical drain channel weld).	Reinforcing welds will reduce the stress.

Table 2-3: BFNP Unit 3 Steam Dryer Inspection Data and Disposition for EPU

Location	Year	Indication	Disposition for EPU	Reason for Disposition
Drain Channel	Nov-91	Indications were reported in three of eight vertical drain channel to skirt welds (Channel 1 right side approximately 12 inches long, Channel 2 left side approximately 12 inches long, Channel 3 right side approximately 10 inches long). Indications were located in throat of the 1/8-inch fillet welds at the lower end of the welds.	Cause: Fatigue Underwater weld repair plus mitigation welds applied to all channels (1/8" fillet size increased to 1/4" for at least lower 76 inches of each vertical weld).	Mitigation welds will reduce the stress.
Tie Bar	Jun-03	During a mid-cycle outage (Cycle 11), it was reported that all three of the center bank tie bars were broken. These 1" x 1" x 3/16" angle cross section tie bars provide lateral bracing across the top of the center steam dryer banks (banks 3 and 4 of 6 total banks). In each case, one end of the tie bar had a fracture through the full bar cross section. A linear indication was reported at the unbroken end of one tie bar. Although the bars were bent, there was no evidence of plastic deformation at the fracture surface. No indications were found as a result of visually examining the other 10 tie bars.	Cause: Fatigue from an unknown cyclic loading Divers removed the broken tie bars and welded three larger section (1.5" x 2.7") replacement tie bars adjacent to the original tie bar locations. Outer bank hoods and cover plates were also inspected and no indications were reported.	Replaced with bigger and stronger tie bars. Failure of this component will not result in a situation where steam could bypass the dryer and require an unplanned plant shutdown to repair.
Support bracket and interfacing dryer seismic block	Mar-04	Number of gouges and contact marks	Cause: Installation or removal Take precautions during movement of the dryer	Unrelated to EPU

Note: Drain channels have cracked during normal operation and may crack at EPU. Additional weld material will minimize the probability of cracking. Drain channel cracking has never led to an unplanned plant shutdown and can be repaired during an outage.

2.3 Motivation for Additional FIV and Structural Analysis

The dryer fatigue cracking 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 more accurately determining the plant-specific loads acting on the dryers and quantifying the stresses in the dryers at EPU conditions.

Based on these needs, this evaluation was initiated to derive plant-specific loads and perform a comprehensive structural assessment for the BFN dryer design to assure that it could operate at EPU conditions. The loads affecting the steam dryer were determined by BFN plant-specific scale model testing, using the same SMT methodology benchmarked to the instrumented QC2 replacement dryer and used as input to a three-dimensional finite element model of the BFN 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 Code-based design load combinations for normal, upset and faulted service conditions were evaluated. Detailed finite element analyses using the dryer model, subjected to these design loads, were 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. This report summarizes the dynamic, stress, and fatigue analyses performed based on the scale model load measurements and provides the basis for developing modifications that will increase stress margins and reduce the likelihood of fatigue cracking at 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 that may lead to fatigue damage. Scale model testing was performed using the BFN Unit 1 configuration in order to determine the fluctuating pressure loads. The overall scale model testing methodology is documented in Reference 1.

The BFN-specific testing is documented in Reference 2. Originally it was anticipated that a load definition would be developed based upon a load interpolation algorithm (LIA) that was being developed by GE. It was also anticipated that a load definition would be developed based using acoustic circuit methodology by CDI that has been previously reviewed by the NRC. The load interpolation algorithm is still being developed and validated. Therefore, it was decided to use the CDI Acoustic Circuit Model (ACM) in place of the LIA to develop the structural load definition. Additional details on the CDI acoustic circuit model are provided in Reference 3. Pressure measurements were taken from the steamlines in the SMT [Reference 2] and used as input to the ACM. The ACM was then used to predict the pressure loading on the steam dryer. This approach uses the ACM in the same manner as it would be used with in-situation plant data. Because this approach is a departure from the methodology described in References 1 and 2, a benchmark comparison was performed by CDI in order to demonstrate the validity of the approach. This benchmark is documented in Reference 3 and submitted separately by TVA. The pressure predicted from the scale model testing and CDI acoustic circuit model were applied as time history forcing functions to the structural finite element shell model of the dryer (Figures 3-1 through 3-4).

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 [Reference 4] macro was written to sweep through each time step on every dryer model component to determine the time and location of the maximum stress intensity. The element stresses at all integration points (4 for quadrilateral and 3 for triangular elements) for the top and bottom element surfaces were surveyed. In addition, membrane stresses were extracted for use in the ASME load combination calculations. ANSYS maximum stress intensity results from this macro are presented in Tables 6-1 and 6-2.

4. Material Properties

The dryer assembly was manufactured from solution heat-treated Type 304 stainless steel conforming to the requirements of the material and fabrication specifications [Reference 5]. ASME material properties were used in the ANSYS finite element model [Reference 6]. The applicable properties are shown in Table 4-1.

Table 4-1 Properties of SS304 [Reference 6]

Material Property	Room temperature 70°F	Operating temperature 545°F
S_m, *Stress Intensity Limit, psi*	20000	16900
S_y, Yield strength, psi	30000	18900
S_u, Ultimate strength, psi	75000	63400
E, Elastic modulus, psi	28000000	25600000

5. Design Criteria

5.1 Fatigue Criteria

The fatigue evaluation consists of calculating the alternating stress intensity from flow induced vibration (FIV) loading at all locations in the steam dryer structure and comparing it to the allowable fatigue design threshold stress intensity. The fatigue threshold stress intensity from ASME Code Curve C is 13600 psi. The fatigue design criteria for the dryer is based on Figure I-9.2.2 of ASME Section III [Reference 7], which provides the fatigue threshold values for use in the evaluation of stainless steels. ASME Code fatigue Curve C assumes a mean stress equal to the material yield strength. The shell finite element model of the full dryer is not refined enough to predict 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 weld locations [Reference 8]. A key component of the fatigue alternating stress calculation at a location is the appropriate value of the stress concentration factor (SCF). 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

The ASME Code stress limits used in the evaluation of the BFN dryer are listed in Table 5-1.

Table 5-1 ASME Code Stress Limits [Reference 7]

Service level	Stress category	Class 1 Components Stress limits (NB)	
			Stress Limit, ksi
Service levels A & B	P_m	S_m	16.9
	$P_m + P_b$	$1.5S_m$	25.35
Service level D	P_m	Min(.7S_u or 2.4 S_m)	40.56
	$P_m + P_b$	1.5(P_m Allowable)	60.84

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 Versions 8.1 and 9.0 [Reference 4]. The direct integration time history analysis method was used for all of the cases described in this report. [[

]] To account for dryer frequency uncertainty, the time step sizes were increased by plus 10% and minus 10% from the nominal case for the pressure loads. [[

]]

6.1 Full Dryer Shell Finite Element Model

The three-dimensional shell model of the BFN dryer is shown in Figures 3-1 through 3-4. The model incorporates distributed masses in the vane banks and submerged portion of the skirt. The steam dryer is built primarily of welded plates. [[

]]

The mass used on the skirt to represent the water was determined from a study using a detailed model of the skirt and water. [[

]]

6.2 Dynamic Loads

The primary dynamic loads of concern are the steam-flow induced fluctuating pressure loads during normal operation. These are the loads responsible for the fatigue damage experienced at EPU conditions by all four of the Dresden and Quad Cities steam dryers. As described in Section 3.1, BFN plant-specific scale model test loads were used as input to CDI's acoustic circuit model to predict the pressures acting on the dryer [Reference 3]. Figure 3-5 shows the applied load at the time when the pressure amplitude is a maximum for EPU operation.

The loads used in this analysis are based on measurements simulating Original Licensed Thermal Power (OLTP) of 3293 MWt and the EPU power level of 3952 MWt.

6.3 Frequency Content of Loads

The frequency content of the BFN SMT loads is shown in Figure 6-1. The loading on the dryer is reasonably symmetric. [[

]]

6.4 Modal Analysis

Frequency calculations were performed with the dryer supported from the RPV dryer support brackets. The boundary conditions described in Section 6.1 were applied to the dryer finite element model for the modal analysis. The entire dryer was surveyed for the component natural frequencies. However, the focus of the assessment was on the outer dryer surfaces. Calculated component natural frequencies for the skirt are shown in Figures 6-11 and 6-12. [[

]]

6.5 Structural Response to Loads

Stress time histories for various components are plotted in Figure 6-2. A comparison of the pressure time history and resulting structural response for the outer hood is shown in Figure 6-3. The structural frequency responses for these components are

shown in Figures 6-4 through 6-8. [[
]]

6.6 Stress Results from Time History Analyses

Maximum stress intensity results from ANSYS for all components of the dryer are shown in Tables 6-1 and 6-2 (for OLTP and EPU, respectively) for three load cases (each power level evaluated at nominal, +10% and –10% frequency shifts [[
]] and plotted in Figures 6-13 through 6-39. These stresses are listed without the weld and weld undersize factors discussed in Section 6-7. Each component has the case that produced the highest stress intensity highlighted.
[[
]]
Design margins for both OLTP and EPU power levels are summarized in Table 6-5 and discussed in Section 6.8.

Table 6-1 Time History Analysis Results from ANSYS: OLTP

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Table 6-2 Time History Analysis Results from ANSYS: EPU

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6.7 Weld Factors

The calculation of fatigue alternating stress intensity using the prescribed stress concentration factors in ASME Code 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 more detailed than that which would be obtained from the standard strength-of-materials formulas and requires added guidance for determining a fatigue stress intensity to be used in conjunction with the ASME Code S-N design curve. Reference 8 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 6-40 summarizes the Reference 8 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 stress. The recommended SCF is 1.8 for a fillet weld when the FEA maximum stress intensity is used. In addition, some of the welds are undersized (weld leg length is less than the plate thickness) and the stresses are further adjusted based on the undersized weld factor shown below:

Undersized weld factor = throat dimension for full sized weld/ throat dimension for undersized weld

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. For BFN dryer, the weld quality factor used was 1.0.

Table 6-3 Time History Results with Weld factors: OLTP

[[

]]

Table 6-4 Time History Results with Weld factors: EPU

[[

]]

6.8 Fatigue Analysis Results

The fatigue analysis results are from a shell finite element model used to assess 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 Tables 6-1 and 6-2. The stresses with the appropriate weld factors applied are summarized in Tables 6-3 and 6-4. All nodes and elements in the steam dryer finite element model are included in one of the model components. Stress Intensity results and design margins for each of these dryer model components are presented in Tables 6-5 and 6-6 (for OLTP and EPU, respectively). The outer hood is the limiting component. The components with the lowest design margins are highlighted in the tables.

Table 6-5 Final Stress Results: Design Margins for OLTP and EPU

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7. ASME Code Loads

The BFN steam dryer was analyzed for the ASME Code load combinations (primary stresses) shown in Table 7-1. The acceptance criteria used for these evaluations are specified in Section 5.2 and are the same as those used for safety related components.

7.1 ASME Code Load Combinations

Browns Ferry is not a "New Loads" plant; therefore, annulus pressurization and jet reaction loads are not part of the design and licensing basis for the plant and are not considered in these load combinations. The resulting load combinations for each of the service conditions are summarized in Table 7-1.

The steam dryer structural analyses consider the transient and accident events listed in Browns Ferry UFSAR Tables 14.4-1 and 14.4-2. The transient and accident events that are of particular interest for the evaluation of reactor internal pressure difference (RIPD) loading on vessel internals are events with one or more of the following characteristics: 1) pressurization, 2) depressurization, 3) core coolant flow increase, or 4) moderator temperature decrease. The load combinations for the limiting transient and accident events evaluated are listed in Table 7-1. The turbine stop valve closure transient (Upset 1 and Upset 2 in Table 7-1) is the limiting transient event for reverse pressure loading on the dryer. The Upset 3 load case bounds the remaining transient events. The Faulted 1 and Faulted 2 load cases address the main steamline break accident outside containment (the design basis event for the dryer). The Faulted 3 load cases address the remaining loss of coolant accidents. Positive reactivity insertion events (e.g., rod withdrawal error, rod drop accident) do not result in a significant change in the reactor system pressure or steam flow rate and, therefore, are not significant with respect to the RIPD loading on the steam dryer.

Each of the load combination cases is briefly discussed below:

Normal: The deadweight, normal differential pressure, and FIV loads are combined for the normal service condition. [[

]] There is a significant pressure variation across the outer vertical hood. [[ ]]

Upset 1: This load combination represents the acoustic wave portion of the turbine stop valve closure transient (TSV1). [[

]] Deadweight and OBE seismic loads are also included.

Upset 2: This load combination represents the flow impingement portion of the turbine stop valve closure transient (TSV2). [[

]] Deadweight and OBE seismic loads are also included.

Upset 3: This load combination bounds the other transient events. [[

]] Deadweight and OBE seismic loads are also included.

Faulted 1: This load combination is for the main steamline break outside containment accident with the reactor at full power. The faulted differential pressure load (DPf) represents the loading due to the two-phase level swell impacting the dryer. The interlock condition value of DPf ([[ ]]) was used for DPf because the vessel blowdown and level swell are more severe at the interlock condition. [[

]] Deadweight and SSE seismic loads are also included.

Faulted 2: This load combination is for the main steamline break outside containment accident with the reactor at low power/high core flow (interlock) conditions. The faulted differential pressure load (DPf) represents the loading due to the two-phase level swell impacting the dryer. [[

]] Deadweight loads are also included.

Faulted 3: This load combination is for pipe breaks other than the main steamline break. [[

]] The normal operating differential pressure load (DPn) was conservatively assumed for the differential pressure load. Deadweight and SSE seismic loads are also included.

Table 7-1 ASME Load Combinations

Service Condition	**Load Combination**	**Screening Criteria**(Note 1)	**Fatigue Acceptance Criteria**
Normal	DW + DPn + FIVn	Pm ≤ 1.0 Sm (Pm + Pb) ≤ 1.5 Sm	FIVn <13,600 psi Note 3
Upset 1	DW + DPn + $[\ TSV1^2 + OBE^2\ ]^{1/2}$ + FIVn	Pm ≤ 1.0 Sm (Pm + Pb) ≤ 1.5 Sm Note 5	FIVn <13,600 psi Notes 2 and 3
Upset 2	DW + DPn + $[\ TSV2^2 + OBE^2\ ]^{1/2}$	Pm ≤ 1.0 Sm (Pm + Pb) ≤ 1.5 Sm Note 5	Not Applicable
Upset 3	DW + DPu + OBE + FIVu (Note 4)	Pm ≤ 1.0 Sm (Pm + Pb) ≤ 1.5 Sm Note 5	FIVu < 13,600 psi Notes 2 and 3
Faulted 1	DW + $[\ DPf1^2 + SSE^2\ ]^{1/2}$	Pm ≤ 2.4 Sm (Pm + Pb) ≤ 3.6 Sm	Not Applicable
Faulted 2	DW + DPf2	Pm ≤ 2.4 Sm (Pm + Pb) ≤ 3.6 Sm	Not Applicable
Faulted 3	DW + DPn + SSE	Pm ≤ 2.4 Sm (Pm + Pb) ≤ 3.6 Sm	Not Applicable

Notes:
1. These criteria are for screening purposes and are not requirements for the dryer components.
2. These transient events are of a short duration; therefore, fatigue is not a critical consideration.
3. The value of 13,600 psi is based on austenitic stainless steel.
4. [[
   ]]; therefore, this load is not explicitly included in the dryer analysis
5. Upset Condition stress limits are increased by 10% above the limits shown in this table per NG-3223 (a) and NB-3223 (a)(1)

7.2 ASME Code Load Case Stress Results

The maximum stresses reported from the ANSYS analysis runs are peak stresses and not general primary membrane or membrane plus bending stresses. In order to determine primary stress, contour plots were obtained for each of the components that do not meet the Code stress limits using the conservative peak stress intensity values. The stress contour plots were evaluated, and a value of primary stress was determined by eliminating high peak stress areas resulting from discontinuities, badly shaped elements, etc. The primary stress values were then used in the calculation of total stress for the ASME load combination calculations. Tables 7-2 and 7-3 summarize the primary stresses for the OLTP cases for normal, upset, and faulted conditions. From these results, the locations which do not meet the ASME limits (Table 5-1) using these very conservative maximum stresses are reviewed in more detail to obtain the average stresses required for compliance with the ASME Code stress limits. Some of the stresses in Tables 7-2 and 7-3 are based on conservative peak stresses, which were not re-evaluated to obtain average stresses because they meet the stress limits. All of the stresses for the OLTP cases meet the ASME Code stress limits.

The ASME Code case evaluations at EPU will be performed with the final modified dryer configuration. For previous EPU dryer analyses, the ASME Code case evaluations have met the stress limits. Based on this experience, it is expected that the BFN dryer will meet the ASME Code stress limits for the modified dryer at EPU conditions.

Table 7-2 OLTP ASME Results for Normal and Upset Conditions: Average Stresses

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Table 7-3 OLTP ASME Results for Faulted Conditions: Average Stresses

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8. Proposed Dryer Modifications

Several dryer modifications are planned for the BFN1 dryer as part of the restart program and Units 2 and 3 prior to extended power operation. These modifications are based on the previous BFN dryer operating experience and in response to the recommendations in SIL 644. The planned modifications are:

1. Manway cover weld reinforcement (SIL 644)
2. Cover plate weld reinforcement (SIL 644)
3. Tie bar replacement (BNF 3 experience)
4. Drain channel weld reinforcement (BNF1, 2, 3 experience)

The stress analysis results show several components with potentially high stresses at EPU conditions. Additional dryer modifications are planned to address these high stress locations in order to increase the structural margin for EPU conditions. The modifications under detailed design analyses are:

1. Outer hood reinforcing panel (outer hood face plates and exterior hood plates)
2. Cover plate tip reinforcement
3. Outer hood top edge reinforcement

Conceptual sketches of the proposed modifications are shown in Figure 8-1.

9. Conclusions

The stress analysis results for OLTP demonstrate that the BFN dryer stresses are generally below the endurance level screening criteria. When conservative stress amplification factors are applied to address local stress intensification, a few dryer components are predicted to be at or near the endurance level.

The Unit 1, 2, and 3 dryers have operated at OLTP for a period of eleven (11) to fifteen (15) years. Additionally the Unit 2 and 3 reactors have operated at 105% OLTP for over six (6) years. Dryer inspections conducted throughout these operating periods have identified no unusual damage due to flow-induced vibration. Inspection has revealed some dryer tie-bar damage and drain channel cracking. Necessary modifications have been implemented to address these issues. The overall BFN dryer experience is representative of the fleet experience for BWR/4 slant hood dryers operating at stretch and EPU power levels.

Consequently, the analytical predictions of stresses exceeding the acceptance criteria for several dryer components are indicative of the conservatism that has been utilized in the BFN load definition. This conservative approach has been carried forward into the analysis for the stress predictions for EPU operating conditions. This approach will assure the conservative identification of components that may require reinforcement modification, further analysis, or monitoring to assure that the endurance criteria are met.

10. References

1 GENE-0000-0045-9086-01, "General Electric Boiling Water Reactor Steam Dryer Scale Model Test Based Fluctuating Load Definition Methodology – March 2006 Benchmark Report," March 2006.

2. GENE-0000-0052-3661-01, "Test Report # 1 Browns Ferry Nuclear Plant, Unit 1 Scale Model Test," April 2006.

3. C.D.I. Report No. 06-11, "Hydrodynamic Loads on Browns Ferry Unit 1 Steam Dryer to 200 Hz," April 2006.

4. ANSYS Release 8.1 and 9.0, ANSYS Incorporated, 2004.

5. Purchase Specification, "Standard Requirements for Steam Dryers" 21A3316 Rev. 1.

6. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, 1989 Edition with no Addenda.

7. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Appendix I, 1989 Edition with no Addenda

8. "Recommended Weld Quality and Stress Concentration Factors for use in the Structural Analysis of the Exelon Replacement Steam Dryer", GENE 0000-0034-6079, February 2005.

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Figure 3-1 BFN Steam Dryer Finite Element Model with Boundary Conditions

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Figure 3-2 BFN Steam Dryer Finite Element Model

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Figure 3-3 BFN Steam Dryer Finite Element Model, con't

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Figure 3-4 BFN Steam Dryer Finite Element Model, con't

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Figure 3-5 EPU Applied Pressure Load to BFN Dryer

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Figure 6-1 Frequency Content of Applied Load at EPU (Outer Hoods)

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Figure 6-2 Stress Time Histories for Several Dryer Components at EPU

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Figure 6-3 Outer Hood Pressure VS Stress Time Histories for EPU Nominal Case

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Figure 6-4 Outer Hood FFT's for Nominal and +/-10% Cases at EPU

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Figure 6-5 Inner Hood FFT's for Nominal and +/-10% Cases at EPU

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Figure 6-6 Cover Plate FFT's for Nominal and +/-10% Cases at EPU

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Figure 6-7 Trough FFT's for Nominal and +/-10% Cases at EPU

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Figure 6-8 Skirt FFT's for Nominal and +/-10% Cases at EPU

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Figure 6-9 Modal Analysis Results: Outer Hoods

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Figure 6-10 Modal Analysis Results: Inner Hoods

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Figure 6-11 Modal Analysis Results: Skirt

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Figure 6-12 Modal Analysis Results: Skirt, con't

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Figure 6-13 Stress Intensity at EPU: Cover Plate

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Figure 6-14 Stress Intensity at EPU: Manway Cover

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Figure 6-15 Stress Intensity at EPU: Outer Hood

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Figure 6-16 Stress Intensity at EPU: Exterior Hood Plates - Outer Banks

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Figure 6-17 Stress Intensity at EPU: Exterior Vane Bank End Plates – Outer Banks

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Figure 6-18 Stress Intensity at EPU: Hood Top Plates

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Figure 6-19 Stress Intensity at EPU: Vane Bank Top Plates

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Figure 6-20 Stress Intensity at EPU: Hood Stiffeners - Outer

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Figure 6-21 Stress Intensity at EPU: Vane Bank Inner End Plates (2)

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Figure 6-22 Stress Intensity at EPU: Closure Plates – Outer Banks

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Figure 6-23 Stress Intensity at EPU: Inner Hoods

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Figure 6-24 Stress Intensity at EPU: Exterior Hood Plates – Inner Banks

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Figure 6-25 Stress Intensity at EPU: Exterior Vane Bank End Plates – Inner Banks

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Figure 6-26 Stress Intensity at EPU: Hood Stiffeners – Inner (1)

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Figure 6-27 Stress Intensity at EPU: Hood Stiffeners – Inner (2)

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Figure 6-28 Stress Intensity at EPU: Vane Bank Inner End Plates (1)

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Figure 6-29 Stress Intensity at EPU: Vane Bank Inner End Plates (3)

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Figure 6-30 Stress Intensity at EPU: Closure Plates – Inner Banks

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Figure 6-31 Stress Intensity at EPU: Steam Dams

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Figure 6-32 Stress Intensity at EPU: Steam Dam Gussets

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Figure 6-33 Stress Intensity at EPU: Baffle Plate

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Figure 6-34 Stress Intensity at EPU: Trough

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Figure 6-35 Stress Intensity at EPU: Base Plate

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Figure 6-36 Stress Intensity at EPU: Support Ring

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Figure 6-37 Stress Intensity at EPU: Skirt

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Figure 6-38 Stress Intensity at EPU: Drain Pipes

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Figure 6-39 Stress Intensity at EPU: Skirt Bottom Ring

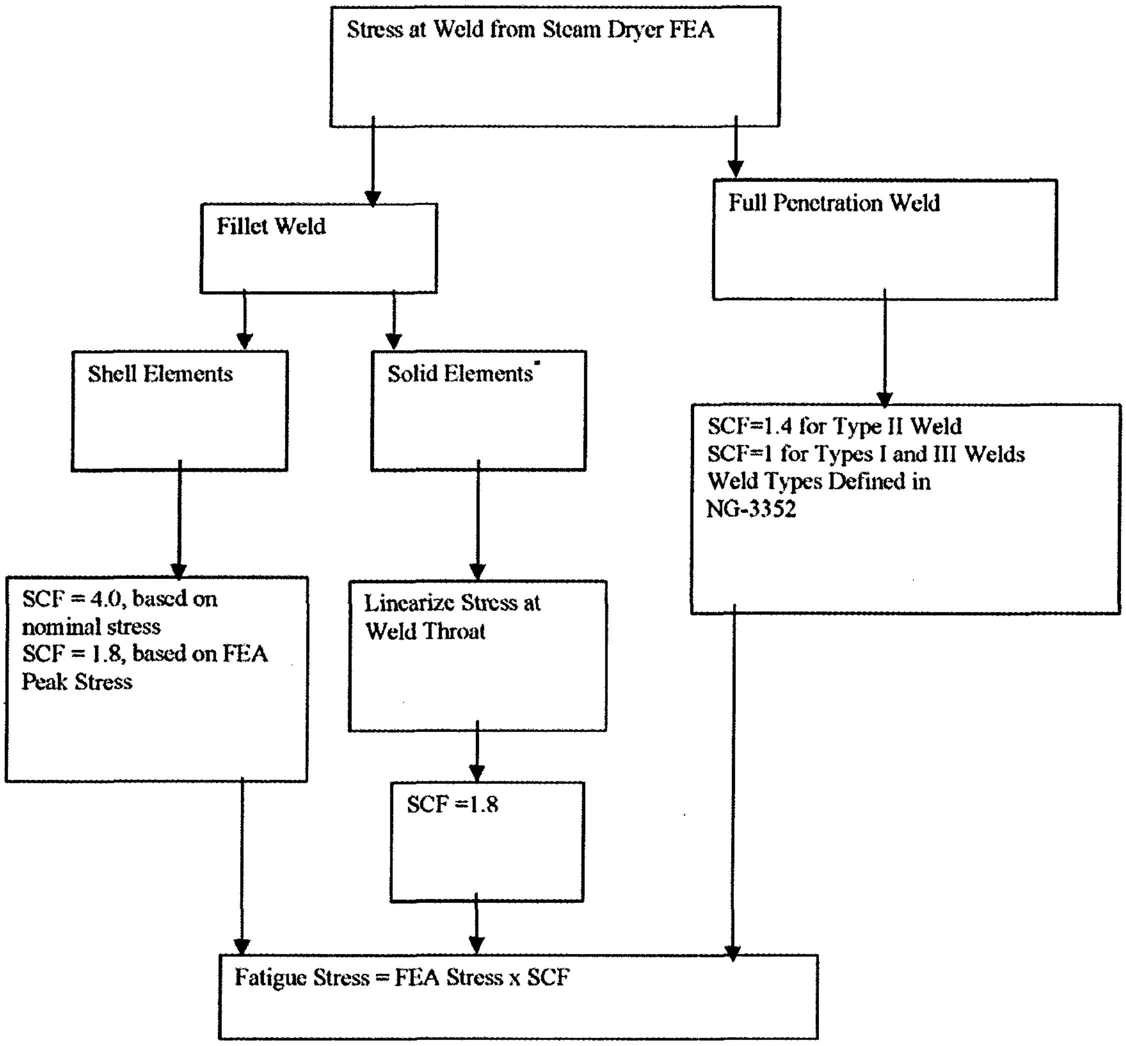

Figure 6-40 Weld Factors

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Figure 8-1 Proposed BFN Steam Dryer Modifications